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Terminology for contractions of muscles during shortening, while isometric, and during lengthening

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Faulkner, John A. Terminology for contractions of muscles during shortening, while isometric, and during lengthening. *J Appl Physiol* 95: 455–459, 2003; 10.1152/japplphysiol.00280.2003.—Communication among scientists must be clear and concise to avoid ambiguity and misinterpretations. The selection of words must be based on accepted definitions. The fields of biomechanics, muscle physiology, and exercise science have had a particularly difficult time with terminology, arising from the complexity of muscle contractions and by the use of inappropriate terminology by scientists. The dictionary definition of the verb "contract," specifically for the case of muscle, is "to undergo an increase in tension, or force, and become shorter." Under all circumstances, an activated muscle generates force, but an activated muscle generating force does not invariably shorten! During the 1920s and 1930s, investigators recognized that the interaction between the force generated by the muscle and the load on the muscle results in either shortening, no length change (isometric), or lengthening of the muscle. The recognition that muscles perform three different types of "contractions" required that contraction be redefined as "to undergo activation and generate force." Modifiers of contraction are then needed to clarify the lack of movement or the directionality of movement. Despite the contradiction, for 75 years the lack of movement has been termed an "isometric contraction." The directionality of the movement is then best described by the adjectives "shortening" and "lengthening." The definitions of "concentric" as "having the same center" and of "eccentric" as "not having the same center" are consistent with hypertrophy, or remodeling of the heart muscle, but are inappropriate to describe the contractions of skeletal muscles.

action; pliometric; miometric; concentric; eccentric

AMONG SCIENTISTS, THE NEED for immediate understanding requires that communication be clear and concise. To avoid ambiguity and misinterpretations, the selection of words must be based on accepted definitions as to their meanings. The fields of biomechanics, muscle physiology, and exercise science have had a particularly difficult time in the use of terms. The difficulties have arisen partly through the complexities of the skeletal muscle contractions themselves and partly through the carelessness of scientists regarding the use of inappropriate terminology, as well as the permissiveness of editors. The dictionary definition of the transitive verb "to contract" is "to draw together, or shorten" and specifically, for the case of muscle, "to undergo an increase in tension, or force, and become shorter." Under all circumstances, an activated muscle develops force. The difficulty with the current dictionary definition is that an activated muscle does not invariably shorten! Depending on the interaction between the force developed by the muscle and the load on the muscle, the muscle will either shorten, remain at a fixed length (isometric), or be lengthened.

During the 1920s and 1930s, the phenomenon of skeletal muscles "contracting" not only during shortening but also while remaining isometric or even during lengthening was recognized widely (13, 21, 22, 24, 34). The recognition that muscles make three different types of "contractions" required a redefinition of contraction and modifiers of contraction to clarify the lack of movement or the directionality of the movement. During the past 75 years, various modifiers have been associated routinely with the verb contract or the noun contraction that were either redundant with or contradictory to the dictionary definition of the term. Despite these problems, for muscle physiologists, contract, contraction, and contractility are the only terms that adequately describe the phenomenon of the response of muscle fibers to activation. As with all "living" languages, the English language is in a constant state of

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revision, as the definitions of words change through usage. Specifically for the case of muscle, many decades ago "to contract" should have been redefined as "to undergo activation and generate force" and not specify the directionality of the movement as "to shorten." An additional nuance of the contractions of skeletal muscles, first recognized by A. V. Hill (22) and B. Katz (30) during the 1930s, was the observation that, even under isometric conditions of the whole muscle, the contractile elements shorten by stretching the elastic elements. Forty years later, advanced optical techniques indicated that, during each of the three types of contractions, the behavior of sarcomeres in series do not necessarily mimic those of the fiber of which they are a part (23, 28). Such heterogeneity of sarcomere behavior, although of great significance as a determinant of muscle performance (9, 22, 23, 28, 30, 38, 41), is not a factor in this context. The focus of this discourse is the change in the end-to-end length of single fibers or whole muscles.

TERMINOLOGY

Biophysicists or muscle mechanicists primarily interested in the mechanisms of the actual contraction itself have tended to stay with accurate but wordier constructs such as "stimulated muscles stretched during the active phase of the contraction," "stretching a muscle during a tetanus" (1), "forcible lengthening of active muscles," or "lengthening of a stimulated muscle" (35). For muscle physiologists describing conditioning (5) or contraction-induced injury (40) protocols or biomechanicists assessing contractions during human movements (13, 24), a more concise terminology is required. In an editorial in *Biomechanics Journal* in 1988, Peter Cavanagh (6) recommended the replacement of the term "muscle contraction" with "muscle action." His basic premise was that the great majority of experiments in the "grand era" of muscle mechanics really were concerned only with "shortening," and consequently these investigators were not challenged by the concepts of contracting muscles being stretched. In fact, throughout the grand era, presumably the 1920s and 1930s, Levin and Wyman (34) and Hill (21, 22) investigated the relation between force and velocity during shortening and lengthening of stimulated dogfish and frog muscles in vitro. Fenn (11–13), Hill (22), and Katz (30) investigated force and heat production during shortening and the increase in force development and the production of heat when stretches of constant velocity were applied to sartorius muscles of frogs and toads during twitches or tetani. Concurrently, Hill (20, 22), Fenn (13), and Hubbard and Stetson (24) performed sophisticated experiments that correlated the three types of muscle contractions with the movements of humans during walking and running. Consequently, the concept that "lengthening contractions are as common as isometric, or shortening contractions" was common knowledge to the muscle physiologists of the 1920s and 1930s (10–12, 20–22, 31).

Furthermore, the premise that the term contraction is an outmoded term that should be discarded and that the substitution of "action" or "activation" for contraction would serve as "a signal of the modern acceptance, derived from the biomechanical study of human movement," of the need for a change in terminology (6) has not happened. The recommendation of any change from contraction has met with widespread resistance, and few, if any, muscle physiologists have adopted such a change. In everyday usage, action does not differentiate between the quiescent and the activated states of muscle with the same clarity as contraction does. The clarity is based on well over a century of consistent usage in scientific journals that, when activated, the activated muscles undergo a sequence of events termed contraction! The activation of muscle fibers is an all-or-none phenomenon and is independent of the directionality, or lack of directionality, of the subsequent contraction that the activation elicited. Regardless of the external factors acting on the muscle, physiologically and mechanically, during "shortening, isometric and lengthening contractions," the sequence of events after activation of muscle fibers is similar but not identical. With activation, muscle fibers contract: globular heads of myosin attach to actin sites, undergo a transition to strong binding, and then depending on the load proceed through some form of the cyclical interactions between the myosin heads and the actin binding sites, termed the "working stroke" (26). During shortening, cross bridges cycle through their working stroke, and energy expenditure is a function of load and shortening velocity (26). At loads greater than muscle force, the stretch produces a reversal in the force-generating working stroke, and energy expenditure is reduced (35, 36). The conclusion is that neither action nor activation provides an adequate substitute for contraction.

Because the dictionary definition of "to contract" is "to generate force" and "to shorten," a number of investigators have modified the terms action (15) and condition (24) to signify the type of contraction that occurred. Fick (15) employed the terms "isometric" and "isotonic" to describe the actions of a contracting heart muscle when the muscle remained at a fixed length or shortened with a fixed load. In 1938, Fenn (12) noted that shortening, isometric, and lengthening more accurately represented the three types of contractions that muscles make than the terms proposed by Fick, but Fenn was careful to dissociate the directionality of the muscle movement from the term contraction. The same year, in correlating the contractions of muscles of humans with the movements of the limbs during walking and running, Hubbard and Stetson (24) recognized that muscles underwent contractions during three different "conditions." The three conditions were termed "miometric," "isometric," and "pliometric," by coupling the Greek prefixes "mio" (shorter), "iso" (same), and "plio" (longer) to the noun "metric," defined as "pertaining to measures or measurement." Consequently, the noun condition was used with the appropriate adjective

to differentiate among the three conditions under which the muscles "contracted."

The introduction of a second term, either action or condition, in conjunction with contraction simply begs the issue as to what is actually happening to the muscle during the contraction. Clearly, if an isometric or lengthening action or condition occurs, the muscle cannot be shortening during the contraction and any reference to shortening is simply redundant. In actuality, investigators have been modifying contraction with adjectives that are at odds with a definition of shortening continuously since 1927 (13, 21, 22, 30, 34), particularly with the use of "isometric contraction" (1, 13, 22, 30). After decades of ignoring the problem, the only rationale conclusion is that the dictionary definition of "to contract" specifically as pertaining to muscle must be "to undergo activation and generate force."

An equally contentious issue is what adjectives should be applied to the term contraction to best describe the lack of movement or the directionality of the movement. Despite their early introduction, the terms miometric and pliometric (24) have never gained wide acceptance. In 1963, Fenn (14) followed the lead of Hubbard and Stetson (24); in a comparison of the contractions of respiratory and limb muscles, he used miometric, isometric, and pliometric as adjectives to modify contraction. Following Fenn's lead, several unsuccessful attempts have been made to reintroduce these terms (4, 25, 37, 39, 47). An additional deterrent to the use of the term pliometric is the increased use of the term "plyometrics" for conditioning with high-power jumps that involve repeated, rapid, and forceful shortening and lengthening actions during almost maximum activation of large muscle groups. Despite suggestions for other terminology for this type of conditioning by Komi (33) and later by Knuttgen and Kraemer (26), the popularity of "plyometrics" and the use of the term have increased dramatically (7, 43).

Of greater concern has been the introduction and spread of inappropriate adjectives to modify contraction. During the 1950s, the terms "concentric" and "eccentric" contractions appeared first in textbooks (29, 44) and later in the exercise science literature (32). The dictionary defines concentric as "circles with the same centers" and eccentric as either "circles with different centers" or "off-center." "Weird" or "unusual" as other definitions of eccentric adds a further complication. Several efforts have been initiated to discourage the use of these completely inappropriate terms. In 1962, during a discussion on muscle performance chaired by D. B. Dill (44), Erling Asmussen used the terms concentric and eccentric and B. J. Ralston made the perceptive comment that these terms led to confusion and should be eliminated from the literature. Asmussen conceded that the terms miometric and pliometric might be better, but Ralston responded that he preferred simply shortening *or* lengthening. A poster by Faulkner and his associates at the American College of Sports Medicine Meeting (1998) made a similar argument against the use of concentric and eccentric and advocated miometric, isometric, and pliometric. Presently, isometric is universally accepted, but shortening and lengthening, miometric and pliometric, and concentric and eccentric are all in use in the physiological, biomechanics, sports medicine, and sports science literature. Despite their inappropriateness, the most commonly used expressions in the conditioning and sports exercise papers are concentric and eccentric contractions (31).

The misuse of the terms concentric and eccentric to describe the types of contractions (3, 42) has extended to the type of work (8), exercise (10, 17), load (16), training (46), strength (48), and actions (6). A serious problem arises from the use of concentric and eccentric as synonyms for shortening and lengthening contractions of skeletal muscles. With either conditioning or disease, the heart may undergo concentric or eccentric hypertrophy, adaptation, or remodeling (2). Subsequently, the heart makes contractions that are under concentric (on center) or eccentric (off center) conditions. Despite the concentric or eccentric condition under which the contractions occur, the activation of the heart muscle would still produce a shortening contraction, an isometric contraction, or possibly under unusual circumstances a lengthening contraction. The inappropriate use of the terms concentric and eccentric in muscle physiology, biomechanics, sports medicine, and sports science literature and meetings makes any meaningful dialogue with cardiovascular physiologists or cardiologists extremely difficult.

RECOMMENDATION

1. The verb "to contract" and the nouns "contraction" and "contractility" need to be defined correctly in terms appropriate with long-term usage as "specifically for muscle, to undergo activation and generate force." For 75 years, muscle physiologists (13, 22, 34), biophysicists (35), and biomechanicists (24, 27) have utilized the terms contract, contraction, and contractility successfully and unambiguously, despite misleading dictionary definitions stipulating "to shorten" or "to draw into a more compact form." The references to "to shorten, or a drawing together and thickening" should be deleted from the definitions, and the terms contract, contraction, and contractility should be preserved by accurate and precise usage.

2. To clarify the type of contraction, the adjectives that provide the greatest clarity are "shortening," "isometric," and "lengthening." One might argue for "fixed-end" contraction rather than isometric, but slightly less than a century of usage weighs heavily in favor of isometric. The adjectives shortening, isometric, and lengthening convey immediately and without equivocation even to the uninitiated the type of contraction that is occurring within the skeletal muscle. The adjectives miometric, isometric, and pliometric have a certain appeal based on their long-term usage and their Greek heritage, but understanding their meaning requires a knowledge of the Greek prefixes mio, iso, and plio. Although dictionaries define the prefixes as denoting shorter, the same, and longer measures, re-

spectively, dictionaries do not provide the complete term with the exception of isometric. Clarity in the usage of contraction requires an indication of the immediate outcome of the interaction between the force generated by the muscle and the load against which the muscle is "attempting to shorten" that result in either a shortening, an isometric, or a lengthening contraction.

3. The adjectives "concentric" and "eccentric" are misleading and inappropriate and should not be used to describe the contractions of skeletal muscles. The definitions of concentric as "having the same center" and of eccentric as "not having the same center" and consequently being "off center" are consistent with the two different types of hypertrophy, adaptation, or remodeling observed for the heart muscle (2, 18, 19, 45). After concentric or eccentric hypertrophy, adaptation, or remodeling of the heart muscle, the totality of the heart will undergo a contraction under concentric or eccentric conditions. If concentric and eccentric are used appropriately for the condition of the heart, the terms make no sense when applied to contractions of either heart or skeletal muscles.

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