Recommendations for the Evaluation of Muscular Strength and Power with Children and Adolescents

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MEMORIAL UNIVERSITY

National Associations Recommending Strength and Power Training for Children and Adolescents

- American Academy of Pediatrics
- Australian Strength and Conditioning Association
- British Association of Exercise and Sport Sciences
- Canadian Society for Exercise Physiology
- National Strength and Conditioning Association (NSCA)

Historical Perspective

- Most child strength tests are field based tests such as
  - Sit-ups, push-ups in 1 min
  - Flexed arm hang
  - Grip strength

Should younger children perform maximal lifts?

1990s

- Council on Child and Adolescent Health
- US Power Lifting Federation

Children should not lift maximal weights till 14-16 years of age or Tanner stage 5

- Growth plate fractures have not been reported in any prospective youth strength-training study that used maximal strength testing (e.g., 1-RM testing methods on the leg press, chest press, or arm curls) to evaluate training-induced changes in children

  (Faigenbaum et al. 2003, 2009)

- Australian Powerlifting Federation includes competitions for 14-18 yrs. (max. squats and deadlifts).

- USA Weightlifting development center
- 534 lifts (max clean and jerks) in competition, not counting heavy warm-up lifts with no injuries that required medical attention

  (Byrd et al. 2003).

US High School Sport Injury Rates

- Football: 4.36 injuries per 1,000 athlete exposures
- Wrestling: 2.5 per 1000 exposures,
- Boys' (2.43) and girls' (2.36) soccer
- Girls' basketball: 2.01 exposures

- Most forces that children are exposed to in sports are greater than supervised and properly performed maximal strength tests.
- DJ and CMJ ground reaction forces = ~5 x BW
- Jumping jacks = 3.5 x Body Weight (BW).
- DJ (10 cm): force rate of change = 514 x BW/s
- CMJ: rate of change in force = 493 x BW/s

(McKay et al. 2005)

Should children perform 1-RM testing?

- Australian SCA (2007) supports the "philosophy" of 1-RM testing for children
- Under no circumstances should children be subjected to unsupervised and poorly performed 1-RM testing (e.g., inadequate progression of loading and poor lifting technique) due to the real risk of injury" (NSCA 1996).
- Chest press and leg press with 8-12 yr. olds

ICC = 0.93-0.98 (Faigenbaum et al. 1998)

1-RM Testing Process

- Adult strength-testing guidelines suggest that the 1-RM should be determined within 5 testing sets (Baechle et al. 2000),
- 7-11 sets may be needed in children who have no experience in strength-testing procedures (Faigenbaum et al. 2003)
- 1-RM testing can be labour intensive, time consuming and needs close, qualified supervision (Behm et al. 2008)

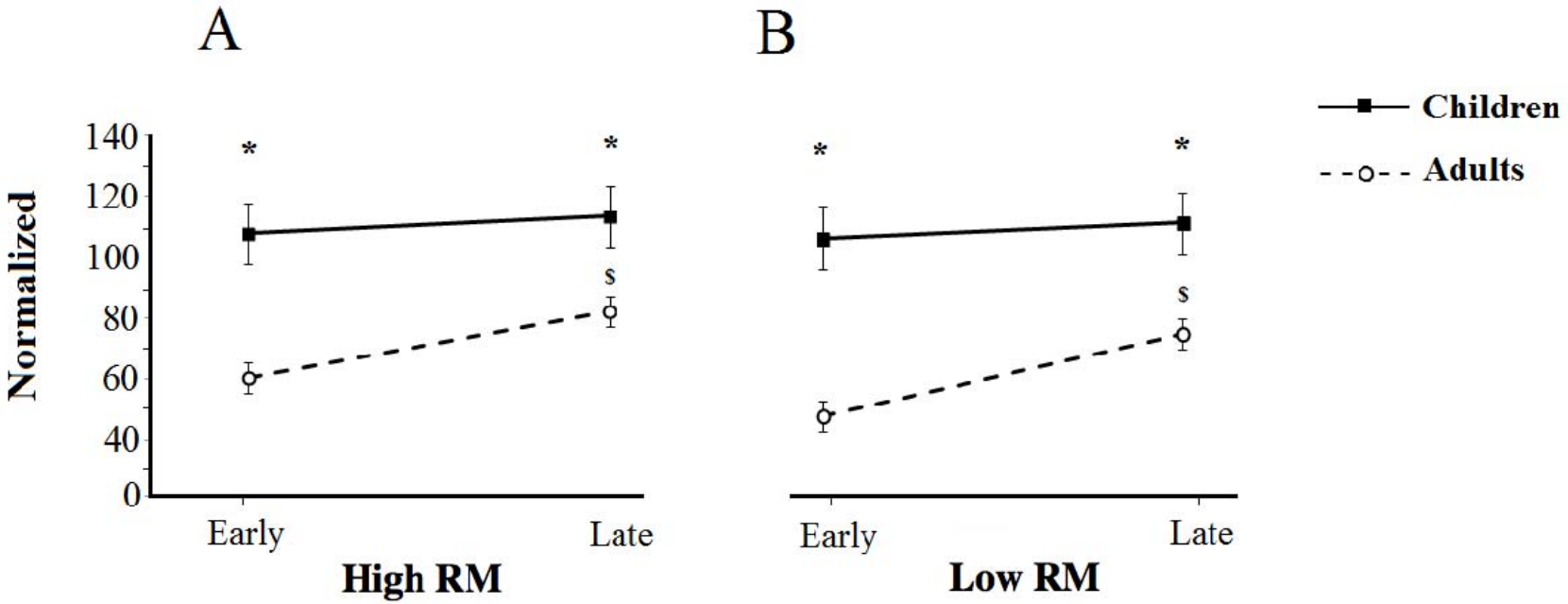
- Thus 1-RM testing can be lengthy

- Test-retest variation in strength testing in children is 5-10%

Is a 1-RM a real 1-RM?

- Children have difficulty providing a maximal exertion (Falk and Dotan 2006, Murphy et al. 2014)
  - Feelings of discomfort
- Difficulty in perceiving maximal vs. submaximal contractions (Murphy et al. 2014)

Children's EMG normalized to MVC does not sig change during the fatigue protocols



Murphy et al. 2014 EJAP

Is a 1-RM a real 1-RM?

- Full muscle activation may be compromised with youth (Falk and Dotan 2006; Ratel et al. 2006).
  - May be due to a lack of experience with this contraction intensity (no prior reference point)
  - Children may be neurologically immature
- Motor control / coordination difficulties
  - Increased antagonistic activity (hamstrings) suggested that the fatigue was more likely to be a result of muscle coordination difficulties (increased co-contractions).

    (Murphy et al. 2014)

- Falk and Mor (1996) reported positive results from resistance and martial arts training in 6-8 year old boys.
- ASCA position is that the youngest a child should commence resistance training/testing is 6 years.
- Children 5 - 6 yrs have benefited from participation with resistance training (Faigenbaum et al. 2009)
- Faigenbaum et al. (2003) demonstrated that 1 RM (repetition maximum) testing using child-sized weight machines was safe and effective for 6-12 yr olds.

64 boys and 32 girls between 6-12 yrs.

Table 2. One repetition maximum results by gender.*

	Girls	Boys
Leg press (kg)	60.2 ± 19.8	59.2 ± 19.3
Leg extension (kg)	19.3 ± 7.3	17.8 ± 7.9
Standing chest press (kg)	24.0 ± 5.7	24.6 ± 7.7
Seated chest press (kg)	22.0 ± 6.5	20.5 ± 5.9

* Values are expressed as mean ± *SD*.

No abnormal responses or injuries from 1 RM testing in this study

Maximal or near maximal strength testing for children or youth?

Could you?	Voisitteko ?
Would you?	Haluatko?
Should you?	Pitäisikö sinun?

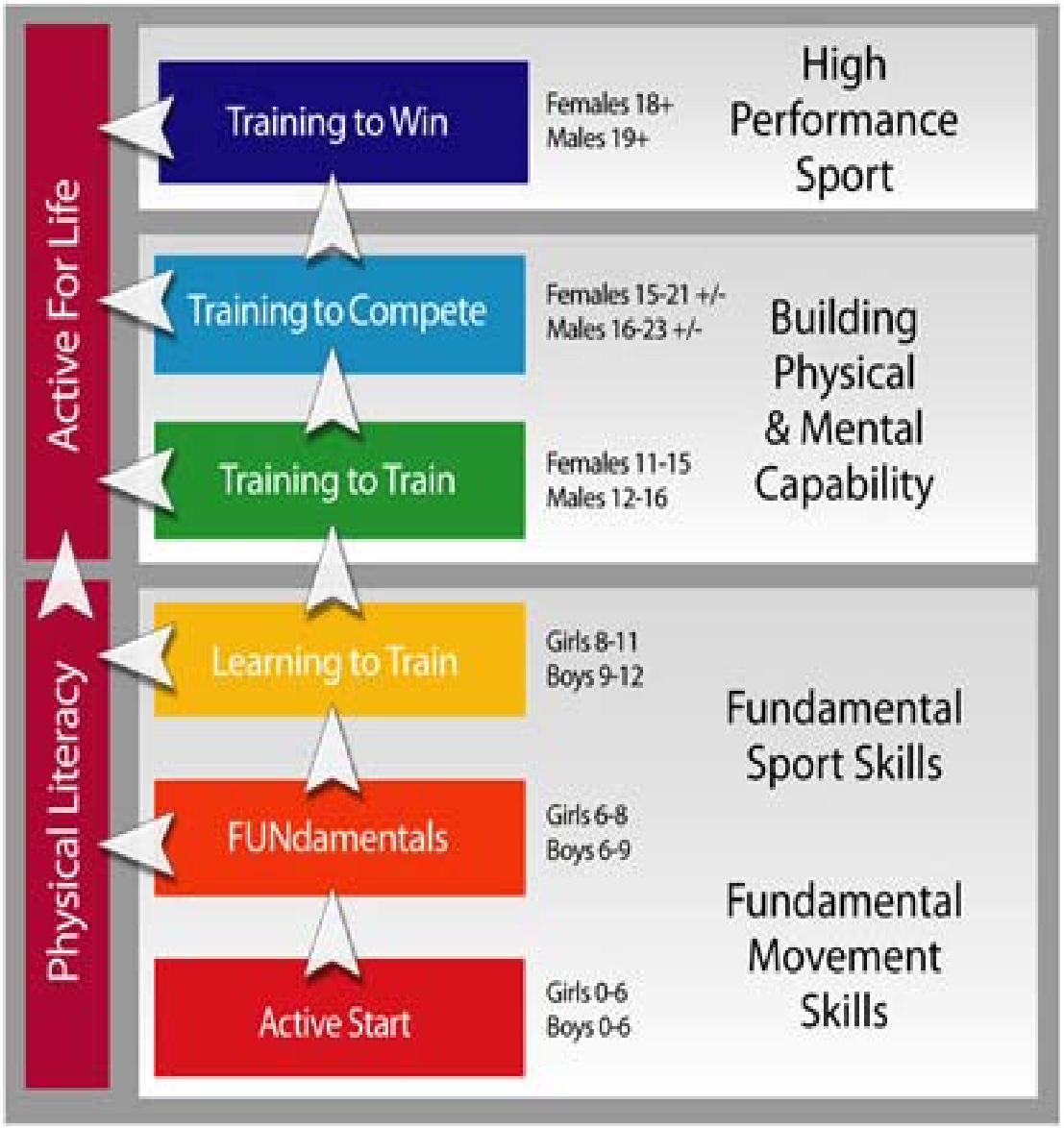
Physiological vs. Functional

- Physiologically: no reports of injuries with children as young as 6 years
- Functionally: What are we really testing?

  - 1-ToD
  - Tolerance of Discomfort?

- Athletic or trained adolescent and adult males and females have experience and may be accustomed with pushing into the discomfort zone.
- Most young children do not have this experience!

Long Term Athlete Development Model

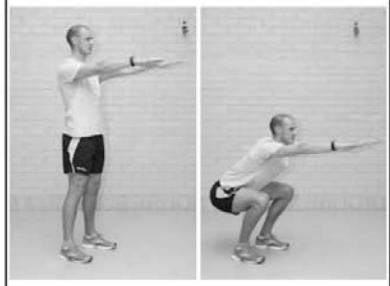


Long Term Athlete Development Model

Active Start	Males and Females 0 - 6	Learn FUNdamental movements and link them together in play
FUNdamentals	Males 6 – 9 Females 6 - 8	Learn all FUNdamental movement skills and build overall motor skills
Learn to Train	Males 9 – 12 Females 8 – 11	Learn overall sport skills
Train to Train	Males 12 – 16 Females 11 – 15	Build aerobic base, develop speed and strength, further develop and consolidate sport-specific skills
Train to Compete	Males 16 – 23 +/- Females 15 – 21 +/-	Optimize fitness preparation and sport-, individual-, and position-specific skills as well as performance
Train to Win	Males 19 +/- Females 18 +/-	Focus on podium performances
Active for Life	Enter at any age	Smooth transition from an athlete's competitive career to a lifelong physical activity and participation in sport

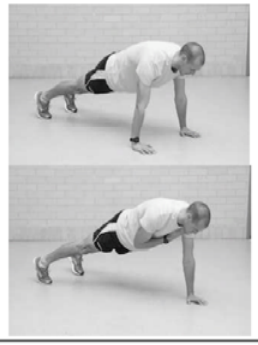
Resistance Training Skills Battery (RTSB)

- Resistance Training Skills Battery (RTSB) developed to assess adolescents' skill competency in resistance training
- considered safe and developmentally appropriate for adolescents,
- require minimal equipment and access to facilities,
- represents movements commonly used in adolescent resistance training programs.
- Competency in these movements will provide the foundation for developing physical strength in a range of bodily movements,
- 6 skills are summed to provide a resistance training competency total quotient (score 0-56) (Lubans et al. 2014).
- Construct validity: RTSQ predicted 39% of variance in muscular fitness (handgrip strength, timed push-up and standing long jump tests)(Lubans et al. 2013).

Resistance Training Skills Battery (RTSB)							
Skill	**Materials**	**Directions**	**Skill Depiction**	**Performance Criteria**	**Set 1**	**Set 2**	**Score**
1. Body weight squat	Flat surface	Provide a demonstration of the movement. Instruct the participant to perform 4 repetitions of the exercise with the arms extended forward at shoulder height. Repeat a second trial.		1. Feet are shoulder width or slightly wider apart and facing forward			
				2. Back is kept straight and stable throughout the movement			
				3. Knees point in the same direction as feet during movement			
				4. Heels remain on floor throughout the movement			
				5. Thighs are parallel to the floor at the bottom of the movement			
						Skill Score	
2. Push-up	Flat surface	Provide demonstrations of modified (on knees) and full (on toes) push-ups. Instruct the participant to perform 4 modified or full push-ups. Repeat a second trial.		1. Hands are shoulder width or slightly wider apart			
				2. Head, back and hips are held in a straight line throughout the movement			
				3. Body is lowered until elbows are at a 90 degree angle			
				4. Shoulders are held down and away from ears (shoulders are not shrugged)			
						Skill Score	
3. Lunge	Flat surface	Provide a demonstration of the movement with hands on hips. Instruct the participant to perform 4 repetitions on the same leg. Second trial is completed with the other leg.		1. Takes an exaggerated step forward and lands heel first			
				2. Torso is kept upright and stable at all times (no twisting)			
				3. Knee of rear leg is almost touching the floor (approx. 10cm)			
				4. There is alignment between hip, knee and foot of each leg			
				5. Returns to starting position in one movement			
						Skill Score	

2 trials of 4 repetitions
1 point for correct performance
0 points for incorrect

Between Rater Coefficient of Variation = 5%
(Barnett et al. 2014)

4. Suspended row	Flat surface and bar suspended at hip height or suspension straps with an anchor point	Provide a demonstration of the movement. Instruct the participant to perform 4 repetitions starting with their upper body at a 45-60 degree angle. Repeat a second trial.		1. Straight line through head and back			
				2. Body is pulled upwards to touch handles or bar at chest height			
				3. Arms are fully extended in the bottom position			
				4. No bending at the hips			
						Skill Score	
5. Standing overhead press	Flat surface and barbell	Provide a demonstration of the movement. Instruct the participant to perform 4 repetitions. Repeat a second trial.		1. Bar is gripped slightly wider than shoulders			
				2. Back is kept straight and stable throughout movement			
				3. Bar starts at chest height and is pressed upward until arms are fully extended			
				4. Bar remains parallel to the ground throughout the movement			
				5. Bar is overhead at the top of the lift			
						Skill Score	
6. Front support with with chest touches	Flat surface	Provide a demonstration of the movement. Instruct the participant to perform 2 repetitions per side alternating sides each repetition. Repeat a second trial.		1. Straight line through legs, hips, shoulders and head			
				2. Feet are approximately shoulder width apart			
				3. Minimal rotation of body while changing hand placement (approx. 10cm is acceptable)			
				4. Both feet remain on the ground throughout the entire trial			
				5. Chest touches are performed in a controlled manner			
						Skill Score	
						Resistance Training Skill Quotient	

- *Australian SCA (2007) supports the "philosophy" of 1-RM testing for children*
- The ASCA does not advocate the use of one-repetition maximum (1-RM) testing to determine appropriate training loads or to monitor progression in training for 6-15 yr.
- Instead the repetitions maximum (RM) method is recommended.

Repetitions till Fatigue (RTF)

- ASCA position that young and less experienced, school-aged resistance trainers be assessed with lighter resistances and performing RTF test.
- 1-RM (or any RM up to 20 RM) can be extrapolated with reasonable accuracy (Baker, 2004).
- Younger athletes do not possess the same intramuscular control and accordingly, this lack of coordination means they cannot perform well with heavier resistances.
- Resistance should be chosen that allows at least 8 repetitions,

Table I – Determining 1-RM from Varying Repetitions

% 1-RM	100	96	94	92	90	88	86	84	82	80
Reps	1	2	3	4	5	6	7	8	9	10
CF	1.0	1.04	1.06	10.8	1.11	1.13	1.16	1.19	1.22	1.25
% 1-RM	78	76	74	72	70	68	66	64	62	60
Reps	11	12	13	14	15	16	17	18	19	20
CF	1.28	1.31	1.35	1.39	1.43	1.47	1.52	1.56	1.61	1.64

Guide for determining 1-RM from varying repetitions performed to maximum effort in novice and younger less experienced resistance trainers performing standard strength exercises. An estimate of 1-RM is made when the weight lifted is multiplied by the conversion factor according to the number of repetitions that were performed with that weight (Table developed by Dr. Dan Baker). Abbreviations: **% 1-RM** = percentage of one-repetition maximum; **Reps** = repetitions; **CF** = conversion factor.

www.strengthandconditioning.org

Isokinetic torque @ $60^0.s^{-1}$

Tabin et al. 1985

- In active but not trained children

- Plantar flexor torque @ $30^0.s^{-1}$ = hamstrings @ $60^0.s^{-1}$
- Dorsiflexors = 1/3 plantar flexors torque

- Pre-pubescent
  - Max quadriceps torque = 70% LBW boys and girls
  - Max hamstrings torque = 60% LBW boys
  - Max hamstrings torque = 40% LBW girls
- Post-pubescent boys
  - Max quadriceps torque = 90% LBW
  - Max hamstrings torque = 55% LBW
- Post pubescent girls
  - Max quadriceps torque = 80% LBW
  - Max hamstrings torque = 50% LBW

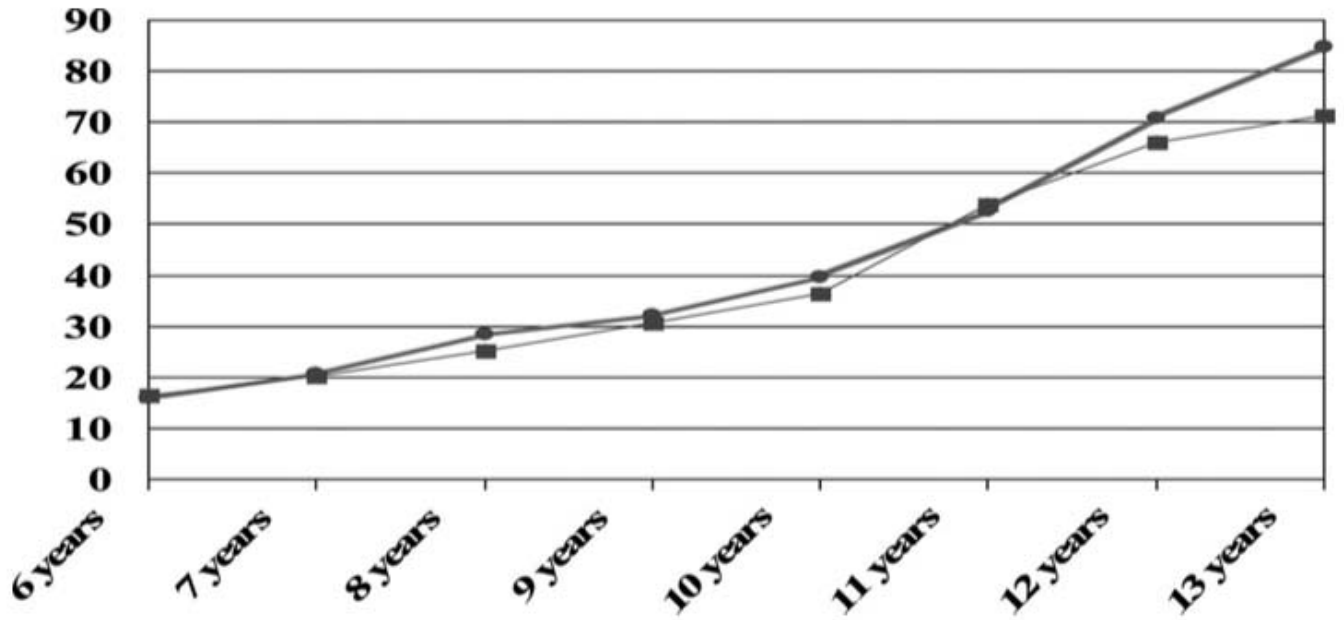


Fig. 2. Fiftieth percentile of peak torque for the hamstrings of the dominant leg at 60 degrees per second for males (—●—) and females (—■—).

Wiggins et al. 2006

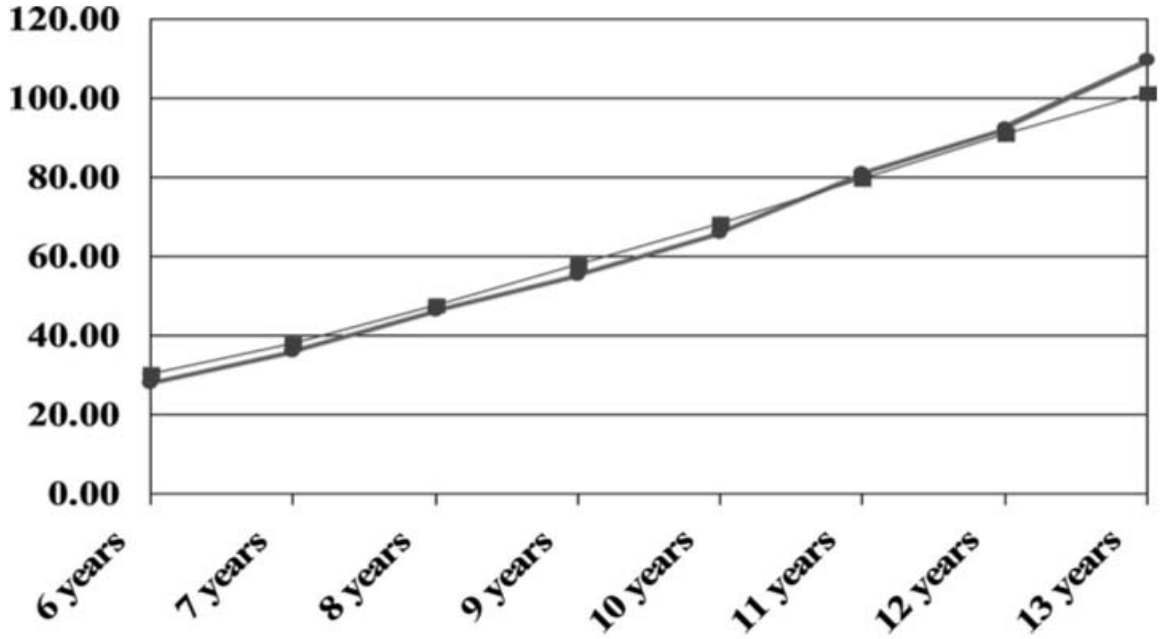


Fig. 1. Fiftieth percentile of peak torque for the quadriceps of the dominant leg at 60 degrees per second for males (—●—) and females (—■—).

Wiggins et al. 2006

- In some instances field-based measures may be more appropriate and time efficient.
- Researchers have documented significant correlations between 1RM strength and common field measures (e.g., handgrip strength and long jump) in children (Milliken et al. 2008).
- Field tests often lack measurement sensitivity

  (e.g. girls performing chin-ups)

Field tests with percentile values for 6-17 year olds

- Explosive Strength
  - Standing broad jump (horizontal jump)(cm)
  - Vertical jump (cm)
  - Overhead Basketball / medicine ball throw (meters)
- Upper Body Muscular Endurance
  - Push-ups (repetitions)
  - Bent arm hang (seconds)
  - Pull-ups (repetitions)
- Abdominal Muscular Endurance
  - Sit-ups (repetitions)
  - Curl-ups (repetitions)

Castro-Pinero et al. 2009

Standing long jump (SLJ) strongly associated
with upper and lower body muscular strength tests.
SLJ test is practical, time-efficient, and low in cost and equipment.
Considered as a general index of upper and lower body muscular fitness
in youth.

TABLE 5. Smoothed age- and sex-specific percentile values for explosive strength tests in boys aged 6 to 17 years.

	n	10th	20th	30th	40th	50th	60th	70th	80th	90th
Standing broad jump (cm)										
6–7	229	74.9	83.6	89.9	95.3	100.3	105.2	110.5	116.7	125.2
8–9	320	93.1	103.5	110.9	117.1	122.9	128.6	134.7	141.8	151.4
10–11	281	109.9	121.3	129.4	136.2	142.6	148.8	155.5	163.2	173.8
12–13	307	127.3	139.3	147.8	155.0	161.8	168.4	175.5	183.8	195.1
14–15	163	145.5	158.6	167.8	175.4	182.3	189.2	196.4	204.6	215.8
16–17	196	164.6	178.6	188.1	195.9	202.8	209.6	216.5	224.4	234.9
Vertical jump (cm)										
6–7	229	11.3	13.1	14.5	15.7	16.8	18.0	19.2	20.8	22.9
8–9	319	13.8	15.9	17.5	18.8	20.1	21.5	22.9	24.6	27.0
10–11	274	16.6	19.0	20.8	22.4	23.9	25.4	27.0	29.0	31.8
12–13	259	21.5	24.5	26.8	28.7	30.6	32.5	34.5	36.9	40.3
14–15	155	27.6	31.3	34.1	36.4	38.6	40.8	43.2	46.0	49.9
16–17	189	33.2	37.4	40.4	43.0	45.3	47.7	50.2	53.1	57.1
Throw ball (m)										
6–7	229	2.31	2.76	3.09	3.37	3.64	3.91	4.20	4.54	5.02
8–9	319	3.81	4.38	4.80	5.16	5.51	5.86	6.24	6.69	7.32
10–11	281	5.17	5.81	6.29	6.71	7.10	7.51	7.95	8.48	9.22
12–13	320	6.87	7.69	8.30	8.83	9.34	9.85	10.41	11.08	12.03
14–15	157	8.32	9.41	10.20	10.87	11.51	12.15	12.84	13.65	14.77
16–17	186	9.39	10.79	11.78	12.61	13.37	14.13	14.93	15.85	17.11

Castro-Pinero et al. 2010

Should children be tested for power exercises / plyometrics?

- Definition of Plyometrics
  - European vs. North American (any SSC activity)
- Baseline of 1-RM squat = 1.5X body weight prior to performing plyometrics???(Baechle 2000)

Reliability of Power tests (ICC)

- Vertical Jumps

  ICC > 0.90 (Alricsson et al. 2001, Walsh et al. 2006)
- Sprints
- 10 m (0.788) 20 m (0.852) 30 m (0.899) 60 m (0.924)
- Agility: 505 test right / left (0.823 and 0.844)
- Medicine Ball throw (0.88)(5-7 yrs)(Davis et al. 2008)

- Test-retest variation in strength testing in children is 5-10%

Child Differences in Jump Capabilities

- Stretch reflex potentiation related to age due to maturation of sensorimotor pathways, increased spindle sensitivity and gamma drive with maturity as well as active muscle stiffness (Sahrom et al. 2013) .
- 100% difference in tendon stiffness between 8-9 yr. boys and adult men (O'Brien et al. 2010).
- At higher velocities, children have lower capabilities for producing eccentric compared to concentric torque (De St. Croix 2007).

Jumping performance indicators for children

- Limited ROM in ankle and knee
- Lack of form in jumping strategy: children may use concentric contractions of joint flexors to get into crouch position rather than eccentric contractions of joint extensors as with adults

Stretch-Shortening Cycle

- Compare Countermovement Jump (CMJ) to Squat Jump (SJ) height (Komi and Bosco 1978)
- Eccentric Utilization Ratio: CMJ / SJ > 1 (McGuigan et al. 2006)
- Pre-stretch Augmentation: ([CMJ-SJ]/SJ)x100 (Walshe and Wilson 1997)
- Hold squat position for 4 seconds to minimize series and parallel elastic components.
- Perform multiple trials; if great variability then it is a sign of less mature motor control
- If SJ > CMJ then motor control and balance problems evident with CMJ control
- With force plate measure contact time to jump height ratio (compares strength to explosive strength) (Young and Behm 2001)

Power testing

- Sadres et al. (2001) trained 9-10 yr. boys and girls with clean pulls, jerk, clean, squats, dead lift, snatch and snatch pulls

- Compared to controls RT children ↑ strength 1% more per week.

Reliability of Power Clean 1-RM testing in 16 yr. olds with 1 year experience

(Faigenbaum et al. 2012)

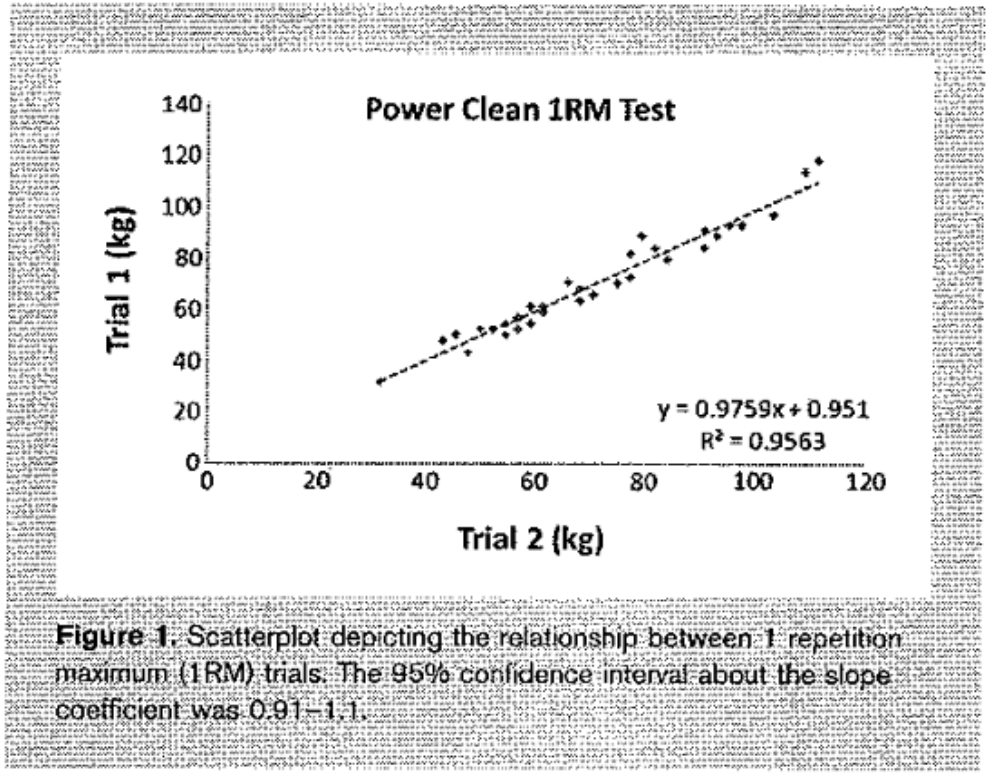


Figure 1. Scatterplot depicting the relationship between 1 repetition maximum (1RM) trials. The 95% confidence interval about the slope coefficient was 0.91–1.1.

ICC: 0.98
CI = 0.96 – 0.99

Power clean with adolescent American football players

ICC = 0.98 (McGuigan and Winchester 2008)

Objective of testing?

- a) establish training parameters
- b) training progress
- c) talent identification

Is maturing earlier better?

- Adolescents who demonstrate advanced anthropometric and fitness characteristics at an earlier stage of adolescence may not improve to as great an extent throughout adolescence and adulthood thus losing their initial advantage (Cobley et al. 2014).
- Peak strength velocity occurs about a year after peak height velocity
  - Girls PHV = 11.4 – 12.2 yrs.
  - Boys PHV = 13.4 – 14.4 yrs.

Ratio Standards

- **Ratio standards**. physiological variable of interest (e.g., VO_2peak, strength), is divided by a measure of body size (e.g., mass).
- Underlying assumption in using ratio standards is that the physiological variable of interest is linearly related to the denominator (Rowland 2005, Welsman and Armstrong 2000 and Nevill 1997
- Preferable to use fat-free mass as the denominator.

Allometric Scaling

- **Allometric scaling**: the physiological variable of interest has a *non*-linear relationship to body size
- VO_2peak = body mass$^{0.66}$ (Welsman and Armstrong 2000)
- Allometric scaling: $Y=aM^b$
- Y is the physiological variable, M is the body dimension (e.g., mass), and b is the scaling exponent.
- Main limitations are mathematical and conceptual complexity and scaling exponents for a given physiological variable calculated in different data sets vary widely.

Table 1
Classical methods of measuring growth and biological maturation

Method	Description
Hand-wrist radiography	Measure skeletal age by studying the number of bone ossifications present (14,16,27).
	Considerations:
	1. Hand-wrist is only a small component of the skeletal system and may not always be representative (79).
	2. Hand-wrist radiographs provide a general idea of the amount of growth but not the direction (79).
Cervical radiography	Lateral cephalographic radiography is used to study the change in morphological characteristics in the cervical vertebrae (31,76). Shown to be equally as sound and effective as hand-wrist radiography and do not require further additional radiography (34,44).
Secondary sexual characteristics	Traditionally has been used as the benchmark standard (21). Involves physical examination of the sexual characteristics of the individual using the Tanner scale or SMR (80).
	Considerations:
	1. Based on white boys and girls and may not be standardized or suitable for other population.
	2. Secondary sex indicators are only limited to the pubertal phase of development.
	3. Invasive and may not be culturally suitable (46).
	4. Reduced reliability for self-examination (77).
Age at menarche	Menarche refers to the first menstrual period. Age at menarche is the event at which it occurs (53).
	Considerations:
	1. Girls only.
	2. Menarche is a late event in the pubertal process and is not appropriate if greater and finer detail of maturation tracking across the puberty span is desired.
	3. Reliability of self-report of age at menarche. The longer the waiting period between examination the less likely one is capable of remembering when the first menstruation was (53).
Height measures	Tracks monthly increase in stature or standing height. Looks for the rate of PHV (8).
	Considerations:
	1. Accuracy of growth charts is based on population studies from different parts of the world. Growth charts must be specific to the populations especially in situations such as developing and developed countries.
	2. Difficult to find growth charts. Growth charts are derived from longitudinal studies, which means they are expensive and might not exist for some populations (8).

PHV = peak height velocity; SMR = sexual maturation rating.

Sahrom et al. SSC 2013)

Tanner Stages

Stage	Female				Male				
	Age range (years)	Breast growth	Pubic hair growth	Other changes	Age range (years)	Testes growth	Penis growth	Pubic hair growth	Other changes
I	0–15	Pre-adolescent	None	Pre-adolescent	0–15	Pre-adolescent testes (≤2.5 cm)	Pre-adolescent	None	Pre-adolescent
II	8–15	Breast budding (thelarche); areolar hyperplasia with small amount of breast tissue	Long downy pubic hair near the labia, often appearing with breast budding or several weeks or months later	Peak growth velocity often occurs soon after stage II	10–15	Enlargement of testes; pigmentation of scrotal sac	Minimal or no enlargement	Long downy hair, often appearing several months after testicular growth; variable pattern noted with pubarche	Not applicable
III	10–15	Further enlargement of breast tissue and areola, with no separation of their contours	Increase in amount and pigmentation of hair	Menarche occurs in 2% of girls late in stage III	1½–16.5	Further enlargement	Significant enlargement, especially in diameter	Increase in amount; curling	Not applicable
IV	10–17	Separation of contours; areola and nipple form secondary mound above breasts tissue	Adult in type but not in distribution	Menarche occurs in most girls in stage IV, 1–3 years after thelarche	Variable: 12–17	Further enlargement	Further enlargement, especially in diameter	Adult in type but not in distribution	Development of axillary hair and some facial hair
V	12.5–18	Large breast with single contour	Adult in distribution	Menarche occurs in 10% of girls in stage V.	13–18	Adult in size	Adult in size	Adult in distribution (medial aspects of thighs; linea alba)	Body hair continues to grow and muscles continue to increase in size for several months to years; 20% of boys reach peak growth velocity during this period

Predictors for Age (year) at Peak Height Velocity (YPHV)

- age, height, sitting height, leg length, weight,
- age x height, age x sitting height,
- age x leg length, age x weight,
- leg length x sitting height,
- weight by height * 100, body mass index,
- sitting height by height * 100,
- leg length by height * 100
- leg length by sitting height * 100

Maturity Offset = years from APHV

- Boys Maturity offset = (−8.128741 − 0.2683693) + 0.0070346 x age ∗ sitting height
- Boys Maturity offset = −7.999994 + (0.0036124 x age ∗ height)
- Girls Maturity offset = −7.709133 + (0.0042232 x age ∗ height)(Moore et al. 2014)
- – 9.236 + (0.0002708 * (leg length * sitting height)) + (– 0.001663 * (age * leg length)) + (0.007216 * (age *sitting height)) + (0.02292 * (weight/height * 100)). (Malina and Koziel 2014)

Summary

- Maximal strength testing could begin as early as 6 years without undue concern for injuries.
- Lack of tolerance of discomfort and inexperience with maximal efforts make these results questionable with younger children.
- LTAD model and others would suggest maximal or near maximal strength and power testing could begin at 12-15 years.

Summary

- Field tests and repetitions to failure techniques may be a better alternative to maximal strength testing.
- Power tests have shown to be reliable with youth.
- Number of tests available to test the SSC.
- Important to consider physiological onset and maturity with talent identification testing.

References

ASCA Position Stand: Resistance training for children and youth 2007

Baechle Essentials of Strength and Conditioning 2000

Barnett L et al. J Sci Med Sport 2014

Behm DG et al. APNM 33: 1-15, 2008

Bosco C and Komi PV. EJAP 45: 209-221, 1980

Castro-Pinero et al. JSCR 23(8): 2295-2310, 2009

Castro-Pinero et al. JSCR 24(7): 1810-1819, 2010

Cobley S. et al. JSCR 2014

Davis KL. JSCR 22(6): 1958-1963, 2008

De St. Croix M. J Sport Sci Med 6: 292-304, 2007

Faigenbaum AD et al. JSCR 17(1): 162-166, 2003

Faigenbaum AD et al. JSCR NSCA Position statement 2009

Falk B, Dotan. Exerc Sport Sci Rev 34(3):107–112, 2006

Lubans DR et al. JSCR 2013

Lubans DR et al. JSCR 28(5): 1373-1380, 2014

Malina RM, *Koziel SM*. J of Sports Sciences; 35: 424–437 2014

McGuigan et al. JSCR 20: 992-995, 2006

McKay H. Br J Sports Med;39:10–14, 2005

Milliken L et al. JSCR 22: 1339-1346, 2008

Moore SA et al. MSSE 2014

Murphy JR EJAP 2014

O'Brien TD et al. J Biomech 43: 1190-1195, 2010

Sahrom SB et al. SSC 35(30): 77-88: 2013

Tabin GC. Amer J Sports Med 13(6): 387-388, 1985

Tanner JM. Growth at adolescence Second Edition, Oxford UK Blackwell Publishers 1962 pp.121-134.

Walshe AD and Wilson GJ CJAP 22: 117-132, 1997

Wiggins M. Ped Physical Therapy 3-18, 2006.

Kiitos
Kysymyksiä ?