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ON THE MEASUREMENT OF HUMAN STRENGTH

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ABSTRACT

Generation of muscle strength is a complex procedure of myofilament activation, nervous feedforward and feedback control, and use of mechanical leverages within the human body. Since strength measurement directly at the muscle is (currently) not feasible, it is usually done at the outside of the body, at the interface with some kind of a dynamometer. This poses various challenges because of difficult mechanical and physiological modelling of the conditions, and because of difficulties in experimental control. To better understand and measure human motor performance, a model of muscle functions and control is discussed, and means for computer-aided position and motion observation are proposed. Experimental variables are classified, and a taxonomy for static (isometric) and several dynamic measurement techniques is described.

RELEVANCE TO INDUSTRY

An understanding of human strength and a taxonomy for strength testing will provide for consistency in strength assessment.

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KEYWORDS

Muscle strength, muscle contraction, motor control, muscle exertion, body coordinate system.

BACKGROUND

The topic of "human muscle strength capabilities" has generated much research interest in biomechanics and physiology and is of great practical importance in ergonomics/human factors engineering. Unfortunately, many different definitions, terms, measurement strategies and exertion techniques have been used. Thus, most existing information is specifically tailored to the researcher's or applier's own area of interest, but the overall knowledge is piecemeal and incompatible (Kroemer, 1970, 1986; Kroemer et al., 1988), partly or largely so because of confusion in terminology which reflects the underlying problem of the absence of a systematically ordered knowledge base (taxonomy).

A standard procedure for static muscle strength testing (Caldwell et al., 1974) has been in general use for about a decade. A panel discussion on "human physical strength" at the 1986 Annual Meeting of the Human Factors Society initiated an effort to clarify and define human dynamic motor performance ("dynamic strength") and to propose standard procedures to measure such dynamic muscle performance. For this, a brief review of muscular contraction and related terminology is helpful.

MUSCLE ACTION ("CONTRACTION")

Muscle is a highly organized system of organic material that uses chemical energy to produce mechanical work under the control of the nervous system.

Muscle architecture and contraction

Skeletal muscle consists of muscle fibers. Each muscle fiber contains hundreds to thousands of smaller fibers known as fibrils. Each fibril contains as many as 2,500 filaments. Filaments, fibrils and fibers are predominantly arranged in parallel, along the length of the muscle.

The filaments are polymerized protein molecules of myosin, actin, tropomyosin and troponin. Near each end of the rod-like myosin, club-like "heads" project toward surrounding actin filaments. If stimulated by a signal from the central nervous system (CNS), actin rods slide along the myosin, using the heads as temporary crossbridges. This is the basic mechanism of muscle shortening (contraction). Following contraction, the crossbridges are released so that filaments return to their initial positions. Thus, muscles can only pull, not push. Actin interaction with myosin is regulated by the tropomyosin and troponin proteins.

Muscle control

Signals are sent from the CNS (from its anterior horn) via somatic efferent neuron axons to muscles. The axon of a motor neuron branches out to innervate from 3 to 2000 fibers. The junction between a nerve and muscle fiber is called the motor end-plate. All muscle fibers innervated by the axon of a single motor neuron are called the "motor unit".

Muscular activation is controlled by the frequency of commands sent by the CNS to a given motor unit ("rate control") or by recruitment of additional motor units ("recruitment control"). Recruiting additional motor units provides coarser control of muscle tension than modifying the excitation rate, but by recruitment a larger muscle strength range can be controlled.

Types of muscle actions

When a muscle shortens against resistance, it develops tension, thus exerting a pull force between its origin and insertion at bones. The force is modulated by elastic components, mostly in the tendons that connect muscle with bones, as sketched in Fig. 1.

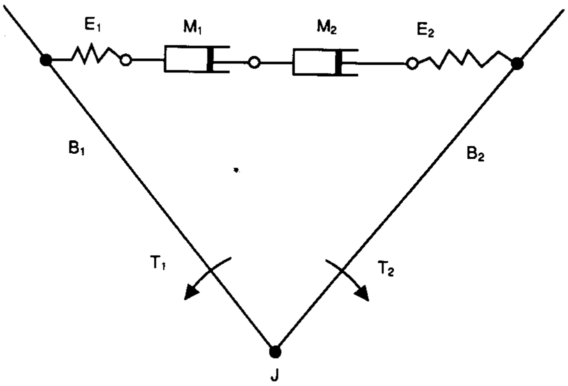

Fig. 1. Schematic model of muscle contraction. Muscle M contraction generates tension in the elastic muscle and tendon elements E that transmit force to the bone B levers which can rotate about the common joint J depending on the existing counteracting torques T.

Movement of either the proximal or the distal bony lever occurs depending on which is fixed and which is free to move. If the force exerted by the muscle on its free bony lever is greater than the resistance offered, then the muscle shortens in a "concentric contraction". When the muscle force developed on the free bony lever is equal to an opposing resistance, no change in lever position is seen and no visible change in muscle length can be perceived: this is an "isometric contraction". When the external load is greater than the muscle force, then the muscle is actually lengthened: this is often called "eccentric contraction" although actually nothing "contracts" since the motor units (sarcomeres) of the muscle are really lengthened.

Cavanagh (1988) discussed the semantic dilemma of calling a muscle element "contracting" when it is actually elongated (in eccentric action), or when it really remains at constant length (in an isometric effort after the initial sarcomere shortening). He proposed not to use the word contraction (unless shortening is truly meant) and instead to employ the term "action". Hence, the terms action, effort (Kroemer, 1970) or exertion will be used in this text as appropriate.

Tension developed in a muscle varies with the type of effort. When muscle force production is constant, the muscle action is "isotonic". Eccentric effort can produce more muscle tension than isometric contraction, which in turn can produce more muscle tension than concentric contraction. This is thought to be due in large part to tension produced in the series of elastic muscle and tendon components (Komi, 1979).

If bony levers move, the biomechanical "advantages" (lever arms and pull angles of muscles) change; also, muscle tension changes with muscle length, and with speed of muscle shortening (Astrand and Rodahl, 1986). Hence, even if the external resisting force is constant while the bony lever moves, the force developed within the muscle is actually changing, and may therefore not be called isotonic (Kroemer, 1967, 1970; Rodgers and Cavanagh, 1984). It is obviously not correct to label all non-isometric efforts "isotonic", as is occasionally done; they are dynamic.

Motor control

Motor programs in the CNS may be innate or based on experience. They generate "executive programs" for automatic postural adjustments and voluntary movements, including learned "subroutines" for motor commands of less common activities (Kroemer, 1979; Keele, 1986). Controlled execution depends on feedback from internal and peripheral sense organs to the CNS for adjustment. Motor skill evolves by optimizing muscular exertions (Nelson, 1983). Availability of knowledge of results, utilization of past experience and continuous monitoring of sensory feedback are all part of skill acquisition.

CNS motor control functions in a hierarchical structure which can be divided into three levels (Brooks, 1983; MacMahon, 1984). The highest level operates in the association cortex, where perception and overall motor planning or strategies are located. The basal ganglia coordinate goal-directed behavior (Brooks et al., 1986).

The middle level consists of the sensori-motor cortex, the cerebellum, the putamen loop of the basal ganglia and the brain stem. Here, the strategy planned by the higher level is converted into motor programs which determine and coordinate body equilibrium, movement directions, force, and speed, with "move and hold" programs. The putamen circuit of the basal ganglia enables updating the programs to keep them appropriate for the intended task. The cerebellum coordinates goal-directed action, initiating and guiding intended motor acts (Brooks, 1983; MacMahon 1984; Brooks et al., 1986).

At the lowest level, the spinal cord translates central command signals into muscular activity, which it regulates through stretch reflexes. Motor execution is guided by task-related parts of the CNS hierarchy (Schmidt, 1976; Brooks, 1983; Henatsch and Langer, 1985; Brooks et al., 1986).

A model of muscular exertion

The model shown in Fig. 2 serves to understand and describe main elements involved in muscular exertion (Kroemer et al., 1986).

Feedforward loop. At the CNS, control initiatives are generated by calling up an "executive program" (also called engram) for all routine muscular activities such as applying force or power to an object outside the body. It is modified by "subroutines" which adapt the general program to the specific conditions such as pushing hard, or pulling carefully. The control initiatives are also modified by motivation ("will") which determines how much of the person's inherent capability will be exerted.

The results of the complex interactions within the central nervous system are the excitation signals E, transmitted along the efferent nervous pathways to the motor units involved, where they trigger muscle actions.

At the muscle M, recruitment and rate coding of the excitation signals arriving from the CNS control the activities of the innervated motor units. However, the effects of the excitation signals on actual muscle output are modified by fatigue existing at the muscle, by the actual length of the muscle, or by signal frequency.

The output of the muscle activities to the bone levers is modified by the prevailing mechanical conditions C, such as lever arms and pull angles at which muscle tendons pull on their respective bone, and by the spring properties of interspaced elastic elements. Lever arms, pull angles and spring tensions change during dynamic activities, as does the contractile capability of the muscle depending on contraction speed and length.

The final output of this complicated chain of central nervous activities, feedforward signals, controlled contractions of muscular elements, and of modifying conditions is the motor performance ("strength") transmitted by the involved body segment to the object against which the body works. If the object provides sufficient resistance, the human can exert (as stipulated by Newton's Third Law) a "maximal voluntary exertion". If less resistance exists, only submaximal motor performance can be executed even if motivation for stronger exertion exists.

Feedback loops. The model also shows a number of feedback loops through which the muscular exertion is monitored for internal control. The first feedback loop, F1, is in fact a reflex-like arc originating at proprioceptors (Ruffini and Golgi organs, muscle spindles). These interoceptors and their signals are not under voluntary control, and allow efferent signal generators in the CNS (special cord) to respond quickly. The other two feedback loops originate at exteroceptors and are rooted through a comparator which modifies the input signal to the CNS. The second loop F2 originates at receptors that signal

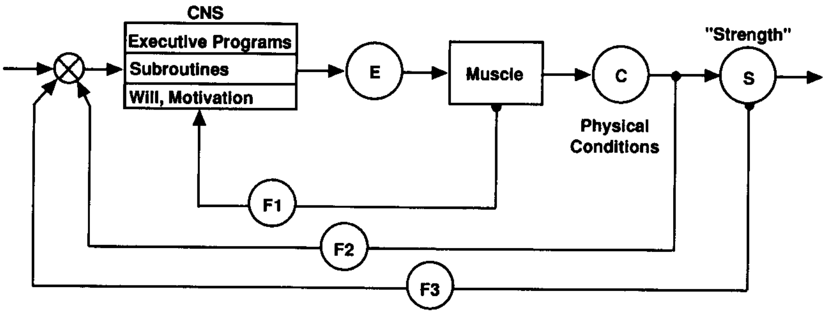

Fig. 2. Schematic model of muscle control (from Kroemer et al., 1986).

touch, pressure, and body position sensations. Such kinesthetic signals are, for example, the pressure that one feels in the hand while moving an object, or in the foot as it presses against the floor. The third feedback loop, F3, originates at exteroceptors of sound or light. For example, one may see or hear an object move under the motoric effort, or one may observe a pointer of an instrument that indicates the present effort, or one may hear the coach exhorting to "try harder".

Measuring opportunities. CNS signals E ("brainwaves") can be recorded via electroencephalogram, EEG, which, unfortunately, is at present difficult to interpret. However, one can fairly easily record the electric activities at the motor endplates by way of the electromyogram, EMG. EMG interpretation is much better understood than that of EEG and is routinely performed in ergonomic analyses of human strength (Basmajian and DeLuca, 1985).

The contractile activities in the muscle M may be qualitatively observed by EMG, but cannot be quantitatively recorded and interpreted in the living human at this time, since no instruments are available that measure directly the tensions within muscle or tendon.

The physical conditions C present during the strength exertion can be observed and recorded as far as they are external to the body. For example, the location of the measuring device with respect to the body, the direction of force or torque or power exertion, the time duration of the exertion, position and support of the body, as well as temperature, humidity, etc., can be well recorded. However, the mechanical conditions within the body are more difficult to quantify. It is, for example, usually not feasible to record the lever arm of the tendon attachment or the pull angle within the muscles during dynamic exertions.

Given these current difficulties and restrictions (which may be overcome with better understanding and measuring procedures), only the overall output "strength" S of the motor system can be easily defined and measured. Strength is measured at the external object (dynamometer) onto which the body exerts force, torque or energy. The magnitude is a function of (a) the individual's motivation to fully exert (b) the inherent performance capability under (c) given the conditions.

TERMINOLOGY

Dynamics, a subset of mechanics, deals with forces on bodies, and their resultant movements. If external forces and torques acting on the body are not in balance, the motion of the object changes. Motion is described by displacement over time and by its derivatives, namely velocity, acceleration, and jerk. All of these vary over the observation time. "Kinematics" address the motion conditions without considering the forces, while "kinetics" address the forces. In the static condition, all forces and torques acting on a given mass system are in balance (Newton's First Law). Therefore, the motion condition of that object remains constant: this includes the case of "zero motion", that is of a stationary object.

In physiology, the term "isometric" describes a theoretical condition in which the length of the muscle considered (or of its components, fibers, fibrils, filaments) does not change during the activity. Thus, an isometric contraction is a "static" exertion which does not generate a body motion. All non-isometric conditions are "dynamic" because motion is caused by changes in muscle length. This usually also involve changes in muscle tension over time.

In static strength testing the assumption is usually made, or at least implied, that muscular capabilities are measured while the person generates a single maximal voluntary exertion, MVC. As indicated by the term "voluntary", the person's motivation or will to generate the muscular effort determines its magnitude. Unfortunately, for the investigator to instigate and control the "maximality" of test effort is difficult, if not impossible. Indeed, a test subject, or the investigator, may not intend to generate the largest possible exertion but to execute, for various reasons, a "sub-maximal" effort. Nevertheless, the MVC concept underlies all current strength testing.

BODY MOTION TAXONOMY

Any body motion measurement system requires a precise description of the motion. Thus, a taxonomy is necessary to specify exactly positions and motions of body landmarks in three dimensions.

This specification must be in such detail that the motion may be duplicated by someone not familiar with the task without any additional documentation.

It is often convenient to identify a body motion as a rotation about a particular joint of the body. For example, a forearm rotation may be described by the angular position of the lower arm relative to the position of the upper arm above the connecting elbow joint. Another technique is to describe the position of a body segment by a vector notation. Also, the movement of an object external to the body may be of interest; for example, the moving of a box from one position to another via movements of hands, arms, and trunk may need to be described.

To achieve such descriptions, a taxonomy must include a coordinate system to describe positions and motions of loci. Also, a precise verbal terminology to describe motions is desirable.

Body coordinate system

A coordinate system must meet several requirements to make it usable in the study of human dynamic motor performance. First, the system should be consistent with engineering and physics terms that are generally used to describe and define positions and motions, i.e., displacement, velocity, acceleration, etc. Second, the use of the system should be clear, complete, unambiguous, feasible, and suitable to be computerized. The system shown in Fig. 3 fulfills these requirements. It is modified from Roebuck's 1968 proposal.

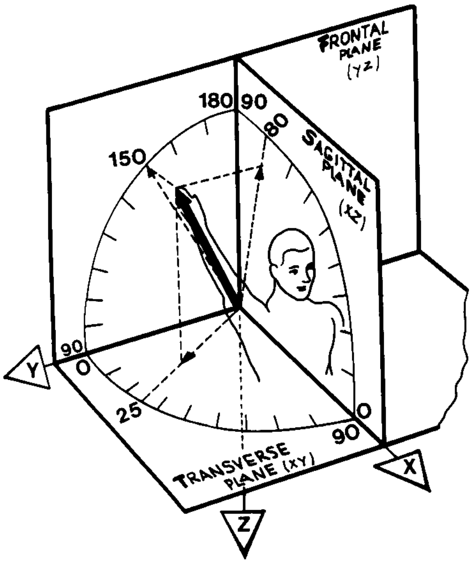

Fig. 3. Reference system of planes and axes, with angular coordinates (adapted from Roebuck, 1968).

The reference is Cartesian, with three planes at right angles to each other. In engineering, the positive directions of the reference axes relative to the subject are: X forward, Y to the right, Z down (NASA, 1989). These axes fall along the edges of the sagittal (S), transverse (T), and frontal (F) planes used in anthropometry—see Fig. 3. The system origin is usually located at the lumbosacral junction of the spine or at the center of mass, but can be moved to any location.

Locating points

This coordinate system allows the use of linear or angular descriptions to locate any point. It permits the use of velocity and acceleration terminology, and can be computerized.

The notation describes the position of a point within the coordinate system by simply stating its projection onto a plane (S, F, or T) followed by a colon (:) and the angular displacement (in degrees). Figure 3 contains an example of this shorthand notation for the right forearm–hand vector: its tip is at S: 80°, T: 25°, F: 150° when the coordinate origin is at the elbow joint. If an angular "twist" of, say 20° about the X axis or about the forearm axis A needs to be recorded, this can be done as X: 20° or A: 20° from a defined zero location (Roebuck, 1990).

Chaffin and Andersson (1984) provide another example: a point "H" (e.g., at the hand) is x cm in front of the frontal plane, y cm right of the sagittal plane, and z cm above the transverse plane. With $x = +16$ cm, $y = +20$ cm, and $z = -30$ cm, the notation to describe the location is H(16, 20, − 30). The direction of a link connecting H with a second point "E" [elbow; e.g., E(8, 10, − 15)] can be described in vector form by

$$\mathrm{HE} = i\,\Delta x + j\,\Delta y + k\,\Delta z \tag{1}$$

Inserting the coordinate descriptors yields, in this example, a link direction of

$$\begin{aligned} \mathrm{HE} &= i(16-8) + j(20-10) + k(-30+15) \\ &= 8i + 10j - 15k \end{aligned} \tag{1a}$$

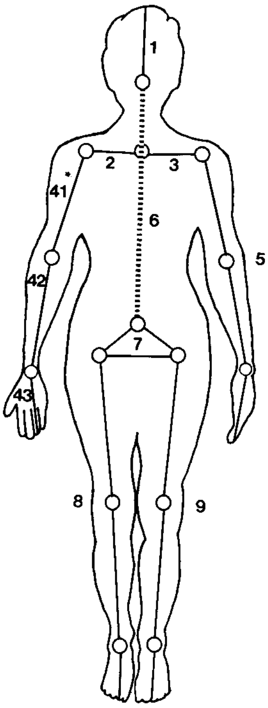

Fig. 4. Scheme to number body links of the whole body.

The magnitude of the vector is

$$|\mathrm{HE}| = |\sqrt{(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2}| \qquad (2)$$

$$\text{here } \sqrt{8^2 + 10^2 + 15^2} = 19.7 \text{ cm} \qquad (2a)$$

Roebuck (1968) also proposed to number the links of the body. An amended numbering system is shown in Figs. 4 and 5. The first digit identifies the major link of the body, succeeding digits describe more subordinate links. The letter J, preceding a number, indicates a joint at the distal end of that numbered link.

Thus, numbering body joints and establishing their coordinates, either in linear or angular terms, accurately documents body position in three-dimensional space. In the case of motion, at least the starting and final positions of the major body segment(s) involved need to be documented. In addition, the angular range or distance transcended by each moving body part can be specified so that some redundancy is provided. Time derivatives of displacement (i.e., velocity, acceleration, jerk) describe precisely the motion parameters of the exertion.

Verbal descriptions

Traditionally, motions of the body have been verbally described in terms commonly used in the medical literature, such as abduction and adduction, flexion and extension, supi- and pronation. However, this terminology contains inconsistencies and ambiguities which make it difficult to use in describing motions of the human body (Roebuck et al., 1975). An alternative verbal terminology, based on Roebuck's 1968 proposal, that minimizes ambiguities is described in Table 1.

Methods of position observation

The documentation of positions can be done in several ways. Film or video recordings of an exertion can be made in several planes so that the position of involved body segments can be determined, e.g., by digitizing techniques or by simply using a protractor to physically measure the positions on the recording. Various goniometers are also available which allow continuous recording of the positions of a body segments of interest during an exertion. Finally, many computer-interfaced motion analysis systems are available. Most

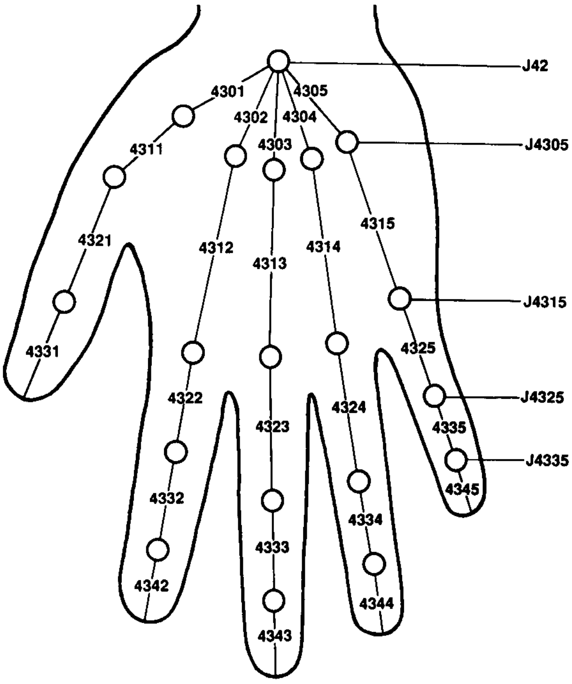

Fig. 5. Scheme to number hand links and joints.

TABLE 1

New terms to describe body motions

New term	Meaning	Replacing
flexion, extension and pivot [a]	Rotation of a body segment about its proximal joint, in two orthogonal axes	-duction -vection
twist [a]	Twisting rotation of a body segment about its internal long axis	-nation rotation
clock(wise)	In clockwise direction, as seen on own body	supi- or pro- (depending on body segment)
counter (clockwise)	In counter-clockwise direction, as seen on own body	pro- or supi- (depending on body segment)
ex-	Away from zero (up, out)	ab- e-
in-	Towards zero (in, down)	ad-
Front-, Trans-, Sag- (F, T, S)	Reference to the plane in which motion is described	uncertainty and confusion

[a] Proposed here by Kroemer, different from Roebuck's (1968) terms "vection" and "rotation".

systems rely on markers on body segments to define their positions in space. Video or infrared cameras are used to document these positions which are digitized and compared to a calibration by computer. Then the positions in space can be documented as a function of time.

EXPERIMENTAL VARIABLES

It is necessary to describe completely and correctly the variables in a testing situation. They are usually divided into the following groups:

Independent variables are those that are purposely manipulated to generate the experimental conditions.

Dependent variables are those that are observed/recorded to provide information about the effects of the manipulations of the independent variables.

Controlled variables are those that are purposely maintained at defined conditions so that they do not interfere with the relationships between independent and dependent variables.

Confounding variables are those that can or do interfere with the relationships between independent and dependent variables.

Experimental situations in which one typically

TABLE 2

Generic variables in motor performance measurements

Independent variables	Dependent variables	Controlled variables	Confounding [a] variables
Muscle motions	Muscle motions:	Individual	Motivation
displacement	displacement	age	Fatigue
velocity	velocity	gender	Health
acceleration	acceleration	anthropometry	Fitness
jerk	jerk	Environment	Skill
Mass	Mass	temperature	etc.
Repetition	Repetition	humidity	
Resistance	Output:	air velocity	
Body posture	force	radiation	
etc.	torque	noise	
	work	vibration	
	power	Clothing	
	etc.	etc.	

[a] Should be controlled.

tries to assess motor performance are listed in Table 2. Note that virtually all variables listed can be either independent, dependent, controlled, or confounding. Their assignment to variable categories is an essential part of the experimental design and procedure.

TECHNIQUES TO ASSESS MOTOR PERFORMANCE

A large variety of techniques exist, or are conceivable, by which one can manipulate independent variables and which permit the observation of variations in dependent variables (Kroemer et al., 1989). Table 3 lists the variables displacement (and its time derivatives), force, mass, and repetition. According to the experimenter's intentions, they may be assigned to the independent or dependent variable categories. For example: setting displacement to zero generates the "isometric" testing condition, in which velocity, acceleration and jerk are also zero, where usually mass is controlled (held constant) and force and/or repetition are dependent variables. In the dynamic "isokinetic" technique, velocity is set to a constant. This means that its time derivatives, acceleration and jerk, are zero while displacement usually becomes a controlled variable. In terms of the dependent variables, force and torque (or work or power), and the number of repetitions (if not controlled) are possible outputs of this measuring technique.

The taxonomy shown in Table 3 allows the definition of techniques that have not been generally used yet, such as "isoacceleration" or "isojerk". Keeping the exerted force (or torque) constant generates the "isoforce" condition. Through proper experimental control one can assure that tension within the involved muscle(s) is kept constant, which generates a truly isotonic condition. Often this is achieved by keeping limb displacement zero, thus employing the isometric technique concurrently. In the "isoinertial" condition, mass properties are held constant, such as in lifting a given weight repeatedly over a predetermined distance. In the "free dynamic" technique, one allows all listed independent variables to "run free" which permits measurement of various dependent variables, as feasible and desired.

The primary independent variables (boxed in Table 3) may not be kept constant ("iso") but varied, establishing a much larger set of measuring techniques than listed. More or other variables than listed in Table 3 can be defined as either independent or dependent, generating further

TABLE 3

Independent and dependent variables in several techniques to measure motor performance

Variables	Names of technique													
	Isometric (static)		Isokinetic		Isoacceleration		Isojerk		Isoforce		Isoinertial		Free dynamic	
	Indep.	Dep.	Indep.	Dep.	Indep.	Dep.	Indep.	Dep.	Indep.	Dep.	Indep.	Dep.	Indep.	Dep.
Displacement linear/angular	$\boxed{\text{constant * (zero)}}$		C or	×	C or	×	C or	×	C or	×	C or	×		×
Velocity, linear/angular	○		$\boxed{\text{constant}}$		C or	×	C or	×	C or	×	C or	×		×
Acceleration, linear/angular	○		○		$\boxed{\text{constant}}$		C or	×	C or	×	C or	×		×
Jerk, linear/angular	○		○		○		$\boxed{\text{constant}}$		C or	×	C or	×		×
Force, torque	C or	×	C or	×	C or	×	C or	×	$\boxed{\text{constant}}$		C or	×		×
Mass, moment of inertia	C		C		C		C		C		$\boxed{\text{constant}}$		C or	×
Repetition	C or	×	C or	×	C or	×	C or	×	C or	×	C or	×	C or	×

Legend: C = variable can be controlled, * = set to zero, ○ = variable is not present (zero), × = can be dependent variable.
The $\boxed{\text{boxed}}$ constant variable provides the descriptive name.

measurement techniques. Yet, the taxonomy presented here provides (for the first time, we believe) a systematic approach to defining the conditions under which dynamic muscle strength can be assessed reliably.

ANALYSIS OF MEASURED OUTPUTS

The content of the output signal representing the dependent variable(s) is of particular importance for the interpretation of data. While this is a common-sense statement, surprisingly many publications have neglected to identify exactly the experimental results actually used for data interpretation.

The output signal is, by definition and implication, a function of time and/or of displacement (and its derivatives), the latter in x, y, and z directions. One may want to observe the output signal during "windows" of time or displacement, i.e., during segments of the experiment, as done, for example, during the 3-second period in static strength assessment according to the Caldwell Regimen (Caldwell et al., 1974).

The signal content could be reported at least in:

Mean, mode, median
Standard deviation (Information about the actual distribution if not Gaussian, as assumed above)
Slopes plus/minus, plateaus, valleys
Cross-overs, inflection points
Integrals (areas)
Fast Fourier Transforms, e.g., spectral analyses

CONCLUSIONS

Advances in measurement and computer technology, better understanding of the human musculoskeletal functions, and increasing information demands for human engineering, have made it both feasible and necessary to systematically measure dynamic muscle performance. The taxonomy proposed here should help in this endeavor.

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APPENDIX

Glossary of terms

acceleration	second time derivative of displacement.
action, activation (of muscle)	see contraction.
concentric (muscle effort)	shortening of a muscle against a resistance.
contraction	literally, "pulling together" the Z lines delineating the length of a sarcomere, caused by the sliding action of actin and myosin filaments. Contraction develops muscle tension only if the shortening is resisted. Note that during an "isometric contraction" no change in sarcomere length occurs and that in an eccentric "contraction" the sarcome is actually lengthened. To avoid such contradiction in terms, it is often better to use the terms action, activation, effort, or exertion instead of contraction.
displacement	distance moved (in a given time).
distal	away from the center of the body.
dynamics	a subdivision of mechanics that deals with forces and bodies in motion.
eccentric (muscle effort)	lengthening of a resisting muscle by external force.
effort (of muscle)	see contraction.
exertion (of muscle)	see contraction.
fibers	see muscle.
fibrils	see muscle.
filaments	see muscle.
free dynamic	in this context, an experimental condition in which neither displacement and its time derivatives, nor force are manipulated as independent variables.
isoacceleration	a condition in which the acceleration is kept constant.
isoforce	a condition in which the muscular force (tension) is constant. This term is equivalent to isotonic.
isoinertial	a condition in which muscle moves a constant mass.
isojerk	a condition in which the time derivative of acceleration, jerk, is kept constant.
isokinetic	a condition in which the velocity of muscle shortening (or lengthening) is constant. (Depending on the given biomechanical conditions, this may not coincide with a constant angular speed of a body segment about its articulation.)
isometric	a condition in which the length of the muscle remains constant.
isotonic	a condition in which muscle tension (force) is kept constant – see isoforce. (In the past, this term was occasionally falsely applied to any condition other than isometric.)
jerk	third time derivative of displacement.
kinematics	a subdivision of dynamics that deals with the motions of bodies, but not the causing forces.
kinetics	a subdivision of dynamics that deals with forces applied to masses.
mechanical advantage	in this context, the lever arm (moment arm, leverage) at which a muscle works around a bony articulation.

mechanics	the branch of physics that deals with forces applied to bodies and their ensuing motions.
motor unit	All muscle filaments under the control of one efferent nerve axon.
muscle	a bundle of fibers, able to contract or be lengthened. Specifically, striated muscle (skeletal muscle) that moves body segments about each other under voluntary control.
muscle contraction	the result of contractions of motor units distributed through a muscle so that the muscle length shortens.
muscle fibers	elements of muscle, containing fibrils.
muscle fibrils	elements of muscle fibrils, containing filaments.
muscle filaments	muscle fibril elements (polymerized protein molecules) capable of sliding along each other, thus shortening the muscle and, if doing so against resistance, generating tension.
myo	a prefix referring to muscle.
proximal	towards the center of the body.
rate coding	the time sequence in which efferent signals arrive at a motor unit and cause contractions.
recruitment coding	the time sequence in which efferent signals arrive at different motor units and cause them to contract.
repetition	performing the same activity more than once. (One repetition indicates two exertions.)
rhythmic	a condition in which the same motion occurs often repeated, and in certain (often: equal) intervals.
statics	a subdivision of mechanics that deals with bodies at rest.
velocity	first time derivative of displacement.