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Isokinetic Versus Isotonic Resistance Training: Defining the Mechanisms of Hypertrophy and Exercise Execution Methods

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Abstract

Purpose: To determine strength changes and hypertrophy differences at the biceps brachii between an isokinetic bicep curl machine created by C&M Machines and preacher curl exercise with a standard curl bar. The study also aimed to determine the effectiveness of the aforementioned machine and to give insight into this unique method of training.

Methods: A medical clearance form and a Physical Activity Readiness Questionnaire was implemented to evaluate ability to exercise. 10 subjects (n=10) were recruited, were 20.3 years old (20 +/- 2), and were cleared for rigorous exercise. Subjects were randomly assigned to a control group (CG) or experimental group (EX). Subjects completed a 10-week training program consisting of 2 training sessions per week with a minimum of 48 hours between sessions, CG completing 5 sets of 5 reps at 80% 1RM on seated preacher curls, EX completing 5 sets of 5 at 80% estimated max force on the isokinetic machine. Pre and post assessments consisted of biceps brachii circumference measurements.

Results: After 10 weeks of training at the given prescription, the experimental group improved in bicep brachii circumference 3.8 cm (+/- .9cm) and the control group improved 1.6 cm (+/- 1.5cm). These results suggest that the isokinetic curl machine is more effective for promoting muscle hypertrophy than the standard, isotonic preacher curl. Both exercises were considered effective in modest bicep brachii growth (Isotonic t-value (-2.359), Isokinetic t-value (-3.559)), and both groups had a statistically significant improvement (Isotonic p-value (.039), Isokinetic p-value (.012)) ($p<.05$).

Discussion: These methods of weight training gave a direct comparison between standard resistance training and isokinetic resistance training. With this comparative study, the physiologic factors of weight training can be better understood on which method may be better for muscle development, which method may be more effective for hypertrophy and if there is notable change with the given prescription. The described machine controls time under tension, measures force production consistently and gives continual feedback on subject effort. The increases in hypertrophy were likely due to these factors.

Keywords: *Hypertrophy, resistance training, isokinetic, isotonic, kinesiology, time under tension*

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Chapter 1: Introduction

Background Information

Within kinesiology, there is significant speculation on the most effective means of developing hypertrophy or muscle growth. Hypertrophy has many applications in athletically competitive groups, in the general population seeking to improve quality of life through body composition improvements, or in clinical populations exercising as a medical intervention (Yang et al., 2020). Defining the most effective means of hypertrophy is a key component to exercise prescription and efficacy. Hypertrophy is well understood as a positive health outcome for individuals (Yang et al., 2020). A problem arises as there are many contributing factors to hypertrophy such as individual needs and health condition variations, several means of promoting muscle hypertrophy, controlling for the external environment and controlling for individual behaviors. These variables and factors make it difficult to determine the best, generalized approach for developing muscle hypertrophy. Adaptations to motor unit recruitment, firing rate and the force production potential from chronic resistance training results in hypertrophic potential (Ruple et al., 2023). But, additional mechanical variables involving force, length, tension and fatigue are not well understood how they work together in regard to muscle growth. To resolve these issues, I plan to compare two forms of resistance training while isolating key differences that influence hypertrophy. During the course of this comparative study, the key variation in resistance training will be evaluated and will give further insight into mechanisms of hypertrophy and what physiologic trait is contributing to body composition changes. This research design can be replicated by isolating other resistance training characteristics for comparative purposes strengthening the significance of this study. I chose this topic as it will directly impact strength and conditioning practice and training efficacy principles within kinesiology. Strength training efficacy is critical within sport performance, clinical practice, and will impact exercise prescription holistically. Further, the primary objective is to identify the most efficacious means of performing exercises with the intent of body composition changes. Determining the most effective methods of resistance training is applicable to general populations to improve outcomes associated with exercise. With every exercise, there is a demand placed on the exerciser to execute the exercise correctly to ensure safety and efficacy. The primary purpose of this study is to identify the most effective means of performing each exercise and identifying the associated hypertrophic stimulus.

Hypertrophy is a beneficial outcome associated with resistance training and is defined as muscle growth. Hypertrophy and development of lean body tissue has significant benefits on cardiovascular, endocrine and metabolic health and prevents physical disability later in life (Hsu et al., 2019). Moreover, the most effective method of developing muscle hypertrophy is useful in improving athletic performance as muscle size is strongly correlated with muscle strength (Kojic et al., 2022). These training methods can be used in strength and conditioning facilities to improve athletic training outcomes. Thus, the topic maintains relevance as it applies to clinical, general and athletic populations. When applying resistance training prescriptions to various populations, a consensus must be made on the most effective means of developing hypertrophy based on generalizable needs. The research question is based on the most effective means of developing muscle hypertrophy: isokinetic or isotonic resistance training. The key difference between each exercise in this context is velocity. Between the two exercises, force output was equated, volume and fatigue were regulated equally and there were no range of motion differences. With this variable isolated, differences in hypertrophy outcomes can likely be attributed to this difference. These four biomechanical/physiologic methods will be discussed at length within the literature review to determine which aspects are most necessary to isolate and which are not. Time under tension compared to velocity differences currently has the most inconclusive findings (Jaric, 2015). Finally, these comparative methods will further determine the most effective means of performing certain exercises. These conclusions can be utilized by all populations to improve body composition from resistance exercise.

Gaps in Research and Scholarship

Based on the aforementioned mechanisms: motor unit recruitment, the length-tension relationship, the force-velocity relationship, and fatigue management, the inferred application to promote the greatest condition of hypertrophy would be sufficient weight and effort (motor unit recruitment), full range of motion with eccentric stretch emphasis (length-tension), increased time under tension (force-velocity) and breaking exertion into multiple sets of effort (managing fatigue). Other contributing conditions to muscle hypertrophy are mechanical tension, muscle damage and metabolic stress (Schoenfeld, 2013). These concepts are not mutually exclusive from the previously stated mechanisms. Motor unit recruitment, force-velocity, length-tension, and fatigue are insights into how resistance training must be executed. Mechanical tension, muscle damage and metabolic stress are necessary outcomes of acute resistance training that make adaptation possible. However, the exact extent to which each of these mechanisms contributes to hypertrophy and if they must be skillfully combined in individual exercises is not well understood. Because muscle adaptations are heavily dependent on individual effort or rating of perceived exertion, sustaining load and therefore motor unit recruitment is considered an important variable when evaluating hypertrophy adaptations (Wilk et al., 2021). However, motor units vary greatly by motor unit type, size and polarization velocity, further complicating the exact exercise prescription necessary for hypertrophy (Enoka et al., 2001). Ultimately, the combination of each mechanism of hypertrophy and their contributing roles have not been discussed. Currently, an abundance of information exists with little information on how to prioritize scientific concepts and application into resistance training. Rather than attempting to attribute all physiologic concepts to individual exercises, it is necessary to determine what are the primary contributors to hypertrophy and the accompanying resistance training implications.

Problem Statement

There are currently many factors that contribute to muscle growth and it is not well understood to what extent they contribute to muscle adaptation. To what extent does each mechanism contribute to muscle growth and how must this be applied to training? To prioritize resistance training strategies, to improve exercise prescription and to further understand muscle hypertrophy, isolated individual physiologic characteristics of resistance training is necessary. To accomplish this, isokinetic exercise will be compared to isotonic exercise while controlling for force output. Moreover, determining the most effective exercise technique to promote body composition change remains an ongoing discussion that needs further consensus. Until then, exercise efficacy declines within the individual exerciser's effective health outcomes.

Hypothesis

The proposed hypothesis for this experiment is that after 10 weeks of training at the given prescription (2 times per week, 5x5 training volume each session), the experimental group will have statistically significant improvements ($p < .05$) in biceps brachii circumference.

Definitions

Independent variable – training modality (isokinetic and isotonic).

Dependent variable – bicep brachii circumference in centimeters.

Isokinetic – an exercise performed at a constant speed (Moffroid et al., 1969).

Isotonic – an exercise performed with a constant load (Remaud, 2020).

Control group – isotonic exercise prescription.

Experimental group – isokinetic exercise prescription.

Motor unit recruitment – the systematic activation of a motor neuron and the innervated muscle fiber (Hodson-Tole et al., 2009).

Force-velocity relationship – the relationship between force-generating capacity of muscle and the contraction velocity of muscle, where slower contractions result in greater force production (Alcazar et al., 2019).

Length-tension relationship – the relationship between the length of muscle and the tension experienced by the muscle (LaCombe et al., 2023).

Fatigue – a temporary reduction in force production capacity (Beardsley, 2018).

Hypertrophy – an increase in muscle volume (Beardsley, 2018).

Assumptions and Limitations

It is assumed that effort is the most important factor when determining the effectiveness of exercise. However, effort can be perceived in a multitude of ways and is not always the best gauge for muscle adaptation. Rating of perceived exertion (modified Borg RPE (0 - 10)) is subjective and can be difficult to accurately quantify based on the variability of pain analgesia, leading to limitations. Moreover, some limitations to the study include controlling for physiologic variables and subject behaviors that may influence hypertrophy. These include subject nutritional habits, sleep quality, stress factors, protein intake and use of ergogenic aids. These limitations have been moderately controlled for using a physical activity readiness questionnaire to determine ability to exercise, all subjects must have moderate resistance training experience (>6 months), all subjects are college-aged between 18 and 22 years old, and must currently be enrolled, full-time at the same University. This will likely result in the subjects living similar lifestyles, similar stress factors and engagement in a similar social environment.

Significance of Study

Hypertrophy and body composition have applications to athletic, general and clinical populations. Improving exercise prescription methods and clearly defining the mechanisms of hypertrophy will: improve athletic performance in those participating in strength-based sports, improve body composition and therefore metabolic, cardiovascular, musculoskeletal health in general populations, and enhance preventative/treatment methods for clinical populations with metabolic, endocrine or cardiovascular disease.

Improvements in body composition has been shown to be an effective means of improving cardiovascular health and preventing disability (Hsu et al., 2019). The most notable conclusion is that resistance training is not commonly used as a means of developing cardiovascular function (Smith & Fernhall, 2011, p. 196) but has been shown to be very effective for promoting structural changes to the heart and functional adaptations. These cardiac specific adaptations include increased left ventricular cavity size, mitral wall thickness improvements, systolic function during exercise including stroke volume and ejection fraction and diastolic function including left ventricle filling time. In an interesting turn, these adaptations are typically considered pathologic but when exercise induced are proven to be cardioprotective (Adler et al, 2008). Experienced (>6 years) weightlifters engaged in 2 hand dynamometer isometric exercise to determine mean end diastolic volume responses. Results of the study were larger left ventricular mass in the weightlifting group, an increased end diastolic volume response in the weightlifting group and increases in stroke volume responses in the weightlifting group (Adler et al, 2008). These findings suggest that chronic weight training not only results in beneficial structural changes of the heart, but also systolic and diastolic response potential to exercise. This is important to note because weight training improves cardiac functionality in addition to promoting cardiac phenotypic results.

These methods of weight training give a direct comparison between standard weight training and isokinetic resistance training. With this comparative study, the physiologic factors of weight training can be better understood on which method is best for strength development, which method is best for hypertrophy, and if there is notable change with the given prescription. Standard weight training is subject to possible force production changes, changes in effort that can be objectively calculated and inconsistent repetition duration. The described machine controls time under tension, measures force production consistently and gives continual feedback on subject effort. With better understanding of these variables and their reported effects, training for strength and hypertrophy will be better understood and improve exercise programming. Furthermore, resistance training offers a host of health benefits that prevent cardiovascular disease. Methods for improving body composition and determining the most effective means of muscle growth have application to every population and will improve quality of life and athletic performance to those that apply these methods.

Chapter 2: Literature Review

Introduction

Hypertrophy is a beneficial outcome associated with resistance training. Hypertrophy and development of lean body tissue has significant benefits to overall health resistance training at even minimal load doses can improve health outcomes (Fyfe et al., 2021). Moreover, the most effective method of developing muscle hypertrophy is useful in sport performance application and improving athletic performance. Thus, the topic maintains relevance as it applies to clinical, general and athletic populations. When applying resistance training prescriptions to various populations, a consensus must be made on the most effective means of developing hypertrophy based on individual needs.

Traditionally, the mechanisms of hypertrophy can be explained in a three-part model that includes metabolic stress, mechanical loading and muscle damage (Schoenfeld, 2013). However, this explanation disregards the mechanical implications. To take into account the mechanical necessities of hypertrophy training and their resistance exercise implications, the three-part model and its physiologic outcomes will be discussed by taking into account how mechanical loading, metabolic stress, and muscle damage can be applied. Furthermore, this three-part model also sets a foundation for what must concurrently be necessary in order for these mechanical factors to be effective. Resistance training must be sufficiently heavy to achieve mechanical loading, metabolic stress is necessary to change the chemical environment to induce hypoxia, and muscle must be damaged to initiate satellite cell activity and protein synthesis stimulation.

Moreover, the purpose of this study is to determine the key mechanisms of hypertrophy and the necessary training implications. Hypertrophy is defined as an increase in muscle fiber size (Lim et al., 2022) whereas strength can be defined as the force capacity of individual exertion (Suchomel et al., 2016, p.1). Increased muscle fiber size is the adaptation associated with hypertrophy. The adaptations associated with muscular strength are improvement in coordination, increased high-threshold motor unit recruitment, reduction in antagonist coactivation, increased muscle fiber diameter, increased lateral force transmission, and increased tendon stiffness (Beardsley, 2020). Note that the adaptations associated with strength include muscle fiber diameter, but have many more adaptations associated. The differences in hypertrophy and strength adaptations are important to note in that this literature review intends to identify methods for hypertrophy development distinct training implications from strength development. Hypertrophy and strength are correlated, but not exclusively. Because the adaptations of hypertrophy have some similarities in strength adaptations, these methods can also be reasonably applied to strength training.

The isokinetic dynamometer controls time under tension, measures force production consistently and gives continual real-time feedback on subject force production (C&M machines, 2020). With better understanding of these variables and their reported effects, training for strength and hypertrophy will be better understood and will improve exercise programming. The considerable mechanisms of hypertrophy are: motor unit recruitment, the force velocity relationship, the length tension relationship, and fatigue management (Beardsley, 2018). To further understand these mechanisms, each exercise tested will be better understood on their benefits for hypertrophy based on these principles. The significance of this study is to further add to hypertrophy literature and clearly define the key mechanisms for hypertrophy to improve training prioritization and programming methods. In this literature review, each mechanism of hypertrophy will be discussed, how each exercise differs based on velocity differences, how this can influence hypertrophy and the role of the role of the original three-part hypertrophy model.

Motor Unit Recruitment

Motor units are characterized as muscle fiber and the motor neurons that innervate them. Neuromuscular stimulation happens largely through motor unit recruitment and is the principal factor behind muscle contraction. After continuous resistance training, motor units hypertrophy thereby increasing firing rating and force production potential at the muscle (Sterczala et al, 2018). This creates the discussion that because motor unit recruitment is the response to an external load and adapts in response, how correlated is this adaptation with muscle hypertrophy? Moreover, with the increased firing rate and force production changes post training, how does this influence hypertrophy potential? The rate by which force is produced in relation to maintaining muscle tension is known as the force-velocity relationship which will be discussed further. Ultimately, motor unit recruitment is considered a key mechanism of hypertrophy development due to its direct necessitation of acting against a mechanical load, creating and maintaining muscle tension, and the muscle damage that is associated with prolonged muscle tension.

Motor unit recruitment can be closely related to voluntary effort of the individual. Resistance training at maximal velocity yet at a lower load has been shown to increase the total amount of motor unit recruitment. But, heavier loads at lower speeds can result in maximal motor unit recruitment as well (Gandevia et al., 1998). Because fast twitch muscle fibers and the innervating motor units are more associated with late adaptation when challenged with repeated excitation, high velocity contractions would seem to be the primary mechanism of hypertrophy if force-velocity inversion were excluded. But fast twitch muscle fibers can be recruited in low velocity contraction if tension is sustained long enough or if load is heavy enough?

Furthermore, motor unit recruitment and the resulting muscle tension is often described as time under tension or the ability to maintain that tension. Time under tension variables have been discussed in the vector quantities of force and its relationship with velocity, but muscle is organized into many groups that are not recruited evenly or always completely. Thus, discussing motor unit recruitment is critical for determining the necessary voluntary effort in time under tension and the potential for hypertrophy. Similarly to muscle fibers, motor units are subject to adaptation and can be determined based on amplitude and action potential changes. In the clinical trial, Action potential amplitude as a noninvasive indicator of motor unit-specific hypertrophy (Pope et al., 2016), authors determined that after chronic strength training, only high-threshold motor units increased action potentials. Because muscle fiber size is strongly related to motor unit amplitude, it is possible that hypertrophy is only possible for fibers innervated with high threshold motor units. This study provides insight into the necessary exertion with resistance training and which muscle fibers are subject to most adaptation. The authors conclude that low threshold motor units are less prone to adaptation than high threshold motor units.

Another topic associated with motor unit recruitment is what type of fibers are predominantly recruited. The more motor units that are recruited, the more force is produced. In the review study, Motor unit physiology: some unresolved issues (Enoka et al., 2001), authors conclude that a given muscle is 50% slow twitch muscle fibers and only 5% type IIx fast twitch muscle fibers. As such, most of the motor units predominately control slow twitch muscle fibers. This means that if voluntary activation is low, there will be no recruitment of the muscle fibers most sensitive to hypertrophy. With minimal exertion, it is likely that only slow twitch fibers are being recruited and therefore no hypertrophic potential.

Muscle contraction velocity can be roughly defined as the shortening speed characteristic of a given muscle. Without an external force, as motor unit recruitment increases, shortening speed also increases. When evaluating the mechanisms of contraction velocity, the two recurring determining themes are Henneman's size principle and fatigue (Grigic et al., 2022) (Fisher et al., 2013). As stated previously, there is a positive, linear correlation associated with motor unit recruitment and contraction velocity (Martinez-Valdes, et al., 2021). But not all motor units are the same and they are recruited in an organized order from smallest to largest depending on force demands. High contraction velocity is associated with greater motor unit recruitment, and high exertion is necessary for fast twitch muscle fiber recruitment. This would imply that high velocity movements are necessary for muscle hypertrophy. However, the force-velocity relationship states a reduction in mechanical tension as velocity goes up. Thus, a contradiction arises. Moreover, high velocity exercises result in greater peripheral fatigue; both metabolite dependent and contraction coupling failure (Morel et al., 2015).

When discussing contraction velocity, the recruitment of fast twitch motor units is necessary to achieve the fastest contraction rate. Henneman's Size Principle influences hypertrophy in that it is a determining factor by which muscle fibers are stimulated (Grigic et al. 2022, p. 202). Fast twitch muscle fibers are generally more susceptible to hypertrophy than slow twitch muscle fibers and are only recruited with greater exertion. Gordon et al. (2004) explains the mechanisms of the size principle and motor unit innervation of skeletal muscles. The relationship between the motor neuron and the number/size of innervated muscle fibers is a critical component to discussing the size principle and how adaptations occur. In this article, nerve injury is discussed and how motor units recover to return back to initial functioning. One important determination from this article is:

> “direct enumeration of the innervation ratio and the number of muscle fibers per motor neuron demonstrated that a size-dependent branching of axons accounts for the size relationships in normal muscle” (p.1).

When muscle tissue and neurons are injured, motor neurons are able to reorganize and rematch with initial synchronous activation patterns and size recruitment matching the size principle. As long as the oligodendrocyte of the neuron is not severed in the injury, axon-dependent size branching remains possible and partially accounts for neuromuscular recovery. These findings suggest that the Henneman’s size principle is susceptible to recovery and adaptation when exposed to training and stimulus. When discussing the mechanisms of hypertrophy, adaptations and efficiency to the size principle is one of the mechanisms behind which hypertrophy is possible. As exertion increases, more motor neurons and therefore muscle fibers are recruited; giving more potential for stimulated tissue. In this context, the greater the contraction velocity, the more tissue that is being stimulated due to greater motor unit recruitment.

From this, one may suggest that hypertrophy is possible simply when applying motor unit recruitment and the resulting stimulated muscle. In the research article, Motor unit recruitment during neuromuscular electrical stimulation: a critical appraisal (Bickel et al., 2011), authors determine the efficacy of neuromuscular electrical stimulation. Authors also make a critical determination between the effects of artificial stimulation and voluntary activation of motor units. When electrical stimulation is artificially introduced, motor unit recruitment is spatial and non-selective. These findings suggest that although the recruitment pattern is localized, synchronous, and differs from voluntary muscle actions, electrical stimulation increases the onset of muscle fatigue. This is important to note that the size principle is a driving mechanism of muscle stimulation even when involuntary and isolated.

Ultimately, motor unit recruitment is a mechanism of hypertrophy as it is a key measure to effort and muscle stimulus.

Force – Velocity Relationship

The force-velocity relationship is the hyperbolic relationship between velocity and force production (Alcazar et al., 2019). Force production is lost as muscle contraction velocity increases and the muscle length is shortened. Tension is lost with increasing contraction velocity due to multiple factors; but primarily, myosin, heavy chain cross bridge formation is reduced with increased detachment rate from actin (Alcazar et al., 2019). The force-velocity relationship is discussed in conjunction with motor unit recruitment in that it further explains muscular tension and acting against mechanical loading. But, the story continues with the shape of the force-velocity relationship; hyperbolic. This means that motor unit recruitment is necessary for contraction velocity and therefore muscular tension but with increasing velocity will eventually reduce muscular tension. This means the motor unit recruitment and velocity can be positively correlated in some kinematic circumstances. Velocity and muscular tension can also be negatively correlated primarily because the load capacity is lower at higher velocities (Fitts and Schluter, 1991). With this third addition of variables, the force-velocity relationship gives insight into the necessary speed of movement and how to maintain muscular tension without sacrificing force and the motor unit recruitment associated. This is the basis by which time under tension is discussed, necessitation of sufficient volume, and repeated efforts. Most of the research regarding the force-velocity relationship describe the relationships shape, and implication due to the bi-phasic aspect of movement (eccentric, concentric), joint articulation, lever type and task type. This is all to say the force-velocity relationship may apply differently to certain muscles and cannot be universally applied. The force-velocity relationship is not linear, but is described as double-parabolic when incorporating both the eccentric and concentric phases (Cuk et al., 2014). In the concentric phase, the relationship is inverse (when velocity is low, force is high) when closest to amortization and toward the end of concentric, the relationship remains inverse (velocity is high, force is now low). In the eccentric phase, the relationship is positive (when velocity is high, force is high) when farthest from amortization and toward the end of eccentric, the relationship roughly remains positive (velocity goes down when force goes down) (Alcazar et al., 2022). For hypertrophy purposes, the movement must be sufficiently slow in order maximize time under tension, to sustain muscle tension, and allow for metabolic stress to accrue. In the context of this study, that relationship can be described as linear because the exercise prescription for the experimental group is isokinetic (both the velocity and force are controlled). No matter the effort of the subject, the movement has a sustained velocity and the external force remains unchanged. In an isotonic circumstance, where the velocity is being compared to the weight lifted, it is not linear due to volitional force changes. The two movements being compared differ only based on velocity. So, changes in hypertrophy among each group could be attributed to differences in time under tension and the speed by which the exercise was executed.

In the review study, Skeletal muscle performance determined by modulation of number of myosin motors rather than motor force or stroke size, (Piazzesi et al., 2007) the force-velocity relationship is defined as the “primary determinant for muscle performance.” . In this context, muscle velocity is load specific in that muscles contract at high speeds in low loads and contract slowly with high loads. The molecular mechanisms of the myosin motor are also explained as driving the force-velocity relationship based on myosin attached in response to filament load (p. 2). Ultimately, authors determined that as shortening velocity increases, mechanical tension is reduced due to reduced amount of actin-myosin cross bridge formation and vice versa. This is a useful determination in the discussion of time under tension as it brings insight to the mechanisms of the force-velocity relationship and possible muscle tension at range of contraction velocities. But it is important to note that this is due to detachment rate, not myosin force production.

Moreover, it is important to quantify and disseminate the force velocity relationship. The review study, On the Shape of the Force-Velocity Relationship in Skeletal Muscles: The Linear, the Hyperbolic, and the Double-Hyperbolic, (Alcazar et al., 2019) discusses different explanations for the physiologic mechanisms on controversial finding on the exact shape of the force-velocity relationship. Unlike the previous study, more variables are taken into account as to why mechanical tension reduces in higher contraction speeds. Namely, the force-velocity relationship can be described as double-hyperbolic as there is a concentric and eccentric phase to a given lift. Molecular insights are also taken into account in that calcium-independent regulatory methods have been noted at low forces and high velocities. This study is important to note in determining the dose response necessary when implementing time under tension and answering questions such as how slow and how long? Resistance training has been recommended at 3 seconds eccentric, 0 second amortization, 1 second concentric but it is difficult to make definitive conclusions regarding tempo as this variable cannot be accurately isolated from perceived exertion and load (Wilk et al., 2023).

Finally, in the review study, Force-velocity Relationship of Muscles Performing Multi-Joint Maximum Performance Tasks, (Jaric, 2015) identified the variability with multi-joint, high effort movements. Authors ultimately determined that the force-velocity relationship remains linear and is influenced by the parabolic power-velocity relationship. This gives great insight into neuromuscular capacity, movement application in exercise prescription and application to varying fitness levels. This study is important and unique from the prior two in that it answers the question, what type of exercise? Authors also accounted for high effort movements to account for training status and the individual’s ability to create muscular tension. Authors ultimately determined that the force-velocity relationship remains linear and is positively influenced by the parabolic power-velocity relationship. This study takes into account training status and therefore recruitment potential. This adds to the list of variables that influence the force-velocity relationship and further demonstrates that application of this relationship to resistance training is dependent on the muscle being worked, the individual's training experience, and the movement being performed. An implication discussed in the introduction of this section referred to mechanical tension being lost due to myosin detachment rate with increasing contraction velocities. Skeletal muscle performance is determined by modulation of number of myosin motors rather than motor force or stroke size and the force-velocity relationship is defined as the “primary determinant for muscle performance.” (Piazzesi et al., 2007). The molecular mechanisms of the myosin motor are also explained as driving the force-velocity relationship based on myosin attached in response to filament load. Ultimately, authors determined that as shortening velocity increases, mechanical tension is reduced due to reduced amount of actin-myosin cross bridge formation and vice versa. When movement velocities are directly compared, velocity-based exercise tends to be more effective for strength development when compared to slower movements (Pareja-Blanco et al., 2014). In the research article, Effect of movement velocity during resistance training on neuromuscular performance, (Pareja-Blanco et al, 2014) contraction velocities were evaluated to determine maximal effects on neuromuscular adaptations and force production. The performance outcomes from maximal velocity performance and half velocities performance were tested. Short term mechanical and metabolic responses to each training velocity was also determined in a satellite study. In most performance outcomes, maximal velocity training appeared to result in greater neuromuscular training adaptations including contraction velocity, squat pattern force production and overall strength development. The authors directly state that, "Movement velocity seemed to be of greater importance than time under tension for inducing strength adaptations"(p. 1).

To effectively apply the force-velocity relationship to resistance training, motor unit recruitment must be discussed in order for mechanical loading to be possible and act as the "force" in the relationship. Once this is established, the shape of this relationship while equating other necessary variables must be determined. To effectively determine the shape of the relationship, the phases of the movement, the type of muscle articulation and ability to recruit motor neurons must also be determined. Lastly, the mechanical tension maintained throughout the course of the movement can be determined. Velocity must be effectively controlled in order to maintain muscular tension but motor unit recruitment should also be maintained with sufficient time under tension.

Length – Tension Relationship

Third, the length-tension relationship is described as the relationship between muscle length and muscle tension (LaCombe et al., 2023). In application to the three-part hypertrophy model, motor unit recruitment and the force-velocity relationship are direct means and necessities to mechanical loading. In this context, the length-tension relationship is an important implication in discussing muscular damage and metabolic stress and determining the most effective means of achieving muscular damage without the tissue becoming necrotic or severe muscle injury (Brughelli and Cronin, 2007). Muscular tension is an outcome associated with increased muscle lengthening therefore a factor within hypertrophy training. The majority of the research regarding the length tension relationship compares the differences between full range of motion repetitions versus partial range of motion repetitions. And again, because movements are bi-phasic, researchers will compare the muscular tension differences between concentric and eccentric lifting phases. Based on this relationship, the eccentric phase is defined as the lengthening of the muscle and will be the phase with most tension and therefore hypertrophy potential. This may explain the additive effects of stretch on muscle appear to be more effective for muscle growth. This denotes range of motion with optimal stretch at the muscle is more effective for hypertrophy. But, because muscles have different pennation patterns and articulations, this is not a universal finding for all muscle groups or even every part of the same muscle. In some instances, the distal region of the muscle resulted in more hypertrophy than the proximal region with differences in range of motion (McMahon et al., 2014). There are also some muscle groups where it may not be reasonable to move through an exaggerated range of motion and is more practical to focus on metabolic stress and inducing muscle hypoxia. In any case, the length-tension relationship is a critical component of hypertrophy research in that it is an effective means of developing maximal muscular tension and therefore muscular damage.

Length-tension of the muscle is a component of hypertrophy as it is also an effective means of inducing metabolic stress and inflammatory markers; both of which are components of muscle adaptations. In the study, Partial range of motion training elicits favorable improvements in muscular adaptations when carried out at long muscle lengths, authors used a typical training model of three workout per week for 12 weeks with the primary difference between exercises being differences in range of motion. Subjects were split into groups of A) initial partial range of motion (100 degrees to 65 degrees knee flexion), B) final partial range of motion (65 to 30 knee flexion), C) full range of motion (reps done from 100 to 30 knee flexion) and D) alternating workouts between partial flexion and full range of motion. Authors determined that longer muscle length during strength training is responsible for the greater hypertrophy caused by full range of motion training and that partial range of motion training does not increase hypertrophy at the distal region of the muscle (Pedrosa et al., 2021). From this we can see the effectiveness of the length tension relationship as it applies to the quadriceps and is considered an effective means of developing hypertrophy. In this controlled trial, authors also determined that as the length of the muscle increases, the tension at the muscle increases resulting in stretch mediated muscle mass gains. However, (Goto et al., 2019) determined that partial range of motion resulted in increased muscle mass at the triceps and increased MVC. This could be attributed to increased metabolic stretch on the muscle. This could denote that ROM is not superior for all muscle groups. Partial squat and full range of motion squats were evaluated for effectiveness on hypertrophy and determined full ROM squat to increase hypertrophy at the distal region and partial ROM resulted in increased strength between 50 to 70 degrees flexion (McMahon et al., 2014). Length-tension muscle research is usually a comparison between full ROM and partial ROM. Full ROM is considered more effective for muscle growth but hypertrophy is not universal for all muscles and every portion of the muscle. Specifically, authors reported no statistically significant difference in muscle hypertrophy at the bicep brachii when comparing partial range of motion (50 to 100 degrees elbow flexion) and full range of motion (0 to 130 degrees elbow flexion) (Pinto et al., 2012). This can likely be attributed to the bicep brachii only experiencing tension at the ascending portion of the length-tension curve (Koo et al., 2002). The portion of the curve where the elbow flexors experience an adjusted decline in tension at 1.0 "normalized length" or 10 degrees of elbow flexion (Ottinger et al., 2022). But, tension still increases rapidly from ranges 110 to 10 degrees of flexion. In this range, the relationship between tension and length is closer to linear when hyperflexion (flexion beyond 110 degrees) and hyperextension (extension beyond 10 degrees) is excluded. In the study, Support for a linear length-tension relation of the torso extensor muscles: an investigation of the length and velocity EMG-force relationships, when active, passive, and combined tension were isolated at the erector spinae and then superimposed, the relationship was empirically linear. All curves intersect at 90% as an artifact for gain estimation (meaning this is where tension changes due to joint angle changes beyond expected range of motion). The limitations to this study were listed, however, as being less applicable to other muscle groups due to the poor ability to predict antagonist muscle group activation. But, antagonist activity was concluded to be minimal. The latissimus dorsi and rectus abdominis were also evaluated, but the length-tension relationship was considered inconclusive (Rashke et al., 1996). The length-tension relationship has also been evaluated at multiple muscle groups in the lower extremities. The tibialis posterior (TP), medial and lateral gastrocnemius (MG, LG) and flexor digitorum longus (FDL) had a symmetric active-force curve, whereas the tibialis anterior (TA), peroneus brevis (PB), peroneus longus (PL), extensor digitorum longus (EDL), and soleus (SOL) had an asymmetric curve which exhibits about 25% of the maximal isometric force at extreme lengths (Gareis et al., 1992). These extreme lengths are usually referring to the hyperextension or hyperflexion component of the relationship and explains the "curve" in the relationship. Tension is lost as the muscle hyperextends as myosin cross bridge overlap potential is lost. When hyperextension is removed, the relationship is now linear. But, it is necessary to evaluate the length-tension relationship at multiple muscle groups as the tension can vary based on muscle architecture, pennation and optimal length. To be successfully fitted into the experimental data curve, the muscle must be homogenous with consistent pennation. Authors conclude, in this context, that the length-tension relationship is highly variable as it is dependent on the primary function of the muscle. While the muscles evaluated in this study were all muscles of the ankle, therefore class 2 levers, the point remains that flexors may have symmetric, active force curves (Gareis et al., 1992). The multiple types of tension and pressure experienced at the muscle have also been analyzed. When a line is drawn relating the tension and the radius (or length), you assume that the pressure is kept constant, so that tension is equal to $P(R/\delta)$ or $P(L/2\pi\delta)$, where P is Pressure, R is Radius, L is Length. The tension is linearly related to the length at constant pressure. Rather than constant pressure, however, we evaluate ambient pressure as that resembles contractile muscle behavior. When a muscle contracts at any given length, the muscle will experience tension. The pressure-tension line, though, traces a complex trajectory using a Laplace Transform converting a real variable to a complex variable. Not only can a single Laplace Line not be used in this context, Hooke's Law must also be incorporated to account for spring-like behaviors. The length-tension relationship is considered linear because we assume pressure is constant and is possible because the muscle sarcomere is considered a ureter with a constant radius, allowing for the Laplace Equation to be used (Johnson, 1971).

With these studies and considerations, we can denote that full range of motion tends to be more effective in eliciting hypertrophy adaptations partially due to stretch mediated muscle gains. But, another important consideration is how it influences metabolic stress and changes to the chemical environment within the muscle. In the study, Changes in calpain activity, muscle structure, and function after eccentric exercise (Raastad et al., 2021), authors sought to determine the degree of inflammatory marker activity in the muscle following eccentric intensive exercise and the degree of associated fatigue. 30 subjects completed an eccentric workout consisting of 30 sets of 10 maximal eccentric isokinetic contractions at the quadriceps with 30 seconds of rest in between each set and fatigue was measured by reference to maximal concentric isokinetic strength. Authors determine that after an eccentric training workout, subjects displayed a large increase in calpain activity and demonstrated evidence of sustained fatigue post exercise (Raastad et al., 2021). These findings may suggest that full range of motion training is effective, but should be used sparingly in order to prevent damage beyond recovery capacity.

Fatigue Management

Fatigue is another factor to achieving muscle hypertrophy as it is a key governor to the upper limit of work capacity and diminishing return to strength training. In essence, as the onset of fatigue occurs both acutely and chronically, potential for stimulus diminishes exponentially. Managing muscle fatigue through effective training modes is a strong point of attention for strength practitioners. In the research article, Contraction velocity influences the magnitude and etiology of neuromuscular fatigue during repeated maximal contractions (Morel et al., 2015), neuromuscular fatigue was evaluated after repeated contractions through a variety of contraction modes. Namely, isometric and concentric training modes and 30 degrees per second and 240 degrees per seconds velocity factorials. The number of contractions, total work performed and time under tension were controlled for. Authors ultimately concluded the velocity and mode of exercise was the main determinant of neuromuscular fatigue. Greater velocities attenuated reduced voluntary contraction and concentric modes were associated with increased metabolic stress. In practical application, muscle experiences the most fatigue and accumulated mechanical tension from full range of motion, high volume and slower contraction speeds (and therefore heavier weight). So, this may suggest that this is the ideal training specification to induce hypertrophy as it results in the greatest stressors. However, training while fatigued does not cause the same stimulus for hypertrophy. If you can repeat an effective exercise more consistently without the onset of fatigue, it is the better training mode.

Directly, time under tension is associated with greater mechanical stress, higher accumulated volume and therefore potential for hypertrophy and fatigue. Contraction velocity is associated with greater motor unit recruitment, lower mechanical stress due to lighter loads needed to achieve higher velocities and lower volumes. But, velocity based exercises are less associated with fatigue and therefore more sustainable. In the research article, Effect of movement velocity during resistance training on neuromuscular performance (Pareja-Blanco et al., 2014), contraction velocities were evaluated to determine maximal effects on neuromuscular adaptations and force production. The performance outcomes from maximal velocity performance and half velocities performance were tested. Short term mechanical and metabolic responses to each training velocity was also determined in a satellite study. In most performance outcomes, maximal velocity training appeared to result in greater neuromuscular training adaptations including contraction velocity, squat pattern force production and overall strength development. The authors directly state that, “Movement velocity seemed to be of greater importance than time under tension for inducing strength adaptations” (p. 1). This creates one clear conclusion that velocity training is more effective for strength development while time under tension is more effective for muscle growth. While muscle size is associated with greater muscle strength, neuromuscular drive is an equally important mechanism of strength. Because velocity training results in greater neuromuscular adaptations, strength improvements are a logical following conclusion. Fatigue varies greatly based on training status, age, cardiovascular risk factors and training volume. To effectively equate fatigue in comparative exercises, subjects must be similar psychological and training ages. Contraction velocity tends to be more fatiguing than slower movements when time is equated (Morel et al. 2015).

Fatigue can be measured in a number of ways, but in this context, it is measured based on the three-part model of hypertrophy and how it pertains to accumulation of metabolic stress. As discussed in the length-tension relationship body of literature, eccentric training and full range of motion are often more effective for hypertrophy but should be used sparingly in order to reduce excessive inflammation and fatigue beyond recovery capacity. From this, we can see that a common method in assessing the stimulus to fatigue ratio is the amount of inflammatory activity and metabolic stress as the muscle. Metabolic stress is necessary to a point and is a byproduct of muscle hypoxia. However, with excessive stress, the muscle becomes necrotic and does not adapt in a favorable manner. Moreover, with excessive fatigue, the total work capacity and mechanical tension potential of the individual is reduced over time. Overall, fatigue must be managed in a way to make short term recovery possible and to maintain performance as much as possible over time. In the research article, Eccentric exercise in vivo: strain-induced muscle damage and adaptation in a stable system (Butterfield, 2010), authors sought to determine "productive" damage and "unproductive" muscle damage, with the differences and causes of each phenomenon are. Muscles can experience damage on a continuum, from minor disruptions to fiber orientation to severe fissures resulting in muscle necrosis. Authors ultimately determined that the most common method of severe muscle damage is caused by accumulated minor damage over time and insufficient time of recovery between training events. Whether the damage be caused by sarcomere instability, intracellular calcium, inflammation, or fiber strain, severe injuries are usually not individual events but rather the accumulation of minor damage. So, in order to prevent “unproductive” damage to the muscle, minor damage should be managed appropriately between training sessions to reduce an accumulation effect. This is an appropriate definition and example of the implications to managing fatigue.

Conclusion

Overall, the primary conditions that must be met in order for hypertrophy to be possible are sufficient tension at the muscle as a result of mechanical load (Wilk et al., 2015). The resulting muscular damage initiates an inflammatory response signaling protein synthesis at the muscle (Lim et al., 2022). So, the conclusion and commonalities in literature is that the best method for hypertrophy is the condition where you exert the most effort but can also sustain it repeatedly. If the exercise results in significant muscle damage, a greater demand is placed on the individual to recover effectively. Otherwise, the training mode loses effectiveness as physiologic fatigue markers accumulate. Overall, velocity training is greater for strength improvements and time under tension is greater for hypertrophy. But fatigue must be managed under all conditions.

In this literature review, the principles of hypertrophy have been discussed in a four part and three part model and the conditions by which hypertrophy is possible. The principles are important to appreciate within the context as it is the basis behind which exercises were chosen, how they were isolated, what is being measured within each exercise prescription, baseline measures, and outcome measures. In order to understand the objectives of this study, the principles discussed within this literature review is necessary to understand.

Chapter 3: Methodology

Participants

Subjects were recruited using course announcements and course emails to exercise science students at Winthrop University. To participate in the study, each individual must be a full-time student at Winthrop University, must be a declared exercise science major, and be in good academic standing. Student co-researchers were required to be recorded within the Institutional Review Board (IRB) application and complete a human research Collaborative Institutional Training Initiative (CITI) certification. All co-researchers were given a checklist (Appendix 1) detailing instructions on how to gain the necessary information from the subjects once they have been identified as a candidate for research. 10 subjects (n=10) were recruited ages 18 - 22 years old and were cleared for rigorous exercise using a medical clearance form (Appendix 2). Once the subjects were recruited and identified for the research protocol, they were given a debriefing form (Appendix 3), a Health Insurance Portability and Accountability Act (HIPAA) authorization waiver (Appendix 4), an Informed Consent Form (Appendix 5), and an Exercise Readiness Questionnaire (Appendix 6). If a contraindication arose and the subject was not considered able to participate in strenuous exercise, they were excluded from the study. Subjects were considered based on the inclusion criteria: an undergraduate exercise science student, college aged (18 – 22 years old), recreationally active, healthy enough to participate in strenuous exercise, no prior injuries, health conditions (cardiac, pulmonary, cancer, musculoskeletal, or metabolic disease), and permitted to exercise by their general practitioner. Simple random sampling selection was used to recruit subjects to further reduce selection bias. Subjects were selected on this basis to maintain internal validity and control external influences that may affect hypertrophy outcomes. External influences controlled were maturation (biological age), training history (exercise experience), and lifestyle (all are college, undergraduate students). External validity was maintained as the results are intended to take a small subject sample and create generalizable conclusions. To promote external validity, subjects were instructed to not engage in any other type of exercise while participating in the study and to not make any significant dietary changes.

Instruments

A medical clearance form and Physical Activity Readiness Questionnaire were used to evaluate the ability to exercise in the subjects. The randomization was completed using a random name generator to eliminate internal validity threats. The primary instrument used was the C&M Machines PYTHON isokinetic bicep curl machine. The features of this device include a touch screen user interface, a velocity and force potentiometer, a seated preacher curl design, two enclosed handles, and force tracking technology (Appendix 7). The machine is set to a .8 m/s velocity for both eccentric and concentric phases of the movement. At this velocity, each repetition will take 4 seconds and the subjects in the isotonic group are instructed to lift at 3 second eccentric, 1 second concentric tempo, making time in tension similar between groups. Subjects were instructed to maintain 80% 1RM force output based on their pretest scores. The force output was plotted real-time on a line graph in 1 second intervals on the touch screen mounted to the left of the subject. This instrument is considered highly reliable as the exercise prescription is exactly repeatable. Similar isokinetic dynamometers have been evaluated in controlled trials demonstrating reliability and validity (Drouin et al., 2004).

The control group performed the bicep curls using a standard preacher curl arrangement. This equipment uses an “EZ curl bar” with a 45 degree, internally rotated barbell design (Figure 8). The barbell was loaded with 80% of the subjects predicted 1RM.

Procedures

10 subjects (n=10) were recruited with an age of 18 to 22 years old (20 +/- 2) and were cleared for rigorous exercise. Subjects were recruited via announcements in an upper-level exercise science course taught by the principal investigator at Winthrop University. Students were given the option to complete 1 of 2 assignments. The first option was to work directly with a client and document a 10-week training program that consists of 2 training sessions per week. A 10-week training period is determined to be an effective period of time before training adaptations can be observed (Martins-Costa et al., 2022) and a training frequency of 2 times per week has also been used in controlled trials for similar purposes (Schoenfeld et al., 2016). The other option was to participate in this research experiment, where students engaged in a 10-week training protocol and each session supervised by the principal researcher. There was no incentive or penalty for choosing one assignment over the other, each assignment was scored on the same criteria, each assignment had the same time contribution, and each assignment was the same point total ensuring that there was no advantage to one assignment and students were not feeling unfairly persuaded to participate in this study. Subjects completed a pre assessment that consisted of bicep brachii circumference measurements in centimeters (measured at the halfway point between the olecranon process of the elbow and acromion process of the shoulder, elbow flexed at 90 degrees with maximal voluntary contraction, circumference taken at the bicep peak) and 10 rep max seated bicep curl in order to estimate a 1RM. The subjects were instructed to complete 3 warm-up sets before attempting their 10RM. In the event that a subject did not complete 10 reps on a chosen weight, a 1RM was calculated ($1.0278 - 0.0278 \times \text{reps}$) using the weight lifted and the number of repetitions rather than attempting another rep max (Read, T., 2023). Each subject was randomly assigned to the control group (CG) or the experimental group

(EX) using an online random team generator (Pickerwheel.com, 2021). Subjects completed a 10-week supervised exercise program that consisted of 2 training sessions per week with at least 48 hours between sessions. The CG completed 5 sets of 5 repetitions at 80% 1RM on a seated preacher curl machine. The EX group completed 5 sets of 5 repetitions at 80% IRM on an isokinetic machine (C&M Machines PYTHON bicep curl machine). The training volume was determined using accepted volume standards at 80% intensity (Hester et al., 2017). Post assessments were then measured using bicep brachii circumference measured in centimeters. A total of 20 training sessions were completed by each subject and any missed training session was rescheduled to a day/time within that individual training week. Any injuries were documented in the subject's data log.

Design and Data Analysis

Subjects were randomly assigned to either the control group (n=5, isotonic) or the experimental group (n=5, isokinetic). The data was analyzed using a paired samples T-test, each pre and post group acting as the pairing. The paired samples T-test was chosen due to the sample size, number of groups, and pre/post testing on the same group with a length of time elapsed between testing. Moreover, to analyze the difference between groups, a bivariate Pearson correlation coefficient was determined between each group. Two groups were being compared (isokinetic vs. isotonic) and each group had 5 subjects. Using a paired sample T-test, data differences between groups were considered statistically significant if ($P < .05$). The descriptive statistics reported were central tendency, ordinal scores, standard deviation, and measure of variability. The research design was pre-posttest control, true experimental research design, random assignment. Due to the small sample size, the statistical power was also kept low to reduce Type 2 error. The larger the sample size, the larger the statistical power due to reduced standard with larger sample sizes. Gender and age were not considered when performing statistical analysis. The findings may be broadly applicable to healthy, college-aged individuals. To maintain internal validity, subject selection was confined to exercise science college students attending the same University. This can effectively reduce questioning about lifestyle differences contributing to hypertrophy differences. Finally, applied research questioning methods were used to create conclusions within the literature review and identify relevant hypertrophy training variables.

Ethical Considerations

Ethical considerations included privacy of each subject, safety implications of strenuous exercise. Privacy of each subject was maintained through a password protected computer and all medical information, research data, or exercise performance is kept in a secure folder on a faculty computer. Safety of each subject was maintained by using a debriefing form, an exercise readiness questionnaire, a HIPAA authorization waiver and a medical clearance form. The procedures ensure that each subject was aware of the risks associated with strenuous exercise, the discomfort associated with strenuous exercise, and the medical information needed to participate. Each subject was also informed that they can discontinue their participation at any time. Finally, student researchers were only able to participate upon completion of a human research CITI certification to ensure the safety of the participants and were not permitted to view or handle any subject medical information.

Chapter 4: Results

Introduction

The objective of this study was to evaluate the efficacy of two forms of resistance training on muscle growth. The isotonic group used a standard preacher curl with a standardized resistance and the isokinetic group used a preacher curl machine using the same amount of force and volume. In both groups, bicep brachii circumference was measured pre and post the 10-week exercise protocol. The primary points of interest were to determine the change in muscle growth between each exercise and to compare the results of each exercise to determine differences in efficacy. To accomplish this, the data was analyzed using descriptive statistics and the mean bicep brachii circumference among each group was determined (Figure 1). While there were two experimental groups (isotonic and isokinetic), each group was further split into four variable groups (pre/post isotonic and pre/post isokinetic). The standard deviation was also presented to give an expected deviation from the mean. Further, paired samples statistics were used to further analyze pre/post outcome means and later use a paired samples T-test (Figure 2). In this table, standard error to the mean was presented as a more precise method to deviation from the mean accounting for sample size. A paired sample correlation is presented (Figure 3) to further evaluate differences between pre and post testing samples. Pair 2 within Table 3 presents non-linear, no correlation determination (.000) and thereby creates potential for an outlier creating a large degree of variance. Later, outlier and sample size variability was accounted for using the statistical methods presented in Figure 5. To effectively answer the research question, a paired samples T-test was used (Figure 4). A paired sample T-test was an effective statistical method as the statistical difference between two time points, the difference between testing conditions and procedures, and difference between two data measurements was needed (Kent State University Library, 2021). A paired T-test was also appropriate based on sample size and number of variables. From this statistical measure, average mean, standard deviation, a two-tailed 95% confidence interval, t-value, degrees of freedom and two tailed p-value is presented. Again, this effectively answers the research question as the sole objective is to determine pre/post exercise differences and variation between each exercise in bicep circumference. Finally, paired sample effect sizes are presented (Figure 5). Because the sample size was relatively small (n=10), average mean can be easily skewed due to an outlier. To accurately represent the data outcomes and to account for sample size, Cohen's d and Hedges' correction was used. Cohen's d is a necessary preliminary procedure to determine the difference of each mean and divide the standard deviation. This creates a standardized difference between the means and allows Hedges' correction to be used. Hedges' correction applies sample variance (correction factor) to Cohen's d and used the sample standard error of each mean. These procedures account for major outliers affecting the small sample size and use standard error rather than standard deviation to eliminate statistical bias. Ultimately, the following statistical methods were used to present the difference between pre and post measures, the difference between each exercise and to correct for sample size bias. All data tables were prepared using IBM® SPSS® Statistics.

Findings

In the initial analysis, each group was further split into pre and post groups. N=5 for each experimental group and the minimum/maximum bicep brachii circumference for each group is presented. From this information, mean and standard deviation was determined. From the initial descriptives (Figure 1), the difference between each mean was determined (Isotonic, -1.6 cm difference) and (Isokinetic, -3.8 cm difference).

Figure 1

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
PreIsotonic	5	20.00	27.00	23.0000	3.00000
PostIsotonic	5	22.00	28.00	24.6000	2.19089
PreIsokinetic	5	24.00	29.00	26.2000	2.16795
PostIsokinetic	5	29.00	31.00	30.0000	1.00000
Valid N (listwise)	5				

In Figure 2, the four groups have been paired into pre/post isotonic and pre/post isokinetic pairs. Standard error was then determined as a deviation from the mean upon a specific sample. Both procedures were necessary to run a paired samples T-test and sample effect size analysis.

Figure 2

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PreIsotonic	23.0000	5	3.00000	1.34164
	PostIsotonic	24.6000	5	2.19089	.97980
Pair 2	PreIsokinetic	26.2000	5	2.16795	.96954
	PostIsokinetic	30.0000	5	1.00000	.44721

A paired samples correlation analysis was also presented to show a two tailed p-value significance and the pre/post findings demonstrate a positive or negative trend. Because strenuous exercise was used, a paired samples correlation can identify how closely consistent the measures were. Because Pair 2 shows a .000 correlation, or no correlation, this represents a large difference in 1 or more data pairing. This brings the necessity of paired sample effect size presented in Figure 5. Pair 1 showed a .875 correlation.

Figure 3

Paired Samples Correlations

		N	Correlation	Significance One-Sided p	Significance Two-Sided p
Pair 1	PreIsotonic & PostIsotonic	5	.875	.026	.052
Pair 2	PreIsokinetic & PostIsokinetic	5	.000	.500	1.000

Further, in Figure 4, the difference of the means between each pair is presented. Pair 1 (pre/post Isotonic) was -1.6 cm and Pair 2 (pre/post Isokinetic) was -3.8 cm. In Pair 1, the one-sided p-value is .039 and Pair 2 is .012 with both pairing demonstrating a statistically significant difference between pre/posttest scores ($P < .05$). T-values (Pair 1 (-2.359 cm) and Pair 2 (-3.559 cm)) did demonstrate, however, the degree of difference between pre/post means. Pair 2 had 1.2 cm difference pre/post outcomes.

Figure 4

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Paired Samples Test

		Paired Differences					t	df	Significance	
					95% Confidence Interval of the Difference					
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			One-Sided p	Two-Sided p
Pair 1	PreIsotonic - PostIsotonic	-1.60000	1.51658	.67823	-3.48308	.28308	-2.359	4	.039	.078
Pair 2	PreIsokinetic - PostIsokinetic	-3.80000	2.38747	1.06771	-6.76443	-.83557	-3.559	4	.012	.024

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Finally, sample size outlier bias was accounted for in Figure 5. After using Hedges' correction in each pairing, Pair 1 had a -.952-point estimate and Pair 2 a -1.437-point estimate. This demonstrated a statistical difference pre/post outcome measure between each pairing with a standardizer and correction factor applied.

Figure 5

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Paired Samples Effect Sizes

			Standardizer[a]	Point Estimate	95% Confidence Interval	
					Lower	Upper
Pair 1	PreIsotonic - PostIsotonic	Cohen's d	1.51658	-1.055	-2.144	.105
		Hedges' correction	1.68004	-.952	-1.935	.095
Pair 2	PreIsokinetic - PostIsokinetic	Cohen's d	2.38747	-1.592	-2.936	-.184
		Hedges' correction	2.64480	-1.437	-2.650	-.166

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Conclusion

After 10 weeks of bicep brachii resistance training, the isotonic group had an average bicep brachii circumference increase of 1.6 cm and the isokinetic group had an average bicep brachii circumference increase of 3.8 cm. While both exercises were considered effective in modest bicep brachii growth (Isotonic t-value (-2.359), Isokinetic t-value (-3.559)), both groups had a statistically significant improvement (Isotonic p-value (.039), Isokinetic p-value (.012)) ($p<.05$).

Chapter 5: Discussion

Interpretation of Findings

Based on these findings, the isokinetic machine exercise was shown to be more effective in muscle hypertrophy than the isotonic exercise, although both groups showed improvements. Both exercises demonstrated a statistically significant increase in muscle growth and these findings give insight into the execution methods necessary for muscle growth. During the isotonic exercise, while the force remains constant by definition, the force and tension applied to the muscle changes at different portions of the repetition range. Tension and force production potential varies greatly based on joint angle at the muscle and therefore an optimal muscle length at 110, 100 and 50 degrees have been determined (Chang et al., 1999). As force capacity changes throughout the repetition range, active tension at the muscle can vary greatly. Moreover, the isotonic group was instructed to maintain a 3:1 eccentric to concentric repetition tempo. Each rep thereby takes approximately four seconds and each set takes approximately 20 seconds. Throughout each rep, the isotonic subjects had the opportunity to rest or reduce exertion at the top of the range. While the subjects are being coached to enforce time under tension, exertion cannot be precisely enforced throughout the rep range. In the isokinetic group, tension changes and force production at varying joint angles were tracked exactly. Despite the changing joint angle, the researcher was able to watch the dynamometer and track force production exactly to ensure the subject was maintaining exertion even at the top end of the rep. Range of motion was standardized between groups and time under tension was standardized between each group. The isokinetic group lifted at a constant velocity of .8 m/s making each rep approximately four seconds and each set 20 seconds. However, the repetition was at a 2:2 concentric to eccentric ratio. So, the comparable differences between each group were lifting velocity and trackable exertion. Because of this, the isokinetic group likely resulted in greater muscle hypertrophy because the velocity is mechanically constant and exertion was easily enforced while the subject was able to see their force production. This is an important point as exertion is a critical factor in resistance training efficacy (Wilk et al., 2021) The isokinetic subject had no opportunity to rest throughout the rep range and changes in force production ability to not change the velocity as it could in the isotonic exercise. This results in repeatable and trackable tension directly applied in each isokinetic set and repetition. The isotonic subjects were not under enforceable exertion standards, were not able to visibly see their force production, could use compensatory factors and had the opportunity to rest throughout the movement. This can result in reduced tension at the muscle and reduced exercise efficacy. In sum, the isokinetic group demonstrated greater changes in muscle hypertrophy. This is likely due to enforced tension at the muscle throughout the course of each repetition and this method is exactly repeatable.

Practical Applications

These interpretations give insight into the methods by which resistance training should be executed in order to maximize muscle hypertrophy. These conclusions were developed with the intent to inform the general consumer of resistance training information on the most efficacious ways to promote muscle growth. With more direct and applicable information to the general public, the reduced discrepancies on weight lifting technique may lead to better health outcomes and less orthopedic injury. Moreover, this information is applicable to strength and conditioning specialists seeking to improve resistance training prescription to athletes. As stated in the introduction, improved body composition is correlated with reduced all-cause mortality (Graf et al., 2016). Because of this, finding the best methods to increase exercise efficacy and increase fat free mass is of great interest to health professionals. Improved body composition is also positively correlated with improved athletic performance (Ilhan et al., 2023). While athletic performance is beyond this scope of this research protocol, this information may still be applicable to athletes seeking to improve body composition.

The primary practical application to these findings are to determine methods to standardize velocity and exertion with the intent of maintaining tension at the muscle. As previously discussed, isotonic resistance training gives opportunity for the exerciser to use compensatory factors (momentum, breaking tempo, etc.), alter the range of motion between each set and rep and reduce exertion based on the force demands of each joint angle. With isokinetic exercise used, there is no opportunity for compensation, the exerciser is unable to use momentum as the velocity cannot change, the range of motion is set and cannot change between each repetition, force production does not change based on joint angle thereby enforcing exertion, and velocity is controlled thereby maintaining tension (Piazzesi et al., 2007). For the average weight lifter, it should be understood that in order to maximize muscle hypertrophy in this context, range of motion should be repeatable, exertion should be maintained throughout the repetition, and velocity should be managed with precise tempo in order to maintain tension. The more variable these factors are within exercise execution, the less dependable the exercise effectiveness becomes. However, exercises should never be deliberately slow, as this reduces motor unit recruitment if load is the same (Wilk et al., 2021).

Contribution to Knowledge and Profession

In the literature review, a three-part hypertrophy model was outlined and is a short list of factors necessary for muscle growth: mechanical tension, muscular damage, and metabolic stress. While these factors are well supported, this model lacks practicality as it does not give insight into weight lifting form or execution. Resistance training carries many variables and must be described to the general public beyond the physiologic characteristics of muscle growth. I then describe a proprietary, four-part hypertrophy model to both expand on these physiologic characteristics and give insight into how resistance training must be executed in order to maximize muscle growth potential. The proposed four-part hypertrophy model is motor unit recruitment, the force-velocity relationship, the length-tension relationship and fatigue (Beardsley, 2018). My contribution to knowledge and profession is to further demonstrate that these variables are collectively explanatory of muscle growth and are practical guidelines for the general public seeking to improve their body composition.

To demonstrate these mechanisms, a strategic method of correlating specific resistance training variables should be done to isolate mechanisms of muscle hypertrophy. Motor unit recruitment is the successive activation of motor neurons stimulating muscle tissue to contract in response to a stimulus. In accordance with Henneman's size principle, as small motor neurons fatigue, larger motor neurons are recruited in order to maintain contraction and force production (Schoenfeld et al., 2013). Further, frequency of stimulus must increase in order for tetanus contraction to occur. This creates questions about what condition results in sustainable tetanus and if motor unit recruitment can be artificially imposed through a transcutaneous electrical neuromuscular stimulating (TENS) unit. A faradic electrical current is high enough frequency to produce tetanus whereas a galvanic current frequency cannot (Lewis, 1946). It is believed that motor unit recruitment creates a faradic current frequency whereas a TENS unit creates a galvanic current frequency. My contribution in this context would be to evaluate each weight lifting variable (volume, weight, intensity) and determine its effect on motor unit recruitment and muscle growth. The goal would be to also determine the manner by which muscle can be stimulated in achieving tetanus.

Second, the force-velocity relationship describes biphasic weightlifting (eccentric and concentric) and how external force influences velocity. This relationship ultimately states that as velocity increases, force increases in the eccentric phase on a parabolic curve and the inverse in the concentric phase (Jaric, 2015). This relationship can also be used to describe internal force production in response to varying lifting velocities. As the velocity of contraction increases, force production at the muscle decreases as myosin cross bridge formation is lost (Piazzesi et al., 2007). Because myosin cross bridge formation is lost, tension is lost and thereby reduces stimuli for muscle growth. This phenomenon demonstrates the need for lifting tempo and managing velocity to maximize muscle growth. To analyze this, the goal is to correlate varying lifting tempos and lifting velocity and their effect on muscle growth.

Third, the length-tension relationship describes the multiple types of tension the muscle can experience at different muscle lengths. Muscle can experience active, passive, combined and elastic tension and vary based on muscle length. This relationship ultimately describes the efficacy of range of motion on muscle growth and how to optimize muscle tension. The goal here is to simply compare different lifting ranges of motion on muscle growth, but to also determine at what point is tension lost at the muscle and at what point does elastic tension jeopardize muscle tension.

Finally, fatigue is the broad evaluation of systemic loss in force production. Onset of fatigue reduces muscle performance and reduces ability to sustain muscular tension. This, of course, leads to the questions as to when deloads are necessary, scheduled breaks, and what are the necessary rest periods between sets. Moreover, it is understood that individuals should train to the extent that they can optimally recover; no more, no less (Coleman et al., 2023). Fatigue can also be roughly correlated with muscular damage: muscular damage should incur for muscle growth with respect to an increased injury risk. So, the goal would be to determine how to evaluate evidence of sustained fatigue, how to auto regulate resistance training to manage fatigue, and what are the recommended intra-set rest periods for muscle growth.

My contribution to knowledge and profession is to demonstrate this proprietary, four-part hypertrophy model on its efficacy to muscle hypertrophy and demonstrate its practicality to the general public. This model should effectively answer how to perform an exercise in regard to effort, speed, tempo, range of motion and recovery.

Action Plan

The action plan is to continue to develop and demonstrate this four-part hypertrophy model in its effects on muscle hypertrophy. The goal is to evaluate how this proprietary concept is responsible for muscle growth and to demonstrate the variables behind each working mechanism. First, motor unit recruitment is the response to an external mechanical load. The two main types of load that are variable in resistance training are weight and volume. To maintain motor unit recruitment and effort of the individual, weight needs to be high enough for the muscle to be effectively stimulated. Additionally, volume needs to be high enough to maintain muscle stimulus. But, as weight increases, volume capacity is reduced and as volume of lifting increases, weight being used will decrease. This gives rise to the rep range continuum where certain weight and the corresponding rep range is recommended. The action plan in this context is to further demonstrate that while weight and volume are correlated when determining load, motor unit recruitment is the key principle to maintain muscle stimulus and not volume versus weight. The plan will be to evaluate different rep ranges while matching load and to compare the effects on hypertrophy. The overarching principle will be to provide more insight into stimulus by this mechanism rather than discussions of weight and rep ranges.

Further, the action plan regarding the force-velocity relationship will be to further expand on the research protocol discussed in this dissertation. The key variables are to determine how velocity influences tension and how force capacity at different velocities also influences hypertrophy. This gives rise to the questions of tempo and weightlifting execution. Resistance training tempo is a biphasic discussion and the force-velocity relationship helps determine what load can be tolerated in each phase and what the effect on velocity is. Because a lifter can tolerate higher load in the eccentric phase and to maximize eccentric stretch, a lifting tempo of 3:1 eccentric to concentric is typically recommended (Butterfield et al., 2017). An issue arises, however, in that lifting a slower velocity, deliberately, jeopardizes motor unit recruitment and is less effective (Piazzesi et al., 2007). Thus, methods for maintaining tempo while ensuring effort from the individual can be challenging. The action plan in this context is to compare lifting tempo and their effects on hypertrophy while discussing how varying lifting velocity influences tension.

Third, the length-tension relationship has been discussed as one of the key principles in this dissertation to promote muscle hypertrophy. The relationship can be loosely described as muscle tension increasing as the muscle lengthens. However, not every portion of the muscle experiences tension the same way (Pedrosa et al., 2021) and not all tension is the same. Mainly, imposing elastic tension will jeopardize muscular tension as it initiates the stretch shortening cycle and allows for loss of effort/tension during the amortization phase of the lift. To maintain tension, the muscle should lengthen to a degree that does not increase injury risk while also reducing elastic tension. This can be effectively managed by assessing the mobility of the individual and enforcing controlled lifting velocity during a full range of motion exercise. Ultimately, the plan is to evaluate different lifting ranges of motions and their effect on hypertrophy while also accounting for growth patterns across each portion of the muscle. In other words, assessing if the distal region of the muscle grew at the same proportion as the proximal region.

Finally, fatigue management is an essential concept within weight lifting literature as resistance training is only as effective as it is sustainable. The stimulus on the muscle should be repeatable and it should also be understood that there is diminishing return to exercise as one experiences more stress. An individual's tolerance for stress can vary greatly and is usually most determined by weight lifting experience. Because of this, rest periods should be carefully determined with regard to training experience (Miranda et al., 2007). Indeed, stress tolerance is a key factor in determining a number of variables of fatigue management including rest periods, lifting frequency, lifting intensity, deloads and velocity. Evaluating the amount of muscular damage, metabolic stress and perceived stress from weight lifting techniques gives valuable insight into the stimulus to fatigue ratio. This essentially answers the question, "Is it really worth it?" Moreover, these methods should be considered for injury prevention. The plan is to evaluate rest periods and scheduled breaks in training in response to certain training methods. The goal is to answer when rest is truly needed and at what rate is it most effective for promoting muscle growth.

The action plan is to evaluate the methods of motor unit recruitment, the force-velocity relationship, the length-tension relationship and fatigue (Beardsley, 2018) effect on hypertrophy and how this proprietary list of variables can benefit the average weightlifter to improve their body composition.

Limitations

Limitations of this research project include sample size, cost of the machine and intrasubject variability. The sample was relatively small (n=10) giving potential for outlier bias. The cost of the isokinetic machine used is approximately twenty thousand ($20,000) dollars so it is not feasible to use these methods exactly in the general public. The machine likely only has use in a scientific setting operated by a trained practitioner. Lastly, intrasubject variability was mostly managed through inclusion criteria and attempting to match the lifestyle of each subject (all subjects were college aged, attended the same University, all exercise science majors with similar knowledge of exercise, etc.). However, each subject's diet and sleep patterns were not observed and can cause great variance in hypertrophy outcomes.

Recommendations for Future Research

To address these validity and repeatability concerns, future research should include larger sample sizes to improve accuracy of the averages taken, alternate training methods should be considered with lower cost, and lifestyle factors should be thoroughly surveyed and considered in future discussions. Moreover, a correlational analysis between demographic specific outcomes is recommended for future investigations. Correlational data identified resistance training outcomes specific to age and gender can further benefit the general public in choosing the best approaches to exercise.

Conclusion

With this comparative study, the physiologic factors of weight training can be better understood on which method may be better for muscle development and what the means for weight lifting efficacy are. The described machine controls time under tension, measures force production consistently and gives continual feedback on subject effort. The changes in hypertrophy are likely due to these factors. Moreover, with better understanding of muscle hypertrophy, weight lifting techniques can be better understood to ultimately benefit the general public in their fitness pursuits.

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Appendix

Appendix 1:

C&M Machines PYTHON Curl Study

Researcher Checklist:

1. Write the following information about your subject:
    a. Name
    b. Email and phone number
    c. Age
    d. Weight (Kg)
    e. Height (cm)
    f. Sex (optional)
    g. Exercise experience (# of years of consistent (3 times per week) exercise)
2. Discuss and explain Debriefing Form
3. Have the subject complete the following:
    a. Medical Clearance Form
    b. PAR-Q+ Form
    c. Exercise Readiness Questionnaire (ERQ)
    d. If it is determined that they are not ready for exercise, refer back to me.
4. In the first session, record the following pre-assessment data:
    a. Before exercise, determine bicep circumference (half way between elbow and medial deltoid)
    b. 10 rep max barbell bicep curl
    c. Predict 1 rep max based on this assessment and multiply by .80
5. Schedule session times on a 2x per week basis:
    a. Record their training schedule day and time
    b. Complete 20 sessions over the next 10 weeks.
    c. Check off session box as they complete each session

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20

6. Complete training tutorial with Charles Brewer with C&M machines for bicep curl device
    a. Schedule tutorial by contact him at 803 792 5817 or at cbrewer@cmmmachines.com
7. Each training session is either:
    a. Standard group: Standing BB curl, 5 sets 10 reps @ 80% 1RM
    b. Machine group: PYTHON curl device, 5 sets 10 reps @ controlled target force based on tested 1 RM (Charles will explain how to set this)
8. After the 20th session, record 10 RM and bicep circumference the following day.
9. Store all data on a password locked computer or return back to Logan.

Appendix 2:

Medical Clearance Form

ExRx.net
Exercise Prescription on the Internet

Dear Doctor:

Your patient ______________________ wishes to take part in an exercise program and/or fitness assessment. The exercise program may include progressive resistance training, flexibility exercises, and a cardiovascular program; increasing in duration and intensity over time. The fitness assessment may include a sub-maximal cardiovascular fitness test and measurements of body composition, flexibility, and muscular strength and endurance.

After completing a readiness questionnaire and discussing their medical condition(s) we agreed to seek your advise in setting limitations to their program. By completing this form, you are not assuming any responsibility for our exercise and assessment program. Please identify any recommendations or restrictions for your patient's fitness program below (Physician's Recommendations).

Patient's Consent and Authorization

I consent to and authorize ______________________ to release to ______________________, health information concerning my ability to participate in an exercise program and/or fitness assessment. I understand this consent is revocable except to the extent action has already been taken. Authorization is not valid beyond one year from date of my signature. Further disclosure or release of my health information is prohibited without specific written consent of person to whom it pertains.

Patient's signature		Date

Physician's Recommendations

☐	I am not aware of any contraindications toward participation in a fitness program.
☐	I believe the applicant can participate, but urge caution because:
☐	The applicant should not engage in the following activities:
☐	I recommend the applicant **not** participate in the above fitness program.

Physician's name (print)		Phone
E-mail		Fax
Physician's signature		Date

Appendix 3:

Debriefing Form

Thank you for participating in our Python Bicep Strength study!

We will be measuring differences in strength at the bicep from using a plate-loaded curl bar on a preacher curl seat and comparing to an eccentrically loaded, isokinetic machine. If there are strength changes seen at the bicep using an eccentric controlled machine, there is logical implication that this resistance training modality could apply to other muscle groups. The machine is a patented device created by C&M Machines. We are ultimately evaluating its efficacy in developing strength and muscle hypertrophy.

If you are interested in learning the results of this study, please contact the researchers after February 28th, 2022.

Researchers:

Logan Daughtry (daughtryg@winthrop.edu)
Mayur Patel (patelm9@winthrop.edu)
Joni Boyd (boydj@winthrop.edu)

If you have any concerns regarding this study, please contact my faculty advisor Joni Boyd or the Office of Grants and Sponsored Research Development.

Grants and Sponsored Research Development
PH: 803-323-2460

If anything about this survey caused you to feel uncomfortable, health and counseling services are available to Winthrop students in the Crawford building. You can reach Counseling Services at (803) 323-2206 or get information at: https://www.winthrop.edu/counseling/

All counseling services are free and confidential.

Appendix 4:

08/29/2019

Winthrop University
Institutional Review Board
Request for a Waiver of Written HIPAA Authorization

Instructions: To request a waiver of HIPAA authorization requirements, complete this form and attach it as a PDF to the electronic copy of the Request for Review of Research Involving Human Subjects. PHI is an acronym for Protected Health Information and is used throughout this document.

Principal Researcher: Name & Title:

Name(s) & Title(s) of other members of the Research Team:

Title of Research Study:

Name and Address of the Health Care Provider:
Health Care Provider Contact:

1.	Protected Health Information (PHI): List in detail, the PHI that is to be collected for the research activity and explain why this health information is the minimum necessary to meet the research objectives:	
2.	Identify the source of the PHI (e.g. medical record etc).	
3.	Waiver of HIPAA Authorization; Indicate below the reason for the waiver request:	
	☐	Seeking IRB approval of authorization waiver – Complete Item 4 below (45CFR164.512(i)(1)(i))
	☐	The collection of the PHI is solely to prepare a research protocol and the researcher will not remove any PHI from the Health Care Provider's premises and the PHI is necessary for the research purpose. (45CFR164.512(i)(1)(ii))
	☐	The use or disclosure being sought is solely for research on the PHI of decedents and the PHI is necessary for the research purpose. (45CFR164.512(i)(1)(iii))
	☐	The researcher has entered into a Data Use Agreement with the Health Care Provider. Attach a copy of this agreement to the Request for Review of Research Involving Human Subjects. (45CFR164.514(e))

08/29/2019

4	Minimal Risk – respond to the following three elements:	
	a.	Describe the plan to protect the identifiers from improper use and disclosure:
	b.	Describe the plan to destroy the identifiers at the earliest opportunity consistent with conduct of the research, unless there is a health or research justification for retaining the identifiers or such retention is otherwise required by law:
	c.	Other that the Researcher or Research Team identified above, describe any other individuals or entities that will have access to, use of or other disclosure of PHI:

I certify that the Protected Health Information will not be reused or disclosed to any other person or entity, except as required by law, for authorized oversight of the research study, or for other research for which the use or disclosure of PHI would be permitted.

Signature of Researcher   Date   Signature of Faculty Advisor for Student Researcher   Date

Approval of Waiver Request by IRB

Chair, Institutional Review Board   Date

Appendix 5:

INFORMED CONSENT FORM

You are invited to take part in a research study whose purpose is to evaluate the strength and muscle development efficacy of the Python Bicep Curl machine compared to standard weight training.

This study is open to adults over the age of 18. Your decision to take part in this study is voluntary. You are free to choose whether or not you will take part in the study. If you should decide to participate, you may withdraw from the study at any time. Even after you sign this informed consent document, you may decide to leave the study, skip, or refuse to answer any questions at any time without penalty or loss of benefits to which you may otherwise be entitled.

Your participation will last about (20 minutes / 30 sessions) and you will be participating in 4 sets of 10 reps in each session of either the Python Curl machine or the plate loaded curl bar with force equated.

This project is deemed as no more than minimal risk. The research team does not foresee or anticipate any risk greater than that encountered in your routine daily activities.

Please tell me if you have any injuries or other problems related to your participation in this study. By signing this form, you do not give up your right to seek payment if you are harmed as a result of being in this study.

Your cost to participate in the study is the time that you will dedicate to this activity and minimal exertion with each training session.

We plan to publish the results of this study. You will not be directly identified in any reports produced as a result of this study. Records will be kept confidential to the extent provided by federal, state and local law. However, the Institutional Review Board, the sponsor of the study (if applicable), or university and government officials responsible for monitoring this study may inspect these records.

If you have any questions about this study, you may contact me at the following:
Researcher: George Logan Daughtry, Instructor of Exercise Science
Address: 701 Oakland Ave. Rock Hill, SC 29730
Telephone: 803-323-3922
Email: daughtryg@winthrop.edu

You may also contact me through my faculty advisor at the following:
Faculty Advisor: Joni Boyd, Professor of Exercise Science
Address: 701 Oakland Ave. Rock Hill, SC 29730
Telephone: 803-323-3924
Email: boydj@winthrop.edu

Should you have questions regarding your rights as a research participant, or wish to obtain information, ask questions, or discuss with someone other than the research team, please contact the Office of Grants and Sponsored Research Development at the following:
110 Macfeat House
Winthrop University
Rock Hill, SC 29733
Telephone: 803-323-2460

One copy of this document will be kept together with the research records of the study. You will also be given a copy to keep.

I have read (or been informed of) the information given above. Logan Daughtry has offered to answer any questions I may have concerning this study. I understand what is involved, and hereby give my consent to participate in this study.

ADULT SUBJECT OF RESEARCH

____

Printed Name Consenting Signature Date

LEGAL REPRESENTATIVE (If Applicable)

____

Printed Name Consenting Signature Date

Relationship to Subject: ______________________

Appendix 6:

Exercise Readiness Questionnaire (ERQ)

First		Last	Age
Phone	E-mail		DOB

Regular exercise is associated with many health benefits. Increasing physical activity is safe for most people. However, some individuals should check with a physician before they become more physically active. Completion of this questionnaire is a first step when planning to increase the amount of physical activity in your life. Please read each question carefully and answer every question honestly.

○ Yes ○ No	1) Has a physician ever diagnosed you with a heart condition **and** indicated you should restrict your physical activity?
○ Yes ○ No	2) When you perform physical activity, do you feel discomfort in your chest?
○ Yes ○ No	3) When you were not engaging in physical activity, have you experienced chest pain in the past month?
○ Yes ○ No	4) Do you ever faint or get dizzy and lose your balance?
○ Yes ○ No	5) Do you have an injury or orthopedic condition (such as a back, hip, or knee problem) that may worsen due to a change in your physical activity?
○ Yes ○ No	6) Do you have high blood pressure or a heart condition in which a physician is currently prescribing a medication?
○ Yes ○ No	7) Are you pregnant?
○ Yes ○ No	8) Do you have insulin dependent diabetes?
○ Yes ○ No	9) Are you 69 years of age or older **and** not used to being very active?
○ Yes ○ No	10) Do you know of any other reason you should not exercise or increase your physical activity?

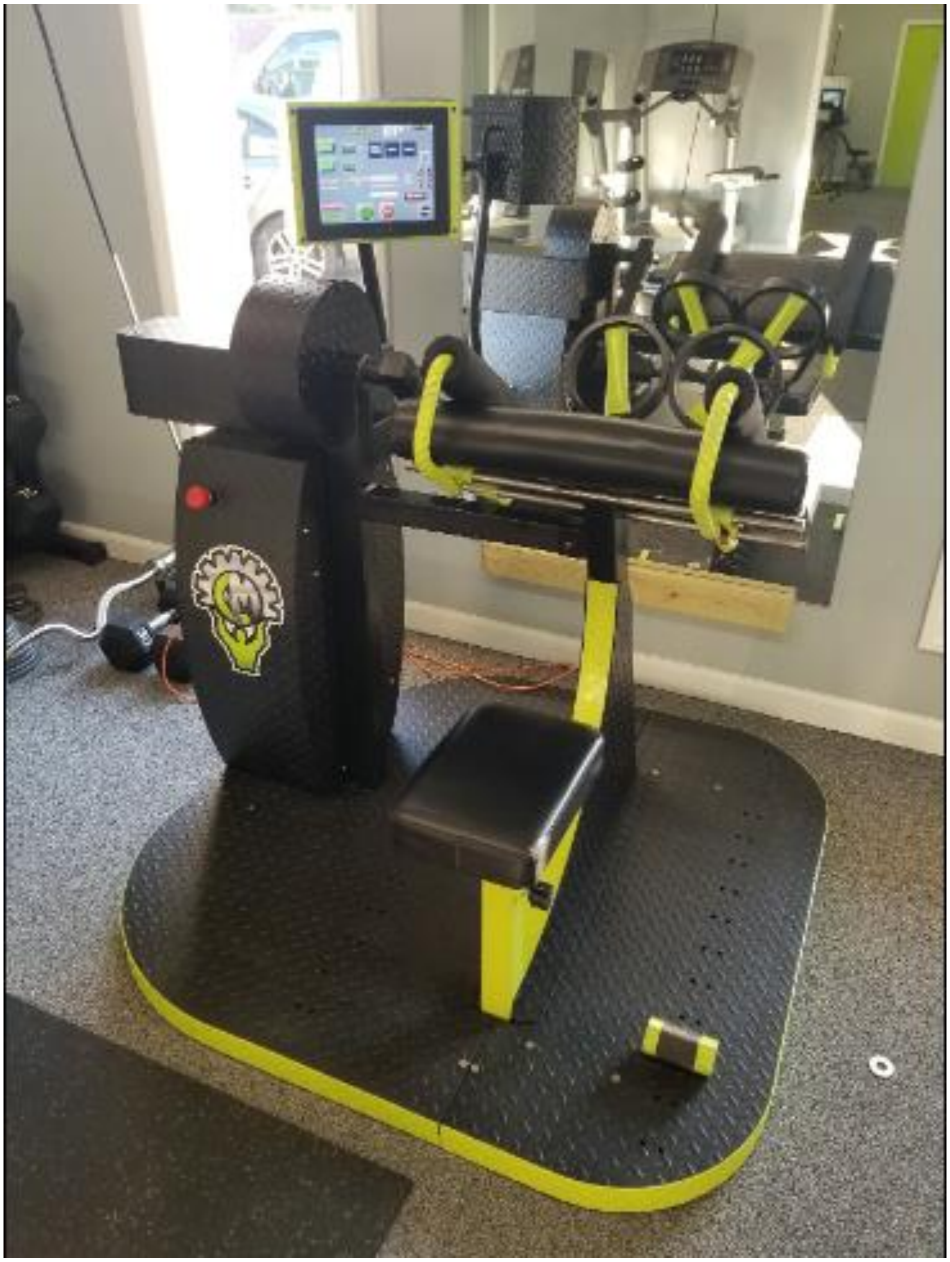
If you answered 'Yes' to any of the above questions, talk with your doctor **before** you become more physically active. Tell your doctor your plan to exercise and to which questions you answer yes.

If you honestly answered no to all questions you can be reasonably certain you can safely increase your level of physical activity **gradually**.

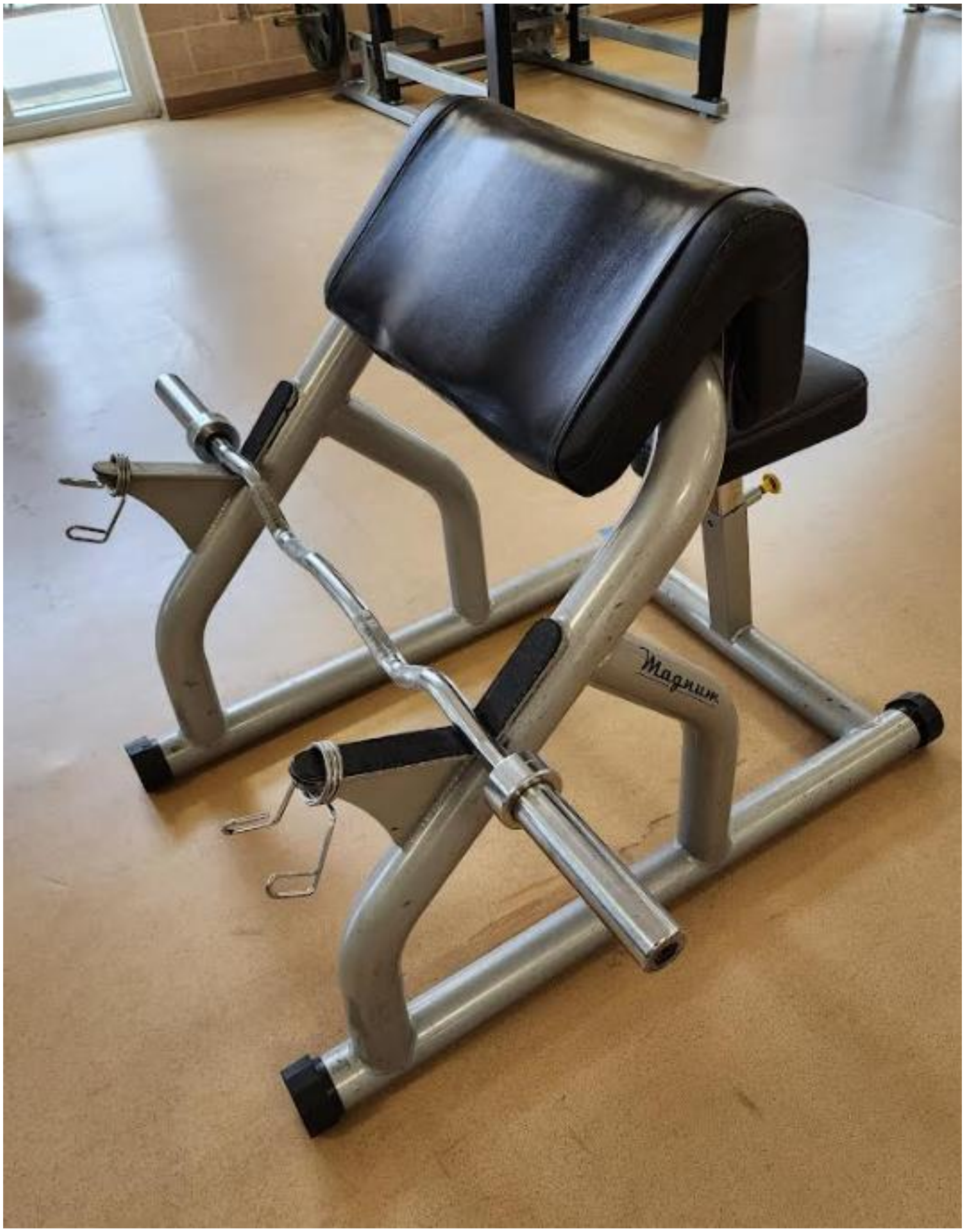
If your health changes so you then answer yes to any of the above questions, seek guidance from a physician.

Participant signature		Date

Appendix 7:



Appendix 8:



Appendix 9:

INFORMED CONSENT

Title of Study: Isokinetic Versus Isotonic Resistance Training: Determining the Primary Mechanisms of Hypertrophy

Investigator: George Logan Daughtry

This is a research study. Please take your time in deciding if you would like to participate. Please feel free to ask questions at any time.

INTRODUCTION

The purpose of this study is to evaluate body composition differences between two forms of exercise; isokinetic versus isotonic. These implications will give insight into muscle hypertrophy, body composition changes in healthy adults and exercise efficacy.

DESCRIPTION OF PROCEDURES

The research methodology will use a true experimental, pre-posttest control research design with randomly assigned subjects to either control or experimental groups to eliminate internal validity threats and no factorials applied. Over a 10-week period, each group will be given a weight training treatment (2x times per week, equated intensity based on volitional fatigue, 30 minute sessions, one group using a curl bar and the other group using the experimental device. 1RM testing and maximal force output using an integrated potentiometer will be used as pretest and posttest measures. Subjects will be healthy, college-aged (18- 24 years old) individuals. Data analyzed using a paired T-test ($r = .9$) and descriptive statistics (central tendency, ordinal scores, standard deviation, and measures of variability).

RISKS

The primary risk is orthopedic injury during strenuous exercise to be minimized by researcher supervision.

BENEFITS

Advancements in exercise technology, hypertrophy/body composition research and exercise efficacy.

COSTS AND COMPENSATION

You will not have any costs from participating in this study. You will not be compensated for participating in this study.

PARTICIPANT RIGHTS

Your participation in this study is completely voluntary and you may refuse to participate or leave the study at any time. If you decide to not participate in the study or leave the study early, it will not result in any penalty or loss of benefits to which you are otherwise entitled.

CONFIDENTIALITY

Records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publicly available. However, federal government regulatory agencies, auditing departments of Concordia University, St. Paul, and the Institutional Review Board (a committee that reviews and approves human subject research studies) may inspect and/or copy your records for quality assurance and data analysis. These records may contain private information.

To ensure confidentiality to the extent permitted by law, the following measures will be taken; participants will be assigned a unique code number that will be used on forms instead of their name. Only researchers will have access to participant records, which will be kept in a locked filing cabinet. Data will be retained for 3 years before destruction. If the results are published, your identity will remain confidential.

QUESTIONS OR PROBLEMS

You are encouraged to ask questions at any time during this study.

- For further information about the study contact Principal Investigator, Logan Daughtry, daughtrg@csp.edu, or 803-730-7429

- If you have any questions about the rights of research subjects or research-related injury, please contact Dr. Steve Ross (sross1@csp.edu), the IRB Administrator at Concordia University, St. Paul.

****

PARTICIPANT SIGNATURE

Your signature indicates that you voluntarily agree to participate in this study, that the study has been explained to you, that you have been given the time to read the document and that your questions have been satisfactorily answered. You will receive a copy of the written informed consent prior to your participation in the study.

Participant's Name (printed) ____

____ (Participant's Signature—if 18 years old or over)

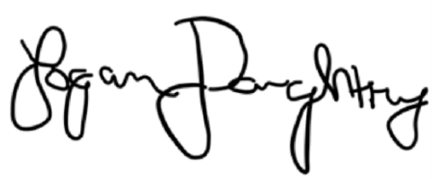
_______________________ (Date)

____ (Signature of Parent/Guardian or Legally Authorized Representative)

_______________________ (Date)

INVESTIGATOR STATEMENT

I certify that the participant has been given adequate time to read and learn about the study and all of their questions have been answered. It is my opinion that the participant understands the purpose, risks, benefits and the procedures that will be followed in this study and has voluntarily agreed to participate.



____ (Signature of Person Obtaining Informed Consent)

8/2/23__________________ (Date)