Defining Skeletal Muscle Performance & Essential Variables in Strength Training Programme Design.

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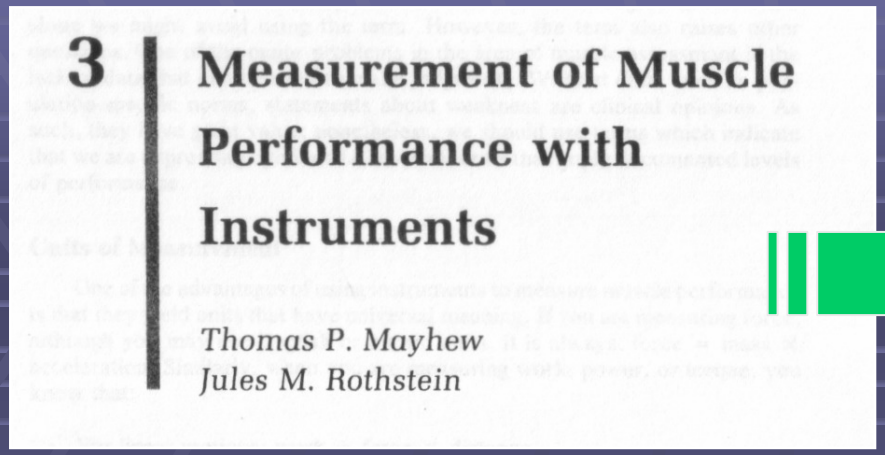

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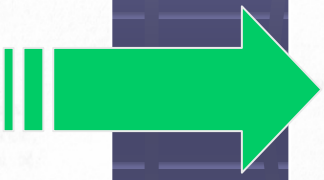
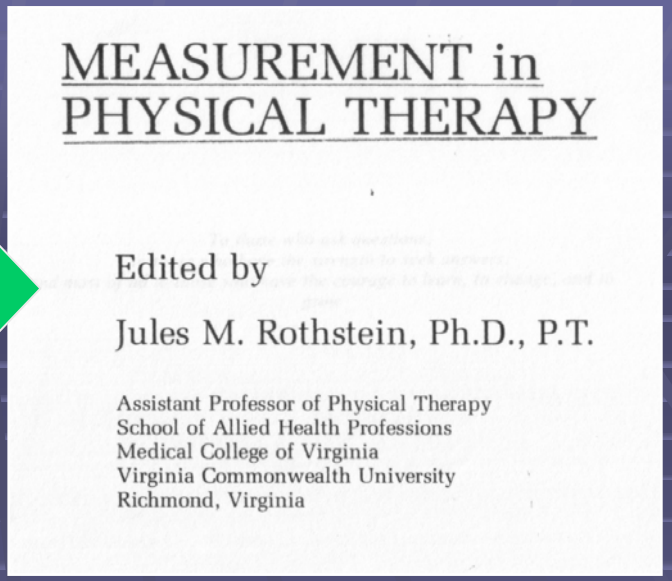
Measurement of Muscle Performance with Instruments

Thomas P. Mayhew
Jules M. Rothstein





MEASUREMENT in PHYSICAL THERAPY

Edited by

Jules M. Rothstein, Ph.D., P.T.

Assistant Professor of Physical Therapy
School of Allied Health Professions
Medical College of Virginia
Virginia Commonwealth University
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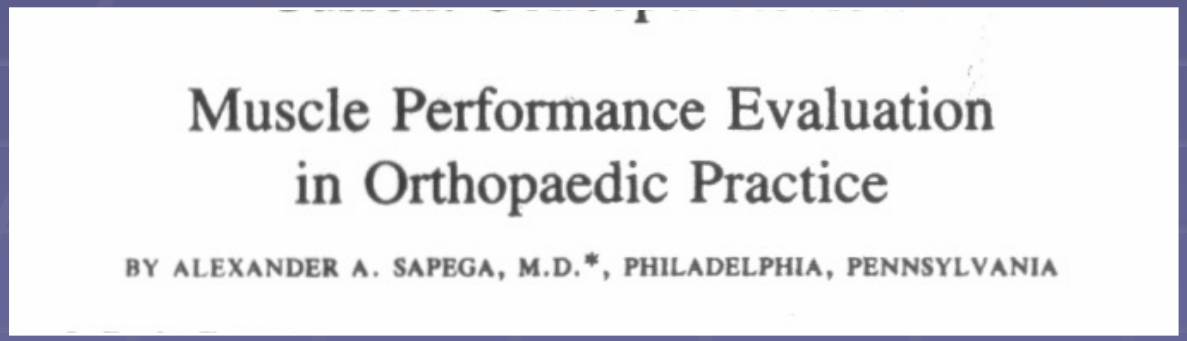
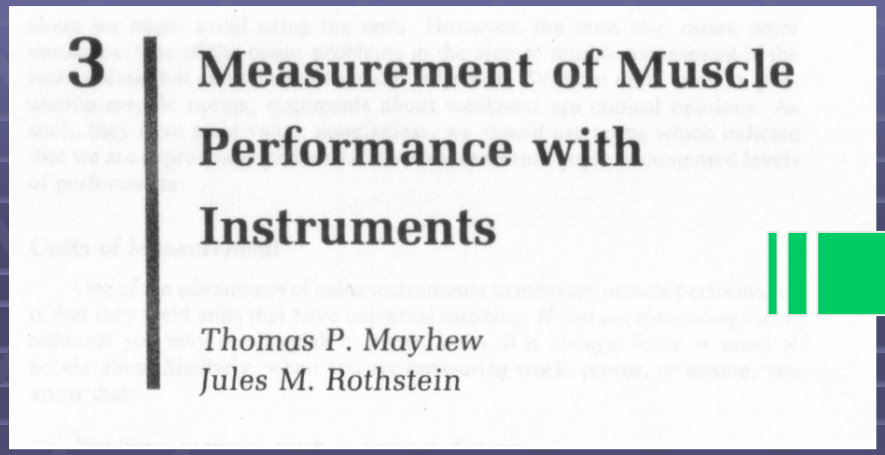
Mayhew T, Rothstein J, 1985, Measurement of Muscle Performance with Instruments, In- Measurement in Physical Therapy, Ed- J Rothstein, Churchill Livingstone, New York, pp 57-102.



Muscle Performance Evaluation in Orthopaedic Practice

BY ALEXANDER A. SAPEGA, M.D.*, PHILADELPHIA, PENNSYLVANIA

Sapega M. 1990. Muscle Performance Evaluation in Orthopaedic Practice. Journal of Bone and Joint Surgery. 72A, 1562-1574.



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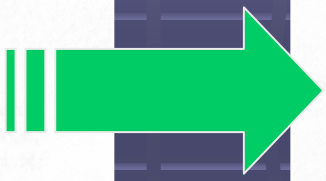

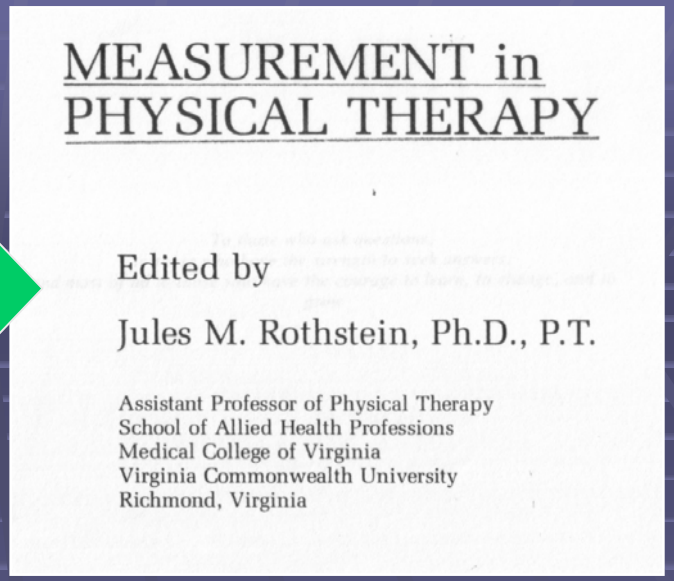

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"The terms most used to describe muscle performance are "strength" and "weakness". Yet there are no units of measurement associated with either … Strength is a non-scientific descriptor when applied to muscle … If we attempt to assess strength we must ***define it operationally*** … There is no one operational definition of strength currently in use … we believe that the use of the term "strength" has encouraged a ***chaotic approach*** to measurement" (p58)

Basic Concepts & Definition – Muscle Action

- Muscle action vs. muscle contraction
- What does the term ***contraction*** imply?

Muscles **NEVER** generate isokinetic muscle actions during real-life function
Clark, 2001, Phys Ther Sp, 2, 91-105

- **Isometric:** remains constant length whilst active
- **Isotonic-concentric:** active shortening with constant tone
- **Isotonic-eccentric:** active lengthening with constant tone
- **Isokinetic-concentric:** active shortening with constant velocity
- **Isokinetic-eccentric:** active lengthening with constant velocity

- What does the term ***isotonic*** imply?

ANISOMETRIC
recommended term

Clark, 2003, Exercise therapy in neuromusculoskeletal rehabilitation
Faulkner, 2003, J App Physiology, 95, 455-459
Jones & Round, 1990, Skeletal muscle in health and disease
McComas, 1996, Skeletal muscle. Form and function
Sapega, 1990, J Bone Joint Surg, 72A, 1562-1574

Basic Concepts & Definition – Muscle Strength

- **Muscle strength:** "the ability of a muscle to produce force"
  Clark, 2001, Phys Ther Sp, 2, 96

ANY exercise which is intended to ↑ 'the ability of a muscle to produce force' is a strength training exercise

- **Maximum strength:** force generated in a ***single*** maximum voluntary muscle action (MVMA)
- **Absolute Strength:** force generated irrespective of bodyweight
- **Relative strength:** force generated relative to bodyweight
- **Elastic strength:** force generated at high velocity of anisometric muscle action → muscle 'power'
- **Strength endurance:** force generated for sustained (isometric) or repeated (anisometric) muscle actions against a ***sub-maximal*** resistance

Clark, 2000, Muscle performance and strength training

Clark, 2003, Exercise therapy in neuromusculoskeletal rehabilitation

Dick, 1989, Sports training principles

Sapega, 1990, J Bone Joint Surg, 72A, 1562-1574

From: Taylor R et al, 2000, Lumbar Segmental Instability: Pathology, Diagnosis, and Conservative Management, In- Physical Therapy of the Low Back, 3rd Edition, Eds- L Twomey, J Taylor, Churchill Livingstone, New York, p230.

ANY exercise which is intended to ↑ 'the ability of a muscle to produce force' is a strength training exercise

IF these exercises are intended to increase the ability of the trunk muscles to produce force, then even these exercises CAN be considered 'strength training' exercises

BUT as 'strength ENDURANCE' exercises

From: Richardson C et al, 2004, Therapeutic Exercise for Lumbopelvic Stabilization, 2nd Edition, Churchill Livingstone, Edinburgh, p239

ELSEVIER

Journal of Electromyography and Kinesiology 13 (2003) 361–370

JOURNAL OF ELECTROMYOGRAPHY AND KINESIOLOGY

www.elsevier.com/locate/jelekin

Pain and motor control of the lumbopelvic region: effect and possible mechanisms

Paul W. Hodges [a,*], G. Lorimer Moseley [a,b]

"Trunk muscles must have sufficient strength and endurance to satisfy the demands of control"

(Hodges & Moseley, 2003, p362)

Basic Concepts & Definition – Muscle Performance

- **Muscle performance** = type of muscle action + type of muscle strength

- Stair ascent (2× 15 stairs)
  → lower limb extensor concentric relative strength endurance
- Single leg static ¼ squat
  → lower limb extensor isometric relative strength endurance
- Parachute jump landing
  → lower limb extensor eccentric relative / maximum strength

Many different 'contexts' in which muscles can express force

Implications for exercise selection?

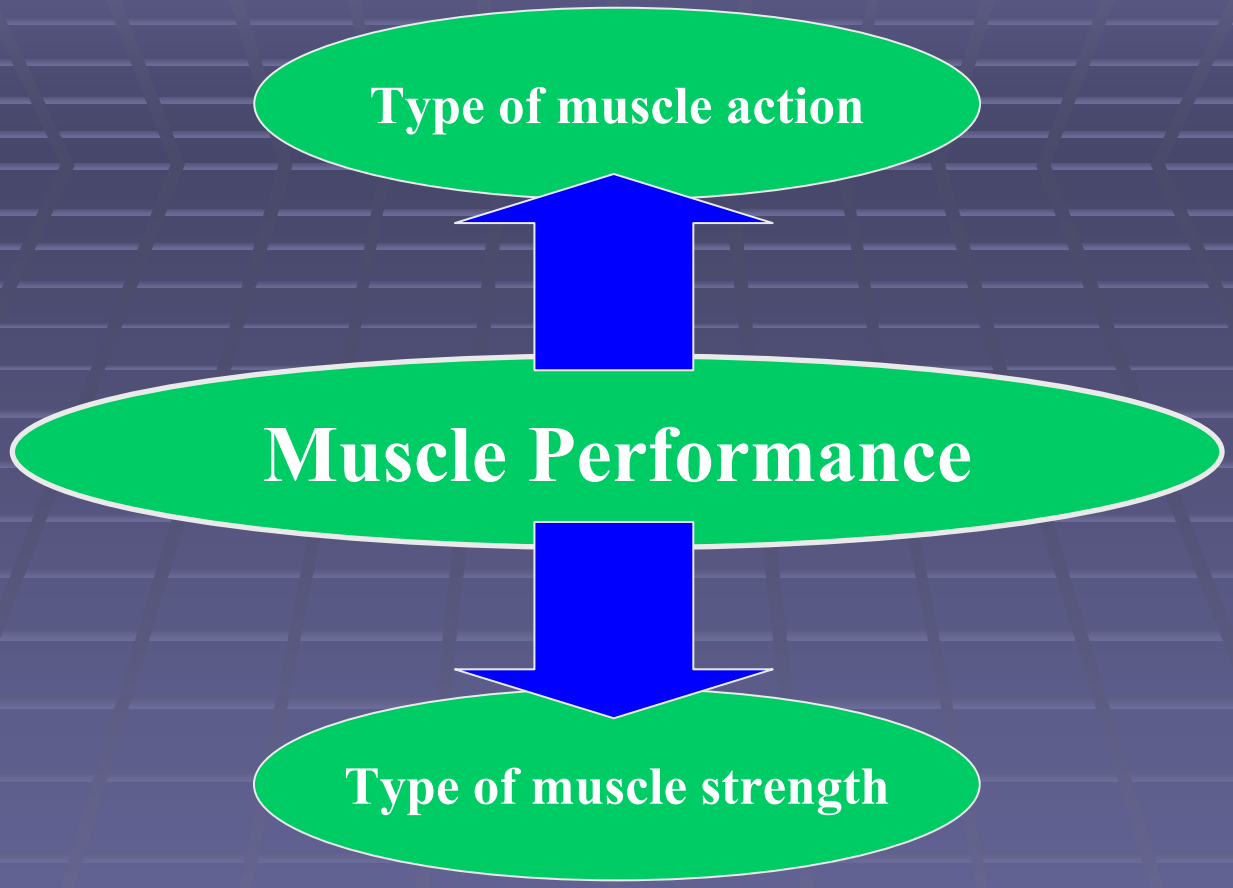
Clark, 2000, Muscle performance and strength training

Clark, 2003, Exercise therapy in neuromusculoskeletal rehabilitation

Dick, 1989, Sports training principles

Sapega, 1990, J Bone Joint Surg, 72A, 1562-1574

Basic Concepts & Definition – Muscle Performance



Clark, 2000, Muscle performance and strength training

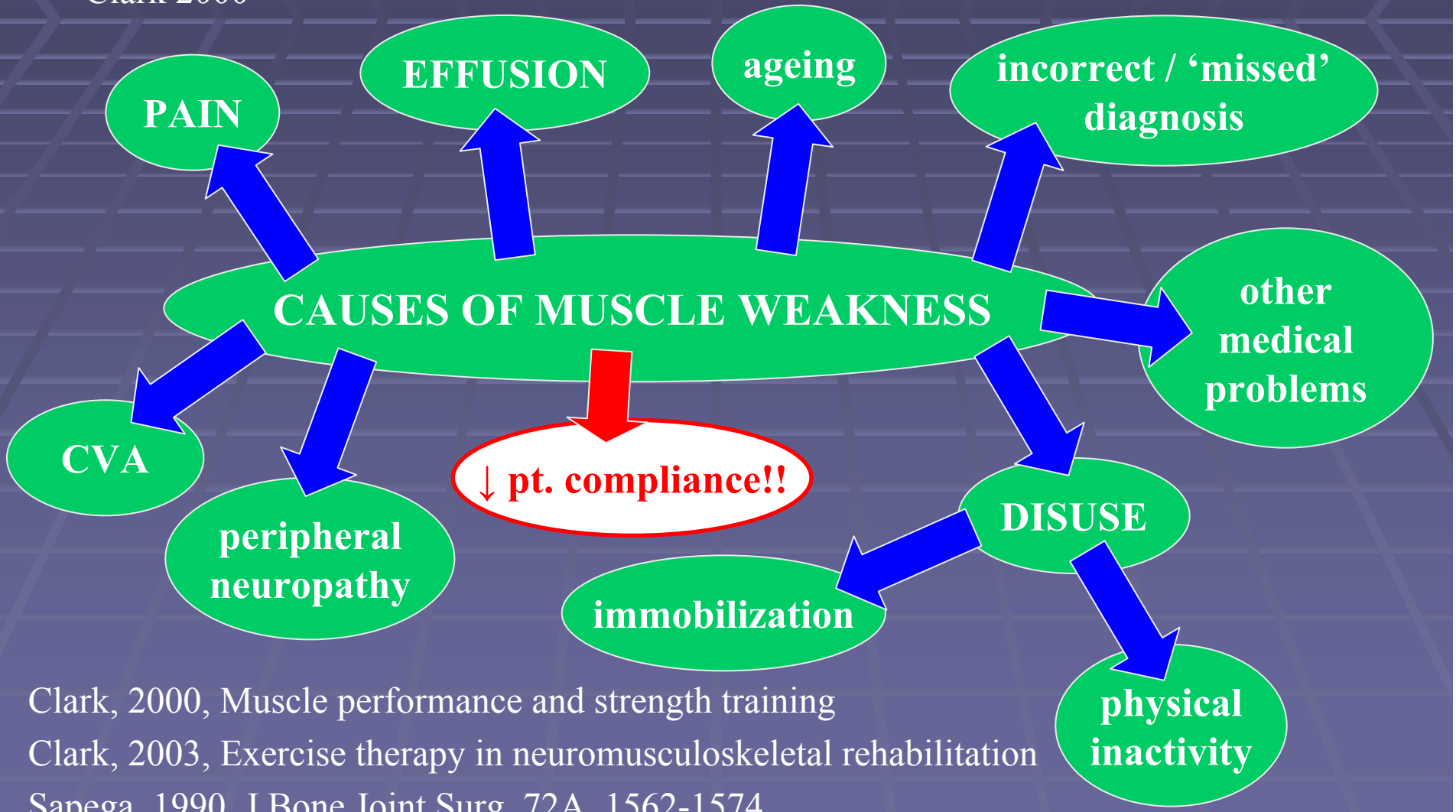
Clark, 2003, Exercise therapy in neuromusculoskeletal rehabilitation

Dick, 1989, Sports training principles

Sapega, 1990, J Bone Joint Surg, 72A, 1562-1574

Basic Concepts & Definition – Muscle Weakness

- **Muscle weakness:** "the inability of a muscle to produce force"
  Clark 2000



Clark, 2000, Muscle performance and strength training
Clark, 2003, Exercise therapy in neuromusculoskeletal rehabilitation
Sapega, 1990, J Bone Joint Surg, 72A, 1562-1574

Exercise Programme Design

Definition & Methods of Strength Training

- Strength training is exercise primarily directed at increasing **local** muscle strength by sustained (isometric) or repeated (anisometric) muscle actions against an opposing force (load / resistance)

- Methods:
  - segment / limb-weight
  - body-weight
  - elastic
  - sand-bag
  - dumb-bell / bar-bell
  - resistance machine (e.g. metal plate / pneumatic / hydraulic, etc.
  - manual resistance (e.g. PNF)

Clark, 2000, Muscle performance and strength training

Clark, 2003, Exercise therapy in neuromusculoskeletal rehabilitation

Fleck & Kraemer, 1997, Designing resistance training programs

Fry et al, 2002, Special considerations in strength training

Kraemer & Fleck, 1988, Phys Sp Med, 16, 69-81

Acute Programme Variables

- Choice of exercise
- Order of exercise
- Mode of muscle action
- Range of motion
- Intensity (magnitude of load = no. of repetitions)
- Number of sets
- Exercise tempo (e.g. 2-1-5 sec. → concentric-isometric-eccentric sequence)
- Duration of between-set rest periods

- Manipulating the acute programme variables dictates the physiological and functional response → **specificity of training**

Clark, 2003, Exercise therapy in neuromusculoskeletal rehabilitation

Fleck & Kraemer, 1997, Designing resistance training programs

Fry et al, 2002, Special considerations in strength training

Kraemer & Fleck, 1988, Phys Sp Med, 16, 69-81

Kraemer & Koziris, 1992, Phys Ther Practice, 2, 54-68

Choice of Exercise

- Physiological and functional adaptations are specific to the muscles / muscle groups actually recruited during the exercise session

- ***Clinical Application***: choose exercises which target muscles / muscle groups affected by the injury, or necessary to enhance whole-limb function

- ***Idiotic Example***: don't do triceps pushdowns to strengthen the quadriceps!!!

Most basic decision in exercise programme design

Clark, 2003, Exercise therapy in neuromusculoskeletal rehabilitation

Fleck & Kraemer, 1997, Designing resistance training programs

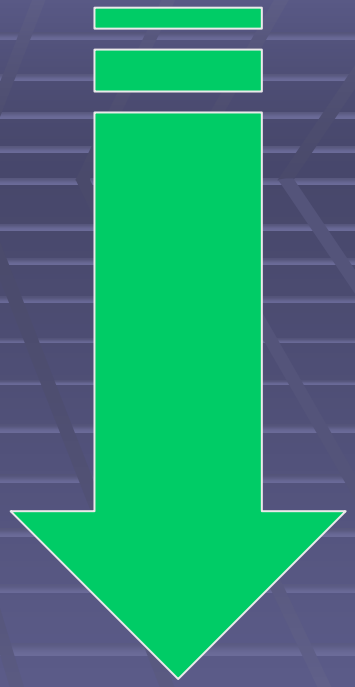
Fry et al, 2002, Special considerations in strength training

Kraemer & Fleck, 1988, Phys Sp Med, 16, 69-81

Kraemer & Koziris, 1992, Phys Ther Practice, 2, 54-68

Order of Exercise

- Sequence of exercises within a single training session
- Improper exercise order most frequent error in exercise programme design
- Primary concern for the effects of fatigue on proper technique / skill execution and injury risk



- Large muscle mass → small muscle mass
- Multi-joint → single-joint
- High-power → low-power
- High-skill → low-skill
- High-impact → low-impact → no-impact

Clark, 2003, Exercise therapy in neuromusculoskeletal rehabilitation

Fleck & Kraemer, 1997, Designing resistance training programs

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Order of Exercise

- Be meticulous with decision-making regarding exercise order because:

1. Muscle fatigue = ↓ max. force generating ability
2. Muscle fatigue = ↓ rate of force development (RFD)
3. Muscle fatigue = ↓ proprioceptive acuity
4. Muscle fatigue = ↓ reflex muscle activity

- Therefore:

  1 + 2 + 3 + 4 = ↓ **joint stability** + ↑ **injury risk**

Clark, 2000, Muscle performance and strength training
Clark, 2003, Exercise therapy in neuromusculoskeletal rehabilitation
Clark, 2003-Present, Proprioception and neuromuscular control in exercise rehabilitation for the lower limb

Mode of Muscle Action

- Type of muscle action: isometric
  anisometric
  isokinetic

- Greatest strength gains are demonstrated if the mode of muscle action used in training matches the mode of muscle action used in testing

- ***Clinical Application:*** Muscle action specificity = exercise muscle action should match that of the patient's intended function

Behm, 1995, J Strength Cond Res, 9, 264-274

Fleck & Kraemer, 1997, Designing resistance training programs

Morrissey et al, 1995, Med Sci Sp Ex, 27, 648-660

Sale, 1988, Med Sci Sp Ex, 20, Supplement, S135-S145

Range of Motion (ROM)

- Range of motion in which an exercise is performed

- **Isometric training**: 1. strength gains are demonstrated approx. 10-20˚ either 'side' of the actual training angle ('carryover'); 2. greater carryover is demonstrated with 'harder', 'longer', and 'more' muscle actions

- ***Clinical Application***: 1. loss of full active ROM can be treated with isometric exercise at the 'sticking point', providing that there is no / minimal loss of passive ROM; 2. patients should perform multiple (50-100) isometric muscle actions per day, for 5-10 seconds each, and as 'hard' as possible **within the limits of pain**

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Fleck & Kraemer, 1997, Designing resistance training programs

Morrissey et al, 1995, Med Sci Sp Ex, 27, 648-660

Sale, 1988, Med Sci Sp Ex, 20, Supplement, S135-S145

Range of Motion (ROM)

- Range of motion in which an exercise is performed

- **Anisometric training:** 1. strength gains are greatest within the ROM in which the exercise is performed; 2. minimal carryover with concentric exercise; 3. carryover is virtually non-existent with eccentric exercise

- ***Clinical Applications*:** 1. exercises should be performed in a ROM specific to the patient's intended function; 2. some carryover can be anticipated with concentric muscle actions; 3. eccentric exercise should be strictly ROM-specific to the patient's intended function

Behm, 1995, J Strength Cond Res, 9, 264-274

Fleck & Kraemer, 1997, Designing resistance training programs

Morrissey et al, 1995, Med Sci Sp Ex, 27, 648-660

Sale, 1988, Med Sci Sp Ex, 20, Supplement, S135-S145

Range of Motion (ROM)

- Range of motion in which an exercise is performed

- **Summary:** ROM specificity
- 1. isometric and anisometric muscle actions should ideally be performed in the ROM specific to the patient's intended function;

  2. isometric training is particularly useful for severe muscle weakness where passive ROM is minimally compromised

Behm, 1995, J Strength Cond Res, 9, 264-274

Fleck & Kraemer, 1997, Designing resistance training programs

Morrissey et al, 1995, Med Sci Sp Ex, 27, 648-660

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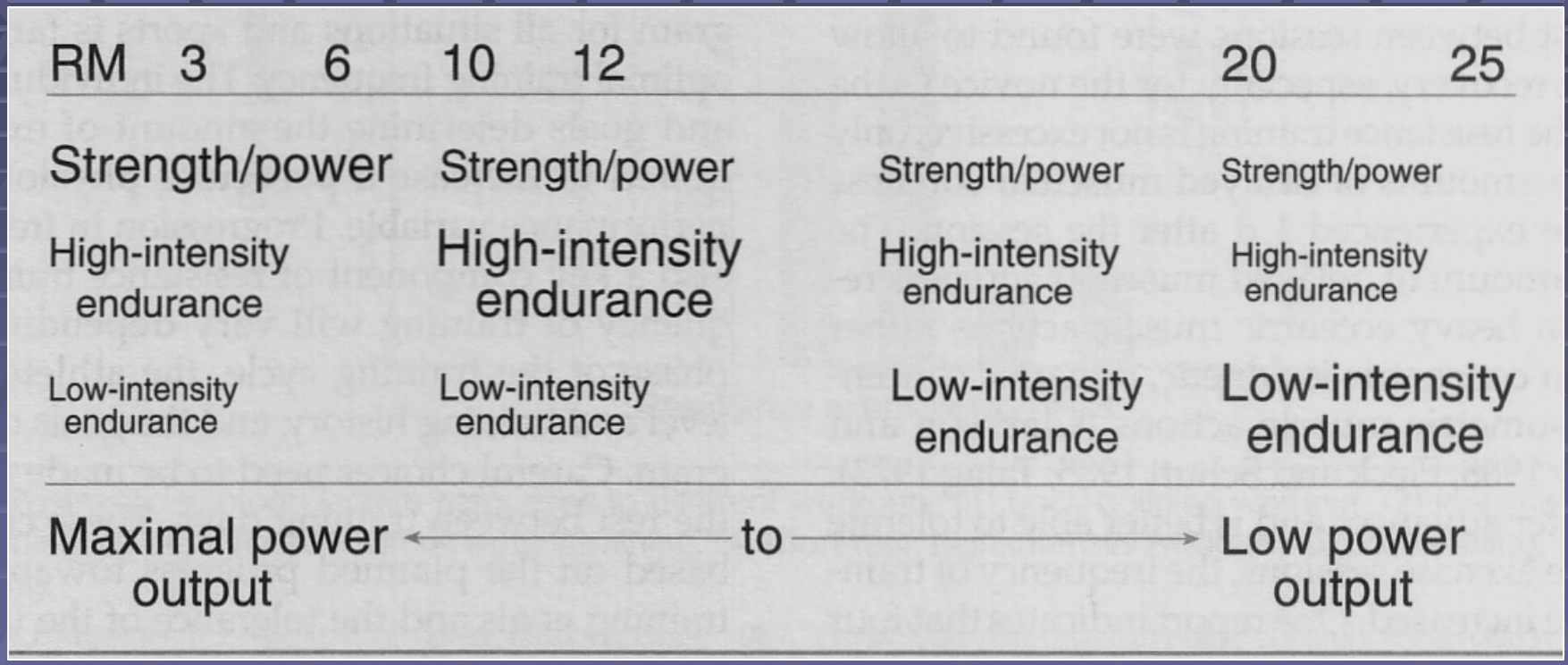
Intensity

- Repetition Continuum



- Heavier load = fewer repetitions

From: Fleck & Kraemer, 1997, Designing resistance training programs, 2nd Edition, Human Kinetics, Illinois

Intensity

- Repetition Continuum

- **Therapeutic Objective**
- ↑ motor unit recruitment = high intensity, low repetition (≤ 8)
  e.g. muscle inhibition

- ↑ muscle hypertrophy = moderate intensity, moderate repetitions (12-15)
  e.g. muscle atrophy

- ↑ muscle strength endurance = low intensity, high repetition (≥ 20)
  e.g. 'stability' muscle function

- **Relative to a muscle's status at a specific point-in-time**

Clark, 2000, Muscle performance and strength training
Clark, 2003, Exercise therapy in neuromusculoskeletal rehabilitation

Number of Sets

- Set = specific number of consecutive repetitions
- Strength gains are greater with > one set per exercise per training session
- Optimal number of sets for strength training following neuromusculoskeletal injury unknown

- **Recommended no. sets in apparently healthy adults = 3-4 sets**

  Kraemer et al, 2002, Med Sci Sp Ex, 34, 364-380

  Rhea et al, 2003, Med Sci Sp Ex, 35, 456-464

Recommendations for injured adults = 2-4 sets · exercise · session
Progressed according to patient response / tolerance

Clark, 2003,
Exercise therapy in neuromusculoskeletal rehabilitation

Byrd et al, 1999, Sport Med, 27, 409-416

Carpinelli & Otto, 1998, Sport Med, 26, 73-84

Fleck & Kraemer, 1997, Designing resistance training programs

Exercise Tempo

- Velocity at which anisometric or isokinetic muscle actions are performed
- Expressed in seconds:

  e.g. 2-1-5 → concentric-isometric-eccentric

- Greatest strength gains are demonstrated if the velocity of muscle action used in training matches the velocity of muscle action used in testing

- ***Clinical Application:*** velocity specificity = exercise velocity should match that of the patient's intended function

Behm, 1995, J Strength Cond Res, 9, 264-274

Behm & Sale, 1993, Sport Med, 15, 374-388

Fleck & Kraemer, 1997, Designing resistance training programs

Morrissey et al, 1995, Med Sci Sp Ex, 27, 648-660

Sale, 1988, Med Sci Sp Ex, 20, Supplement, S135-S145

Between-Set Rest Periods

- Refers to duration of rest between each set of a specific exercise
- Too short rest periods 2nd most frequent error in exercise programme design
- Affects metabolic, hormonal, and cardiovascular responses to strength training
- Greater strength gains with 'long' (2-3 min.) vs. 'short' (30-40 sec.) rest periods

Magnitude of load will affect the duration of between-set rest periods required to ensure adequate recovery

↑ load = ↑ rest period

- **Structural / multi-joint exercises: 2-4 min.**
- **Isolation / single-joint exercises: 1-2 min.**

Fleck & Kraemer, 1997, Designing resistance training programs

Fry et al, 2002, Special considerations in strength training

Kraemer & Fleck, 1988, Phys Sp Med, 16, 69-81

Kraemer & Koziris, 1992, Phys Ther Practice, 2, 54-68

Kraemer et al, 2002, Med Sci Sp Ex, 34, 364-380

Specificity of Strength Training

- **Summary:**
- Muscle group specificity
- Muscle action specificity
- ROM specificity
- Intensity specificity
- Velocity specificity

- Task / movement pattern specificity
  → **functional strength**

Functional Muscle Strength
"whole limb force expression during multi-joint, multi-muscle group movements specific to a person's unique activity or purpose"
Clark, 2003,
SportEx Med, 19, p8

Behm, 1995, J Strength Cond Res, 9, 264-274
Behm & Sale, 1993, Sport Med, 15, 374-388
Fleck & Kraemer, 1997, Designing resistance training programs
Morrissey et al, 1995, Med Sci Sp Ex, 27, 648-660
Sale, 1988, Med Sci Sp Ex, 20, Supplement, S135-S145

Example Programme:

- Patient: 60♀
  (L) knee OA
  Lives in a house with two flights 12 stairs

Exercise Order	Sets	Reps	Load*	ROM*	Rest
Wall-squat	3	10-15	BW	0-45°	2 mins.
Standing calf-raise	3	8-15	BW	Full	2 mins.
Seated knee ext.	3	10-15	2kg	0-90°	90 secs.
Side-lying glute. med.	2	10	45°**	Full	2 mins.

Yellow = Essential information for the patient

* = limited by / progressed according to the presence of pain

** = feet together, 45° hip flexion, 90° knee flexion