The Role, Direction, and Future of Biomechanical Research in Strength and in Resistance Training

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INTRODUCTION

There is a plethora of literature related to strength training, resistance training, weight training, weight lifting, body building, and rehabilitation. The majority of the literature is physiological in nature, involving the neural, muscular, skeletal and hormonal systems. These studies have focused on the physiological response and muscular adaptations that occur with different: (1) training programs (circuit weight training, light-heavy, pyramid, etc.); (2) exercise prescriptions (intensity, volume, variation, progression, rest intervals, specificity); (3) resistance modalities (free weights, machines, etc.); and (4) types of contractions (isometric, isokinetic, dynamic). The biomechanical literature on strength appears to be quite extensive, whereas the literature on the biomechanics of resistance training appear to be very limited.

This dichotomy may be attributed to an number of reasons, including: (1) insufficient interest, expertise and/or experience in the field of biomechanics and resistance training; (2) confusion and differences in opinion as to what defines biomechanical research in resistance training; (3) the overlap of resistance training research with other disciplines; and (4) the generally atheoretical nature of biomechanics. This paper proposes to address the role of biomechanics in strength research, probable directions for future strength research; and possible biomechanical research in resistance training.

ROLE OF BIOMECHANICS IN STRENGTH RESEARCH

Strength research in biomechanics, involving cable tensiometers, dynamometers, and isometric contractions has described how force/tension/strength changed with changing joint angle (Clarke, 1950; Kulig, Andrews, Hay, 1984; Williams & Stutzman, 1959) . Based on the tension-length curve, as a muscle length deviates from its normal resting length, force production decreases. Isometric force production will also change with different joint angles because a change in joint angle occurs in conjunction with an alteration in muscle length. This force or tension plotted through the full range of motion of a joint will: (1) produce a strength curve; (2) provide information regarding muscle torque production at different joint

angles; and (3) provide insights regarding the interaction between muscle length and muscle moment arm length with changes in joint angle. However, strength curves have often been described with respect to changes in one joint angle and not of multiple joints. Since many muscles are multi-joint muscles, it is important to determine how angle manipulation of multiple joints will affect muscle length and the resulting tension and force produced.

For example, isometric force production at the elbow joint is expected to be affected by changes in radio-ulnar joint angle because the biceps brachii and brachioradialis, both, not only cross the elbow joint, but also the radio-ulnar joint (Winter & Kleweno, 1993). Changes in shoulder joint angle will also alter the biceps brachii's muscle length and affect elbow force production. Systematic and simultaneous manipulations of the shoulder and/or radio-ulnar joint can be used to provide a 3-dimensional plot of how elbow flexor force production at different elbow angles change with manipulations in shoulder and radio-ulnar angles, and to provide information regarding the absolute and relative force production by the various elbow flexors (brachialis, brachioradialis, biceps brachii) at different combinations of shoulder, elbow, and radio-ulnar joint angles.

With information of the forearm length, force production, and resistance moment arm length at different elbow angles; torque at the elbow joint can be determined and used to provide insights regarding the interaction between muscle length and muscle moment arm length of the various elbow flexors.

DIRECTION OF BIOMECHANICAL STRENGTH RESEARCH

The direction of biomechanical strength research, like many other areas in biomechanics, is expected to evolve and progress from description to prediction, from prediction to validation, and from validation to application. With technological advances and the use of magnetic resonance imaging, changes in muscle moment arm length and muscle length of the various elbow flexors with changes in elbow, shoulder, and radio-ulnar joint angles can be monitored and recorded. This information, combined with data on corresponding changes in elbow flexor force production and EMG activity patterns, can be used to develop a

biomechanical muscle performance model. This model can be used to predict and explain how isometric muscle torque is generated and affected by the interaction of the elbow flexors (individually and collectively) with changes in shoulder, elbow and radio-ulnar joint angles in conjunction with changes in muscle length and muscle moment arm length. With this information, similar models for other joints and for multi-joint muscles crossing the elbow and wrist, hip and knee, knee and ankle, etc.; can then be developed and compared (Lunnen, Yack, & LeVeau, 1981; Nemeth & Ohlsen, 1985; Pohtilla, 1969).

After the development of models to describe isometric force and torque with changes in joint angle, the next step would be to validate and determine how accurately these models can predict performance in dynamic strength tests. Dynamic strength research, is more complex than isometric strength research because of the resulting interactions that occur with factors other than changes in muscle length, muscle moment arm lengths, and joint angles. These factors include: (1) different types of contractions (concentric, eccentric); (2) speed of contraction; and (3) torque produced by the resistance (which is affected by resistance load, resistance location relative to the joint axis of rotation, resistance moment arm length, and body/limb orientation with respect to the ground). Complexity is further increased when these factors interact with the muscle force/torque produced with dynamic changes in joint angles (e.g., shoulder, elbow, radio-ulnar), muscle lengths and muscle moment arm lengths. Currently, there has not been any biomechanical research involving dynamic constant resistance (free weights) to validate existing isometric models or to develop new ones.

To validate, dynamically, muscle models which had been developed from isometric data would require a series of experiments (or combination of experiments) where one variable is systematically manipulated while all others are controlled. If the elbow joint example is used, a minimum of three investigations would be required, where: (1) the shoulder and radio-ulnar joint are systematically manipulated to alter muscle length of the various elbow flexors; (2) the limb/body orientation with respect to the ground is systematically manipulated (possibly from anatomical position, in an upright position perpendicular to the ground, to a supine position parallel to the ground. This would be to alter resistance moment arm length

and it's corresponding torque at the elbow joint); and (3) different types of contractions (concentric and eccentric) are used.

The velocity of contraction would be not be controlled, but would be load dependent, subject selected, and predicated on the force-velocity curve. The variables (dependent variables) measured and recorded would be: (1) the load (free weight) that results in muscular failure (inability to lift the weight through a full range of motion); (2) the elbow angle at which the "sticking point" (muscular failure) occurred; (3) the EMG activity of the various elbow flexors (i.e., biceps brachii, brachioradialis, brachialis) at the sticking point; and (4) muscle length and muscle moment arm length at muscular failure (if magnetic resonance imaging is available). Electrogoniometers (or videography) would be required to determine the shoulder, elbow, and radio-ulnar joint angles at the point of muscular failure during a dynamic test. Greater loads would be used to vary and control the angle at which muscular failure occurs; and comparisons between load-to-failure joint angles and those from isometric models would be used to: (1) determine accuracy, predictability, and validity of isometric models when applied dynamically; and (2) promote development of dynamic strength models.

Because maximal velocity of contraction is dependent on the load, and velocity is not controlled in dynamic constant resistance testing; isokinetic studies may be implemented to provide force and torque data over a variety of contraction velocities (Motzkin, Cahalan, Morrey, An, & Chao, 1991). Isokinetic torque curves, in conjunction with isometric and dynamic strength models will provide a more complex (but more complete) and accurate model during dynamic conditions.

FUTURE OF BIOMECHANICAL STRENGTH RESEARCH

With the increased popularity and implementation of weight training machines in fitness centers, another category for research appears to be emerging. This area includes machines incorporating various combinations of cams, pulleys, double pulleys, levers, wheel and axles and/or friction devices. Manufacturers of resistance training machines have made claims

regarding the successful development of machines that model the strength curve at various joints, and maximizes strength development throughout the joint range of motion. Currently, without appropriate dynamic models available, such claims cannot be substantiated (nor can they often be refuted). It would appear that biomechanical research is needed in this area; to establish not just dynamic models, but models accounting for changes in lever, pulley, and cam systems of different types of resistance training machines, and the resulting interactions with the neuro-musculo-skeletal system.

Once these models have been developed and validated, resistance training research can be implemented to determine whether strength development can be maximized with machines, and whether such development is beneficial or desired (because how applicable would this be in daily activities where resistance normally encountered are dynamic constant resistance?). Resistance training research may entail training programs on different types of machines, and observing how strength development (and strength curves) is affected when tested isometrically, dynamically, and isokinetically. Electromyography and electrogoniometry may be used to provide information regarding the neural and/or muscular adaptations with changes in joint angles when training on different machines, and to provide insights as to the interactions that may be occurring.

In summary, strength research in biomechanics has focused exclusively on description and model development based on isometric contractions. It is believed and expected that this research will evolve, progress, and be directed towards evaluation and validation of dynamic muscle models, followed by development of more complex ones. A valid model will be able to accurately predict performance under non-laboratory conditions and real world situations and activities. These models should apply to resistance training machines, and lead to the initiation and implementation of biomechanical resistance training research.

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