

Eccentric Strength Training: A Review of the Available Technology

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Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (<http://journals.lww.com/nsca-scj>).

ABSTRACT

ECCENTRIC (ECC) STRENGTH TRAINING IS BECOMING INCREASINGLY POPULAR AMONG STRENGTH AND CONDITIONING COACHES AND PRACTITIONERS GIVEN THE PROVEN BENEFITS FOR PERFORMANCE IMPROVEMENTS, INJURY PREVENTION AND REHABILITATION. THE PURPOSE OF THIS ARTICLE IS TO UNDERSTAND THE DEVICES THAT ARE AVAILABLE FOR THE TRAINING OF ECC STRENGTH, THE TECHNOLOGY INVOLVED, AND THE ASSOCIATED ADVANTAGES AND DISADVANTAGES. IT IS HOPED THAT WITH THIS KNOWLEDGE THE PRACTITIONER IS BETTER INFORMED AT MATCHING ECC STRENGTH TRAINING NEEDS WITH THE APPROPRIATE TECHNOLOGY. FOR A VIDEO ABSTRACT DESCRIBING THIS ISSUE, SEE VIDEO, SUPPLEMENTAL DIGITAL CONTENT 1, <http://links.lww.com/SCJ/A198>.

INTRODUCTION

Muscular contractions are typically classified as; concentric (CON—active muscle shortens); isometric (active muscle is neither shortening nor lengthening); and eccentric (ECC—active muscle lengthens under tension). CON contractions occur when the total tension developed in a muscle is sufficient to overcome any resistance to shortening. ECC contractions occur when the tension developed in the muscle is less than the external resistance, and the muscle is therefore lengthened (13). When ECC and CON contractions are coupled, this is termed the stretch-shortening cycle (SSC) (9). Developing ECC strength is thought to be beneficial to sporting performance (2,5,7,14,16), rehabilitation (4,6,10,11,17), and injury prevention (11,17,18), and provides the focus of this article.

ECC contractions are unique in a number of ways as evidenced in the force-velocity relationship of muscle (Figure 1). During a CON contraction, the force generated is always lower than the maximum voluntary isometric contraction. As the load the muscle is required to lift decreases, contraction velocity increases. This occurs until the muscle reaches its

maximum contraction velocity, V_{max} . The force-velocity relationship for a CON muscle contraction is defined as a steep rectangular hyperbola. When the contraction velocity is negative (the muscle is lengthening), the muscle is contracting eccentrically. The force-velocity relationship for an ECC muscle contraction is significantly different from a CON contraction. Supramaximal forces can be generated at both slow and fast contraction velocities. This creates a method of training with high forces at high velocities, which is impossible to produce with CON contractions according to the CON force-velocity relationship (12).

Cowell et al. (2012) discussed how the stress (force/load), strain (length or amplitude of movement), and velocity during the ECC phase could be used to impose a variety of mechanical stimuli that have different adaptational and functional effects. Specifically, they mentioned that different forms of ECC resistance training could be

KEY WORDS:

resistance; equipment; overload; X-Force; REACT; BTE Eccentron; Lifter; YoYo; Flywheel; nHANCE; Cyclus; Exerbotics; Exentrix

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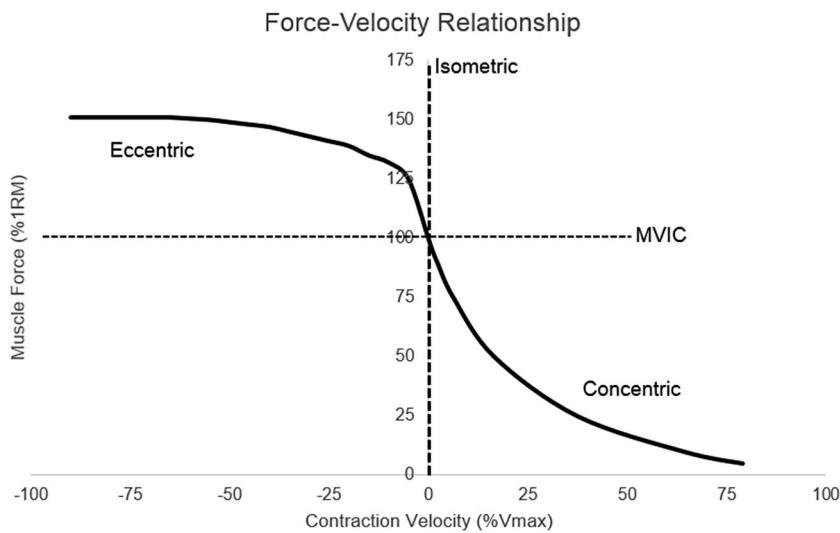


Figure 1. Force-velocity relationship (adapted from Lieber (12)). RM = repetition maximum; MVIC = maximum voluntary isometric contraction.

used for the following: (a) tendon injury rehabilitation by tendinous remodeling; (b) muscle injury prevention by shift in the optimum length of the muscle; (c) supramaximal and/or accentuated ECC loading (i.e., loads

exceeding the 1 repetition maximum and/or greater than the CON load) for strength, performance, and hypertrophy; and, (d) high velocity eccentrics for improved sports performance through SSC optimization.



Figure 2. X-Force seated press.

Given the publicized benefits of ECC training, researchers and practitioners have been interested in designing and developing equipment that can improve the ECC strength of the client/athlete. The aim of this article is to review the technologies available for the development of ECC strength. First, the device is described to understand the nature of the mechanical ECC stimulus. Thereafter, the advantages and disadvantages of each device are discussed. It is hoped that such a treatise of the technology affords the reader a greater understanding of the options available for the training of eccentrics in relation to specific athlete or program needs.

X-FORCE

OVERVIEW

X-Force (Stockholm, Sweden) offer a range of training devices that focus on delivering ECC overload to the user. The devices achieve ECC overload by tilting the entire weight stack 45° during the CON phase and rotating the stack back to the vertical during the ECC phase. X-Force claim that their devices can achieve 40% higher forces during the ECC phase using this technology. The company offers 14 training devices, and each of them eccentrically train a specific movement or muscle group. For example, the conventional leg press machine can be replaced by the X-Force ECC Leg Press. This allows their users to train using familiar movements without having to learn and adapt to new equipment (Figure 2).

ECCENTRIC MECHANISM

The underlying principle behind all X-Force products is to tilt the weight stack by 45° to reduce the load during the CON phase and increase the load during the ECC phase. The free body diagram below explains this concept in more detail:

Figure 3A depicts that the force during the ECC phase will be the total weight of the stack. For example, if the stack

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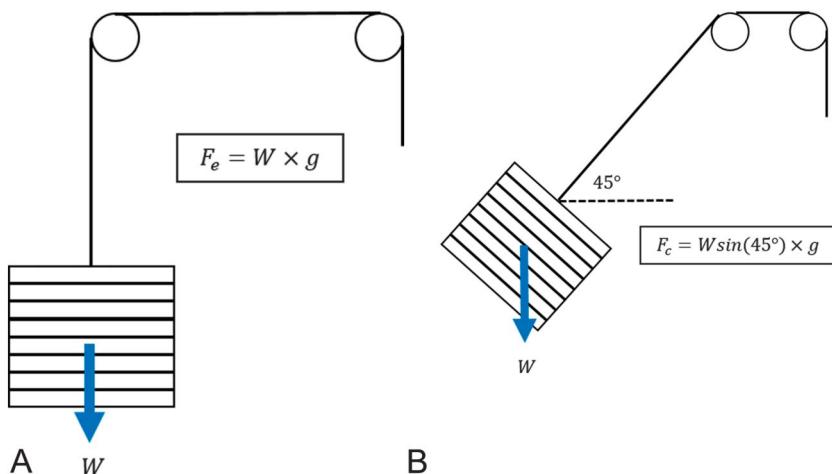


Figure 3. (A) X-force eccentric mechanism. (B) X-force concentric mechanism.

weighs 100 kg, then the ECC force will be 981 N ($F_e = 100 \times 9.81 = 981$ N). Figure 3B depicts the CON phase force. The CON force will now be

a component of the total gravitational force on the stack because it has been tilted by 45°. The CON force for a 100 kg weight stack rotated 45° will be

693.7 N ($F_c = 100 \sin(45^\circ) \times 9.81 = 693.67$ N). In essence, the ECC force is approximately

$$40\% \left(\left[\frac{981}{693.67} - 1 \right] \times 100\% = 41.42\% \right)$$

larger than the CON force thus providing ECC overload.

To use the X-Force device for a training session, the user would set their CON load on the weight stack as per their requirement. They simply move the locking pin to the desired weight, as is the same in most conventional weight stack equipment. At this point the weight stack is already tilted by 45° as the user starts the CON phase. There is a start button on the device which the user engages to initiate the exercise. As the user moves in the positive direction (CON), the weight stack remains tilted. As the user reaches the maximum point in their

Table 1
Advantages and disadvantages of the X-Force devices

Advantages	Disadvantages
Simplicity: The X-Force devices use a very simple concept to achieve the ever so complex goal to overload eccentrically without the need for a second person or spotter. The rotation of the entire weight stack overloads 40% more eccentrically, and it does it automatically. The devices are simple and easy to use. They are based on the conventional weighted stack machines found in most gyms. Therefore, users can train with this technology straight away. The smart programming of the machine removes the need for users to enter or manually set their range of motion. The machine detects when the user is at the positive apex and tilts the stack for the negative/ECC muscle action.	Power, size, and weight: A conventional weight stack in a leg press machine would weigh approximately 100 kg. This equates to a very large moment of inertia ($I \approx 100 \text{ kg} \cdot \text{m}^2$ [for a simple pendulum approximation at $r = 1 \text{ m}$]) and requires a large torque ($\tau = I\alpha$, α = angular acceleration) to tilt the weight stack assembly. This means that the size of the motor and the power it requires would be large. Having all 14 of the devices operating in the gym would increase the overall power consumption. Alterations may have to be made on the switchboard (separate circuit breakers, higher rated fuses, etc.) before any of the devices are installed. The devices are also similarly sized to conventional weighted stack gym equipment. This means they are not portable and cannot be moved easily.
CON and ECC coupled training: X-Force incorporates both CON and ECC motions rather than an ECC only motion. There is evidence which suggests that a coupled CON and ECC overload training method will yield improvements in power (increase in CON force, contractile velocity, and muscle cross-sectional area) (5,6).	Synergistic muscle activation: Because the devices X-Force provide are based on conventional gym equipment, they have a limited number of DOF. They focus on a particular movement or muscle group and limit the contribution from fixators and synergistic muscles (i.e., the seated chest press focuses primarily on the pectoral muscle group and does not engage the core to provide stability).
Safety: Safety features on these devices are identical to the safety features found on conventional weighted stack gym equipment (i.e., safety pins and range of motion limits). Hence, users will be familiar with the safety risks and hazards.	Nonadjustable ECC overload: The ECC overload is set and cannot be changed (40%). Users may want a higher or lower ECC overload depending on their training requirements or training status. Ideally, a device that can allow users to alter the ECC overload would be the most beneficial.

CON = concentric; DOF = degree of freedom; ECC = eccentric.

range of motion (ROM) and starts to move in the negative direction (ECC), the device tilts the weight stack to the vertical position which overloads the movement by an additional 40%. The device tilts the stack every time the user transitions between CON and ECC phases. This is an isoinertial device, which means the inertia of the load is constant and the speed of movement is controlled by the user (i.e., free weights).

TECHNOLOGY

To tilt the weight stack, X-Force devices use an electric servomotor. Apart from this, X-Force does not reveal any technical details about the technology it is using. The size, weight, and color of the devices are the only other technical specifications X-Force shares with the public.

ADVANTAGES VERSUS DISADVANTAGES

Advantages and disadvantages of the X-Force devices are described in Table 1.

VALIDATION

X-Force alludes to the benefits of negative or ECC training; however, there is no mention as to whether their devices have been used in any empirically validated research at this time. Furthermore, the magnitude of the loading associated with the technology is estimated by free body calculations. The validation of the actual loading provided by this technology is not readily observed from the Web site. For example, a stack load of 100 kg could be very different depending on the design/inertia of the system.

REACT ECC TRAINER

OVERVIEW

The REACT ECC trainer (Atlanta, GA) is a device that provides isokinetic ECC overloading for the lower body. The user is on a rotating platform, and he/she absorbs the force generated with their knees. The name REACT



Figure 4. REACT ECC Trainer.

stands for Rapid Eccentric Anaerobic Core Trainer (Figure 4).

ECCENTRIC MECHANISM

This is an isokinetic device which means it is moving at a constant speed. In this case, the platform is rotating at a constant range of speed (rpm), which can be adjusted by the user before and during the workout. The device has a touchscreen panel to set the speed and a safety tag that clips on the user's clothes (similar to a treadmill). The device has 2 rotating drums that are joined together with a platform. This creates an elliptical path for the platform (Figure 5).

Because this is an isokinetic device, the ECC overload or resistance is entirely dependent on the user. The user can simply ride the device, but to benefit

eccentrically from the exercise, the user must absorb the rotation by bending their knees and engaging the lower-body muscles. The faster and deeper the user does this, determines the magnitude of the ECC overload. The user can hold on to the rail or let go, which engages the core musculature to a greater extent as the user tries to stay balanced. The user stands on the platform and begins to exercise by pressing the start button on the touchscreen. They can stand either facing forward, sideways, left, or right on the device to perform various exercises.

TECHNOLOGY

REACT provide a list of technical specifications on their Web site. The rotating speed ranges from 30 to 70 rpm. The features of this device are similar to a conventional treadmill. It

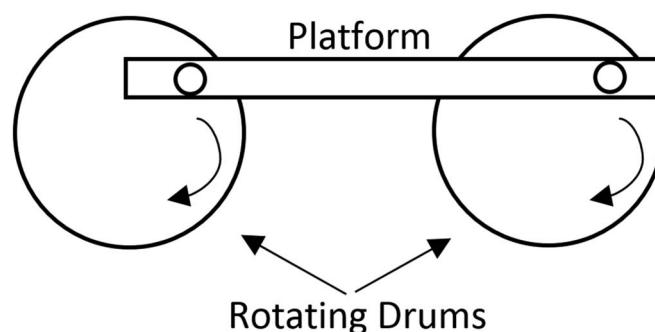


Figure 5. REACT ECC mechanism.

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has the same safety tag feature with an emergency stop on either side. It also has a touchscreen control panel which is becoming more common among recreational fitness equipment.

ADVANTAGES VERSUS DISADVANTAGES

Advantages and disadvantages of the REACT ECC Trainer are described in Table 2.

VALIDATION

This rotating platform concept, also termed “quadmill”, first originated from skiing. It was developed for skiers to simulate the absorbing motion of the lower body when skiers navigate moguls in the snow. REACT have tried to introduce this to the recreational gym-goer. To

state its reliability and validity, REACT references the various benefits of ECC training. However, there is no mention as to whether this device has been used in any empirically validated research at this time.

BTE ECCENTRON

OVERVIEW

BTE is a company based in Maryland, USA, and their ECC training device is called the Eccentron. The Eccentron is an isokinetic device that simulates downhill walking. It can be described as an ECC recumbent cycle. The device provides adjustable resistance of up to 3,300 N at speeds between 12–48 rpm. It has a touchscreen where the user can see their workout progress and a remote to control the speed.

ECCENTRIC MECHANISM

The Eccentron aims to bring the benefits of downhill running ECCs to the user. As stated earlier, the device is the ECC version of a conventional CON recumbent cycle. The pedals of the Eccentron push toward the user, and the user must resist this push to perform the ECC exercise.

The user initiates the exercise by simply pressing the start button on the remote. This remote also controls the speed of the exercise allowing users to go faster or slower depending on the training requirement.

TECHNOLOGY

BTE states that the Eccentron is capable of producing forces up to 3,300 N on each leg and an operating speed of 12–48 rpm. BTE does not reveal

Table 2
Advantages and disadvantages of the REACT ECC Trainer

Advantages	Disadvantages
Synergistic muscle activation: By absorbing the rotation and keeping your hips level, this compound ECC squat recruits more synergistic contribution than devices such as the X-Force leg press. The exercise can be made more difficult by simply letting go and holding your hands over your head. This engages the core muscles as well.	Simplicity: The general population of users such as athletes and patients will not be familiar with this technology and familiarization with the exercise and the permutations will take some time. This will be especially so when the individual starts to let go of the railing and engage their core.
Adjustable ECC load and velocity: The ECC overload can be adjusted by the user and depends on how hard they resist the rotation of the platform. The RPM of the platform can also be adjusted by the user. This allows coaches and practitioners the ability to train with a large number of permutations. The ability to change the velocity of the exercise is an important factor, allowing users to train to various goals. For example, athletes can train at higher velocities to increase the volume of work and also increase power. Rehabilitation patients can train at lower velocities to slowly strengthen without exposing them to further injury risk.	CON and ECC coupled training: The device overloads the ECC contraction only. As the platform rotates from the bottom-most position to the top, the lower body is absorbing the resistance, and the muscles are working eccentrically. As the platform rotates from the top-most position to the bottom, the resistance is removed, and the muscles are relaxed. This cycle continues throughout. As mentioned earlier, a coupled CON and ECC overload training method can be more beneficial.
Safety: There is a safety tag similar to those found on conventional treadmills. The device also has 2 large emergency stop buttons and infrared light beams that stop the device when broken. These safety features reduce the risk of injury by immediately stopping the rotating platform in the event of an emergency.	Power, size, and weight: The REACT device weighs 280 kg and is 2,300 × 1,090 × 1,420 mm (L × W × H). The size and weight of this device are similar to a conventional treadmill and hence will not be portable and easy to move. It runs on single-phase 120–140 V power. For countries that operate with 230 V power, an additional voltage transformer will have to be purchased to operate the device. There is no indication of current or power rating. This must be accounted for before installation in the switchboard as most domestic limit single-phase current to 10 A only. This is equivalent to 2,400 W of electrical power.

CON = concentric; ECC = eccentric.

anything else about the technology inside the device.

ADVANTAGES VERSUS DISADVANTAGES

Advantages and disadvantages of the BTE Eccentron are described in Table 3.

VALIDATION

Similar to the other device manufacturers, BTE states the various benefits of ECC training for different types of patients. They provide a list of references on their Web site citing the benefits of ECC training to validate the device. At this time, no empirically validated research has directly investigated the benefits or the technology of the BTE Eccentron. Furthermore, the validation of the specifications stated by BTE is not readily observed from the Web site.

EXENTRIX BY SMARTCOACH

OVERVIEW

Exentrix by SmartCoach (Stockholm, Sweden) is a multixercise cable pulley training device that is based on the conventional weight stack cable pulley. However, instead of a weight stack, the Exentrix has an electric motor that controls the load. The device is wall mounted and has a 4-m cable drum.

Because it is a cable pulley device, it allows users to train many modes and exercises, just as a conventional cable pulley device would. The device allows users to manually change the level of ECC overload, as well as train in iso-inertial and isokinetic modes. It has a smart touchscreen user interface that controls the device.

ECCENTRIC MECHANISM

The device uses an electric servomotor to provide resistance and the ECC overload. For example, if the user wishes to perform an isokinetic squat (the speed of the movement is constant), they would first wear a harness that connects to the end of the cable from the device (as shown in Figure 6). The coach then configures the exercise settings (ROM, repetitions, and velocity) on the touchscreen panel. During the CON phase of the squat, the electric servomotor unwinds the cable at a constant velocity, and during the ECC phase, the cable is wound back in at a constant velocity. In isokinetic mode, the resistance is controlled by the user. This mechanism is similar to other isokinetic modes found on devices such as the BTE Eccentron and the REACT ECC Trainer.

TECHNOLOGY

SmartCoach provide a detailed list of technical specifications for the Exentrix device on their Web site. The 2 most important specifications are the maximum force of 800 N (1,600 N with pulley) and the maximum velocity of 3.9 m/s (1.9 m/s with pulley). Exentrix uses an electric servomotor to control the force and the velocity of the exercise. The electric servomotor is connected to a cable drum which either winds the cable in (ECC) or resists the unwinding of the cable (CON). Electric servomotors are uniquely versatile as their position, velocity, acceleration, and torque/force can be accurately controlled by software. This allows the Exentrix device to operate with various training modes such as isotonic (resistance is a constant force); iso-inertial (creates an inertial load proportional to acceleration); and isokinetic (velocity is constant regardless of force).

ADVANTAGES VERSUS DISADVANTAGES

Advantages and disadvantages of the Exentrix by SmartCoach are described in Table 4.

Table 3
Advantages and disadvantages of the BTE Eccentron

Advantages	Disadvantages
Simplicity: The simplicity of the machine wins it some credibility among recreational users and physical therapists working with patients. The gait pattern associated with recumbent cycling is somewhat natural to humans. To elaborate, the user does not need a long learning session to familiarize themselves with the exercise.	Power, size, and weight: This device weighs 325 kg and is 2,490 × 710 × 1,500 mm (L × W × H). It operates on single-phase universal voltage (100–250 V). There is no indication of current or power rating.
Adjustable ECC load and velocity: Similar to the REACT trainer, the ECC load depends on how hard the user resists the push of the pedals. The speed is also controlled by the user. This is achieved using a remote near the hand grip. This allows the speed to be adjusted during a session.	Synergetic muscle activation: The Eccentron focuses solely on lower-body muscle groups. During the exercise, no other fixator or synergetic muscles are activated to aid the exercise such as core muscles.
Safety: Because this device is a recumbent bike, safety is not a big issue. The likelihood of harm to the user is minimal. The user can “ride” the bike without exerting any force, and there is an emergency stop in the remote controller next to the user.	CON and ECC coupled training: The Eccentron does not enable overloading of the CON contraction.

CON = concentric; ECC = eccentric.



Figure 6. Exentrax squat.

VALIDATION

Exentrax by SmartCoach does not seem to have any evidence of validation on their Web site. The Web site also does not reference any literature regarding ECC training. It is unclear whether the device has been used in any studies or literature. The validity of their products relies heavily on the credibility of the cofounder, Per Tesch, Professor of Muscle Physiology at Karolinska Institute of Stockholm.

EXERBOTICS

OVERVIEW

Exerbotics (Tulsa, Oklahoma) provide a range of isokinetic devices.

Similar to the X-Force, these devices are based on conventional weighted stack devices, such as chest press; shoulder press; leg press; leg extension/curl; and squat machine. Each device is powered by a linear actuator that delivers the load and controls the speed. There is a load cell that displays the CON and ECC force on a touchscreen for the user (Figure 7).

ECCENTRIC MECHANISM

Exerbotics label their technology as “iso-velocity” that is isokinetic. They are implying that the speed is constant during both CON and ECC phases. The display outputs a detailed strength curve for both phases, which

is graphed in real time as the exercise is executed.

To perform the exercise, the user has to first set their desired ROM. They do this by moving the machine with the software to the desired start and end positions. Each exercise can be customized in terms of number of repetitions. The device starts with the CON phase first. It carries on until the number of reps has been completed. During both the CON and ECC phases, the device moves at a constant speed. The speed is independent of the force the user produces.

TECHNOLOGY

All the Exerbotics devices share the same linear actuator technology. This linear actuator provides a single degree of freedom (DOF) of motion. The linear actuator uses a roller screw and a brushless servomotor. A maximum force of 6,220 N is produced by the Exerbotics squat machine at a speed of 0.341 m/s as reported on their Web site. There is a load cell which is mounted directly on the shaft of the actuator. This load cell provides the data for the strength curve.

ADVANTAGES VERSUS DISADVANTAGES

Advantages and disadvantages of the Exerbotics are described in Table 5.

VALIDATION

Again similar to the other devices, Exerbotics states the benefits of ECC overload training. A reliability study was undertaken using the Exerbotics Squat device and found moderate-to-high reliability for the peak and mean force values obtained from the device (19). At this time, there seems to be no other empirically validated research that has used the Exerbotic devices.

nHANCE FLYWHEEL YoYo

OVERVIEW

nHANCE (Stockholm, Sweden) is a company that provides flywheel

Table 4
Advantages and disadvantages of the Exentrix by SmartCoach

Advantages	Disadvantages
Power, size, and weight: The device is relatively small. It comprises a motor and cable drum that is then mounted on the wall for stability. The exact dimensions are not given, but looking at the images and videos, it is a lot smaller compared with the other ECC devices. It runs on single-phase power and has a current rating of 5 A. It is electrically protected, and there is no need for modifications on the switchboard.	Simplicity: Having multiple DOF and the ability to choose specific training modes can confuse the user. Although having more variable parameters creates a versatile design, it also adds complexity to the interface. A user cannot simply start an exercise on this device without familiarizing themselves with the equipment first. Thorough instruction manuals and video tutorials are needed. It is unclear whether SmartCoach provide this on purchase of the device.
Synergistic muscle activation: Because the concept of this device is based on a conventional cable pulley, there are a large number of exercises that can be performed by the user. The device also has a larger number of DOF than other ECC devices and therefore greater potential use of synergistic and fixator muscle groups.	
CON and ECC coupled training: The device can overload both the ECC and CON contractions. The user can also choose between ECC only or CON only.	
Safety: The device has an emergency stop switch/pedal, a safety class BF logic controller, and an electronically controlled range of motion. The risk of injury to the user is mitigated through these features by stopping the motor and removing the load.	
Adjustable ECC load and velocity: The ability to change contraction modes shows that it is a complex system with multiple adjustable parameters. Coaches and practitioners can optimize the parameters (velocity, force, and contraction mode) depending on the user.	
CON = concentric; DOF = degree of freedom; ECC = eccentric.	

or inertial ECC training devices. They offer 5 different training devices (squat, knee extension, leg curl, leg press, and multigym). These devices are all based on the same flywheel principle. A flywheel uses the concept of inertia and the conservation of energy to provide ECC overload, similar to a yo-yo (Figure 8).

ECCENTRIC MECHANISM

The flywheel is the component that provides the ECC overload. It does this by releasing the energy stored during the CON phase. For example, as the user pushes up during the CON phase, energy is being stored into the flywheel. As the user reaches the end of the CON phase and starts to move in the other direction,

the flywheel releases all the stored energy in the form of a large torque. This torque is greater than the torque applied during the CON phase. This is because the flywheel wants to return to its original state as fast as it can. Therefore, there is a large angular acceleration in the opposite direction which equals to a large torque ($\tau = I\alpha$, where τ = Torque, I = Moment of Inertia, α = angular acceleration). This large torque generates a large force on the subject, and hence, the ECC overload is achieved.

The reason a flywheel behaves this way is because of the first law of thermodynamics (conservation of energy) and Newton's laws of motion (an object at rest stays at rest and an object

in motion stays in motion with the same speed and in the same direction unless acted on by an unbalanced force. This is also known as conservation of angular momentum). The flywheel has an inertia I . When a subject rotates the flywheel at an angular velocity ω , the energy the flywheel absorbs is governed by this equation:

$$E_k = \frac{1}{2}I\omega^2$$

This means that the faster the subject performs the CON phase, the greater the energy stored in the flywheel and a greater ECC overload results. A point to note is that the energy exerted by the athlete during the CON phase is the same during the ECC phase (neglecting heat loss

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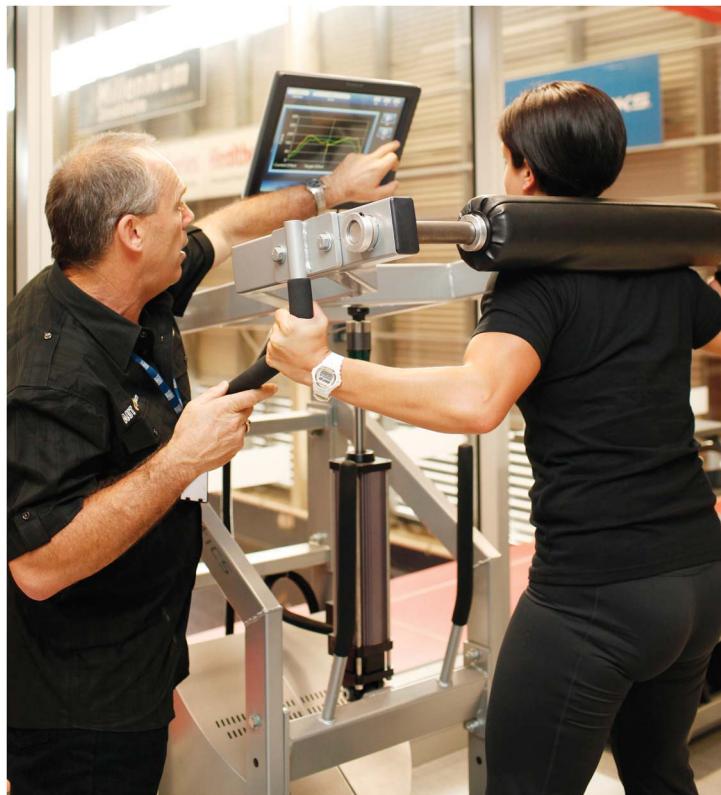


Figure 7. Exerbotics squat machine.

and vibrations), even though the ECC phase creates a greater force. The difference between the 2 phases is the velocity of the movement. During the ECC phase, the initial angular acceleration of the flywheel is large but the angular velocity is small.

TECHNOLOGY

nHANCE state that they use an aluminium flywheel with an inertia of up to $0.05 \text{ kg}\cdot\text{m}^2$. Because this design is purely mechanical, there is no electronic control or interface software.

ADVANTAGES VERSUS DISADVANTAGES

Advantages and disadvantages of the nHANCE flywheel YoYo are described in Table 6.

VALIDATION

The flywheel device, compared with the other devices reviewed, has been thoroughly validated through published studies. There are hundreds of studies that have used the flywheel devices to administer ECC overload. Some of these studies

Table 5
Advantages and disadvantages of the Exerbotics

Advantages	Disadvantages
Simplicity: The Exerbotics devices, just like the X-Force devices, are based on conventional weighted stack equipment. This makes it easier for the user to learn and start using the device. From personal experience, the software is also very simple and easy to use. The software is operated on a touch screen. It is a minimalist design with large buttons, texts, and a real-time strength curve.	Power, size, and weight: The Exerbotics devices are slightly larger and heavier than conventional weighted stack gym equipment. The specifications for individual devices are listed on their Web site. They also require 110 V single-phase power. This means countries that operate on 230 V power supply have to buy a special voltage converter to change the voltage to 110 V at 60 Hz.
CON and ECC coupled training: The Exerbotics devices overload both CON and ECC muscle actions.	Nonadjustable contraction velocity: The speed of the exercise is set and cannot be changed by the user. For the squat machine, it is set to 0.341 m/s. The default speed varies with different machines.
Safety: The Exerbotics has software-configured ROM limits and an emergency stop in short reach of the user to stop the linear actuator and bring the moving platform to a halt. The user can also "ride" the device by exerting no force. This is an advantage for all isokinetic devices.	Synergetic muscle activation: Similar to the X-Force devices, the Exerbotics devices only have a single DOF. For example, chest press or squat. These exercises limit the number of synergetic muscles activated.
Adjustable ECC and CON load: Because this is an isokinetic device, the load is dependent on how hard the users resist during the ECC phase and push/pull during the CON phase.	

CON = concentric; DOF = degree of freedom; ECC = eccentric; ROM = range of motion.

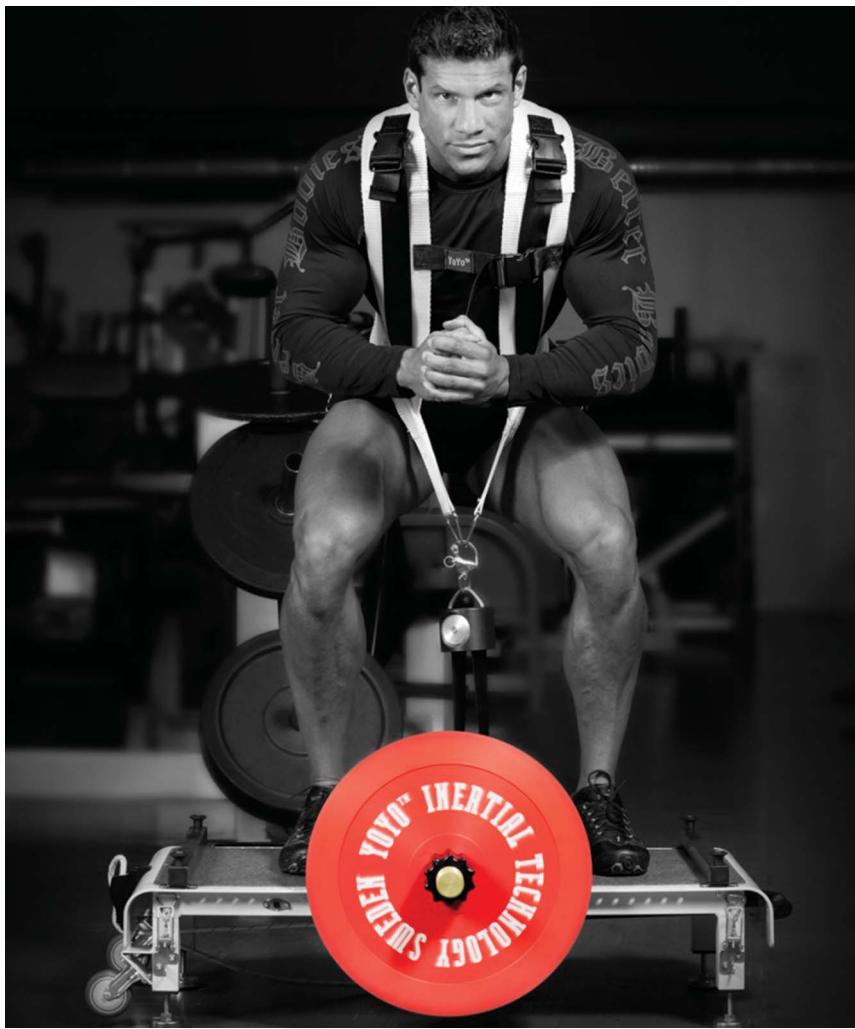


Figure 8. nHANCE YoYo.

prove that the ECC overload administered by this machine increases performance (4,8,15,20). Per Tesch is a major contributor to the studies around the flywheel devices and its validation.

LIFTER BY INTELLIGENT MOTION

OVERVIEW

Intelligent Motion (Linz, Austria) has developed an ECC training device called the Lifter. This device uses moving support arms that spot the athlete during the CON phase. This reduces the CON load and allows users to train with heavier ECC loads. A conventional barbell is used

which allows for a variety of exercises. The device can perform simulated loads with a fixed bar. The device also has an isokinetic measurement feature similar to the Exerbotics device.

ECCENTRIC MECHANISM

The ECC overload is achieved by reducing the CON load during the exercise. The device uses 2 moving support arms. During the ECC phase, there are optical sensors in the support arms that track the position of the barbell. The support arms are then lowered at the speed the user lowers the barbell during the

ECC phase. Once the user has reached their lower ROM limit, the support bars drive the barbell up, reducing the CON load. A touchscreen user interface allows the user to program their ROM and choose their CON assist.

This mechanism of ECC overload is isoinertial, where the contraction velocity is determined by the user. However, this device is also capable of isokinetic ECC and CON loading. Intelligent Motion has called these simulated forces. In the support arms, there is a slot for a bar to be placed. The support bars then "simulate force" by moving at a constant speed, and the user resists. This mechanism is the same mechanism the Exerbotics devices use. The support bars can also be used for isometric loading and force measurement.

TECHNOLOGY

The moving support arms are the source of the ECC mechanism. Intelligent Motion has not disclosed the technology used to drive the support arms. However, an assumption can be made with the size and power requirements of the device. The structure of the device is tall rather than wide, suggesting linear actuators are used, similar to the Exerbotics devices. The 3-phase power requirement suggests the likelihood of alternating current servomotors driving the linear actuators in a roller-screw arrangement, similar to the Exerbotics device. The support arms can produce a maximum simulated force of 250 kg and can withstand maximum free barbell load of 400 kg. The speed of the support arms is limited to a maximum of 1.4 m/s.

ADVANTAGES VERSUS DISADVANTAGES

Advantages and disadvantages of the Lifter by Intelligent Motion are described in Table 7.

VALIDATION

Intelligent Motion does not provide any evidence of validation through

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Table 6
Advantages and disadvantages of the nHANCE flywheel YoYo

Advantages	Disadvantages
CON and ECC coupled training: The nHANCE flywheel devices deliver both CON and ECC training stimuli. An added benefit of the flywheel device is that it encourages users to be explosive during the CON phase, and this will generate an even greater force during the ECC phase. A larger volume of work can be achieved with fewer repetitions.	Nonadjustable ECC load and velocity: The flywheel device works on the principle of conservation of energy. This means that the more energy the user puts in the CON phase, the more the device will exert during the ECC phase. The force and speed is solely based on the user. None of the parameters can be monitored by a coach or practitioner. The force and velocity cannot be measured without adding external sensors and data acquisition hardware. This limits performance analysis significantly as there is no feedback for the coach or practitioner.
Power, size, and weight: These devices are small, lightweight, and portable. They do not require any power source. This allows them to be used in any environment.	
Synergistic muscle activation: On each of the nHANCE devices, the user can perform multiple exercises. For example, the squat machine can perform squats, deadlifts, and vertical row. The user is tethered to the flywheel using a flat band. This increases the DOF allowing the activation of synergistic and fixator muscles.	
Simplicity: No doubt this device has to be the simplest design of all the ECC training devices. It uses the laws of physics to effectively achieve ECC overload. The device itself seems straight forward and simple to use. Users will take little time to get familiarized with it.	
Safety: Because of the device's simplicity, the risk of injury is very low. Therefore, it does not require additional safety features.	

CON = concentric; DOF = degree of freedom; ECC = eccentric.

published research. They state the benefits of ECC training and discuss the involvement of academics in the development of the Lifter but do not reference their claims.

CYCLUS 2 ECCENTRIC

OVERVIEW

The Cyclus 2 Eccentric (Leipzig, Germany) is an ECC cycling ergometer. ECC cycling is a concept that has been around since the 1950s ever since Abbott et al. (1) made the first ever ECC cycle. Instead of pedaling the crank forward (CON), the cycle pushes back and the user must resist the push, driving the crank backward (ECC). ECC cycles have since been developed and used for research and training purposes (3). However, now there is a commercially available

technology that can be purchased by coaches and practitioners. The user attaches a bike onto the device (12T sprocket 1/2 × 1/8 inch). It can be driven in isokinetic (constant cadence, rpm) or isotonic (constant torque—Newton meter, or constant power—Watts) mode. It has a maximum power of 900 W (Figure 9).

ECCENTRIC MECHANISM

When the force the user exerts on the pedals is large enough to rotate the crank, the motion is termed CON. If the force the pedal exerts on the user is larger than the resisting force exerted by the user, the pedals will drive the user's feet backward. This is termed an ECC motion. As the pedals move toward the user, the user resists by applying force to the pedals. Because the magnitude

of the force produced by the electric motor on the device exceeds that produced by the user, leg extensors actively lengthen (ECC muscle action).

The ECC force is difficult to produce through the entire revolution of the crank. The bike also has a tendency to oscillate left to right. When resisting at maximal loading, the crank drives the user out of the seat. It is difficult to stay seated while resisting maximally.

TECHNOLOGY

The Cyclus 2 Eccentric uses an electric motor to drive the pedals of the bike. The maximum power the system can produce is 900 W. There is no other technical information that can be gathered from their Web site.

Table 7
Advantages and disadvantages of the Lifter by Intelligent Motion

Advantages	Disadvantages
Simplicity: This device can be compared very closely with the Exerbotics device. It shares the same isokinetic mechanism and software that is user friendly and easy to use. A brief look through their instruction manual and users can operate the software with little difficulty. The isoinertial mechanism also aides in the device's simplicity as it allows users to train with a barbell. Users can train with familiar exercises such as squats, bench press etc. without needing to go through a long familiarization session.	Power, size, and weight: The device requires 3-phase 400 V electrical power, and it consumes 15 A current. To install this, an electrician will have to route power from the main board and install protection circuitry. The device weighs 650 kg and stands 2,650 mm tall. To install this equipment, it will need to be forklifted and hoisted into its place, and it cannot be moved once installed.
CON and ECC coupled training: The assist during the CON phase allows users to train with both CON and ECC loads. The isokinetic mode also allows users to train with both CON and ECC loads.	
Synergetic muscle activation: The isoinertial mode uses a free-weight barbell and, hence, increases the DOF of the device. This not only increases the number of exercises that can be trained but also increases the use of synergistic and fixator muscle groups.	
Safety: The moving support arms enable users to train with high ECC loads without increasing the risk of injury. In an emergency, the arms can be used as safety bars to dump the weight.	
Adjustable ECC load and speed: During the isoinertial mode, the CON load assist can be adjusted. Hence varying the CON to ECC load ratio. During the isokinetic mode, the speed can be increased to 1.4 m/s for high-speed ECC training.	
CON = concentric; DOF = degree of freedom; ECC = eccentric.	

There is no indication of the rpm the device can produce. However, it can be assumed that it will not exceed 120 rpm, and the range will be within normal operating speeds (approximately 30 rpm–100 rpm).

ADVANTAGES VERSUS DISADVANTAGES

Advantages and disadvantages of the Cyclus 2 Eccentric are described in Table 8.

VALIDATION

This device has not been empirically validated through research. However, similar ECC cycles have been validated. Elmer et al. (2013) proved that ECC cycling is an effective method for improving leg spring stiffness and

maximum power during multijoint tasks that include SSCs (3).

ARX FIT

OVERVIEW

ARX Fit (Chicago, IL) offer 2 isokinetic training devices (ARX Omni and ARX Alpha). These devices are similar to the Exentrix device. They are based on conventional cable pulley weight stack equipment. An electric motor replaces the weight stack to provide the resistance. The name ARX stands for adaptive resistance exercise.

ECCENTRIC MECHANISM

The ECC mechanism of the ARX devices is identical to the Exentrix devices. They both use electric

servomotors to achieve ECC overload. However, ARX devices operate in isokinetic training mode only.

TECHNOLOGY

The ARX devices use an electric servomotor and a drive belt system. The drive belt is attached to a load cell which measures the force. The software is displayed on a standard monitor and is controlled by wireless controllers in the handles. An additional wireless controller can be used by the coach/practitioner. ARX does not reveal any other technical information regarding the maximum force output of the motor. ARX state on their Web site that the fastest movement velocity permitted is between 3 and 5 seconds during each CON and ECC

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Figure 9. Cyclus 2 Eccentric.

phase. The slowest speed permitted is approximately 1 minute during each CON and ECC phase. Because ARX have stated the movement velocities in units of time (seconds) rather than velocity (meters per second), the actual movement velocity will vary depending on the ROM.

ADVANTAGES VERSUS DISADVANTAGES

Advantages and disadvantages of the ARX Fit are described in Table 9.

VALIDATION

ARX do not provide any evidence of validation through published research.

They focus on their “adaptive resistance exercise” mechanism by comparing it with conventional weight stack equipment. They state that their device matches the force produced by the user, whereas in a weight stack machine the force is constant. They are essentially comparing isokinetic with isoinertial training modes. They claim that isokinetic training is better without stating any particular training adaptations or referencing empirically validated research.

CONCLUSIONS

ECC training has proven benefits; however, over time the challenge has always been to find a training tool that coaches and practitioners can use to safely and efficiently administer an ECC training stimulus. More and more ECC training devices are being developed to try and resolve this issue, and this review aimed to provide a better understanding of commercially available ECC training devices, the technology used, and the advantages and disadvantages.

Table 8
Advantages and disadvantages of the Cyclus 2 Eccentric

Advantages	Disadvantages
Simplicity: The device is very simple and easy to use. The user interface is simple to operate, and a real-time measure of the power shows the user how hard they are resisting the push.	CON and ECC only coupled training: This device only performs ECC loading.
Adjustable ECC load and speed: The device can be controlled in 3 modes; isokinetic (cadence), power controlled (Watts), and torque controlled (Newton meter). The speed and load can both be changed. The load, speed, and power are measured as real-time feedback for the user and the coach or practitioner. The software allows the data to be exported for further analysis.	Synergistic muscle activation: The device has 1 DOF and does not activate synergistic or fixator muscle groups.
Safety: Similar to the other isokinetic devices, the user can “ride” the device to reduce the ECC load. There is an emergency stop that the coach can operate to stop the motor. It is essential to have a coach or practitioner to operate the device for the user.	
Power, size, and weight: The device is small, lightweight, and portable. The user connects his or her bike which removes the need of having to change the height of the seat and other settings for different users. The device uses single-phase power and does not require any additional circuit protection. The device can be easily moved from one training environment to another.	

CON = concentric; DOF = degree of freedom; ECC = eccentric.

Table 9
Advantages and disadvantages of the ARX Fit

Advantages	Disadvantages
Synergetic muscle activation: Similar to the Exentrix device, this device is based on a conventional cable pulley, and there are a large number of exercises that can be performed by the user. The device also has a larger number of DOF than other ECC devices and, therefore, greater potential use of synergistic and fixator muscle groups.	Power, size, and weight: The Omni is $3,353 \times 762 \times 2,438$ mm (L \times W \times H). The Alpha is $2,438 \times 762 \times 1,524$ mm (L \times W \times H). They both weigh approximately 227 kg and require 120 V power supply to operate. This means countries that operate on 230 V power supply have to buy a special voltage converter to change the voltage to 110 V at 60 Hz. There is also no current or power rating provided. These devices are large and heavy.
Simplicity: The ARX devices are based on conventional cable pulley machines found in most gyms. Therefore, users can train with this technology straight away.	
CON and ECC coupled training: The device can overload both the ECC and CON contractions.	
Safety: Similar to the other isokinetic devices, the user can "ride" the device to reduce the ECC load. There is an emergency stop that the coach or user can operate to stop the motor.	
Adjustable ECC and CON load and velocity: Because this is an isokinetic device, the load is dependent on how hard the users resist during the ECC phase and push/pull during the CON phase. The movement velocity is also adjustable.	

CON = concentric; DOF = degree of freedom; ECC = eccentric.

In summary, devices were isoinertial (X-Force and nHANCE YoYo), isokinetic (REACT, Eccentron, Exerbotics, and ARX), or both (Exentrix, Lifter, and Cyclus 2 Eccentric). Devices that enable both isokinetic and isoinertial, and allowed coaches or practitioners to switch between modes, may better optimize the training of the athlete and/or client. The ability to adjust the load and the speed on a device is another advantage to the coach or practitioner in terms of program design. Devices such as the X-Force and the nHANCE YoYo do not have the capability to adjust these parameters and are hence at a disadvantage to the rest of the training devices reviewed. CON and ECC coupled training has proven to be a better training method than ECC only (5,6). Hence, devices such as the BTE Eccentron, REACT, and Cyclus 2 Eccentric are disadvantaged in this respect; that is, they offer only one contraction mode. Safety of the user

is extremely important when performing ECC training because ECC overload can involve supramaximal loads and faster speeds, which increases the risk of injury. All devices acknowledged and mitigated this risk. The number of DOFs in terms of movement associated with a device can limit the utility and applicability to activities of daily living and sporting performance. Devices such as the Lifter, Exentrix, REACT, ARX, and nHANCE YoYo provide larger number of DOF and, hence, have the ability to provide better activation of synergistic and fixator muscles. The simplicity of a device determines how easily the device can be set up and used and also how long users take to become familiarized with the device. The Exentrix device comes with a large number of options and settings that it may confuse the user. The REACT device uses an ECC mechanism and technique that most users will take some time to familiarize themselves with. All

devices, except the nHANCE YoYo and Cyclus 2 Eccentric, are large, heavy, and immovable once installed. The nHANCE YoYo is also the only device that does not require a power source. Power, size, and weight may not be significant factors for most coaches and practitioners, but they still need to be considered nonetheless.

Please note that the authors have only had first-hand experience with the Exerbotics, the nHANCE YoYo, and the Cyclus 2 devices, and most of the information for this review has been derived from Web site information, the veracity of which is unknown. The reader needs to be cognizant of this limitation and that the details provided by manufacturers are sometimes inadequate for a full understanding of the devices. If the reader is interested in a particular device, we advise they contact the manufacturer directly and request a trial of the device to experience the ECC overload it provides.

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From the devices reviewed, it can be concluded that there is no one device that will benefit all needs of the coach and the practitioner. The user must be cognizant of the strengths and limitations of each of the devices and clearly understand the nature of the adaptation required before investing in ECC technology. It is the belief of these authors that the ideal ECC training device should include the following features:

- Incorporate multiple training modes such as isoinertial, isotonic, and isokinetic.
- Train with CON and ECC coupled modes and with CON or ECC only.
- Adjustable speed during isokinetic and load during isoinertial for both CON and ECC phases.
- Large number of DOF so exercises can be performed in both horizontal and vertical planes.
- Easy-to-use interface. Simple set of instructions and use a simple ECC mechanism to decrease familiarization time.
- Hardware and software safety protocols to minimize risk of injury to athlete.
- Software real-time feedback and easy data download capability.
- Can be installed in a training area without the need for modifications to the room or the power distribution.

Finally, what is apparent is that most of the devices load the musculoskeletal system in the vertical plane, or in a rotating plane (BTE Eccentron and Cyclus 2 Eccentric). The Exentrax and ARX devices are the only devices that load in the horizontal plane while using the cable pulley system found in most gyms. Most research has investigated the effects of ECC training in the vertical plane or in 1 dimension and consequently the preponderance of vertical ECC loading technology. Horizontal ECC training has not been explored to the knowledge of these authors, the design of and loading/training with such equipment should be the focus of future research.

*Conflicts of Interest and Source of Funding:
The authors report no conflicts of interest
and no source of funding.*



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