SPORTS-SENSOR – FOR IMPROVED QUANTITY AND QUALITY OF EXERCISE TRAINING

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The report is part of the project GameLab4Health. The project is co-funded by:

THE EUROPEAN UNION
The European Social Fund

THE EUROPEAN UNION
The European Regional Development Fund

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Background

Literature shows that elderly people who are being acutely hospitalized spend up to 17 hours a day in bed, which has severe health consequences (Pedersen et al 2013). Immobility enhances not only the risk of lung complications and bedsore but also induces losses of muscle mass and muscle strength, which further influence everyday life function (Poulsen & Beyer 2010; Convertino et al 1997; Coker et al 2015).

Studies on younger individuals showed that immobilization for seven to ten days reduced muscle strength with up to 20 % in large muscle groups (Convertino et al 1997). In another study it was found that only four days of immobilization induced a ten percentages reduction in muscle strength, and these results were present for both young and elderly individuals (Suetta et al 2009). Furthermore and especially with regards to elderly individuals, impaired balance was demonstrated after immobilization (Suetta et al 2009).

These negative effects have serious consequences for elderly, frail individuals being hospitalized, as they already have a relatively low reserve capacity due to sarcopenia (Santilli et al 2014). Statistics show that many elderly patients fail to regain their level of function and self-care before admission to hospital (Suetta et al 2007).

Thus, there is a great incentive to counteract losses of muscle mass and muscle strength and begin the rehabilitating process already when the elderly individuals are hospitalized. Strength training has shown to be effective in improving muscle strength but also with regards to maintaining muscle strength and preventing muscle atrophy (Suetta et al 2007; Suetta et al 2008). However, being hospitalized and newly operated puts certain demands on what training exercises and equipment to choose (Brown et al 2007).

Elastic bands are easily applied and studies have demonstrated their effectiveness when compared to e.g. dumbbells (Andersen et al 2010). However, at today's hospitals, the physical training of patients is limited due to the fact that a physiotherapist has to be present in order for the patient to exercise. The consequences are a limited number of training sessions and hence fragile elderly individuals who experience problems with daily activities. There is a need for evidence based training exercises that can be performed unsupervised. In this matter, the use of a sports-sensor might be an opportunity. The sports-sensor is a custom build device containing a three-axial piezo-electric accelerometer, a rate gyroscope, and a capacitor facility. The latter feature of the sports-sensor has been developed to measure repetitions and force in exercises using elastic bands by measures of capacitance changes in pico Farad (pF) with changes in elastic band elongation.

Purpose

The purpose of the present study was to study if the sports-sensor is applicable for quantifying human movement during various elastic bands exercises performed in bed.

This study validates the sports-sensor with regard to the following objectives:

1. Is the sports-sensor's output valid during four different exercises when compared to actual performance observed by an instructor?
2. What is the correlation between Newton based on pF values and Newton based on elongation?

Additionally, the present study investigated muscle activation of selected muscle groups during the four exercises performed in bed.

Methods

Subjects

Six subjects volunteered to participate in the study. All women (mean(range) age 44(27-56) years; 1.66(1.52-1.77) m; weight 62(60-90) kg) and familiar with physical exercise training.

Sports-sensor

The sensor used in this study is a custom build device consisting of two connected parts that are mounted on either side of an elastic band, held together by internal magnets. The two parts form a sensor that measure deformation and hence stretch of the elastic band. The measured data are stored on the device and transmitted via Bluetooth-4 low Energy, directly to a mobile device that can visualize instantaneous stretch of the elastic exercise. After testing the mobile device was connected to a computer and data were downloaded through iTunes and stored as Excel files containing data in pF over time.

Furthermore, the sensor contains a three-axial piezo-electrical accelerometer and a rate gyroscope, however these data are not analyzed in the present study.

Elastic bands

TheraBand™ latex exercise bands are available in eight color-coded levels of resistance (figure 1).

Figure 1: TheraBand™ latex exercise bands

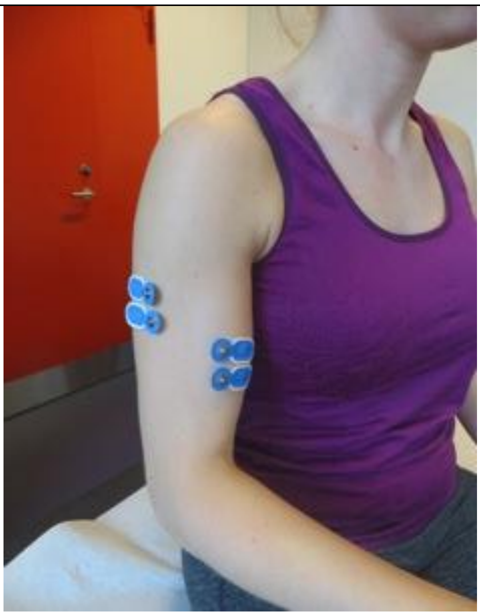
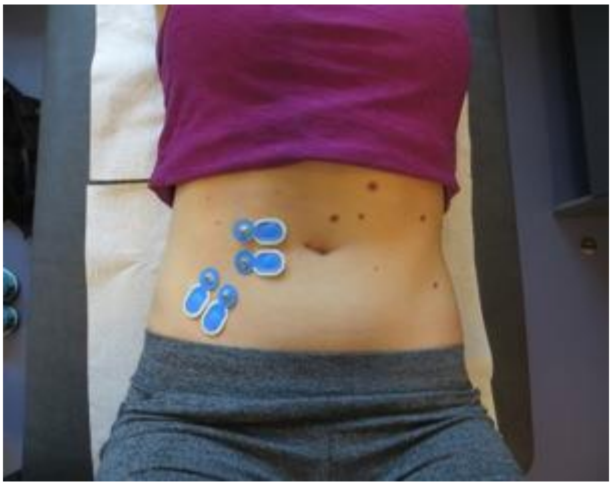
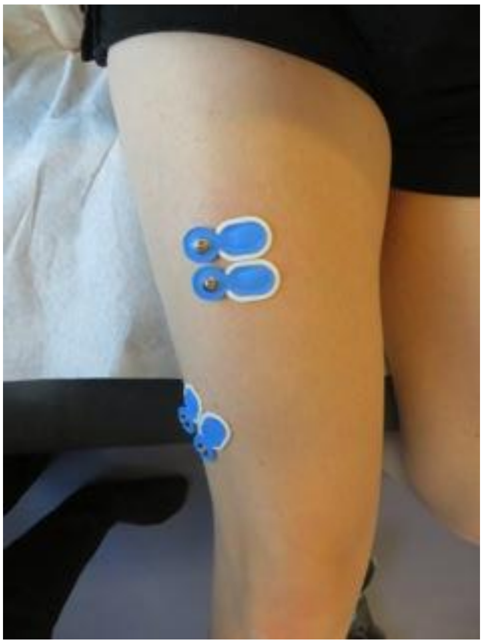
Different resistance levels are determined by the thickness of the elastic band. The force produced by the elastic bands is directly related to elongation. Each color will provide a specific amount of resistance at the same percentage elongation, regardless of initial resting length. For example, stretching from 20 centimeters to 40 centimeters (100% elongation) will request the same force as stretching from 50 centimeters to 100 centimeters. The force slowly increases as the band or tube is stretched.

Perceived exertion registration

Rating of perceived exertion (RPE) was measured using the 10-point Borg scale, which is a numerical 10-point category scale with linguistic descriptors anchored at selected positions along the scale (Borg 1987). Straight after each training set, the participant was asked "How exerted do you fell in [muscle group] on a scale from 0 to 10? 0 represents "not at all" and 10 represents "extremely exerted". The muscle group inquired about was the target muscle group for each of the four exercises, respectively.

Electromyography

For electromyography (EMG), we used wireless MYON 320 (Myon AG Switzerland). Electrodes were placed according to standard guidelines (Criswell 2011; Seniam http://www.seniam.org) on the following muscles: *biceps brachii* (Placed parallel to the muscle fibers and in the centre of the mass); *Triceps lateral head* (Placed parallel to the muscle fibers, approximately two centimeters lateral from the midline of the arm, approximately 50% of the distance between the acromion and the olecranon); *Lattisimus dorsi* (placed approximately four centimeters below the inferior tip of scapula, half the distance between the spine and the lateral edge of the torso, oriented in a lightly oblique angle of approximately 25 degrees); *Rectus abdominis* (Placed three centimeters apart and parallel to the muscle fibers of rectus so that they are located approximately two centimeters lateral and across from the umbilicus over the muscle belly); *External oblique* (Placed two centimeters apart, lateral to the rectus abdominis and directly above the anterior superior iliac spine, halfway between the crest and the ribs at a slightly oblique angle so that they run parallel to the muscle fibers); *Rectus femoris* (Placed approximately half the distance between the knee and the iliac spine, parallel to the muscle fibres); *Vastus lateralis* (Placed approximately ten centimeters above the patella, on a oblique angle just lateral to the midline); *Biceps femoris* (Placed parallel to the muscle fibers on the lateral aspect of the thigh, two-thirds of the distance between the trochanter major and the back of the knee). Relative muscle activity ≥ 10 % is considered an EMG signal interference pattern.

Triceps Brachii Lateral head and Biceps Brachii	Lattisimus Dorsi
	
Rectus abdominis and External Oblique	**Vastus Lateralis and Rectus Femoris**
	

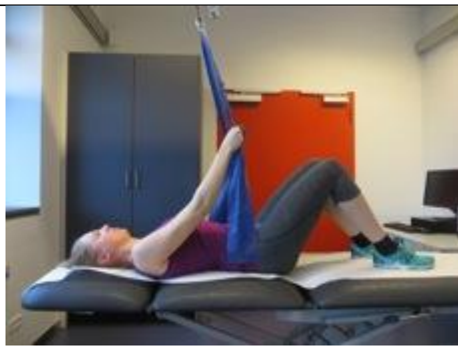
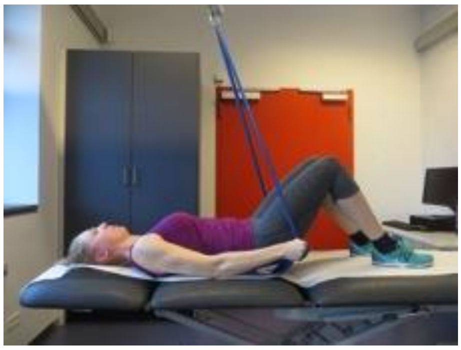
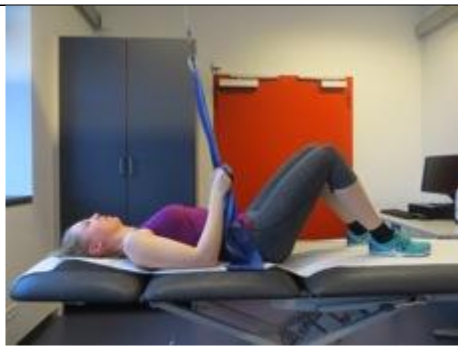
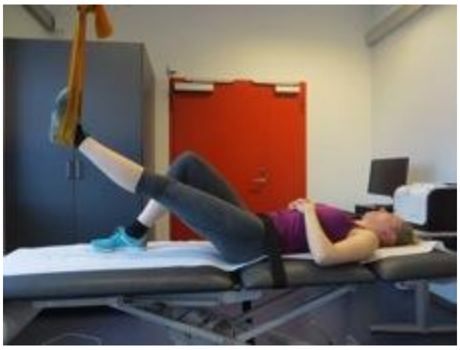
Biceps Femoris


Table 1: Placement of surface EMG electrodes

All 8 muscles were recorded for each exercise. Before the start of each exercise, an isometric test was performed to reach one repetition maximum (RM) for which maximum isometric voluntary electrical muscle activation (MVE) was recorded. The EMG data has been analyzed in absolute values in microvolt as well as in percentage % relative to the one RM test.

Test-procedure

The participants were tested individually. The study consisted of two parts. The first part was the familiarization part where all four exercises (see tab. 2) were performed with regard to finding the correct elastic band color and length in order to reach 15RM and 8RM, respectively.

Exercise 1: Shoulder extension The participant lies with bended knees and the elastic band just above the joint of the elbow. The participant is asked to grip the elastic band at a 45-degrees measured between the madras and upper arm. The participant now lowers the arm down to a vertical line from shoulder to hip.	Start position:  End position: 
Exercise 2: Elbow extension The participant lies with bended knees and the elastic band just above the joint of the elbow. The upper arm is rested on the madras and the participant is asked to grip the elastic band at 90 degrees in the elbow. The participant now lowers the arm down to a vertical line from shoulder to hip.	Start position:  End position: 
Exercise 3: Hip extension The participant lies with the elastic band just above the ankle and with one knee bended. The other leg is fastening in the elastic band so there is a 45 degrees angle	Start position: 

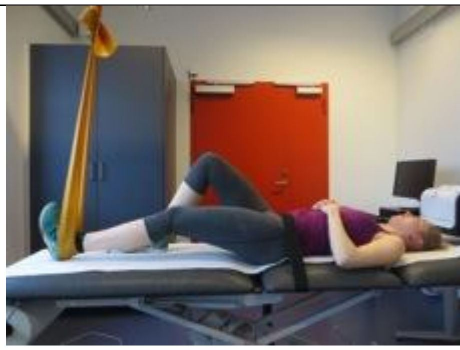
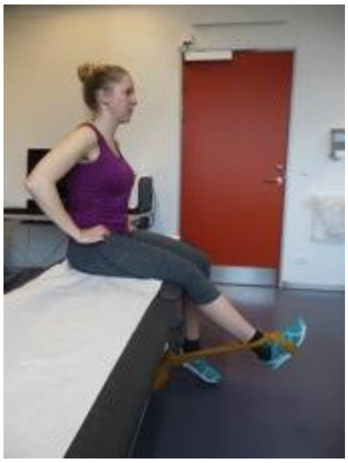
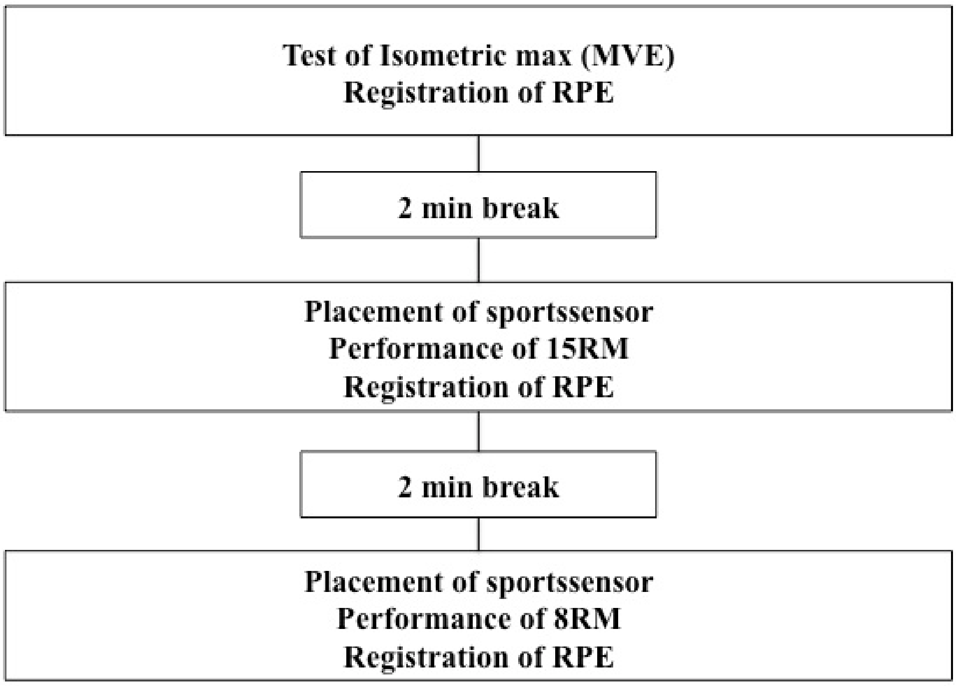
between the madras and the leg. Arms are placed on the belly in a relaxed position and a belt is fastening at the crest of the hip in order to secure isolated activity of the leg. The participant now lowers the leg to a vertical line from hip to feet.	End position: 
Exercise 4: Knee extension The participant sits on the bed with straight back and arms held at the crest of the hips. The elastic band is attached to the bed near the floor and at the ankle. With control, the participant extends the knee.	Start position:  End position: 

Table 2: Description of the four exercises

The second part was the testing part, where after placement of electrodes, a short warm up was performed before conducting the test series. The test series for each exercise was as follows:



The order of the exercises is described in table 2. All exercises were conducted in a controlled, smooth manner without sudden jerks or accelerations, and after each execution, the participant was asked to rate their perceived exertion. An instructor registered the repetitions, counting the number of repetitions and informing the participant when it was the second last repetition.

Statistic

Data were analyzed with non-parametric testing. To analyze for differences between 15RM and 8RM, the Mann-Whitney Test was applied. The Pearson correlation was applied to demonstrate association between elastic band elongation and force calculated in Newton.

Results

Sports-sensor

Six participants performed 4 exercises with a load of 15RM and a load of 8RM, in total 48 training sets. Three training sets were not conducted due to the fact that no elastic band was strong enough to meet the RM requirements, leaving a total of 45 training sets. Out of the 45 conducted training sets, 75 % (33 training sets) was registered by the sports-sensor (registered training sets/total possible training sets*100). The percentage of registered repetitions for the 33 training set was on average 89 % with a range of 13-100 % (sum of registered repetitions/registered training sets).

Mean pF for the 33 registered training sets was 750.413 (range: 292.016 – 1.733.581), and max pF was 88.9432 (range: 334.909 – 1.885.672). There was no difference between 15RM and 8RM with regard to mean or max pF.

Estimated Newton

Newton based on elongation

For the estimation of Newton based on elongation, the following equations were applied for each of the elastic bands: Gold (37x+23); Silver (28x+14) and Black (17x+22), where x represents elongation, e.g. 150 % elongation = 1.5. These equations were derived from a previous study on calibration of the sports-sensor (Rasmussen, 2014).

The mean force for 15RM and 8RM was 60.6 (SD: 12.3) N and 69,9 (SD: 12.9) N, respectively.

Below figure (fig. 2) represents mean force based on the above equations - a significant difference was found between 15RM and 8RM in the exercises – *Shoulder extension* and *Elbow extension*, but not for the exercises *hip extension* or *knee extension*.

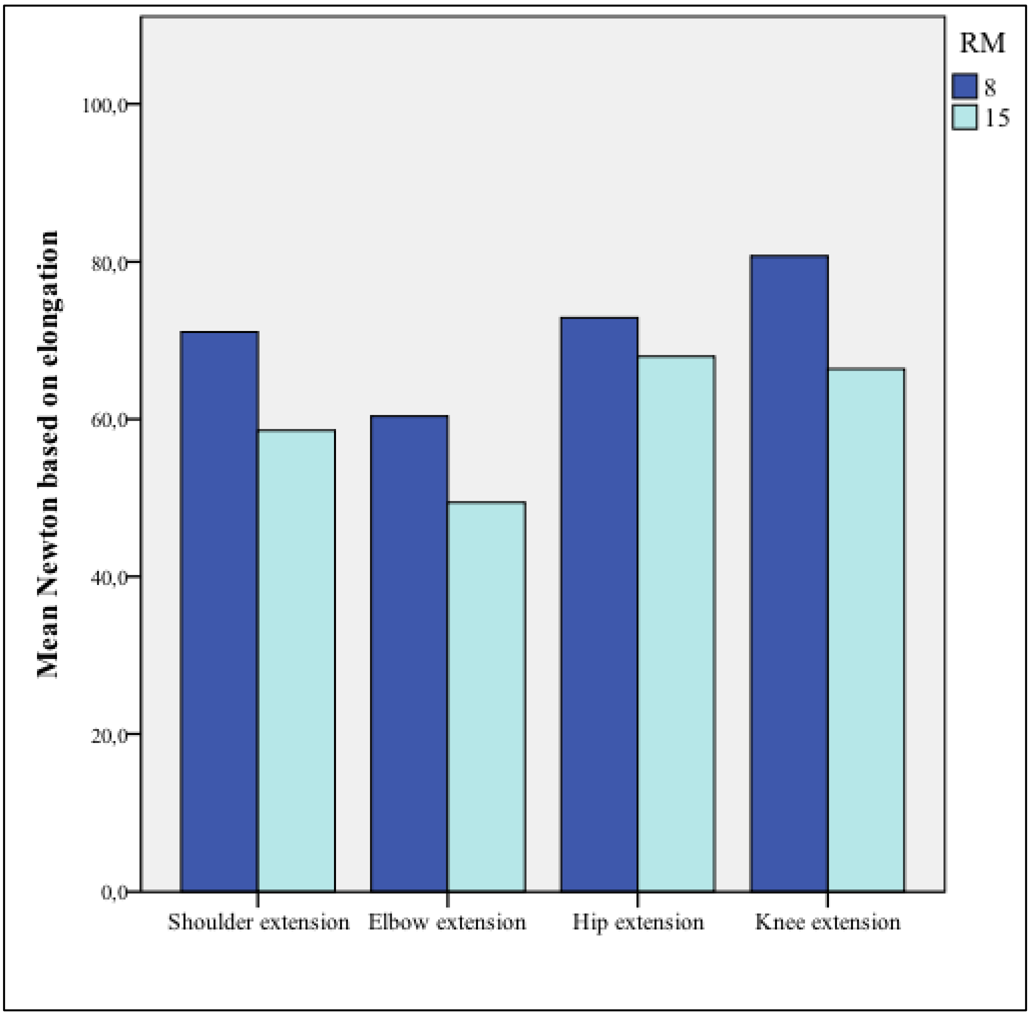


Figure 2: Mean Newton based on elongation, grouped by exercise and split by RM.

Newton based on pF values

For the estimation of Newton based on pF values, the following equation was applied 0,0001x+2,7376 (Rasmussen 2014). The mean Newton for 15RM and 8RM was 77.3 (SD: 30.1) and 78,4 (SD: 31.5) respectively. Figure 3 represents mean force in Newton based on pF values for the four exercises, split by RM - no significant difference was found between 15RM and 8RM for any of the four exercises.

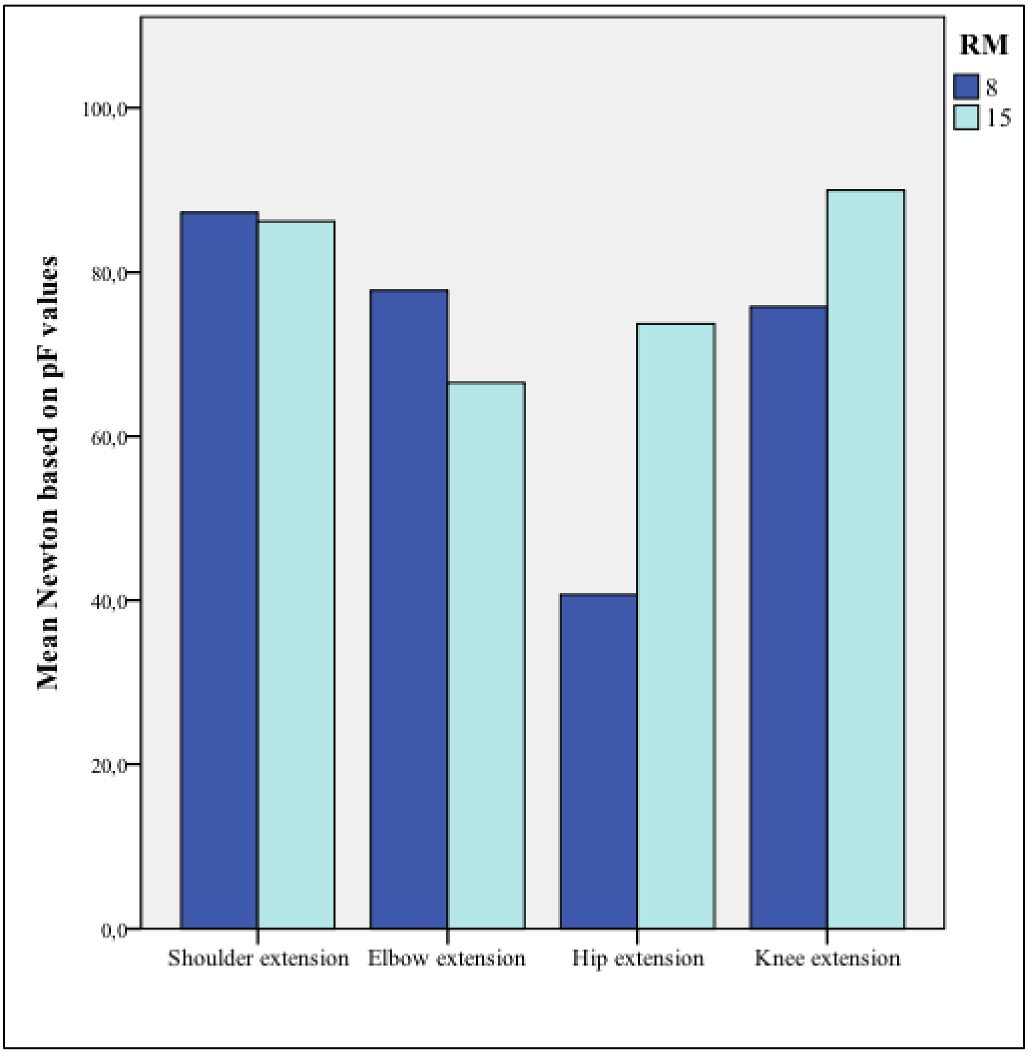


Figure 3: Mean Newton estimated based on pF values, grouped by exercise and split by RM.

Correlations

Correlations between estimated Newton based on pF values and based on elongation showed no significant correlations for 15RM or 8RM, with R2 values of 0.007 & 0.044 respectively.

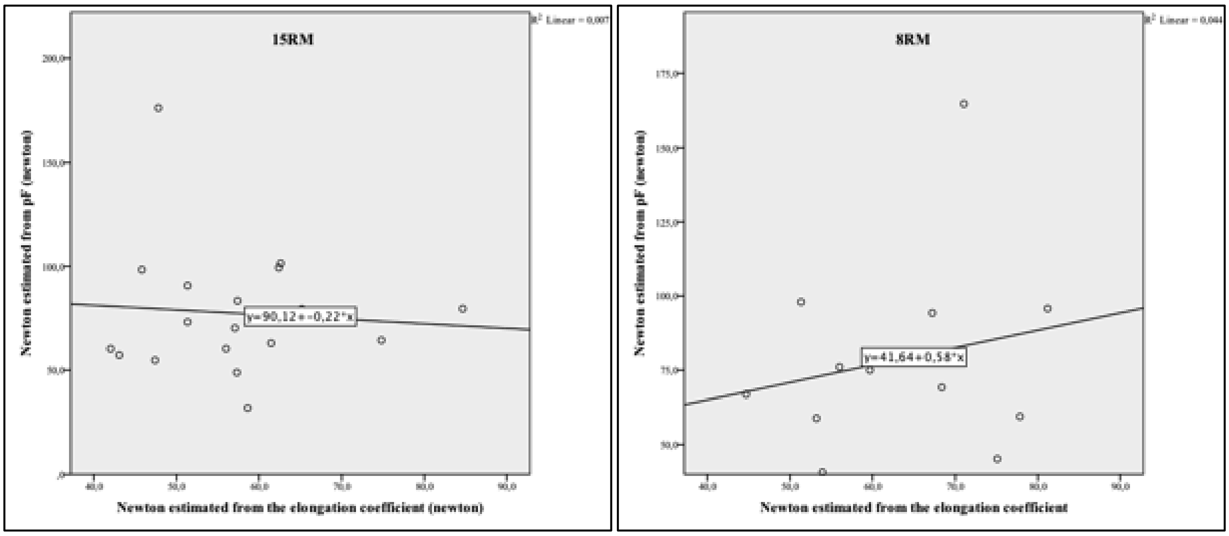


Figure 4: Correlation between Newton estimated based on pF values and based on elongation. Left figure represents 15RM and right figure 8RM.

Perceived exertion

There was no difference between 15RM and 8RM with regard to mean RPE nor when analyzed with exercise as grouping variable. Mean RPE for 15RM was 8 (SD: 1) and for 8RM 8 (SD:1).

EMG

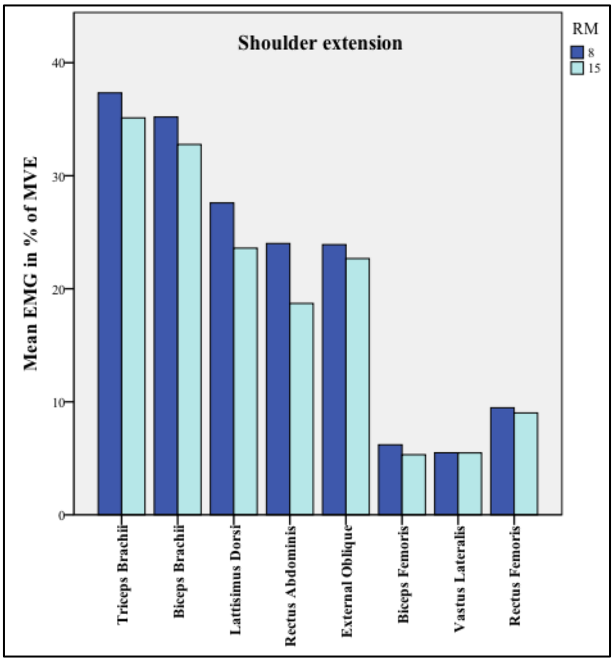
The below table shows MVE determined as the highest value in µV attained during one of all test contraction, and respective values in µV for max peak, mean of max peak, and mean for the whole period for each of the four exercises.

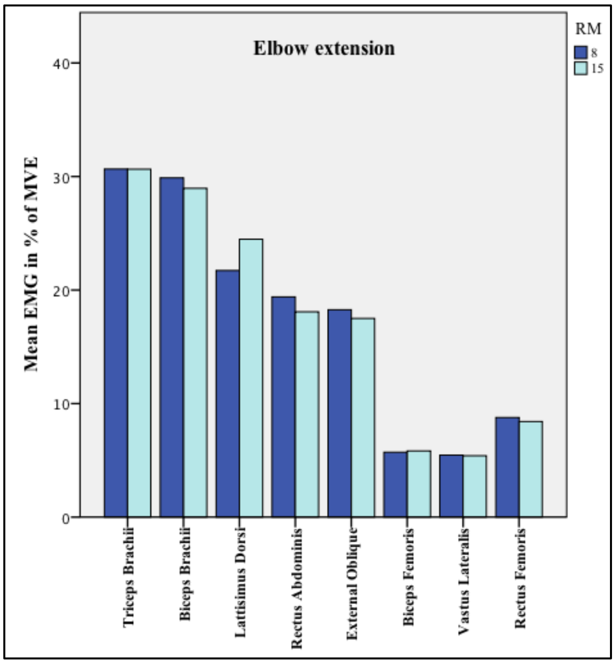
				Shoulder extension						Elbow extension						Hip extension						Knee extension					
RM	**Muscle group**	**MVE (µ)**	**SD**	**Max peak (µ)**	**SD**	**Mean max peaks (µ)**	**SD**	**Mean EMG (µ)**	**SD**	**Max peak (µ)**	**SD**	**Mean max peaks (µ)**	**SD**	**Mean EMG (µ)**	**SD**	**Max peak (µ)**	**SD**	**Mean max peaks (µ)**	**SD**	**Mean EMG (µ)**	**SD**	**Max peak (µ)**	**SD**	**Mean max peaks (µ)**	**SD**	**Mean EMG (µ)**	**SD**
8	**Triceps Brachii**	511	103	669	193	**566**	169	193	74	636	261	542	222	160	69	100	47	51	31	18	8	28	23	18	8	10	1
	Biceps Brachii	140	46	152	64	**133**	61	50	27	145	56	125	53	41	18	67	35	47	25	20	8	20	7	17	7	12	3
	Lattisimus Dorsi	481	256	643	438	**536**	372	134	75	497	350	395	293	110	71	124	48	92	50	33	15	123	175	90	124	37	45
	Rectus Abdominis	232	192	281	245	**222**	197	59	52	224	174	173	141	44	32	23	10	17	5	9	2	19	0	16	1	8	0
	External Oblique	153	132	135	104	**88**	74	31	18	93	77	71	69	23	13	47	26	34	18	17	3	39	19	25	8	16	3
	Biceps Femoris	275	91	32	26	27	19	16	8	22	13	22	13	15	5	315	174	**252**	131	81	38	217	297	203	286	62	70
	Vastus Lateralis	231	67	17	4	15	1	12	1	16	1	15	0	12	1	76	96	57	68	24	21	239	185	**179**	138	67	48
	Rectus Femoris	198	101	64	90	35	27	18	6	31	28	25	15	15	1	90	135	71	101	27	25	138	103	**113**	86	49	34
15	**Triceps Brachii**	511	103	671	263	**527**	187	182	78	637	199	521	181	158	63	71	42	39	13	15	3	49	32	15	2	9	0
	Biceps Brachii	140	46	153	71	**119**	58	46	24	141	58	119	47	40	18	110	98	51	32	23	13	68	50	17	3	10	1
	Lattisimus Dorsi	481	256	598	383	**456**	327	114	65	561	400	433	327	120	68	137	70	89	53	33	16	122	150	52	58	23	19
	Rectus Abdominis	232	192	200	146	**152**	126	42	32	239	150	155	124	41	31	40	32	22	11	10	2	31	14	16	2	8	1
	External Oblique	153	132	155	90	**76**	45	26	11	102	81	62	56	22	13	54	25	30	9	16	1	44	9	29	9	16	3
	Biceps Femoris	275	91	23	9	18	5	13	3	31	21	22	11	15	5	323	182	**245**	133	78	45	220	303	163	220	50	51
	Vastus Lateralis	231	67	23	11	16	1	12	1	16	1	15	1	11	1	90	97	60	70	25	22	222	192	**167**	134	61	45
	Rectus Femoris	198	101	92	122	27	10	16	4	27	16	19	2	15	1	117	122	73	102	28	25	152	109	**111**	82	48	32

Table 3: Absolute values for each muscle group in the 4 exercises split by RM. N = 6 except for exercise *Knee extension* (N=4). Red-labelled cells represent highest value for that column and row.

Mean EMG activity

Below figures show mean EMG activity for each exercise in percentage of MVE, grouped by muscle group and split by RM. The exercises – shoulder and elbow extension primarily activated Triceps Brachii, Biceps Brachii, Lattisimus Dorsi and to some extend Rectus Abdominis and External Oblique. The exercise hip extension activated primarily Biceps Femoris and secondary Biceps Brachii, Biceps Femoris and External Oblique as well as Vastus Lateralis. For the knee extension, primarily Rectus Femoris and Vastus Lateralis were activated and to some extend also Biceps Femoris and External Oblique were primarily activated.





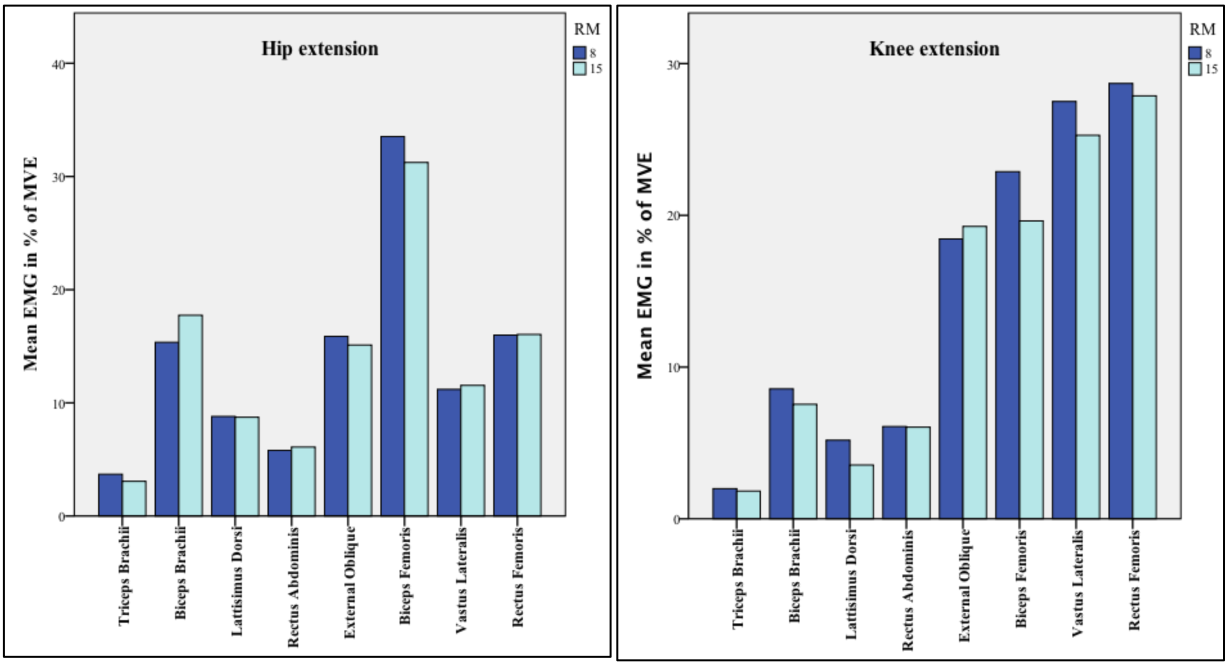


Figure 5: Mean EMG activity in percentage (%) of MVE for all 4 exercises.

For muscle groups with a relative activity level ≥ 10 % of MVE, there were significant differences between 8RM and 15RM in the exercise *Shoulder extension*, where a significant difference was seen in Lattisimus Dorsi and Rectus Abdominis, all with a higher relative EMG activity in 8RM compared with 15RM. No other differences were observed.

Max peak EMG

Figure 6 shows max peak in percentage of MVE, where a significant difference was observed in the exercise *Elbow extension* for Lattisimus Dorsi, with a higher relative max peak in 15RM compared to 8RM. Also, in the exercise *Hip extension* a significant difference was observed for Vastus Lateralis, with a higher relative max peak in 15RM compared to 8RM.

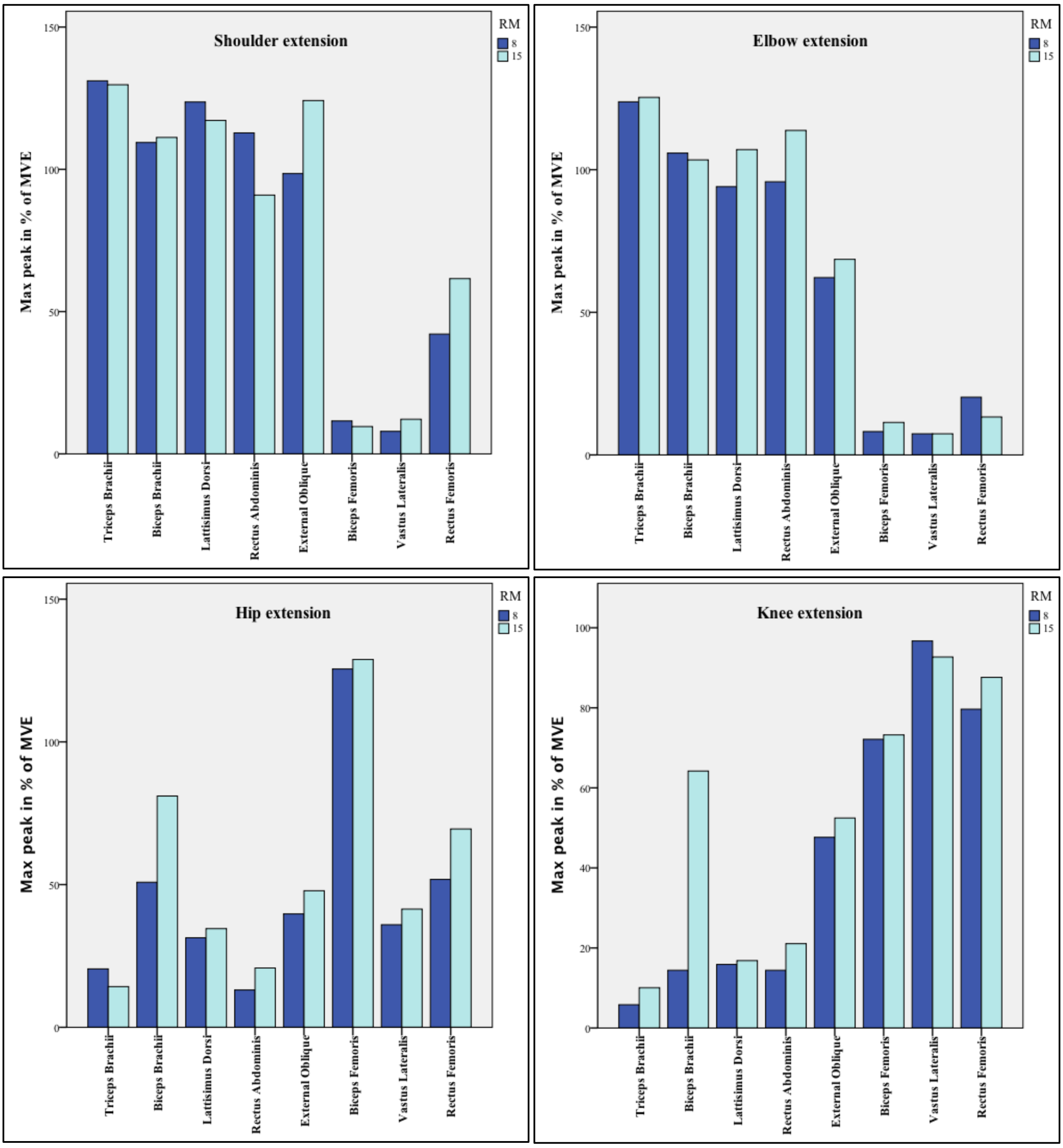


Figure 6: Max peak in percentage (%) of MVE for all 4 exercises.

Mean max peaks

Figure 7 shows differences between 15RM and 8RM in mean of max peaks in percentage of MVE in the exercise Shoulder extension, where Biceps Brachii, Lattisimus Dorsi and Rectus Abdominis were significant different, all with higher relative mean of max peaks in 8RM compared with 15RM. For the exercise Hip extension, a significant difference was observed for Rectus Abdominis, with a higher relative mean of max peaks in 15RM compared to 8RM.

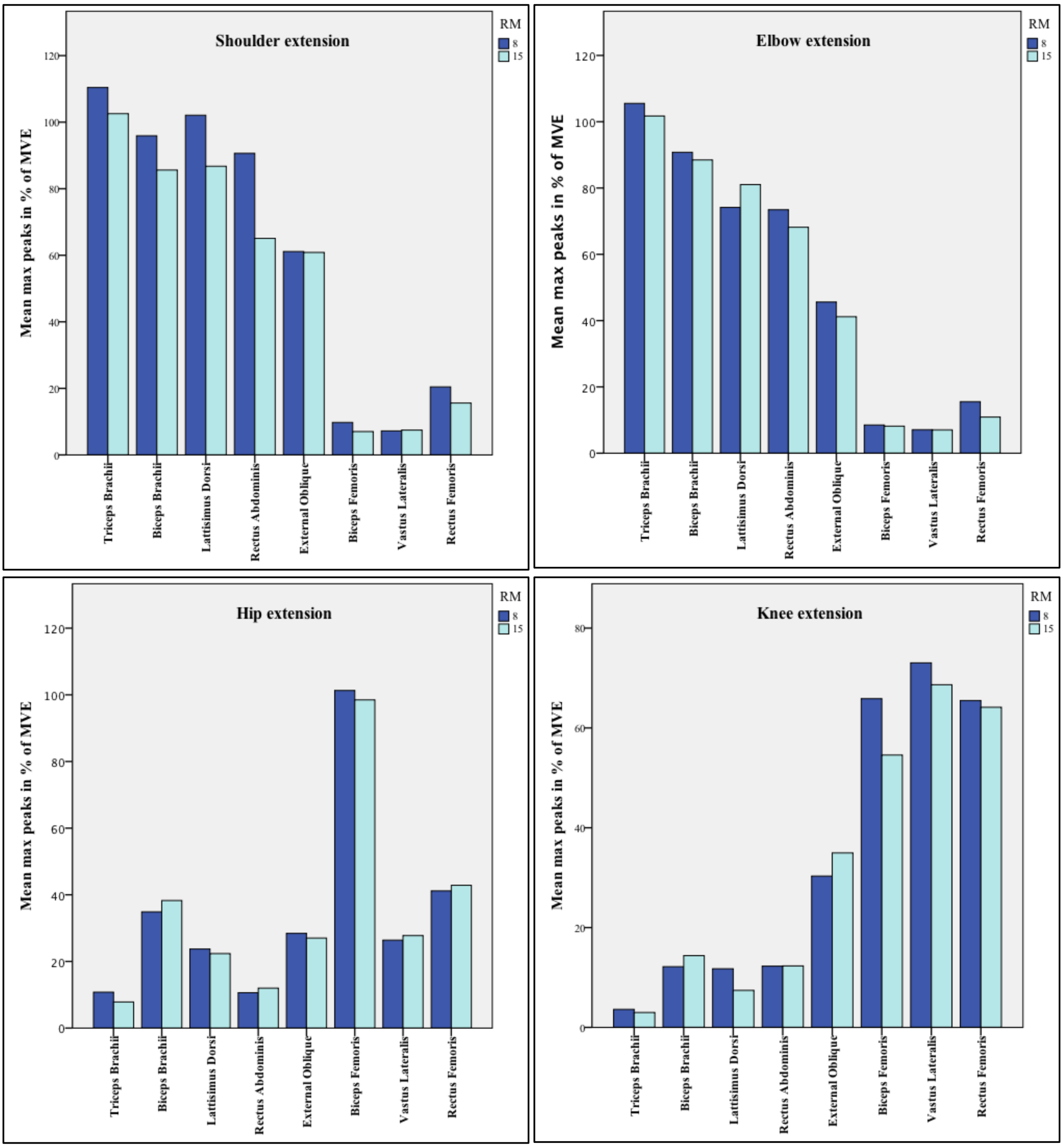


Figure 7: Mean max peaks in percentage (%) of MVE for all 4 exercises.

Discussion

Sports-sensor

The present study demonstrates a potential for the sports-sensor as applicable for quantifying human movement during various elastic bands exercises performed in a hospital bed. In total, 33 training sets out of 45 possible training sets were registered. On average, 89 % of all repetitions were registered (range: 14-100%). The reason for not registered the training set was primarily due to the color of the elastic bands. The thickness of the elastic band increases with strength and silver and gold was too thick for the sports-sensor to register and be held together by the magnetic field. Furthermore was it observed that the repetitions were not registered 100 % - there is no guideline on how to place the sports-sensor and whether the placement of the sports-sensor is the reason for not counting the correct number of repetitions remains unknown. It was observed under testing, that participants had a good grip of the elastic band resulting in folding of the elastic band. As it is two magnetic fields that hold the sports-sensor together, this folding might play an role in the lack of registration of both training sets and repetitions throughout the exercise.

The correlation between estimated force in Newton based on elongation and based on mean pF values demonstrated poor R^2 values (<0.044) and more investigation needs to be conducted. Results demonstrate a significant difference between 15RM and 8RM for the exercises hip and knee extension when measured based on elongation. No other differences were found between 15RM and 8RM for Newton based elongation nor Newton based on pF values. A reason for not finding other significant differences may be part of the difficulty of estimating a realistic 15RM and 8RM, which also can be seen in the RPE values not reaching over 9. However, there was no difference in RPE between 15RM and 8RM, which eliminates this as a possible explanation.

EMG

The four selected exercises were chosen to activate the upper body in Shoulder extension and Elbow extension as well as the lower body in Hip extension and Knee extension. The EMG recordings show that Triceps Brachii and Lattisimus Dorsi are the two muscle groups that were activated the most in the exercises Shoulder extension and Elbow extension. Also Rectus Abdominis and External Oblique were activated and witness the need for stabilising the trunk under these upper body exercises.

Regarding Hip extension, Biceps Femoris was primarily activated and for Knee extension, Vastus Lateralis and Rectus Femoris were primarily activated. Also, for these exercises there is a need for activating External Oblique for stabilising the trunk. In Hip extension, there is a rather high activation of the Biceps Brachii, which is surprising. By looking into the data, it was found that it derives from one single participant who perhaps has performed an isometric contraction.

When looking at differences in muscle activity between 15RM and 8RM, no consistent picture can be drawn, neither when looking at mean EMG activity in percentage of MVE, mean max in percentage of MVE nor max peak in percentage of MVE. The lack of consistent significance between 15RM and 8RM must be related to the fact that 15RM and 8RM may not have been truly attained.

Perspectives into practice

There is a great potential for implementing elastic band exercises into practice and start the rehabilitation process early in order to counteract some of the potential consequences associated with bed rest. The upper arm exercises could possibly be done using dumbbells but it would require a lot of different dumbbells to do progressive resistance training and may imply a risk in case they are being dropped. This can be achieved by only one or two elastic bands. As mentioned, this can be supervised by a therapist but this is only possible to a limited extent. Using the sports-sensor we have a possibility for the therapist to see what the patient has performed of exercises and potentially the patient can use the output as a motivator.

We also see a great potential in supported strength training in bed. Using the elastic band as a support instead of a resistance will enable the bed-bound patient to get the adequate amount of support while trying to do for example a pelvic lift or a straight leg lift. The ability to facilitate activation of these muscles would mean a lot for the patient's ability to participate in the daily routines as hygiene situations and mobilization which could potentially relieve the staff.

As it came for the strength training the sports-sensor could here be used as a control or motivator device.

Conclusion

There is a need for further investigation regarding the potential of the sports-sensor for improved quantity and quality of exercise training. The chosen exercises activated the aimed muscle groups and additionally some important stabilizing muscles. There is a great potential for bed bound patients to start the rehabilitation phase early with elastic bands exercises. More attention should be paid to reach the desired RM, though in the perspective of the patient – little is more than nothing.

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