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Different Inertia Resistance Training on the Performance of the Biceps

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Abstract

Background: In recent years, resistance training has been widely used to improve physical capacities such as strength, agility, and power. Resistance training quantifies the weight in the linear guides, allowing the neuromuscular system to adapt to the load. Purpose: In this study, dynamic inertia resistance training was used to generate a faster velocity during the concentric phase and accumulate more angular momentum during eccentric contraction. Muscle contraction speed and strength curve were combined with rapid action and inertia, resulting in eccentric contraction intensity. Methods: Eight male physical education college students were recruited to perform extension and flexion of the biceps by using a spontaneous magnetron inertial resistance training machine. All participants were asked to undergo a maximal voluntary isometric contraction (MVC) test and an inertia resistance training test. Electromyography (EMG), load cells and an electrogoniometer were used to collect and analyze the EMG (maximum (max) and mean), maximum force (MF), range of motion (ROM), and percentage of action time (PAT) during muscle contraction. A two-way ANOVA mixed design was applied to obtain the variance for four phases of the biceps: adjustable resistance concentric (ARC), adjustable resistance eccentric (ARE), fixed resistance concentric (FRC) and fixed resistance eccentric (FRE). The significant level was set at $\alpha = .05$. Results: The results showed that for EMG max, ARC was greater than ARE and FRE, and FRC was greater than ARE. For EMG mean, ARC was greater than all others. For MF, ARC was greater than all others, and FRC was greater than ARE. For ROM, FRC was greater than ARE, FRE was greater than ARE, and ARC was less than all others. For percentage of action time, FRC was greater than all others, and FRE was less than all others. Conclusion: Inertial resistance training, due to the moment of inertia, is used to produce faster speeds during concentric phases and accumulate more angular momentum during eccentric contractions.

Keywords: Physical Capacities, Dynamic Inertia Resistance Training, Adjustable Resistance Concentric, Adjustable Resistance Eccentric.

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Introduction

Muscular power, strength, and endurance are essential in daily life. Training is required to enhance these aspects of physical fitness. Training programs that employ mechanical resistance equipment with different intensity schedules are effective for such enhancements. Previous studies have compared inertial resistance training (IRT) with conventional resistance training and revealed that IRT outperforms conventional approaches in improving muscle peak power and lower limb balance (Onambélé et al., 2008). Other studies have demonstrated that inertial training enhances the one-repetition maximum and muscular endurance (Norrbrand et al., 2008), with significant increases in tendon strength and muscle mass (Romero et al., 2011; Norrbrand et al., 2008) and decreases in pain levels (Romero et al., 2011). Inertial resistance equipment has been used to conduct training programs to improve motor coordination (Glady et al., 2008) and balance among older people (Mickiewicz & Jaskólski, 2012; Caruso, 2012; Norrbrand, 2008; Alkner & Tesch, 2004).

Numerous studies have shown that eccentric training methods have crucial clinical and training applications in rehabilitating injuries among athletes or other at-risk groups, such as older adults (Greenwood et al. 2007; Onambele et al. 2008; Romero-Rodriguez et al. 2011; Fernandez-Gonzalo et al. 2014c; Abat et al. 2015; Oliveira et al. 2015; Gual et al. 2016; Fernandez-Gonzalo et al. 2016a). Several studies have examined the positive feedback and assistance that result from eccentric exercises, revealing that such exercises are high-performance and safe training methods. In one study, a motor-driven device was used to conduct an experiment comparing elbow flexors undergoing resistance training during the eccentric and concentric phases. The results showed that muscle strength increased considerably during the eccentric phase (Komi and Buskirk 1972). Because of the favorable associated outcomes, eccentric training has been widely discussed, and research has been conducted on its effects on muscle mass, muscle strength, explosiveness, and metabolic capacity (Tesch et al. 1990; Tous-Fajardo, et al., 2006; Norrbrand et al. 2010; Martinez-Aranda and Fernandez-Gonzalo 2017). Training equipment has begun to incorporate inertia concepts. Such equipment requires pulling, pushing, or curling the trunk to move a flywheel and spinning cables on a fixed axis. Inertia can determine the resistance by adjusting the wheel mass, location, and diameter. When a cable is coiled around an axis, force continuously pulls the cable back to its axis. This causes resistance that an exerciser must move against, momentarily bringing the flywheel to a stop and producing eccentric phase resistance. The eccentric phase of the exerciser's muscle absorbs the energy stored in the flywheel. Eccentric training using inertial resistance enables participants to adapt to resistance because the linear factor generates little friction, and thus the concentric and eccentric resistances are similar. This method provides maximum strength and muscle loading for a particular joint angle during the concentric phase.

IRT has numerous benefits. For example, such training effectively elevates the strength and power of the muscles responsible for shoulder adduction among young active men (Naczk et al., 2016), and a 10-week IRT program using a flywheel has been shown to significantly increase the strength of the knee extensors in older adults (Caruso et al., 2005).

IRT yields more desirable outcomes than conventional resistance training because conventional training aims to maintain resistance until the end of a movement. This approach triggers a buffering reaction in the central nervous system. Under such circumstances, movements are likely to decelerate before fully stopping because of the resistance (Elliott et al., 1989). When a movement decelerates, high-velocity muscle contraction cannot be performed. Hence, such patterns may differ from those of specific movements, thus limiting the performance of movements that require high speed or power. By contrast, IRT focuses on accelerating the maximal voluntary contraction through a movement's action force and reaching the target training volume based on the length–strength relation.

IRT enables muscles to create a stretch–shortening cycle (SSC). During the movement, the elastic tissues store elastic energy and stimulate muscle spindles to react when muscles quickly stretch, resulting in a myotatic reflex. Komi and Bosco (1978) indicated that the SSC was the most evident during the catch phase between concentric and eccentric contraction. In this phase, neurotransmitters and elastic substances recruit muscles within a short period, thus accelerating concentric contraction. Albert (1991) reported that this phenomenon enables more muscle spindles and fibers to engage in a movement, in turn producing dynamic joint stability and manipulating the SSC effect during eccentric contraction. Additionally, the level of elastic energy is affected by the stretch intensity, including stretch speed and length. The efficacy of elastic energy increases with stretch speed.

Muscle contraction can be divided into concentric and eccentric contraction according to the type of movement and joint angle during resistance training. Numerous studies have examined eccentric exercise training and found that such training increases muscle mass and enhances muscle strength and power (Dudley et al. 1991b; Hather et al. 1991; Hortobagyi et al. 1996). It does so by stimulating the nerves and promoting potential muscle activation (Enoka 1996; Hedayatpour and Falla 2015). The intensity of eccentric resistance inertial training has a positive correlation with the intensity of concentric contraction applied by the exerciser. A lower-limb IRT intervention for rehabilitating patients with stroke increases muscle mass and improves gait and balance (Fernandez-Gonzalo et al. 2014c; Fernandez-Gonzalo et al. 2016a).

In general training, concentric and eccentric muscular contraction is produced when a motion in the opposite direction is performed repeatedly. The effect of such motion can be evaluated by examining the increase in muscular recruitment. Studies have demonstrated that IRT outperforms conventional plate training in terms of muscular recruitment (Norrbrand et al., 2008). Eccentric contraction occurs when an individual initiates a movement. When an individual performs a movement against a flywheel, the energy provided to the wheel is transformed into rotational potential energy, thus causing a motion that requires the individual to resist once the eccentric phase starts. The energy of such eccentric stretching is depleted gradually after the motion finishes (Mickiewicz & Jaskólski, 2012;

Romero et al., 2011). An inertial flywheel produces complete resistance during the concentric phase, and the force during the eccentric phase tends to exceed that during the concentric phase (Norrbrand et al., 2008). Additionally, IRT produces higher muscle activation than does conventional training. This pattern can be observed by using an electromyogram.

Numerous studies have found that eccentric exercise induces muscle damage and causes delayed onset muscle soreness (Newham et al. 1983; Hortobagyi et al. 1998; Krentz & Farthing 2010; Fernandez-Gonzalo et al. 2012). In the present study, the intensity of inertia eccentric training varied in accordance with the concentric contraction force applied by the participants. This prevented overtraining, thereby avoiding delayed onset muscle soreness and any consequent discomfort for the participants. One study showed that low- and intermediate-intensity inertial training did not cause creatine kinase and lactate dehydrogenase to notably increase after training (Fernandez-Gonzalo et al. 2014b).

The momentum–impulse relationship can be inferred on the basis of Newton's second law of motion (i.e., F = ma). Acceleration *a* can be written as $(v_2 - v_1)/t$, where v_1 is the initial velocity and v_2 is the terminal velocity. Multiplying the force *F* by the duration of the force results in the impulse, and the change in momentum is the area of overlap between the time and strength curves. Therefore, increasing the impulses can help improve the training efficacy. To maximize the training velocity, three possible approaches are as follows: (1) increasing the maximum strength, (2) increasing the duration of the force; and (3) increasing the slope of the strength curve. Increasing the moment of inertia (MOI) is likely to elevate the action force and its velocity. Hence, using IRT can enlarge the impulse areas. According to the momentum formula (i.e., momentum = mass × velocity), the angular velocity of the flywheel increases with the maximal velocity provided by the action force against the IRT equipment. According to the angular momentum formula (angular momentum = MOI × angular velocity), a higher angular velocity results in more angular momentum accumulated in the flywheel and thus in stronger eccentric contraction.

Commercially available inertial training equipment is widely employed by different people. For example, athletes use such equipment for training assistance, older adults use it to enhance their physical condition, and patients use it to accelerate rehabilitation. These diversified applications demonstrate the effectiveness of inertial training. Sports science has flourished alongside developments in science and technology, particularly in terms of training models and the neuromuscular adaptation capacity of athletes, and equipment manufacturers can now tailor their designs according to the ability of their target athletes by utilizing these advances. However, commercially available inertial training equipment has seen limited variation. For example, studies on fixed resistance have employed the inertial resistance training YoYo (YoYo Technology AB, Stockholm, Sweden). However, the moment of inertia on this equipment is not adjustable; therefore, it is not possible to establish a complete training guide for the equipment, nor is it possible to establish complete operational parameters. Studies using such equipment have divided the moment of inertia into light (0.11 kg/m^2) and heavy (0.1452 kg/m^2) moments, with the training intensity set in accordance with the maximum voluntary speed of the participant. Inertia equipment has also been limited by nonadjustable inertial disks (Mickiewicz and Jaskólski, 2012; Onambélé et al. 2008; Norrbrand et al. 2008; Alkner, 2005). Because of such limitations, the action principles of IRT equipment remain unclear. Additionally, complete training methods have not been established; therefore, this study aimed to explore the resistance of adjustable and fixed training patterns and compared their efficacies for the training of bicep flexion–extension.

Methods

Subjects

Eight male students from universities or colleges were involved in this study (age = 19.63 ± 1.07 years; height = 180.95 ± 6.46 cm; weight = 74.37 ± 8.49 kg). These participants reported that they had neither diseases associated with the bones or muscles of the upper limbs nor peripheral or central neuropathies. Moreover, the participants had never experienced inertial training.

The participants were asked to thoroughly read the guide for participants. Next, researchers informed the participants of the research process and relevant notifications. All participants signed informed consent documents, and the research was approved by the ethics committee of the Fu Jen Catholic University in Taiwan.

Experimental Design

A self-designed magnetic machine for IRT was employed to conduct a training program for the stretching and contraction of the biceps. Data were collected by using electromyography (EMG), load cells, and an electrogoniometer to analyze the maximum and mean EMG, maximum force (MF), range of motion (ROM), and percentage of action time (PAT) during the movement process. The fixed and adjustable approaches were compared during the concentric and eccentric contractions, which were divided into four biceps phases as follows: adjustable resistance concentric (ARC), adjustable resistance eccentric (ARE), fixed resistance concentric (FRC), and fixed resistance eccentric (FRE).

Instrumentation

For this study, a self-made special spinning bike was employed for the biceps strength test. This test requires a rapid shift in the movement characteristics of biceps muscle projection, from elbow joint flexion to extension and a return to the origin flexion phase, and repeated movement. Equipment also included a laptop computer, a BIOPAC EMG 150 (BIOPAC Systems, Santa Barbara, CA), load cells, and an electrogoniometer (sampling frequency, 1000 Hz).

Testing Procedures and Data Processing

Maximal Voluntary Isometric Contraction test

The Participants started with 10 Minutes of Autonomous warm-up before the Experiment. Electrode Sheets were attached to the Belly of the Biceps of Each Participant's Dominant Hand. An Electronic Protractor was used to define the joint angle. The angle was defined as 0° When the Arm was stretched out straight, whereas it was defined as 150° when the elbow flexed completely to reach the maximum flexion angle. The Participants underwent a percentage of maximal volitional contraction test when the joint angle reached 90°. Each test lasted for 5 seconds and was conducted twice, with a 60-second rest between tests. Verbal encouragement was given to the participants during each test to obtain maximum isometric contraction.

Inertia Resistance Training Test

The equipment used in this experiment focused on the flexion and extension of the biceps. Displacement caused by the flexion and extension was measured before the experiment. In addition, the participants were given a chance to familiarize themselves with the movement and understand how to resist inertial force during the eccentric phase.

Participants completed both adjustable and fixed resistance training of the biceps by separately performing seven repetitions of maximal voluntary elbow flexion and extension. A counterbalanced sequence method was employed in this study to prevent the sequence of movements affecting the experimental results. The participants were asked to complete the required movements at full force and then to rest for 5 minutes to mitigate any effects of biceps fatigue on the experimental data.

Data of the third to fifth repetitions were analyzed. A force transducer and angular gage were synthesized using the AcqKnowledge 4.2 software to capture the EMG signals. Next, the EMG signals were exported using a 20–500 Hz band pass filter and full-wave rectifier with a 20 ms time window. Data were then analyzed using the Matlab 2015b software. The data collected by the force transducer and angular gage were smoothed using a 10 Hz low pass filter. The stages of concentric and eccentric contraction were distinguished based on the bending angles of the elbow during data collection.

Statistical Analysis

SPSS 22.0 software for Windows was used for statistical analysis and for identifying significant differences. A two-way ANOVA mixed design was applied to obtain the variance for the different phases. The significant level was set at $\alpha = .05$.

Results

After completion of the biceps tests, the testing outcomes for two phases were analyzed by two-way ANOVA. Significant differences were found for the two phases.

There were significant differences among ARC, ARE, FRC and FRE in EMG_{max}, EMG_{mean}, MF, ROM and PAT. The results are listed in Table 1. The EMG_{max} post hoc indicated that ARC was greater than ARE and FRE, and that FRC was greater than ARE. The EMG_{mean} post hoc indicated that ARC was greater than all others. The MF post hoc indicated the ARC was greater than all others, and that FRC was greater than ARE. The ROM post hoc indicated that FRC was greater than ARE, that FRE was greater than ARE, and that ARC was lower than all others. The PAT post hoc indicated that FRC was greater than all others, and that FRE was lower than all others.

Table 1. *Two-way ANOVA Mixed Design Results of the Tests measured at Various Phases of Biceps (mean ± SD)*

	ARC	ARE	FRC	FRE	F	*p*
MF (kg)	37.8 (2.4)	22.9 (6.5)	29.7 (3.0)	23.3 (5.6)	17.369	0.01
EMG_{max} (%)	73.1 (8.5)	33.2 (4.8)	59.6 (18.9)	36.6 (16.4)	16.032	0.01
EMG_{mean} (%)	25.9 (2.5)	12.2 (1.1)	17.6 (5.2)	12.5 (5.1)	21.655	0.01
ROM (°)	77.8 (2.8)	78.3 (3.1)	83.5 (2.0)	83.4 (2.0)	12.021	0.01
PAT (%)	48.9 (3.4)	51.1 (3.4)	60.0 (5.5)	40.0 (5.5)	26.164	0.01

ARC: adjustable resistance concentric; ARE: adjustable resistance eccentric; FRC: fixed resistance concentric; FRE: fixed resistance eccentric; EMG_{max}: Electromyography maximum; EMG_{mean}: Electromyography mean; MF: Maximum force; ROM: range of motion; PAT: Percentage of action time. Significant difference from control group ($p < 0.05$).

Discussion

When adjustable resistance for the biceps was applied, the angular velocity during concentric contraction exhibited an MOI greater than that produced using fixed resistance. This indicated that adjustable resistance training could effectively accelerate a training program. The results also revealed a statistical difference between ARC and FRC. During the early concentric stage, the eccentric resistance decreased when the motion accelerated because fewer impulses and muscles were activated for the high velocity. Conversely, for the fixed MOI, more time, impulses, and muscle activation were required to perform concentric contraction. Beck et al. (2004) identified a positive linear relationship between EMG and torque, concluding that more motor units were recruited when the strength increased. The results of iEMG were affected by the range of action potential and discharge frequency. The range of action potential indicated the discharge intensity (i.e. the engagement of muscular fibers or motor units for contraction), whereas the discharge frequency was determined by the intensity of motor unit activation. Near the end of the concentric contraction, the impulses and muscle activations of the adjustable MOI were greater than those of the fixed MOI. Furthermore, sufficient energy was stored in the adjustable MOI to create resistance for the training of eccentric contraction. Cuenca-Fernandez et al. (2015) employed a fixed gear method before a competition. This training method comprised IRT with squatting and a barbell for one-time stimulation in order to produce a postactivation potentiation effect 8 minutes before sprint swimming (Hodgson et al. 2005). This method was effective because stimulation during the contraction-enhancing phase caused the Ca^2+ concentration in the muscle to increase and the myosin crossbridge to activate. This one-time stimulation was demonstrated to improve speed during sprint swimming because higher overall muscle loading and mechanical stress with greater loading during the eccentric phase means that greater force can be applied during the concentric phase. This is the basis for fixed gear exercise and explains why inertial resistance training can enhance muscle strength.

IRT focuses on the unique nature of eccentric contraction (Mickiewicz & Jaskólski, 2012; Alkner & Tesch, 2004). Based on SSC theory, IRT manipulates the elastic energy stored in muscular fibers and spindles to trigger reactions from muscular spindles under fast muscle extension, thus yielding a power increase (i.e., myotatic reflex). Regarding the impulses created by different MOIs during initial eccentric contraction, a significant difference was found between the adjustable and fixed ROMs (i.e., adjustable ROM > fixed ROM). The fixed weight in the fixed training approach (i.e., conventional training) caused strength deficiency during the contraction of the biceps. IRT can be used to overcome such problems, for the inertia affects muscle activation and inertial energy is increased through changes in speed, which can be used to establish a pattern of positive concentric and eccentric training. Hence, the impulses stimulated using an adjustable approach exceed those created using a fixed approach.

The impulses and muscle activations produced through adjustable resistance were greater than those produced through fixed resistance. During the initial eccentric contraction, the impulses and muscle activations produced through adjustable resistance were greater than those of fixed resistance because the adjustable resistance accumulated energy more quickly during concentric contraction. However, the optimal acceleration could not be achieved during concentric contraction for the fixed and adjustable groups when the self-designed dynamic MOI equipment was used, possibly because the duration of the single-joint exercise was insufficient to reach the optimal acceleration. In this study, we identified biceps activation by observing the flexion–extension of the elbow. For different sports and muscular strengthening objectives, the IRT equipment should be modified to meet the specific training needs, and multiple joint motion should be selected to increase the ROM. Studies have revealed that, compared with the resistance created through conventional weight exercise, the resistance produced through movement enhances muscular strength, power, and mass. This enhancement occurs because eccentric loading during movement tends to improve neural stimulation, muscular adaptation, elastic energy, and the mechanism of muscular contraction, thus accelerating the process of repeated muscular flexion–extension. If the aforementioned approaches are adopted, the exported strength during the concentric phase could be effectively increased. For example, eccentric exercise is preferred for loading type because eccentric loading provides more loading impulses than does concentric loading. Therefore, eccentric exercise could be implemented to increase strength, power, and mass.

Inertial training can be incorporated in sports injury prevention classes. Studies have revealed that incorporating inertial training into such classes helps to mitigate the occurrence of sports injuries. Moreover, inertial training has been shown to be effective in preventing muscle strain and its consequent effects on sports performance (Askling et al., 2003; De Hoyo et al., 2015; Romero-Rodriguez et al., 2011). However, the majority of studies on the subject have employed fixed gears with the same weights in their experimental training; however, the intensity of eccentric training originates in concentric contraction. Therefore, in this study, a dynamic inertial resistance source that generated a second resistance source by using eddy currents was designed. This design aimed to adjust the resistance intensity to further reflect the characteristics of muscle contraction and to increase the intensity according to changes in angular velocity.

McLoda et al. (2003) recruited baseball and softball players for 4 weeks of IRT, and the results revealed no effect on pitching velocity, arm velocity, or throwing accuracy. Upper-limb movements (e.g., grabbing and throwing a ball) involve the movement of multiple joints; the torso, hip joint, knee joint, and foot muscles are all required to make isometric contractions during training to control body posture. However, the stabilizing process necessary for IRT may affect training of the shoulder joint and muscles, negating any effect on upper-limb training outcomes. In contrast to other studies, the present study focused solely on training the biceps. This may be more effective in improving sports performance because a particular exercise can be trained more readily through multiple joint movements than can a set of complex actions such as throwing a ball.

Conclusions

In this study, we investigated the effects of different types of inertia resistance training on the performance of the biceps. Inertial resistance training, due to the moment of inertia, is used to produce faster speeds during concentric phases and accumulate more angular momentum during eccentric contractions. Despite certain limitations, the recording and training system we developed in this study can properly help trainers to improve strength. The training equipment developed in this study requires single-joint movements during training, and new evaluation systems which are more in accordance with reality should be developed in future research.

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