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ORIGINAL RESEARCH

PERCEIVED LOADING AND MUSCLE ACTIVITY DURING HIP STRENGTHENING EXERCISES: COMPARISON OF ELASTIC RESISTANCE AND MACHINE EXERCISES

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ABSTRACT

Objective: Decreased hip muscle strength is frequently reported in patients with hip injury or pathology. Furthermore, soccer players suffering from groin injury show decreased strength of hip muscles. Estimating 10-repetition maximum can be time-consuming and difficult, thus, using the Borg category rating 10 scale (Borg CR10 scale) can be a useful tool for estimating the intensity of exercise. The aims of this study were 1) to investigate the feasibility of the use of the Borg CR10 scale for rating strength training intensity of the hip abductor and hip adductor muscles, and 2) to compare hip muscle activity during hip abduction and hip adduction exercises using elastic resistance and isotonic machines, using electromyography (EMG).

Methods: EMG activity was recorded from 11 muscles at the hip, thigh and trunk during hip adduction and hip abduction exercises in 16 untrained women, using elastic resistance and isotonic exercise machines. These recordings were normalized to maximal voluntary contraction (MVC) EMG (nEMG). The exercises were performed at four levels of perceived loading reported using the Borg CR10: light (Borg ≤2), moderate (Borg >2–<5), heavy (Borg ≥5–<7) and near maximum (Borg ≥7).

Results: Moderate to strong associations were observed between perceived loading and nEMG obtained during the adduction exercise with elastic resistance ($r = 0.8 \pm 0.3$) as well as in machine ($r = 0.69 \pm 0.55$) and the abduction exercise with elastic resistance ($r = 0.66 \pm 0.29$) as well as in machine ($r = 0.62 \pm 0.54$). The abduction exercise performed with elastic resistance displayed significantly higher gluteus medius nEMG recruitment than the in machine exercise.

Conclusions: The results of this study show that the Borg CR10 scale can be a useful tool for estimating intensity levels during resistance training of the hip adductor and hip abductor muscles. Although elastic resistance and exercise machine seem equally effective for recruiting muscle activity of the hip adductors, the elastic resistance condition was able to demonstrate greater muscle recruitment than the exercise machine during hip abduction.

Key Words: Elastic resistance, hip adduction, hip abduction, strength training

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INTRODUCTION

Decreased hip muscle strength is frequently reported in patients with hip osteoarthritis (OA),[1–3] external snapping hip,[4] iliotibial band syndrome,[5] patellofemoral pain syndrome (PFPS),[6,7] and after total hip replacement.[1] However, hip strength deficits are common among athletes with groin injuries, such as soccer players.[8] Consequently, strengthening exercises that can be used in many different settings and easily adjusted in intensity would be of great benefit for therapists, coaches, and athletes worldwide.

In strength training, estimation of a 10 repetition maximum (RM) is often used for determination of resistance load. However, estimating 10 RM can be time-consuming and difficult especially in patients that experience pain due to injured or healing tissues. Perceived loading using the Borg category ratio 10 scale (Borg CR10 scale)[9] can be an alternate tool for estimating the intensity of a given exercise. Accordingly, previous studies have shown strong associations between perceived loading and electromyographic (EMG) activity during shoulder strengthening exercises.[10] Estimating muscle intensity by external load regulation is essential in order to ensure accurate rehabilitation. While elastic resistance exercises have shown to provide a stimulus sufficient to improve muscle strength in the neck, shoulder and arm,[10,11] trunk,[12] and legs[13] compared with free weight training, their proficiency for effectively stimulating hip muscles remain unknown.

The aims of this study were 1) to investigate the feasibility of use of the Borg CR10 scale for rating strength training intensity of the hip abductor and hip adductor muscles, and 2) to compare hip muscle activity during hip abduction and hip adduction exercises using elastic resistance and isotonic exercise machines, using EMG.

METHODS

Muscular activity EMG and perceived loading using the Borg CR10 scale, were obtained during hip abduction and hip adduction exercises performed in isotonic training machines or with elastic resistance were evaluated using a cross-over design.

A group of 16 untrained adult women (Age 45.7 $\pm$ 8.6) years; Height 165.4 $\pm$ 5.2 cm; Weight 61.8 $\pm$ 7.2 kg: BMI 22.6 $\pm$ 2.8 $kg{\cdot}m^{-2}$, and hip pain intensity during the last three months of 0.9 $\pm$ 1.9 on a scale of 0-10) were recruited from a large workplace with various job tasks (e.g. office workers and laboratory technicians). Exclusion criteria were blood pressure above 160/100, disc prolapse, pregnancy or serious chronic disease. All participants were informed about the purpose and content of the study and gave their written informed consent to participate. The study conformed to The Declaration of Helsinki and was approved by the Local Ethical Committee (H-3-2010-062).

Study design

Participants visited the laboratory on two occasions. On the first occasion one week prior to testing participants were habituated in rating their perceived loading during the elastic tubing exercises with different loads using the Borg CR10 scale. On the second occasion the participants were tested with EMG with the aim of comparing the two different exercise types (elastic resistance and isotonic weight machines) in a cross-over design. The exercise loads followed the verbal descriptions used on the Borg CR10 scale:[9] Light load (Borg ≤ 2), moderate load (Borg >2-<5), heavy load (Borg ≥ 5-<7) and near maximum load (Borg ≥ 7).

Exercise equipment

Two different types of training equipment were used; 1) elastic tubing with resistances ranging from light load to near maximal load (red, green, blue, black, gray colors) from Thera Band™, (Akron, Ohio, USA) and 2) conventional, seated isotonic exercise machines (abductor and adductor) by Technogym (Gambettola, Italy).

Testing protocol

On the day of EMG measurements the participants performed a light warm up session that consisted of ten repetitions of all exercises using moderate load (Borg ~3). Then the participants performed three consecutive repetitions at four perceived resistance levels, ranging from light to near max load. All exercises were performed unilaterally in a slow and controlled manner, i.e. concentrically (~1 sec.) and eccentrically (~1 sec.) without sudden jerky movements or acceleration using the dominant leg (preferred leg) as the exercising leg. The rest period between exercise conditions was approximately five minutes. The order the exercises and resistance was randomized for each participant by drawing a piece of paper from an opaque bag. The exercises are shown in Figure 1.

Adduction with elastic resistance

The exercise band was placed using a cuff as distal as possible on the participant`s ankle. The other end of the tubing was fixed around a wall bar. The elastic tube(s) was 150 cm long and were pre-stretched to ~200% (300 cm) of the initial length. In the starting position the participant was standing on the non-test leg with the hip of the test leg abducted to approximately 45°. The participant started adducting the hip to 0°, and then returned to the starting position at 45°. The participants were instructed to maintain their upper body in an upright position during the exercise.

Isolated hip adduction in machine

The participant was seated in upright position in an adductor machine, with an 80° hip flexion and the legs placed in bilateral hip abduction of 45°. The participant was instructed to use the handles on the machine for balance and performance optimization. The participant started adducting the hip to a 0° hip joint angle, and then eccentrically abducted the hips to the stating position (45° hip joint angle).

Abduction with elastic resistance

The exercise band was placed using a cuff as distal as possible on the participant's ankle while the other end of the tubing was fixed around a wall bar. The elastic tubes were 150 cm long and were pre-stretched to about 200% (300 cm) of the initial length. In the starting position the participant was standing on the non-test leg with the legs together

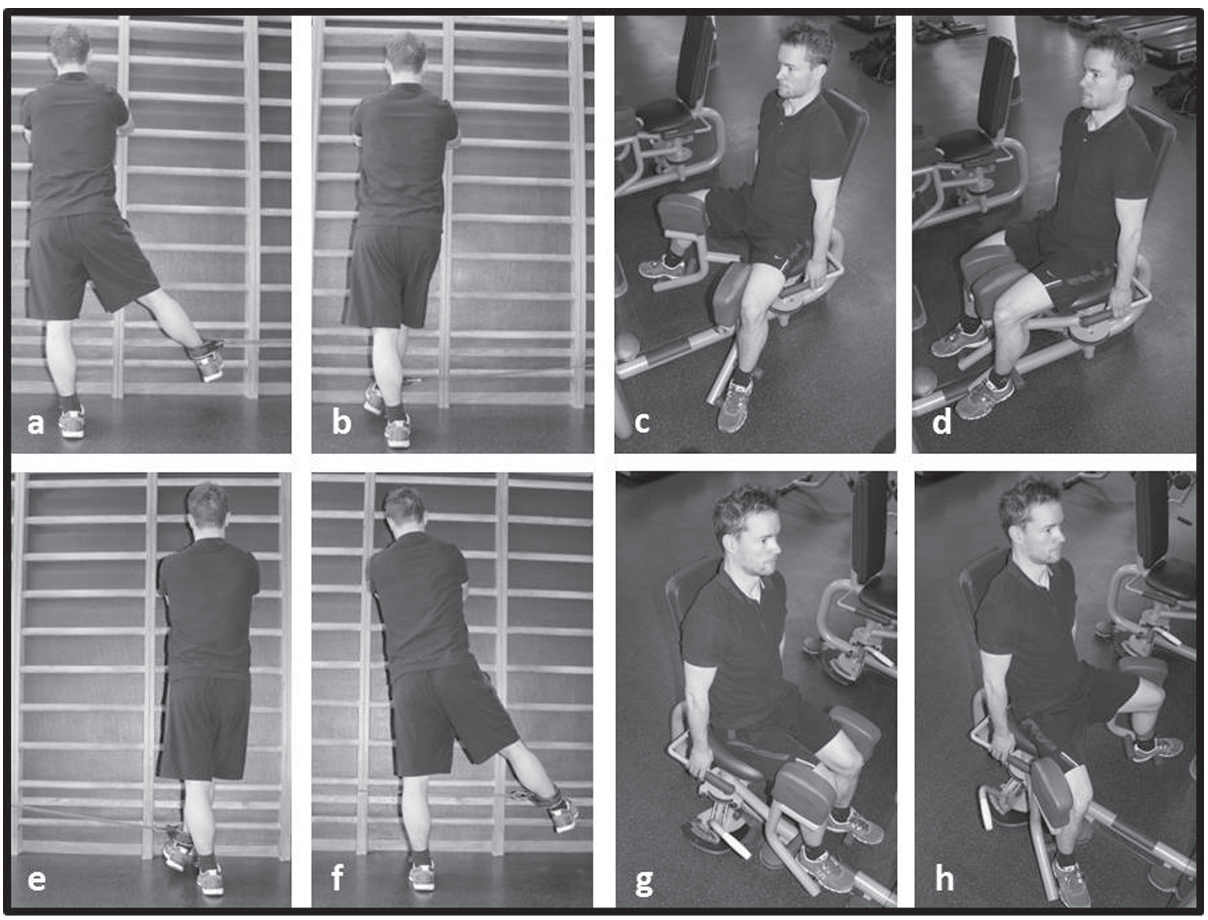

Figure 1. *(a) Start position for hip adduction against elastic resistance. (b) End position for hip adduction against elastic resistance. (c) Start position for hip adduction in machine. (d) End position for hip adduction in machine. (e) Start position for hip abduction against elastic resistance. (f) End position for hip abduction against elastic resistance. (g) Start position for hip abduction in machine. (h) End position for hip abduction in machine.*

(at approximately 0° hip abduction). The participant started abducting the hip to approximately 45°, and returned the starting position of 0°. The participants were instructed to maintain their upper body in an upright position during the exercise.

Isolated hip abduction in machine

The participant was seated in upright position in an abductor machine, with an 80° hip flexion and the legs placed in bilateral hip abduction of 0°. The participant was instructed to use the handles on the machine for balance and performance optimization. The participant abducted the hips as far as possible (to approximately a 45° hip joint angle), and then eccentrically adducted the hips returning to the 0° hip joint angle.

Perceived loading

Immediately after each set of exercise the Borg CR10 scale[9] was used to rate perceived loading during the resistance exercise. The authors have previously validated this scale in the evaluation of neck/shoulder resistance exercises with elastic resistance.[10]

Maximal voluntary isometric contraction

Prior to the dynamic exercises described above, maximal voluntary isometric contractions (MVC) were performed, according to standardized procedures during 1) hip adduction (lying flat on the back and pressing the knees against a solid ball), 2) hip abduction (lying flat on the back with a 10° bilateral hip abduction and pressing the knees outwards against a rigid band) 3) static knee extension and 4) flexion maneuvers (positioned in a Biodex dynamometer: knee angle: 70° and hip angle: 110°), 5) hip extension (lying flat on the stomach with the knee flexed (90°) and pressing the foot upwards against the instructors hands), 6) trunk extension and 7) trunk flexion (in standing posture and pelvis fixated the trunk was extended against a rigid band) to induce a maximal EMG response in the tested muscles.[14] Two MVCs were performed for each muscle, and the trial with the highest root mean square (RMS) EMG value was subsequently used for normalization of the RMS EMG signals obtained in the resistance exercises. During the MVCs, participants were instructed to gradually increase muscle contraction force towards maximum over a period of two seconds, sustain the MVC for three seconds, and then slowly release the force again. Strong and standardized verbal encouragement was given during all trials.

EMG signal sampling and analysis

EMG signals were recorded from eleven leg, abdominal, and lower back muscles, on the participants' dominant side, including: gluteus medius (prime mover for hip abduction), adductor longus (prime mover for hip adduction), gluteus maximus, vastus medialis, vastus lateralis, rectus femoris, biceps femoris, semitendinosus, erector spinae, external oblique, and rectus abdominis (non-prime movers for hip adduction and hip abduction). A bipolar surface EMG configuration (Blue Sensor N-00-S, Ambu A/S, Ballerup, Denmark) with an inter-electrode distance of 2 cm were used.[15,16] Before affixing the electrodes, the skin of the respective area was prepared with scrubbing gel (Acqua gel, Meditec, Parma, Italy) to effectively lower the impedance to less than 10 kΩ.[10] Electrode placements for all muscles followed SENIAM recommendations (www.seniam.org). The SENIAM recommendations do not have a suggested placement for adductor longus, therefore these electrodes were placed distally, at one third of the distance between the pubic symphysis and the adductor tubercle.[17]

The EMG electrodes were connected directly to wireless probes that pre-amplified the signal (gain 400) and transmitted data in real-time to a 16-channel 16-bit PC-interface receiver (TeleMyo DTS Telemetry, Noraxon, Arizona, USA). The dimension of the probes was 3.4 cm x 2.4 cm x 3.5 cm. Data was collected at a sampling rate of 1500 Hz. Common mode rejection ratio was higher than 100 dB.

During later analysis all raw EMG signals obtained during MVCs as well as during the exercises were digitally filtered, consisting of 1) high-pass filtering at 10 Hz, and 2) a moving root-mean-square (RMS) filter of 500 ms. For each individual muscle, peak RMS EMG of the 3 repetitions performed was determined, and the average value of these 3 repetitions was then normalized to the maximal RMS EMG obtained during MVC.[10]

Statistical analysis

A two-way repeated measures analysis of variance, mixed procedure (Proc Mixed) using SAS version 9, (SAS Institute, Cary, NC) was performed in order to determine if differences existed between exercises and perceived loadings for each muscle. Factors included in the model were *Exercise* (elastic resistance and machine) and *perceived loading* (light, moderate, heavy, near maximal), as well as *Exercise* by *perceived loading* interaction. Normalized EMG was the dependent variable. Values are reported as least square means (SE) unless otherwise stated. p-values <0.05 were considered statistically significant. A priori power analysis showed that 16 participants in this paired design were sufficient to obtain a statistical power of 80% at a minimal relevant difference of 10% and a type I error probability of 1%, assuming standard deviation of 10% based on previous research in the authors laboratory.[18]

RESULTS

Borg vs. nEMG

The results of regression analysis shows a strong correlation between the nEMG and the perceived loading on the Borg CR10 scale $r = 0.8 \pm 0.3$ for the adduction exercise performed with elastic resistance and moderate correlation $r = 0.69 \pm 0.55$ for the adduction exercise performed in the machine. For the abduction exercise the correlations were moderate with $r = 0.66 \pm 0.29$ when performed with elastic resistance and $r = 0.62 \pm 0.54$ when performed in the machine.

Normalized EMG (nEMG)

For descriptive purposes, the percentages of normalized EMG for the nonprime movers are shown are shown in Table 1. Figures 2 and 3 present the percentage of nEMG for the abduction and adduction exercises performed in machine and with elastic resistance. There was a significant *exercise by perceived loading* interaction ($P<0.0001$) during the hip abduction exercise. The abduction exercise performed with elastic resistance displayed significantly higher nEMG for the gluteus medius when compared with the machine exercise during all four resistance levels: light load ($p<0.0001$), moderate load ($p<0.0001$), heavy load ($p<0.0001$) and near maximum load ($p=0.0008$).

For the adduction exercise there was a no significant difference in nEMG output for the adductor longus between elastic resistance and the machine conditions. ($p=0.0738$).

DISCUSSION

This study shows that the Borg CR10 scale can be a useful tool for estimating intensity levels during resistance training of the hip adductor and hip abductor muscles. Although elastic resistance and machine exercises seem equally effective in providing a stimulus to elicit muscle activity in the hip adductors, the elastic resistance seems more effective in activating the hip abductors.

The abduction exercise showed higher nEMG activity in the gluteus medius when performed with elastic resistance than performed in machine. This difference could, in part, be explained by the difference in hip flexion position of the two exercise modalities; flexed in the machine vs. extended using the elastic

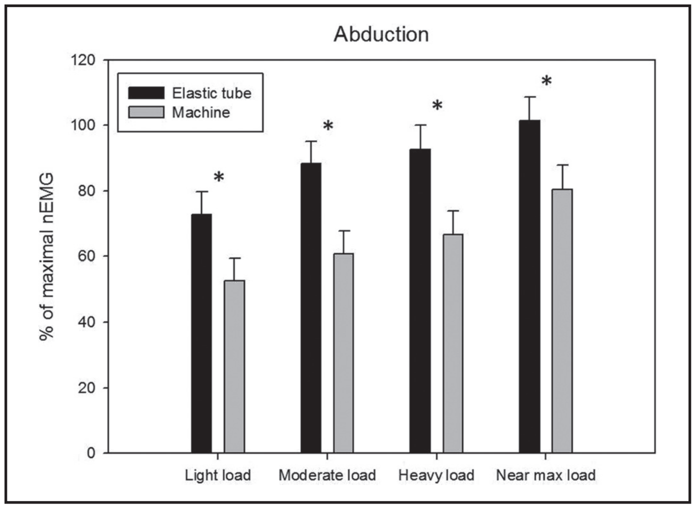

Figure 2. *nEMG for the abduction exercise. * indicate statistically significance.*

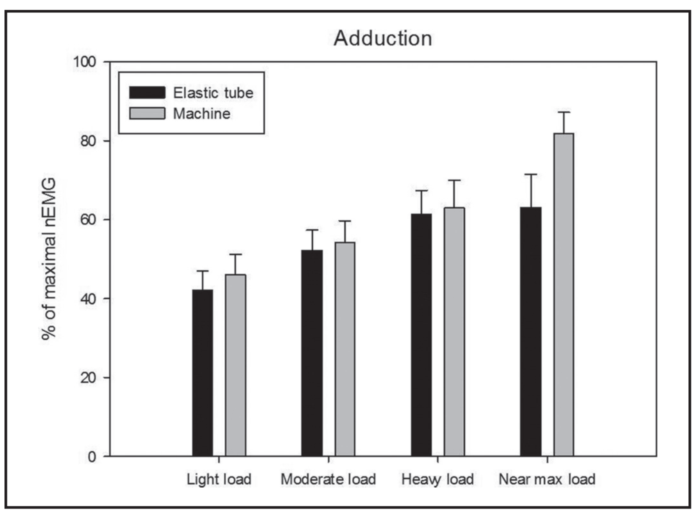

Figure 3. *nEMG for the adduction exercise.*

Table 1. *nEMG for all muscles.*

Muscle	Load	Abduction nEMG (% of max) E	M	E SE	M SE	Adduction nEMG (% of max) E	M	E SE	M SE
Adductor longus	Light	14	7	2	2	42	46	5	5
	Moderate	15	7	2	2	52	54	5	6
	Heavy	16	9	2	2	61	63	6	7
	Near max	17	7	2	3	63	82	8	5
Gluteus medius	Light	73	53	7	7	45	10	6	6
	Moderate	88	61	7	7	48	7	6	6
	Heavy	93	67	7	7	47	14	7	8
	Near max	101	80	7	8	40	31	9	6
Gluteus maximus	Light	59	67	10	9	35	9	6	6
	Moderate	65	65	9	10	46	10	6	6
	Heavy	68	69	11	10	41	6	7	8
	Near max	73	70	11	11	39	16	9	6
Rectus femoris	Light	44	31	5	4	16	7	1	1
	Moderate	55	41	4	5	17	10	1	2
	Heavy	59	49	5	5	21	11	2	2
	Near max	57	52	5	5	25	14	2	2
Vastus lateralis	Light	11	12	4	4	16	4	2	2
	Moderate	18	16	4	4	18	8	2	3
	Heavy	14	24	5	4	24	6	3	3
	Near max	18	29	5	5	26	13	4	2
Vastus medialis	Light	13	10	4	4	16	6	3	3
	Moderate	17	16	4	4	15	8	3	3
	Heavy	15	24	4	4	19	10	3	4
	Near max	16	27	4	5	23	17	4	3
Biceps femoris	Light	6	2	1	1	19	4	3	3
	Moderate	8	4	1	1	21	8	3	3
	Heavy	9	5	1	1	27	14	4	4
	Near max	13	10	1	1	38	39	5	3
Semitendinosus	Light	7	3	1	1	20	5	3	3
	Moderate	8	5	1	1	23	8	3	4
	Heavy	9	6	1	1	29	14	4	5
	Near max	11	13	1	1	49	41	6	3
Rectus abdominis	Light	18	7	3	3	9	7	3	3
	Moderate	20	11	3	3	8	9	3	3
	Heavy	20	9	4	3	10	13	3	3
	Near max	33	13	3	4	14	22	4	3
Right external obliqu	Light	27	10	5	4	16	5	2	2
	Moderate	44	13	4	5	17	10	2	3
	Heavy	52	14	5	5	19	13	3	3
	Near max	44	21	5	5	29	25	4	2
Left external oblique	Light	18	12	3	3	10	10	3	3
	Moderate	22	14	3	3	12	12	3	3
	Heavy	29	17	4	4	14	18	3	4
	Near max	30	21	4	4	29	35	5	3
Right erector spinae	Light	31	7	4	3	22	5	3	3
	Moderate	43	8	3	4	28	8	3	3
	Heavy	48	9	4	4	26	12	3	4
	Near max	45	12	4	4	29	32	5	3
Left erector spinae	Light	10	17	6	5	15	6	3	3
	Moderate	23	12	5	5	21	6	3	3
	Heavy	27	11	7	6	27	12	4	4
	Near max	19	14	6	7	29	25	5	3

E = Elastic resistance, M = machine exercise, E SE = Standard error elastic resistance, M SE = Standard error machine exercise.

resistance. When using elastic resistance the nEMG was higher than 70% during all loads (light to near max) whereas nEMG was higher than 60% during only moderate to near max loads when performing the abduction exercise in the machine. It has been recommended by the ACSM (American College of Sports Medicine) position stand that training intensities above 60% of 1 RM are necessary for sufficient training stimulus for building muscle mass and muscle strength.[19] Accordingly, the high intensity of the exercises, as documented by the high level of nEMG, especially during the elastic resistance exercises, suggests that these exercises could lead to hypertrophy and strength gains if performed on a regular basis.

RM tests are frequently used for estimating intensity of resistance to be used during strength training and rehabilitation.[20] However, repeating resisted lifts to failure may be unpleasant and inconvenient, especially for patients with hip OA or external snapping hip. Additionally, the 10RM test can be time-consuming, and needs to be done quite frequetly in order to assure that the optimal load is being utilized. As an alternative, the Borg CR 10 scale can be a clinically relevant tool for external load adjustment and thus ensure optimal training intensity.

Perceived loading using the Borg CR10 scale has previously shown to be useful for estimating intensity during strength training,[21] and has been evaluated during upper extremity exercises.[10] The Borg CR10 scale during hip abduction and hip adduction offers the therapist a relevant tool for controlling the intensity of the exercise throughout the training session.

Distance runners injured with iliotibial band syndrome or patellofemoral pain syndrome (PFPS) demonstrate diminished muscle strength of the hip abductors when compared to non-injured controls.[5–7,22] The strength deficit may be addressed by specific resistance exercises targeting the gluteus medius.[6] In the present study, the abduction exercise performed with elastic resistance demonstrated high EMG activity in the gluteus medius at all four resistance levels. In targeted strengthening of the gluteus medius following iliotibial band syndrome or PFPS the abduction exercise using elastic resistance potentially serves as a strong alternative to conventional hip abduction exercises in machines.

Rasch et al studied muscle strength in patients following total hip arthroplasty and suggested that exercises targeting the hip abductors should be intense to accelerate the strength gain post operation.[1] Because elastic resistance hip abduction exercises can be performed at home and induce higher muscle activity than the conventional machine exercise, this exercise may be a feasible exercise for inducing a sufficient stimulus for strength gains in the abductor muscles. Furthermore, the use of the Borg CR10 scale may be a practical and relevant tool for estimating intensity levels and ensuring accurate progression during rehabilitation in hip injury patients.

Groin injuries are frequently reported in soccer players,[23,24] and eccentric hip adduction strength has shown to be greater in the dominant leg in soccer players.[8] Furthermore, soccer players suffering from a groin injury shows a strength deficit around the hip compared to pain free soccer players.[25] Eight weeks of hip adduction strength training using elastic resistance showed an increased eccentric hip adduction strength in soccer players.[26] Serner et al studied muscle activity during hip adduction exercises in machine and with elastic resistance[27] and, in general, demonstrated higher nEMG-values than the values obtained during exercises performed with elastic tubing and in exercise machines in the present study. A possible explanation for this difference could emerge from the different starting positions utilized in the two studies. The main difference is that the hip adduction exercise in machine was performed with only a slight knee flexion in the Serner et al study, as compared to the 90° knee flexion angle in the present study. Furthermore the exercises in the present study were performed with a 2 second contraction phase compared to a potentially more fatiguing 6 second concentric phase in the Serner study.[27]

Limitations

The present study was conducted on untrained women, and thus limits the generalizability to this group. Therefore, the authors cannot conclude that the results are applicable to athletes, males, or different types of patients.

Surface EMG has a number of limitations that can directly influences the EMG signal such as thickness of tissue layers, crosstalk and changes in the muscle tissue conductivity.[28,29] These limitations were minimized by having the same examiner to do the electrode placement on all the subjects and by cleaning the skin properly during preparation before the electrodes were secured.

There is some learning required before the subject and the therapist are comfortable using the Borg CR 10 scale. In this study the authors attempted to minimize this limitation by conducting a practice session a week prior to testing where the participants were familiarized with the Borg CR 10 scale.

CONCLUSION

The results of this study indicate that the Borg CR10 scale can be a useful tool for estimating intensity levels during resistance training of the hip adductor and hip abductor muscles. Although elastic resistance and exercise machine seem equally effective for recruiting muscular activity of the hip adductors, the elastic resistance condition was able to demonstrate greater muscular recruitment than the exercise machine during hip abduction, as measured by EMG.

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