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The Flywheel Leg-Curl Machine: Offering Eccentric Overload for Hamstring Development

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***Key Words**:* concentric and eccentric muscle actions, inertial resistance, semitendinosus, biceps femoris EMG

For the sole purpose of developing knee-flexor strength, power, and size, almost any weight room or training facility is equipped with a prone, face-down leg-curl weight-stack machine. Such commercially available machines all aim at targeting and isolating the knee-flexor muscle group. Depending on mechanical design, they differ somewhat with regard to external torque offered and hence muscle use in the desired range of motion. Given the high rate of injury reported for the flexor-muscle group in athletes relying on high horizontal speed and power[1] and the fact that leg-curl machines are frequently used both in prevention and rehabilitation of hamstring injuries, the scant information describing the basic kinematics of this exercise is rather surprising.[2,3] A novel leg-curl device (YoYo™ Technology AB, Stockholm, Sweden) uses the inertia offered by rotating flywheels to provide resistance. Contrary to traditional weight-stack machines, this loading feature allows for exercise with eccentric overload, as shown elsewhere for configurations aimed at other muscle groups.[4-6] With use of the flywheel leg curl, an 8-week training program improved maximal running speed and, perhaps even more important, reduced the incidence of hamstring strains in elite soccer players.[7] Unfortunately, force–velocity profiles and electromyographic (EMG) activity during concentric–eccentric actions on this device were never examined. Here, we report kinematic data in athletes performing all-out knee flexions at different inertial settings using this particular flywheel configuration.

Methods

Twenty male soccer or rugby players volunteered for this study. Ten of these men (age 24.9 ± 2.6 years; body mass 81.3 ± 20.2 kg and height 181.3 ± 7.8 cm) had previous experience (>5 sessions consisting of 4 sets of 7 maximal repetitions) with

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use of this particular exercise device, and 10, with similar physical characteristics and training history (26.3 ± 3.6 years, 85.6 ± 10.3 kg, 179.0 ± 7.3 cm), had only experienced 1 or 2 familiarization sessions. After adjusting leg-pad position and presetting range of motion using the rail-bar pin, subjects performed bilateral knee-flexor actions in the prone, face-down position (hip angle 140° and feet in a neutral position; Figure 1) while holding on to the handlebars of the machine. Acceleration of flywheel rotation was achieved by pushing against the padded lever arm with maximal effort and through the entire range of motion (from close to 180º knee angle). After completion of this concentric action and on rewinding of the flywheel strap in the subsequent eccentric, descending action and while slightly resisting, maximal effort was applied on passing 90° to make the flywheels come to a stop before the next cycle was initiated. One such bout consisted of 6 coupled concentric–eccentric actions. In a random fashion this protocol was executed at 2 different inertial settings using either 1 or 2 polymer wheels: weight 4.2 kg, density 1.4 kg × cm^{-3}, diameter 380 mm, thickness 20 mm, resulting in moment inertia of 0.11 and 0.22, for 1 and 2 wheels, respectively. Force, position, velocity, and root-mean-square electromyography (EMGrms) were recorded in a synchronized manner using the MuscleLab 4000e system (Ergotest AS, Langesund, Norway). Force was measured with a strain gauge (MuscleLab Force Sensor) fixed between the nylon strap that is anchored to the moving lever and winds around the flywheel shaft and a pin at the rear pulley. Position and velocity were measured with a linear encoder placed below the pulley (Figure 1). EMGrms activity was recorded from biceps femoris (BF) and semitendinosus (ST) of the dominant limb, using disposable bipolar Ag-Ag/Cl surface electrodes (Blue Sensor, Medicotest, Olstykke, Denmark) with a 25-mm interelectrode distance and aligned in the fiber direction. In addition, EMG activity was recorded during 3 maximal voluntary isometric actions sustained for 5 seconds at 30º knee flexion. The highest activity measured for each muscle in a 4-second window was used to normalize EMG recorded in the subsequent experiments.

Results

The results are shown in Table 1. Both groups showed greater peak force with increased inertia. Although eccentric peak force was greater than concentric peak force in the experienced subjects, regardless of inertial setting, peak force was no different across different actions in the inexperienced subjects. Average force was markedly greater during concentric than eccentric actions in both groups, regardless of inertia. The average eccentric force increased with increased moment inertia. Peak power was higher during concentric than during eccentric actions only at the lower inertial setting. Peak velocity was higher during eccentric than during concentric actions, regardless of inertia. Concentric and eccentric average velocities were higher with 0.11 than 0.22 moment inertia in both groups. Collectively, EMGrms of both ST and BF during concentric actions exceeded those elicited by MVC. There were no differences in EMG amplitude across muscles. Both subject groups, however, showed greater eccentric:concentric ratio for BF than for ST when the higher-moment inertia was applied. This response was also evident with the lower inertia in the experienced group.

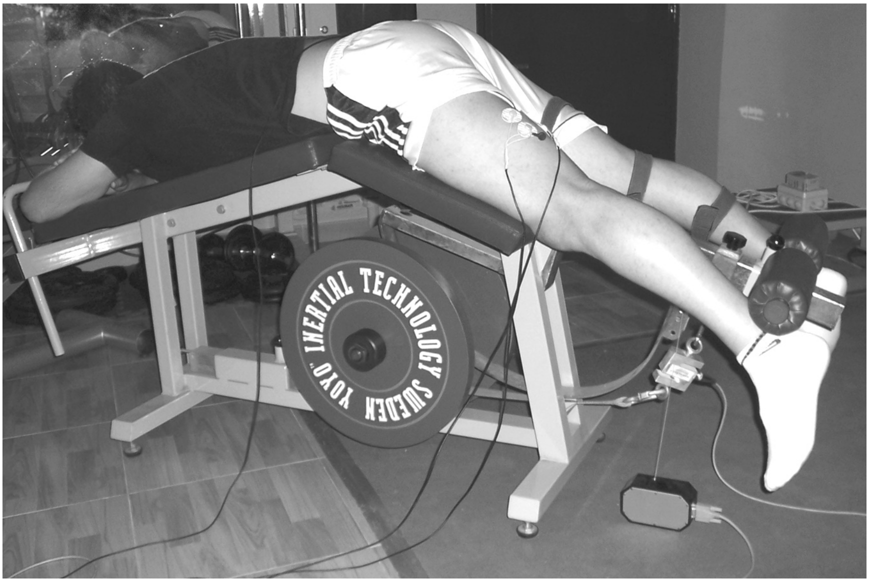

Figure 1 — Leg-curl flywheel machine.

Discussion

Any athlete or coach in the field can witness the difficulties in targeting the hamstring muscles using established resistance-training modalities. The flywheel leg-curl machine described here is designed so that it offers eccentric overload in a range of motion near complete extension about the knee joint. The magnitude of this overload is largely dictated by the trainee. Fine-tuning this strategy appears to require some practice because the athletes who had previous experience using this novel technology showed greater eccentric and concentric peak forces than athletes of the same caliber who were novices with regard to the flywheel exercise. Thus, a certain amount of coordination is needed to apply braking forces at completion of the action near extension eliciting the desired eccentric overload. This adaptation can occur readily and is possible because of the unique inherent features of the flywheel-exercise system. Hence, a trainee could voluntarily delay the braking action of the movement and as a result promote greater eccentric overload. In fact, although range or strategy of applying force in the concentric path were similar across groups, the window where substantial eccentric force was generated occurred later in the range of motion in the experienced group. Whether this indicates that the inexperienced athletes, by means of any involuntary self-protection mechanism, avoided high peak forces in that final part of the eccentric action where the hamstrings are more prone to injury we can only speculate. Nevertheless, a "learning" period appears necessary to fully benefit from this exercise paradigm. Given the complexity of the exercise, providing instant visual force or power feedback could perhaps aid in readjusting performance and getting the athlete accustomed to proper use of the flywheel.

Table 1 Average and Peak Force, Power, Velocity, as Well as Average Normalized EMGrms Activity, in Eccentric and Concentric Phases With Moment Inertias 0.11 (1 Wheel) and 0.22 (2 Wheels)*

Variable	Inertia 0.11		Inertia 0.22	
	Concentric	Eccentric	Concentric	Eccentric
Peak force (N)				
experienced	691 ± 88	722 ± 101†	809 ± 121‡	852 ± 153†‡
inexperienced	596 ± 51	548 ± 45	773 ± 125‡‡	797 ± 137‡‡
Average force (N)				
experienced	523 ± 65†††	295 ± 45	533 ± 67†††	349 ± 33‡
inexperienced	475 ± 83†††	165 ± 55	503 ± 107†††	314 ± 63‡‡
Peak power (W)				
experienced	282 ± 36††	233 ± 46	242 ± 66	225 ± 64
inexperienced	274 ± 72††	174 ± 51	243 ± 70	219 ± 74
Average power (W)				
experienced	189 ± 33†††‡	68 ± 24	146 ± 32	67 ± 24
inexperienced	153 ± 26†††	53 ± 19	147 ± 43††	82 ± 23
Peak velocity (m/s)				
experienced	0.53 ± 0.03‡‡‡	0.67 ± 0.80†††‡‡‡	0.43 ± 0.05	0.49 ± 0.07†††
inexperienced	0.50 ± 0.06‡‡	0.67 ± 0.16 †††‡‡	0.43 ± 0.06	0.54 ± 0.10†††
Average velocity (m/s)				
experienced	0.36 ± 0.02	0.37 ± 0.06	0.28 ± 0.02	0.30 ± 0.03
inexperienced	0.31 ± 0.02	0.40 ± 0.06†	0.28 ± 0.03	0.30 ± 0.04
Average EMGrms (%)				
inexperienced ST	104.7 ± 32†††	57.6 ± 29	111 ± 26†††	82.6 ± 22‡‡
inexperienced BF	103.1 ± 19.0†††	66.4 ± 26.0	97.7 ± 25.0†	83.0 ± 21.0‡
Eccentric:concentric ratio ST		0.55 ± 0.20		0.74.00 ± 0.10
Eccentric:concentric ratio BF		0.63 ± 0.18		0.86 ± 0.13§§
Experienced ST	106.0 ± 11.0†††	62.2 ± 18.0	115.7 ± 20.1†††	71.2 ± 24.0
Experienced BF	102.4 ± 13.0††	76.6 ± 27.0	108.4 ± 15.5††	88.2 ± 24.0
Eccentric:concentric ratio ST		0.59 ± 0.16		0.61 ± 0.16
Eccentric:concentric BF		0.74 ± 0.22§		0.81 ± 0.15§§

*EMGrms indicates root-mean-square electromyography; ST, semitendinosus; and BF, biceps femoris.
†Denotes difference between action types for a given inertia (†$P < .05$, ††$P < .01$, †††$P < .001$).
‡Denotes difference between inertia settings for a given action type (‡$P < .05$, ‡‡$P < .01$, ‡‡‡$P < .001$).
§Denotes difference between muscles for a given action type (§$P < .05$, §§$P < .01$).

With use of conventional leg-curl weight-stack machines, biceps femoris and semitendinosus muscles show modest involvement.[8] This contrasts the current finding of maximal EMG activity of both muscles. Perhaps even more interesting, the biceps femoris muscle showed higher eccentric:concentric EMG ratio than the semitendinosus, and this observation was most evident in the experienced trainees. This finding might suggest that the biceps femoris muscle plays a more critical braking role than the semitendinosus. There were obvious differences in force, power, and velocity profiles elicited depending on the moment inertia applied during exercise. Clearly, employing greater moment inertia is preferable if eccentric-force production and overload and associated training adaptations are emphasized. Conversely, muscle-power and speed enhancements would benefit more from training using reduced moment inertia. Although the optimal requirement to improve either quality clearly would vary among individuals, general guidelines in regard to moment inertial settings have yet to be defined.

If desired, and once the trainee has been properly familiarized, this particular leg-curl flywheel machine offers eccentric overload in a critical window near full extension and after flexion about the knee joint. In contrast, the vast majority of commercially available exercise machines aimed at using the hamstring muscles do not allow for such a loading profile. Indeed, it appears that most machines used in the weight room and elsewhere offer only modest resistance in this particular range of motion.

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