Editors

Jürgen Gießing
Michael Fröhlich
Roland Rößler

Current Results of Strength Training Research

Various aspects on fitness and performance

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D-66386 St. Ingbert

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Telefax: 0551-54724-21
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JÜRGEN GIEßING, MICHAEL FRÖHLICH & ROLAND RÖßLER

Strength training and its various effects on fitness and performance

There was a time when scholars and coaches advised athletes to avoid strength training because it was believed that it would make them slow and muscle-bound and would thereby have a negative impact on their athletic performance. Another concern was that strength training would have a detrimental effect on joints and ligaments. Athletes faced the dilemma of needing strength to perform at a certain level without the increase in muscle weight caused by strength training. Science seemed to prove that gaining muscle weight makes athletes slower since force, (body) mass and acceleration interact with each other ($f = m \times a$). Based on this formula a (acceleration) decreases, when m (body mass) is increased.
Many athletes already knew from personal experience that in fact this was not inevitably the case. If the increase in body weight is mainly caused by hypertrophy of fast-twitch muscle fibre, athletes can indeed move faster even when there is a slight increase in body weight. Since muscle hypertrophy often goes along with a reduction of body fat, body weight changes may be negligible.
In the meantime, the beneficial effects of strength training for many aspects of fitness and performance have been proven. It has become generally accepted that resistance training not only improves performance of competitive athletes in many sports but also offers multiple health benefits. Strength training is a topic that is being researched and studied from many different perspectives as shown in the diverse contributions to this book. These aspects include: Strength testing in basketball, eccentrics and HIT, applying social cognitive theories of behaviour to explain resistance exercise participation, muscle conditioning for soccer players, protein supplementation strategies, repetition speed and TUT in single- vs. multiple-set training, insights gained from kinematic and kinetic analyses of movement which make it obvious that children are not miniature adults, outcome-effects of high intensity pre- vs. post-exhaustion in hypertrophy training, and the effects of high intensity interval training on insulin action.

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Landau and Saarbrücken, February 2012
Jürgen Gießing, Michael Fröhlich and Roland Rößler

Topic

ANNE DELEXTRAT & NEIL D. CLARKE

Strength testing in basketball

Keywords: Strength testing, basketball, power, playing position, performance

Introduction

Basketball is an intermittent team sport characterised by the repetition of high-intensity activities during four quarters of 10 minutes each (McKeag, 2003). Time-motion analysis of competitive matches has shown that a game involves a large number of jumps (44 to 46 in males and 35 in females), sprints (55 to 105 in males and 49 in females) and high intensity shuffle movements (63 to 94 in males and 58 in females) (Ben Abdelkrim et al., 2007; Matthew & Delextrat, 2009; McInnes et al., 1995). Although high-intensity activities only represent a small proportion of live time (15.0 % to 16.1 %), they are crucial to the outcome of a game and could potentially make the difference between winning and loosing (Ben Abdelkrim et al., 2007; McInnes et al., 1995). Consequently, most authors have highlighted that strength and power, rather than endurance, should be the main focus of physical conditioning programes for basketball players (Drinkwater et al., 2008; McKeag et al., 2003).
In contrast with other team sports, such as soccer and rugby, where a specific test has been validated and is commonly used for strength assessment, no single test has been acknowledged standard evaluation of strength in basketball, and several methods are currently used (Hoffman & Maresh, 2000). The following paragraphs aim to review the methods of the most common tests used in strength and power assessment, inspecting the relationship between strength and other aspects of performance as well as comparing strength and power of different playing positions.

Methodological considerations

The most common tests used in the strength and power assessment of basketball players include laboratory-based tests, such as the Wingate Anaerobic Power Test (WanT) and isokinetic testing of specific muscle groups, and field-based tests, such as one repetition maximum (1-RM) tests, vertical jump test and basketball chest pass. The difficulty to identify a single test as a standard tool for strength assessment mostly lies in the lack of specificity and applicability of these tests to basketball.

The most frequently reported strength testing measure in the literature is the 1-RM test in the bench press for the upper body and squat for the lower body (Caterisano et al., 1997; Groves & Gayle, 1993; Hoffman et al., 1991, 1996; Hunter et al., 1993; Jukic et al., 1999; Latin et al., 1994; McKenzie Gillam, 1985). The aim of such tests is to reach a maximal effort within three to five attempts, as described by Knuttgen and Kraemer (1987). The specificity of these tests is acceptable because even if performed in a gym setting, they focus on the muscle groups responsible for the movements involved in real game situations (McKeag, 2003). Moreover, the squat test is weight-bearing and thus any performance improvement measured by this test potentially provides a better transfer of strength to specific actions on the court, compared to non weight-bearing tests. A very good test-retest reliability of 1-RM determinations in the squat and bench press has recently been shown in various populations, as evidenced by intraclass correlation coefficients ranging from 0.95 to 0.99 (LeBrasseur et al., 2008). Latin et al. (1994) discussed the advantages of using the power clean rather than squat test because it integrates strength, explosive power and neuromuscular coordination and therefore represents a closer replication of movements involved in a real game situation. However, very few measurements of maximal strength in the power clean have been reported in basketball players (Latin et al., 1994). The difficulty in learning the appropriate technique for this test could be one reason responsible for the lack of data.

As an alternative to the bench press test a few authors used the performance in the chest pass to assess upper-body strength of female players (Delextrat & Cohen, 2009; Hoare, 2000). It involves throwing a basketball from the chest in a seated position against a wall, with the legs rested straight horizontally on the floor. This test is specific and more convenient for coaches to use. However Cronin and Owen (2004) highlighted that its reliability is lower than laboratory tests (coefficient of variation between test-retest of 3.47 %) and that performance in that test is highly influenced by players' anthropometric characteristics.

The last field test described in this section is used to measure power rather than strength and involves converting vertical jump height (in cm) to power (in kg × s^{-1}), using the Lewis nomogram (Fox & Matthews, 1996). This conversion is classically used in the basketball literature, although the scientific bases for its use have been questioned by several authors (Keir et al., 2003). In particular, the result of the test seems to depend mostly on the effects of gravity during the descending phase of the jump, rather than the explosive power of the legs (Sayers et al., 1999).

Laboratory assessments of strength are generally described as more valid and reliable, compared to field assessments. However, their main limitations are the cost of the equipment necessary to run the tests and their specificity with regards to the movements performed in basketball. Several authors have measured the peak power, mean power and fatigue index during the 30-second Wingate anaerobic test (WanT) as an indicator of the anaerobic fitness of basketball players (Apostolidis et al., 2003; Delextrat & Cohen, 2008, 2009; Hoffman et al., 1995, 2000; LaMonte et al., 1999). This test is characterised by high reliability (correlation coefficients between test-retest higher ranging from 0.89 and 0.98, see Bar-Or, 1987). The main limitation raised regarding this test is the major difference in locomotion modes and muscle contraction patterns between cycling and running, which questions its relevance for basketball (Tharp et al., 1985). Maud and Shultz (1989) have also argued that the load limitations imposed by the test (commonly 7.5 % of body mass), although designed to maximise power output in the general population, could prevent taller and heavier subjects like basketball players from expressing their real peak power. Finally, it could be argued that variations of the Wingate test, such as the 10-s WanT or the 5 × 6-s maximal cycling repeated sprint test, could be more relevant to basketball than the 30-s WanT because they involve work durations that are closer to sprint times performed in competition (McGawley & Bishop, 2006; Zajak et al., 1999). Unfortunately, no data on basketball players has been reported using such tests.

The piece of equipment that has undoubtedly been the most used in the past 20 years to measure lower limb strength of basketball players and record changes during the season is the isokinetic dynamometer (Delextrat & Cohen, 2008, 2009; Häkkinen, 1993; Hoffman et al., 1991; Smith & Thomas, 1991; Theoharopoulos et al., 2000). Classically, authors have tested the maximal concentric and eccentric torque of the quadriceps and hamstrings muscle groups at angular speeds ranging from $60° \times s^{-1}$ to $300° \times s^{-1}$. Two main issues have been raised regarding that test. The first one is the choice of a relevant angular speed, with higher speeds being more specific to the movements involved in basketball, and lower speeds characterised by higher test-retest reliability (Impellizzeri et al., 2008). Greater test-retest reliability has also been reported for knee extensors compared to knee flexors, and for concentric compared to eccentric contraction modes (Li et al., 1996). The second issue is the effect of speed testing order when several speeds are used. Within this context, Wilhite et al. (1992) suggested that testing slower speeds before faster speeds is preferable and leads to a higher reliability. An interesting application of isokinetic testing is assessing muscle imbalances between quadriceps and hamstrings. Authors classically calculate conventional hamstrings-to-quadriceps ratios (ratio of the peak concentric strengths of the hamstrings and quadriceps) and functional hamstrings-to-quadriceps ratios (ratio of the hamstrings peak eccentric strength to the quadriceps peak concentric strength), with values lower than 0.6 for the conventional and 0.7 in the functional representing a potential greater risk of knee injury (Aagaard et al., 1995; Gerodimos et al., 2003; Schiltz et al., 2009).

Relation between strength measurements and performance

Two main methods have been used in the literature to assess strength could be identified as a determinant of successful performance in basketball, namely correlations between strength measurements and other performance variables, and comparisons between elite-level and average-level basketball players (or between basketball players and players from other team sports of the same fitness level). Table 1 shows the correlation coefficients between strength and other performance variables established on players of different levels. Performance in basketball is multifactorial and it is therefore difficult to identify one single measurement of success. Hoare (2000) used ratings of players' performance by coaches according to several criteria (offensive and defensive skills, catch/pass skills, overall ability) to reflect successful performance. After testing the strength, power, speed, acceleration, agility and aerobic capacity, they found that the best predictors of success were power in females, and strength and power in males (Hoare, 2000). The parameter that most closely reflects basketball performance is probably the playing time. To our knowledge, only one study investigated the relationship between strength, power and playing time during four entire seasons (1998 to 1992) in 29 National Collegiate Athletic Association (NCAA) division 1 players (Hoffman et al., 1996). They showed that the variable with the greatest correlation with playing time was vertical jump height, followed by 1-RM squat performance. Interestingly, a recent study showed that 1-RM squat performance was also significantly correlated to speed (from 5-m to 20-m) (Chaouachi et al., 2009). The performance in the 1-RM bench press was not significantly correlated to playing time (Hoffman et al., 1996). Among the other parameters investigated, peak isometric torque of the knee extensors was significantly correlated to jump height in the squat jump (SJ) and countermovement jump (CMJ) (Häkkinen, 1991, 1993). An interesting finding is that stronger correlations with agility and speed were found between the mean power than the peak power achieved in the WanT (Apostolidis et al., 2003; Hoffman et al., 2000). The methodological considerations evoked in the previous paragraph could partly be responsible for these findings.

In an attempt to identify if strength was a determinant of performance in basketball, a few authors have compared basketball players and athletes from other sports with a similar fitness level (McKenzie Gillam, 1985; Zakas et al., 1995). The main results of these studies emphasise that a significantly greater explosive power rather than strength differentiates basketball players from physical education students (McKenzie Gillam, 1985).

Table 1: Correlations between strength measurements and other aspects of performance

Variables	Significant correlations with performance	Subjects and authors
Vertical Jump (VJ)	Playing time ($r = 0.68$, $p < 0.05$)	29 NCAA division 1 male players (Hoffman et al., 1996)
Squat Jump (SJ)	Peak isometric torque of the knee extensors ($r = 0.69$, $p < 0.05$)	10 national level female players (Häkkinen, 1993)
Countermovement Jump (CMJ)	Peak isometric torque of the knee extensors ($r = 0.81$, $p < 0.01$)	11 male and 9 female national level players (Häkkinen, 1991)
Explosive power balance*	Distance covered in the Yo-yo test ($r = 0.62$, $p < 0.05$)	22 regional level male players (Castagna et al., 2009)
1-RM squat	Playing time ($r = 0.64$, $p < 0.05$)	29 NCAA division 1 male players (Hoffman et al., 1996)
	5-m sprint time ($r = -0.63$, $p < 0.05$) 10-m sprint time ($r = -0.68$, $p < 0.05$)	14 international level male players (Chaouachi et al., 2009)
Mean Power in the Wingate anaerobic test (WanT)	Agility ($r = -0.58$, $p < 0.05$) 20-m sprint with the ball ($r = -0.62$, $p < 0.05$) Line drill with the ball ($r = -0.73$, $p < 0.05$) and without the ball ($r = -0.56$, $p < 0.05$)	13 international junior male players (Apostolidis et al., 2003)
	15-s anaerobic Jump test ($r = 0.76$, $p < 0.05$) Line drill time ($r = 0.61$, $p < 0.05$)	9 international junior male players (Hoffman et al., 2000)
Peak Power the Wingate anaerobic test (WanT)	15-s anaerobic Jump test ($r = 0.59$, $p < 0.05$)	9 international junior male players (Hoffman et al., 2000)
Peak isometric torque of the knee extensors	Squat Jump ($r = 0.69$, $p < 0.05$) Countermovement Jump ($r = 0.68$, $p < 0.05$)	10 national level female players (Häkkinen, 1993)
	Squat Jump ($r = 0.80$, $p < 0.01$) Countermovement Jump ($r = 0.81$, $p < 0.01$)	11 male and 9 female national level players (Häkkinen, 1991)
	Countermovement Jump ($r = 0.52$, $p < 0.01$)	33 national male junior players (Ugarkovic et al., 2002)
Peak isometric torque of the hip extensors	Countermovement Jump ($r = 0.38$, $p < 0.05$)	33 national male junior players (Ugarkovic et al., 2002)

*: Explosive power balance was calculated as (stiff leg Jump height / CMJ height), (McClymont et al., 2004)

Secondly, peak torque of the knee flexors and extensors was significantly higher in basketball players compared to soccer players of the same level (Metaxas et al., 2009; Zakas et al., 1995). These authors suggested that these differences could be mainly explained by the specific demands induced by basketball, in particular the many physical contacts experienced in a smaller pitch to get into a strategic position in the key or box-out in defence, for example. However, when torque was expressed relative to body weight, no significant differences were revealed between basketball and soccer players (Zakas et al., 1995). This suggests that the differences observed could be partly attributed to the greater body size and mass of basketball players, compared to soccer players.

Comparison of players of different levels can also contribute to the identification of successful parameters of performance. Again, it seems that overall parameters, such as peak torque of the knee extensors as well as explosive power differentiate elite players from players of lower levels (Delextrat & Cohen, 2008; Hoare, 2000; Zakas et al., 1995). Contrasting results were reported regarding the 1-RM performances, while the different parameters recorded during the WanT do not seem to discriminate between players of different levels (Caterisano et al., 1997; Delextrat & Cohen, 2008).

Table 2: Strength performances of basketball players of different levels and other athletes

Study	Measure	Basketball	Physical education
13 male college basketball players *vs.* 14 physical education majors (McKenzie Gillam, 1985)	1-RM bench press (kg):	76.3 ± 11.3	82.4 ± 19.2
	1-RM squat (kg):	15.3 ± 18.0	104.2 ± 21.0
	Push ups (reps):	23.2 ± 7.9	27.1 ± 7.8
	Squat thrust (reps):	58.5 ± 31.2	38.1 ± 17.6*
	Power (kg × m/s from VJ):	154.1 ± 16.4	135.2 ± 24.9*

Study	Measure	Division	Basketball	Soccer
61 basketball players *vs.* 51 soccer players from different divisions (Zakas et al., 1995) (in this study, division 1 includes international players)	Peak torque of quadriceps at $60^\circ \times s^{-1}$	Division 1	284 ± 30	246 ± 43*
		Division 4	271 ± 35	226 ± 34*
	Peak torque of quadriceps at $180^\circ \times s^{-1}$	Division 1	170 ± 23	154 ± 30
		Division 4	165 ± 30	142 ± 21*
	Peak torque of hamstrings at $60^\circ \times s^{-1}$	Division 1	201 ± 21	168 ± 33*
		Division 4	188 ± 21	150 ± 20*
	Peak torque of hamstrings at $180^\circ \times s^{-1}$	Division 1	130 ± 25	122 ± 22
		Division 4	122 ± 23	105 ± 14*

Study		Quadriceps		Hamstrings	
		$60^\circ \times s^{-1}$	$180^\circ \times s^{-1}$	$60^\circ \times s^{-1}$	$180^\circ \times s^{-1}$
61 basketball players from different divisions (Zakas et al., 1995) (in this study, significant differences were reported only between international players and players of lower divisions)	International	314 ± 37	195 ± 28	210 ± 19	147 ± 26
	Division 1	255 ± 22*	146 ± 18*	192 ± 23	112 ± 24*
	Division 2	271 ± 21*	165 ± 28*	186 ± 18*	117 ± 18*
	Division 3	271 ± 45*	159 ± 34*	197 ± 21	122 ± 25*
	Division 4	271 ± 35*	165 ± 30*	188 ± 21*	122 ± 23*

Study	Measure	Starters	Reserves
9 starter players (playing time of at least 30 min per game) vs. 8 reserve players (playing time of less than 10 min per game) from a Division 1 university team (Caterisano et al., 1997)	Start of the season:		
	1-RM bench press (kg)	112.7 ± 11.5	111.3 ± 19.2
	1-RM leg press (kg)	272.1 ± 41.1	252.2 ± 16.4
	End of the season:		
	1-RM bench press (kg)	104.2 ± 10.0	98.0 ± 10.6
	1-RM leg press (kg)	234.0 ± 33.0	241.4 ± 27.4

Study	Measure	"Best"	"Rest"
260 junior male and female players divided into "best" and "rest" players (8 best and 8 weakest players in each position, as determined by coaches) (Hoare, 2000)	VJ (cm)		
	Female point guards	52.6	44.8*
	Female power forwards	50.5	40.2*
	Male shooting guards	68.6	60.6*
	Chest pass (m)		
	Female power forwards	8.48	7.41*
	Male point guards	11.80	9.99*
	Male shooting guards	11.13	9.81*
	Male centres	11.63	10.02*

Study	Measure	Division 1	Division 3
8 players from division 1 university league vs. 8 players from division 3 university league (Delextrat & Cohen, 2008)	VJ (cm)	56.6 ± 4.4	51.6 ± 3.3*
	1-RM bench press (kg)	101.3 ± 26.9	82.5 ± 24.0*
	PP in WanT ($W \times kg^{-1}$)	10.2 ± 0.9	10.0 ± 0.9
	MP in WanT ($W \times kg^{-1}$)	8.2 ± 0.9	7.8 ± 1.2
	Peak torque of the quadriceps at $60^\circ \times s^{-1}$ (Nm):	167 ± 25	133 ± 15*
	Peak torque of the quadriceps at $180^\circ \times s^{-1}$ (Nm):	127 ± 25	102 ± 18*

Study		Basketball		Soccer	
61 basketball players vs. 100 soccer players (Metaxas et al., 2009)	Peak torque of quadriceps at	$180^\circ \times s^{-1}$	$300^\circ \times s^{-1}$	$180^\circ \times s^{-1}$	$300^\circ \times s^{-1}$
	Division 1	209 ± 40	151 ± 30	179 ± 21*	129 ± 15*
	Division 4	195 ± 33	152 ± 26	176 ± 25*	123 ± 18*
	Peak torque of hamstrings at	$180^\circ \times s^{-1}$	$300^\circ \times s^{-1}$	$180^\circ \times s^{-1}$	$300^\circ \times s^{-1}$
	Division 1	113 ± 27	80 ± 21	104 ± 13	77 ± 15
	Division 4	100 ± 27	82 ± 23	102 ± 18	74 ± 16

*: Significant differences between groups, $p < 0.05$

Differences between playing positions

In senior male basketball players, differences in maximal aerobic power (Cormery et al., 2008), speed (Smith & Thomas, 1991), agility and strength (Harris et al., 2000) have been reported as a consequence of playing position. Furthermore, it has been suggested that the physiological responses (blood lactate and mean heart rate) to a basketball match vary according to playing position (Rodriguez-Alonso et al., 2003). Significantly higher blood lactate and mean heart rate values have been observed in guards compared with forwards and centres in national and international female players (Rodriguez-Alonso et al., 2003). These reports have lead to suggestions that player's physiological attributes differ according to their playing position (Delextrat & Cohen, 2009). Consequently, a number of investigations into the influence of playing position on strength have been conducted (Table 3).

In a position-by-position analysis of the strength, by measuring squat performance, of collegiate male players, forwards were significantly stronger in the lower extremities than centres, although similar to guards. However, when lower-body strength was expressed as a function of body weight, centres were significantly weaker than both guards and forwards (Latin et al., 1994). Comparable results have been reported for maximal strength assessed using the power clean in NCAA Division 1 male college basketball players (Latin et al., 1994), forwards were significantly stronger than guards but not centres. A similar pattern has been reported in national levels female players (Delextrat & Cohen, 2009), when compared with centres, forwards produced a greater peak torque of the knee extensors. However, when the relative peak torque of the knee extensors was assessed guards were significantly stronger than centres. In contrast, in an assessment of elite male players (Ben Abdelkrim et al., 2010) a lower absolute value for 1-RM squat for point guards was observed in comparison with the other playing positions although when these values were divided using the 0.67 body mass exponent, similar results were obtained across all playing positions. This may not be unexpected as squat exercises have been reported to be a major component of basketball conditioning (Chaouchi et al., 2009). Furthermore, Ellis et al. (2000) suggested that leg strength is important for "boxing out" and positioning during a game. When vertical jump height has been assessed in elite male (Ostojic et al., 2006) and national level female (Delextrat & Cohen, 2009) basketball players no differences between positions have been observed although when converted to vertical jump power, higher values have been reported for centres in comparison to guards (Delextrat & Cohen, 2009; Ostojic et al., 2006). It has been concluded that jumping ability is important for all playing positions in terms of jump shots and rebounding although one possible explanation for the higher power output observed in centres is their relatively high body mass (Delextrat & Cohen, 2009). It should be noted that there are limitations comparing vertical jump data due to a variety of protocols employed and at different stages of the season (Ostojic et al., 2006). However, these results suggest that lower-body strength is equally developed in basketball players across all of the positions. McKeag (2003) suggested that some playing positions such as power forward and centres require high levels of upper-body strength and Ben Abdelkrim et al. (2010) concluded that the success of power forwards and centres relies on high levels of upper-body strength in order to resist and perform physical challenges in terms of winning ball possession and positioning. This opinion is supported by the finding that power forwards and centres are stronger than the other positions when assessed using a 1-RM bench press when expressed in absolute, but not relative, terms (Ben Abdelkrim et al., 2010). Furthermore, Hoffman and Maresh (2000) speculated that isometric strength is an important attribute for both power forwards and centres in order to perform activities such as screening, body opposing and rebounding, which are all relatively static in nature. However, the physical challenges for guards are not that robust and there is a greater emphasis on skill levels and therefore, there is less emphasis on upper-body strength (Ben Abdelkrim et al., 2010). In contrast, a number of studies have reported that the upper body strength of female basketball players as assessed by the chest pass is different between playing positions (Delextrat & Cohen, 2009; Hoare, 2000) and for the 1-RM bench press in men (Latin et al., 1994). Some of these differences could be as a consequence of different measurement procedures and changes to the physical demands due to rule changes. However, these findings, and those previously highlighted, suggest that specific strength training may need to be undertaken according to playing position. Furthermore, more research is required to clarify the impact of playing position on strength, especially upper-body strength.

Table 3: Impact of playing positions on measures of strength

Variable	Results			Subjects and Authors
	Guards	Forwards	Centres	
Vertical Jump height (cm)	44.4 ± 5	42.8 ± 6	40.6 ± 6	30 national level female players (Delextrat & Cohen, 2009)
	49.4 ± 6	49.4 ± 11	43.5 ± 5	46 female college players (LaMonte et al., 1999)
	45.7 ± 5	42.7 ± 7	46.6 ± 5	123 female junior players (Hoare, 2000)
	73.4 ± 10#	71.4 ± 10#	66.8 ± 11	437 college male players (Latin et al., 1994)
	59.7 ± 10	57.8 ± 2	54.6 ± 7	60 elite male players (Ostojic et al., 2006)
	63.3 ± 8	58.8 ± 8	57.9 ± 9	125 male junior players (Hoare, 2000)
Vertical Jump power [(kg × s^{-1}) unless stated]	88.3 ± 5	94.6 ± 7	105.6 ± 12*	30 national level female players (Delextrat & Cohen, 2009)
	158.2 ± 17	178.5 ± 22*	182.1 ± 17*	437 college male players (Latin et al., 1994)
	1485 ± 200 W	1579 ± 138 W	1683 ± 192 W*	60 elite male players (Ostojic et al., 2006)
Countermovement Jump height (cm)	49.3 ± 6#‡	46.7 ± 4#	41.6 ± 4	45 elite level male players (Ben Abdelkrim et al., 2010)
Countermovement Jump relative power (w × $kg^{-0.67}$)	235.5 ± 8#‡	223.4 ± 5#	215.9 ± 8	
1-RM squat (kg)	151.1 ± 36	161.9 ± 38†	138.1 ± 32	437 college male players (Latin et al., 1994)
	179.5 ± 13	194.5 ± 21*	198.0 ± 15*	45 elite level male players (Ben Abdelkrim et al., 2010)
Relative 1-RM squat	180.9 ± 45 %#	167.8 ± 39 %#	136.9 ± 33 %	437 college male players (Latin et al., 1994)
	9.4 ± 1 kg × $kg^{-0.67}$	9.4 ± 1 kg × $kg^{-0.67}$	9.2 ± 1 kg × $kg^{-0.67}$	45 elite level male players (Ben Abdelkrim et al., 2010)
1-RM Power Clean (kg)	94.5 ± 13	105.1 ± 17*	99.8 ± 14	437 college male players (Latin et al., 1994)
Relative 1-RM Power Clean (%)	112.9 ± 15#	107.6 ± 14	98.5 ± 14	
Peak isokinetic torque of the knee extensors (Nm)	60° × s^{-1}: 101 ± 9 180° × s^{-1}: 89 ± 9	60° × s^{-1}:110 ± 12 180° × s^{-1}: 98 ± 16	60° × s^{-1}:103 ± 17 180° × s^{-1}: 95 ± 10	30 national level female players (Delextrat & Cohen, 2009)
Relative peak isokinetic torque of the knee extensors (% BW)	60° × s^{-1}: 162 ± 22# 180° × s^{-1}: 147 ± 17	60° × s^{-1}: 166 ± 21# 180° × s^{-1}:154 ± 14#	60° × s^{-1}: 136 ± 30 180° × s^{-1}: 126 ± 13	
1-RM bench press (kg)	100.8 ± 18	104.0 ± 22	104.4 ± 17	437 college male players (Latin et al., 1994)
	73 ± 8	81.0 ± 7*	90.4 ± 5*	45 elite level male players (Ben Abdelkrim et al., 2010)
Relative 1-RM bench press	121.0 ± 20 %#†	109.1 ± 21 %	103.1 ± 17 %	437 college male players (Latin et al., 1994)
	3.8 ± 0 kg × $kg^{-0.67}$	3.9 ± 1 kg × $kg^{-0.67}$	4.2 ± 0 kg × $kg^{-0.67}$*	45 elite level male players (Ben Abdelkrim et al., 2010)
Chest pass (m)	6.71 ± 1	6.89 ± 1	7.17 ± 1	30 national level female players (Delextrat & Cohen, 2009)
	7.39 ± 1	7.50 ± 1	7.58 ± 1	123 female junior players (Hoare, 2000)
	10.21 ± 1	10.59 ± 1	10.71 ± 1	125 male junior players (Hoare, 2000)

* Significantly higher than guards #, Significantly higher than centres

† Significantly higher than forwards ‡, Significantly higher than power forwards

Conclusion

Physical strength and power are important factors in basketball performance. However, when assessing the strength of players coaches need to be aware of the methodological issues associated with each test. In addition, playing position influences the strength profile of players and therefore, strength training needs to reflect the demands of the specific playing positions.

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JOHN A. BABRAJ, NIELS B. J. VOLLAARD, CAMERON KEAST,
FERGUS M. GUPPY, GREG COTTRELL & JAMES A. TIMMONS

Extremely short duration high intensity interval training substantially improves insulin action in young healthy males

Keywords: High intensity interval training, isulin, cardiovascular disease, type 2 diabetes, exhaustion

Introduction

In 2007 the rapidly rising prevalence of type 2 diabetes (T2D) in the United States reached 17.5 million people (American Diabetes Association, 2008a). Aside from the associated reduction in quality-of-life and the increase in morbidity and mortality for the affected individuals, the economic burden was estimated at $ 116 billion in excess medical expenditures and $ 58 billion in reduced productivity (American Diabetes Association, 2008a). Similarly, the estimated direct and indirect economic costs of cardiovascular disease (CVD) in the US for 2008 are estimated at $ 287 billion (American Heart Association & American Stroke Association, 2008). The risk of developing CVD and T2D can be modified by regular physical activity (Pedersen & Saltin, 2006). However, there is no consensus on the nature of exercise therapy required to provide adequate health benefits, particularly with regard to the volume-intensity relationship. Furthermore, as we do not understand the precise mechanisms which link physical activity and a reduced risk of developing CVD or T2D, the scientific basis for current health guides needs to be improved (Burgomaster et al., 2005). For exercise guidelines to yield a positive economic benefit for society, as well as a health benefit for the individual, not only should the regime reliably modify key disease risk factors, it must also be plausible to implement.

Metabolic adaptations associated with traditional aerobic exercise training correlate with improved insulin action and glycemic control (Hickey et al., 1995; Houmard et al., 1991). These effects appear to be independent of changes in body composition (DiPietro et al., 1998), and some evidence suggests that greater improvements in insulin sensitivity may be achieved with higher training intensities (DiPietro et al., 2006; Kang et al., 1996; Seals et al., 1984). Current recommendations for improving glycemic control involve performing moderate to vigorous intensity aerobic and resistance exercise for several hours per week (American Diabetes Association, 2008b; Lakka & Laaksonen, 2007). However, the general population fails to follow such regimes due to lack of time, motivation and adherence (Gibala & McGee, 2008). This suggests that the current focus on time-consuming moderate intensity physical activity, aimed at increasing total energy expenditure, may not be optimal for reducing the risk of developing T2D. Recently an extremely low volume high-intensity interval training paradigm (HIT), consisting of no more than 7.5 minutes of exercise per week, has been proposed as a novel, time-efficient exercise regime for improving aerobic fitness (Burgomaster et al., 2007; Burgomaster et al., 2005). We speculated that it should be possible to substantially improve insulin action using HIT since despite a negligible contribution to total energy expenditure. This training model would acutely and rapidly reduce muscle glycogen stores. Compared to traditional strategies for reduction of risk factors of CVD and T2D, the extremely low volume of exercise required with HIT may promote adherence and thus represent a genuinely preventative public health strategy.

Methods

Subjects

Twenty-five young healthy sedentary or recreationally active men were recruited to participate in this study, with none engaged in a structured endurance training program. Subjects were randomly allocated to one of two parts of the study. Sixteen subjects (mean ± SD: 21 ± 2 y; 82 ± 17 kg; 1.83 ± 0.08 m; BMI: 23.7 ± 3.1 kg × m^{-2}; VO_2max: 48 ± 9 ml × kg^{-1} × min^{-1}) were allocated to the main part of the study, and completed the full experimental procedures. The remaining nine subjects (mean ± SD: 23 ± 8 y; 73 ± 9 kg; 1.78 ± 0.09 m; 23.0 ± 1.4 kg × m^{-2}; VO_2max: 47 ± 11 ml × kg^{-1} × min^{-1}) took part in a separate experiment to determine intra-individual variation in response to an oral glucose tolerance test, and did not perform HIT. There were no significant differences in the age, height, weight, BMI or VO_2max between the two groups of subjects. Subjects were informed of the experimental protocol both verbally and in writing before giving informed consent. Furthermore, all subjects were informed about how potential life-style changes could affect the results of the study, and were requested to maintain their normal diet and levels of physical activity (apart from the training program) throughout the duration of the study. The study protocol was approved by the institutional Ethics Committee and conducted in accordance with the Helsinki Declaration.

Experimental procedures

Baseline aerobic performance and health parameters were determined over a 2-week period prior to commencement of the training program.

Oral glucose tolerance test (OGTT)

Subjects refrained from performing any strenuous physical activity for 2 days prior to the OGTT, and attended the laboratory having fasted overnight. Venous blood samples were collected by venepuncture before, and 60, 90 and 120 min after ingestion of 75 g glucose (Fisher Scientific, Loughborough, UK) dissolved in 100 ml of water. Plasma was separated by centrifugation (10 min at 1600 g) and stored at -20 ºC until analysis of glucose, insulin and NEFA concentrations. Plasma glucose concentrations were measured using an automatic analyzer (YSI Stat2300, Yellow Spring Instruments, Yellow Spring, OH) and plasma insulin concentration was determined by ELISA (Invitrogen, UK). Plasma insulin was measured only for samples taken at 0, 60, and 90 min. Plasma NEFA concentrations were determined by a colorimetric assay (Wako Chemicals, Germany) using a modified protocol. Briefly, 3.75 µl of plasma samples and standards of known concentration were pipetted into a 96-well plate. 75 µl of colour reagent A was added to each well and incubated at 37° C for 10 min. 150 µl of colour reagent B was added and incubated for a further 10 min at 37 °C. The plate was then removed from the incubator and allowed to cool to room temperature prior to the absorbance being read at 550 nm. Coefficients of variation (CV) for duplicate samples were 3 % for glucose, 5 % for insulin, and 8 % for NEFAs.

VO_2peak test

On a separate occasion, subjects performed an exhaustive incremental cycling test (Lode Excalibur Sport, Groningen, the Netherlands) to determine maximal power output (Wmax) and maximal oxygen uptake capacity (VO_2peak) using an online gas analysis system (SensorMedics, Bilthoven, the Netherlands). After cycling at 30 W for 1 min, power output was increased by 30 W × min^{-1} until volitional exhaustion. VO_2peak was determined as the highest value achieved over a 20-s period.

Time trials

Endurance performance was determined to provide an integrated physiological readout to facilitate comparison of the present study with previous studies which provided data from muscle biopsy samples. Subjects performed two self-paced cycling time trials in which they were instructed to complete 250 kJ of work as fast as possible. The linear factor was chosen to produce a power output corresponding to 75 % of Wmax at a pedal rate of 90 rpm. No encouragement was given, and subjects were blinded from information on time, power output and pedal frequency. The amount of work (kJ) completed was called out every 25 kJ. Time trials were spaced at least two days apart. Although the first of the two trials was mainly used as a familiarisation trial, the fastest time achieved in the two trials was considered to best represent the pre-training performance level and used in the analysis (19 out of 25 subjects performed better in the second trial than in the familiarisation trial).

Sprint interval training

The sprint training protocol was similar to that used previously by Burgomaster et al. (Burgomaster et al., 2005; Burgomaster et al., 2007). Six sessions of sprint interval exercise were spread over 14 days, with 1 or 2 days of rest between each session. Each training session consisted of 4-6 repeated 30-s all-out cycling efforts against a resistance equivalent to 7.5 % of body weight (Wingate tests), with 4 min of recovery between sprints. During recovery, subjects remained on the bike and either rested or cycled at a low cadence without resistance. The number of sprints increased from 4 during the first two sessions, to 5 in the third and fourth sessions, and 6 in the last two sessions. Total time commitment was 17-26 min per session, of which 2-3 minutes sprint exercise.

Post-training assessment

A second OGTT was performed after completion of the training program. In order to determine whether potential changes were due to acute effects attributable to the last training session, subjects were tested either two (n = 10), or three (n = 6) days after the last bout of exercise. One day after the second OGTT subjects performed a third cycling time trial in order to determine changes in aerobic performance.

Intra-individual variability in time trial performance and OGTT-response

In order to assess normal intra-individual variation in response to an OGTT over a period of several weeks as used in the present study, nine subjects performed an identical protocol to the training group but without performing the six training sessions. Coefficients of variation (CV) for repeated measurements within individual subjects were determined for baseline glucose and NEFA levels, for glucose and NEFA area under the plasma curve, and for time trial performance.

Calculations and statistical analysis

Area under the plasma curve (AUC) was calculated using the conventional trapezoid rule. Cederholm index, which represents peripheral insulin sensitivity (Cederholm & Wibell, 1990), was calculated using the formula:

$$ISI_{Cederholm} = 75000 + (G_0\text{-}G_{120}) \times 1.15 \times 180 \times 0.19 \times BW / 120 \times G_{mean} \times \log (I_{mean})$$

Where BW is body weight, G_0 and G_{120} are plasma glucose concentration at 0 and 120 min (mmol × l^{-1}), and I_{mean} and G_{mean} are the mean insulin (mU × l^{-1}) and glucose (mmol × l^{-1}) concentrations during the OGTT.
All data are presented as means ± SEM. Plasma glucose, insulin, and NEFA responses to the pre-training and post-training OGTTs were analyzed using two-way repeated measures ANOVA with post hoc Student Newman-Keuls tests. Differences between pre-training and post-training data for time trial performance, AUCs for plasma glucose, insulin, and NEFA levels, and insulin sensitivity as measured by the Cederholm Index were analyzed using paired sample t-tests. Pearson's correlation coefficient was used to assess bivariate correlations between baseline values and changes in the variables performance, AUCs of glucose, insulin, and NEFAs, and the Cederholm Index. Significance was accepted at $P < 0.05$.

Results

Glucose responses

Fasting plasma glucose concentrations were unaltered after 2 weeks of HIT. In the pre-training OGTT, plasma glucose concentration was elevated 60 min after the 75 g glucose bolus (Figure 1A; 0 min: 5.0 ± 0.1 vs. 60 min: 6.5 ± 0.4 mmol × l^{-1}; $P < 0.0001$), but not post-HIT (Figure 1A; 0 min: 5.0 ± 0.1 vs. 60 min: 5.0 ± 0.2 mmol × l^{-1}). The plasma glucose area under the curve (AUC) was significantly reduced post-training (Figure 1A: AUC pre 664 ± 103 vs. AUC post 585 ± 65 mmol × min × l^{-1}; $P < 0.001$).

Insulin responses

Fasting plasma insulin concentrations were unaltered after 2 weeks of HIT. In the pre-training OGTT, plasma insulin concentration was elevated 60 min after the 75 g glucose bolus (Figure 1B; 0 min: 10.5 ± 1.6 vs. 60 min: 74.0 ± 8.9 mU × l^{-1}; $P < 0.05$). Post-training this increase was significantly attenuated (Figure 1B; 0 min: 10.6 ± 1.6 vs. 60 min: 42.6 ± 6.0 mU × l^{-1}; $P < 0.01$). Although plasma insulin levels were still elevated 90 min after the 75 g glucose bolus both pre- and post-training, levels were no longer significantly higher than at 0 min (pre: 38.8 ± 6.3 mU × l^{-1}; post: 27.7 ± 2.7 mU × l^{-1}). The plasma insulin AUC was significantly reduced post-training (Figure 1B: AUC pre 4226 ± 1912 vs. AUC post 2654 ± 1252 mU × min × l^{-1}; $P < 0.001$). Insulin sensitivity significantly improved following 2 weeks of HIT (Cederholm index: pre 80 ± 6 vs. post 98 ± 5 mg × l^{2} × $mmol^{-1}$ × mU^{-1} × min^{-1}, $P < 0.01$).

NEFA responses

There was a trend towards a decrease in baseline plasma NEFA concentrations following HIT (Figure 1C; pre: 350 ± 36 µmol × l^{-1} vs. post: 290 ± 39 µmol × l^{-1}, $P = 0.058$). In the pre-training OGTT, plasma NEFA concentration was decreased 60 min after the 75 g glucose bolus (Figure 1 C; 0 min: 350 ± 36 µmol × l^{-1} vs. 60 min: 255 ± 48 µmol × l^{-1}; $P < 0.01$), and to a greater extent post-HIT (Figure 1C; 0 min: 290 ± 39 µmol × l^{-1} vs. 60 min: 153 ± 17 µmol × l^{-1}, $P < 0.001$; pre 60 min: 255 ± 48 µmol × l^{-1} vs. post 60 min: 153 ± 17 µmol × l^{-1} $P < 0.05$).

The plasma NEFA AUC was significantly reduced post-training (Figure 1C: AUC pre 31584 ± 13205 vs. AUC post 23370 ± 8630 µmol × min × l^{-1}; $P < 0.001$), whereas despite the decreased insulin AUC post-training the incremental NEFA AUC was similar pre- and post-training (pre: -12748 ± 2752 µmol × min × l^{-1}; post: -13513 ± 2541 µmol × min × l^{-1}).

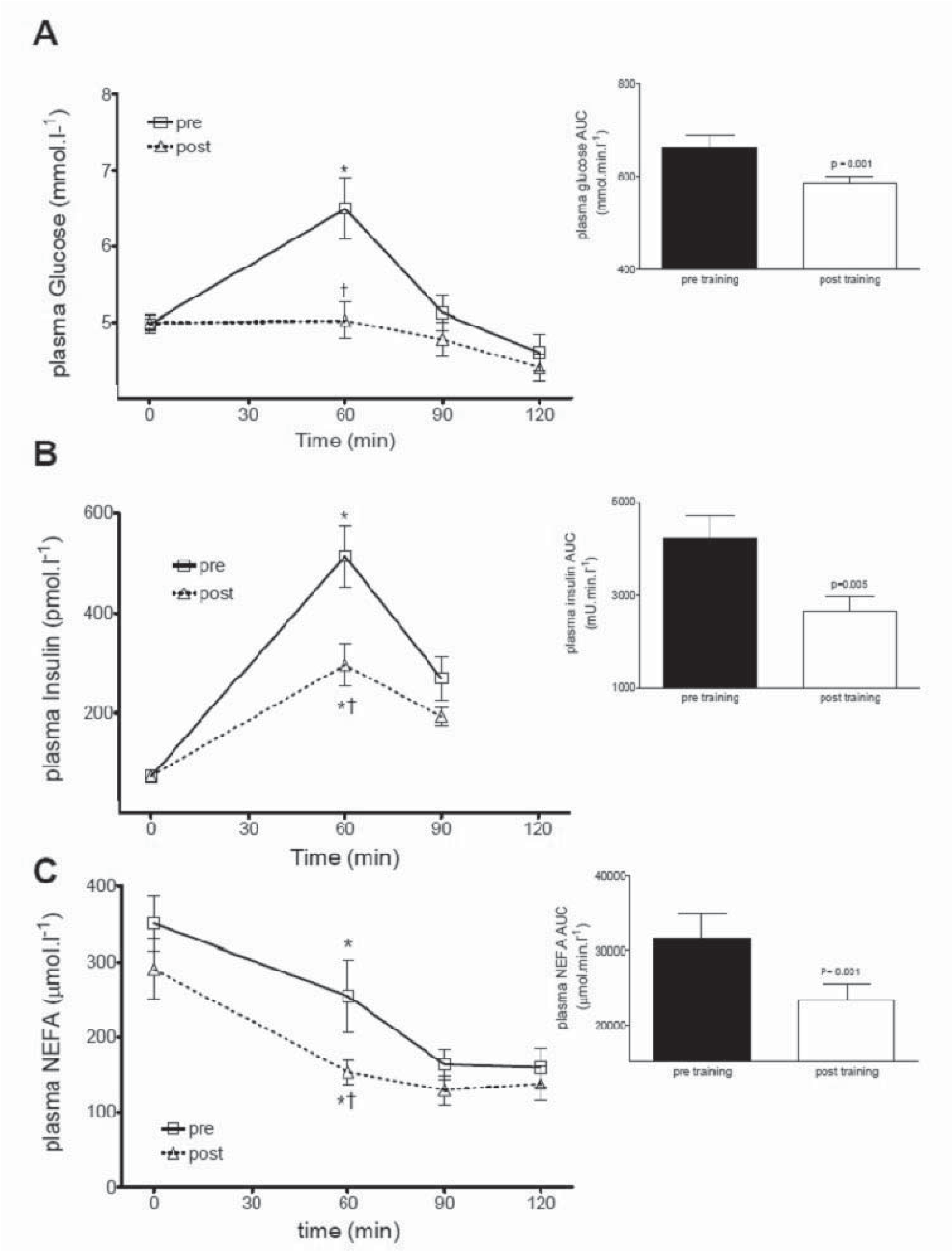

Figure 1: Response to an oral glucose load pre- and post-HIT. Plasma concentrations and AUC for A: glucose, B: insulin and C: NEFAs. (: P < 0.01 for 0 min vs. 60 min; †: P < 0.01 for pre vs. post)*

Physiological considerations

To bench-mark our results with recently published studies, we determined the impact of HIT on performance. Work done in the 250-kJ time trial was significantly increased by an average of 6 % following 2 weeks of HIT (mean difference: 75 s, 95 % CI: 21-126 s; $P < 0.01$). At baseline, the only physiological parameter which related to a metabolic parameter, was aerobic capacity vs. NEFA response to the OGTT ($R^2 = 0.43$, $P < 0.001$). There was a modest correlation between changes in glucose and insulin AUC ($R^2 = 0.25$, $P < 0.05$). Changes in performance did not correlate with baseline values for, or changes in the AUCs of glucose, insulin, and NEFAs, and insulin sensitivity as measured by the Cederholm index. We also considered whether the timing of the post-training assessment impacted on the observed metabolic changes. Improvements in glucose or NEFA responses were similar whether assessed two or three days following the final training session (mean reduction in glucose AUC: 2 d post 12 ± 10 %, 3 d post 19 ± 4 %; NEFA AUC, 2 d post 23 ± 21 %, 3d post 27 ± 9 %).

Intra-individual variation in time trial performance and response to an OGTT

In subjects not performing the HIT program, no significant differences between the first and second OGTTs were observed for plasma glucose (AUC: 671 ± 47 vs. 659 ± 40 mmol × min × l^{-1}) and NEFAs (AUC: 24035 ± 1611 vs. 22599 ± 2544 µmol × min × l^{-1}), nor for time trial performance (1477 ± 214 vs. 1491 ± 245 s). Coefficients of variation for repeated measurements were 2.1 % for the time trial, 4.9 % and 7.0 % for fasting glucose and NEFA concentrations, and 8.1 % and 8.2 % for glucose and NEFA AUCs respectively.

Discussion

While exercise training represents one of the most powerful strategies to reduce future development of metabolic disease in healthy adults (Blair et al., 1989), most adults fail to meet current guidelines for participation (Duncan et al., 2005). These guidelines largely focus on the accumulation of time spent carrying out moderately intense activity (or total energy expenditure) and ultimately require many hours of exercise each week. This is perceived as a major time commitment, driving or contributing to low compliance. In the present study we demonstrate for the first time that only a few minutes of high intensity interval exercise performed over two weeks is required to substantially improve insulin action and glucose homeostasis in healthy men. This is both an important and useful finding, as preventative interventions should logically be implemented as early as possible to prevent age related development of cardiovascular disease.

Interestingly, despite employing long-term training interventions (2-16 months) the majority of studies investigating classic aerobic (Dengel et al., 1996; Hersey et al., 1994; Katzel et al., 1995; Lampman et al., 1985; Lampman et al., 1987; Potteiger et al., 2003; Seals et al., 1984) or strength training programs (Craig et al., 1989; Hurley et al., 1988; Miller et al., 1994) have observed only a reduction in insulin area under the curve (AUC) in response to a glucose load following training, without a concomitant reduction in glucose AUC, indicating only a partial improvement in insulin action. Some longitudinal studies have shown reductions in glucose AUC (Angelopoulos et al., 1998; Angelopoulos et al., 2002; O'Leary et al., 2006), but performed post-training OGTTs within 24 hours of the last exercise bout, therefore studying the combined impact of acute and chronic exercise (Rogers, 1989), whereas Hughes et al. demonstrated reduced glucose AUC in elderly subjects without a concomitant change in insulin AUC (Hughes et al., 1993). In contrast, the low volume, but high intensity training utilized in the current study significantly reduced both glucose AUC (-12 %) and insulin AUC (-37 %), with a sustained benefit observed with OGTTs performed 2 or 3 days after the last exercise session. This was achieved without changes in body weight, and with a weekly energy-cost of training of ~225 kcal during the first training week and ~275 kcal during the second training week (compared to ~2000-3000 kcal × week^{-1} in typical aerobic training programs (Evans et al., 2005; Potteiger et al., 2003)). This implies that the mechanism underpinning the benefits we observed with HIT may be distinct from those responsible for the more modest improvements in insulin action with classic time-consuming aerobic training.

Skeletal muscle is considered the major tissue responsible for the uptake of glucose following a glucose or insulin challenge (Baron et al., 1988) such that it is entirely reasonable to assume that muscle glucose uptake was substantially enhanced following HIT. The limiting step in glucose disposal is considered to be its transport into the skeletal muscle (Houmard et al., 1991) and GLUT4 is the most abundant glucose transporter in skeletal muscle. Increased GLUT4 concentration with endurance training has been suggested to be an important factor regulating insulin sensitivity (Houmard et al., 1991; Hughes et al., 1993). Burgomaster et al. reported that skeletal muscle GLUT4 levels increase by ~20 % after one week of HIT, and remain elevated over 6 weeks of training and a subsequent 6-week period of detraining (Burgomaster et al., 2007). Given the similarity in the aerobic performance improvements between our subjects and those involved in the Burgomaster studies, our studies should be comparable and thus an increase in GLUT4 may partly explain our findings. However, increased GLUT4 concentration does not always fully explain training-induced improvements in insulin sensitivity. It has been demonstrated that key regulatory proteins in the insulin signalling pathway within skeletal muscle become more activated in response to insulin following aerobic training (Kirwan et al., 2000). HIT produces similar changes in skeletal muscle markers of carbohydrate and lipid metabolism to aerobic training (Burgomaster et al., 2008), so it should be investigated whether HIT also produces similar adaptations of the insulin signalling pathway as seen following aerobic training (Kirwan et al., 2000).

A novel feature of HIT is the relatively large muscle mass recruited during exercise, causing glycogen breakdown and turnover to occur within a greater proportion of fibres than with classic aerobic training. Muscle contraction under conditions of metabolic stress (such as incurred during HIT) results in very rapid glycogen degradation (Timmons et al., 1996) and this would almost certainly acutely alter the binding of a variety of glycogen associated proteins (Meyer et al., 1970; Wojtaszewski et al., 2002). Improved whole body glucose disposal following training has been associated with an increase in insulin stimulated glycogen synthesis (Perseghin et al., 1996). Therefore, remodelling of the glycogen pool, altering the molecules' branching architecture (Calder, 1991), may well be important in regulating skeletal muscle insulin sensitivity following HIT.

Insulin sensitivity may also be regulated by plasma NEFA concentration. Pharmacological lowering of plasma NEFA levels positively regulated insulin sensitivity during an OGTT (Santomauro et al., 1999), whereas raising plasma NEFA concentration, through lipid infusion, lowers glucose infusion rate during peripheral insulinemia-euglycemia in young men (Krebs et al., 2001). In contrast, exercise training has been shown to have little or no effect on fasting plasma NEFA concentration, insulin mediated lipolysis or NEFA release during exercise (Friedlander et al., 1999; Horowitz et al., 2000; Ostergard et al., 2006; Sial et al., 1998). In the present study, HIT was associated with a 17 % decrease in fasting plasma NEFA concentration without a concomitant change in fasting insulin. Further, there was a 26 % reduction in NEFA AUC during OGTT following HIT despite a 37 % reduction in the plasma insulin AUC. This suggests that insulin was able to inhibit lipolysis to a greater extent following HIT, consistent with the findings of Stallknecht et al. (2000) who found that traditional endurance training caused a greater fall in adipose tissue interstitial glycerol concentration during insulin infusion (Stallknecht et al., 2000).

Conclusion

In conclusion, we demonstrate for the first time that low volume high intensity interval exercise is sufficient for significant improvements in glycemic control in healthy young adults. This study is limited to the measurement of whole body insulin sensitivity which makes the interpretation of the data more complicated. Analysis of tissue specific responses through biopsy studies would enhance the present study by allowing determination of the molecular mechanisms involved in the improvements witnessed at the whole body level. However, this data and the findings by Gibala's lab suggest that the advice being given to people, with regards to exercise, may not be optimal. Our findings, and those of others, warrant further studies investigating the effectiveness of HIT in improving glycemic control in individuals at risk of developing T2D and in patients with T2D.

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BRIAN C. FOCHT

The utility of applying social cognitive theories of behavior to explain resistance exercise participation

Keywords: Social cognitive theories of behavior, participation, resistance exercise, perceived behavioral control, control beliefs

Introduction

Regular resistance exercise (RE) participation results in numerous health and fitness benefits. RE produces increases in muscular strength, endurance, and hypertrophy and is an integral part of the training regimens of competitive athletes. In addition to these well-established fitness and performance benefits, RE is also linked to a meaningful improvement in a variety of health outcomes (Graves & Franklin, 2001). It is clear that RE is a popular mode of exercise that yields valuable health and fitness benefits across the lifespan (Feigenbaum & Pollock, 1999).

Despite the considerable evidence supporting the efficacy and beneficence of strength training, RE participation rates among U.S. adults remain disturbingly low. Results from recent epidemiological evidence suggest that only approximately 14 % of adult Americans report engaging in any leisure-time RE in the past month whereas only 9 % report participating in regular RE participation (Galuska et al., 2002). The low percentage of individuals reporting any or regular RE participation clearly suggest that most U.S. adults are failing to accrue recommended amounts of RE participation suggested in established national physical activity guidelines (ACSM, 2002). Consequently, RE promotion efforts are needed to improve participation rates in this valuable mode of exercise.

In order to design effective RE programs or interventions, it is necessary to identify the factors which may systematically promote, and or impede, one's motivation for regular RE participation. In this regard, several social cognitive models of health behavior have been successfully applied to the study of exercise participation. For example, the "Theory of Planned Behavior" (Azjen, 1991) and "Social Cognitive Theory" (Bandura, 1997) have both been show to explain meaningful amounts of variability in exercise participation (for reviews Hagger et al., 2002; McAuley & Blissmer, 2000; Symons Downs & Hausenblas, 2005). Unfortunately, however, the majority of studies examining the efficacy of applying these conceptual perspectives to explain exercise participation have focused primarily upon aerobic activity. Knowledge of the potential value of social cognitive theories for predicting RE participation remains limited. Consequently, the purpose of the present review is to provide a brief summary of the research addressing the utility of applying well-established social cognitive theories of health behavior to explain RE participation.

Do inconsistent weight lifters need an attitude adjustment? The theory of planned behavior and resistance exercise participation

The theory of planned behavior (TPB) is one of the most commonly employed theoretical frameworks used to explain the adoption and maintenance of health behaviors (Ajzen, 1991). The TPB posits that the positive and/or negative evaluation of a behavior (attitude), perceived social pressure to engage in a behavior (subjective norm), and perceived control over participation (perceived behavioral control) determine an individual's intention to engage in health behaviors. In turn, intention is proposed to serve as the primary proximal determinant of engaging in the behavior. Furthermore, perceived behavioral control is purported to influence exercise participation through two pathways: Through both a direct effect on exercise behavior and indirectly operating through intention (Figure 1).

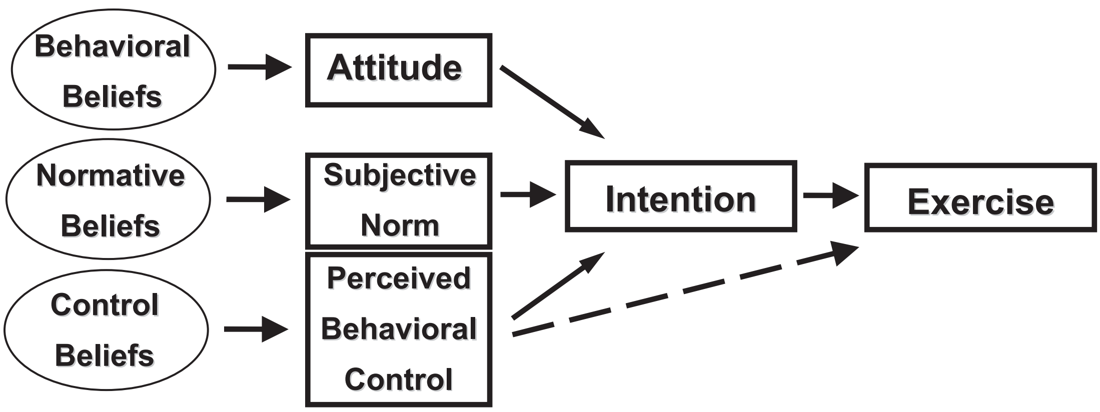

Figure 1: The theory of planned behavior applied within the exercise domain

Thus, within the exercise domain, if one: (a) holds favorable attitudes about exercising, (b) feels social pressure or support from valued others to exercise regularly, and (c) feel confident they are capable of successfully engaging in exercise and managing common barriers to that could impede this participation, they will have strong intentions to exercise. Those forming strong intentions to exercise are more likely to exercise regularly. There is considerable evidence supporting the utility of the application of the TPB in the exercise domain (Hagger et al., 2002; Symons Downs & Hausenblas, 2005). However, the TPB has only recently been applied to the study of RE participation.

In one of the earliest studies to address theory-based determinants of RE participation, Bryan and Rocheleau (2002) compared the efficacy of TPB constructs to predict RE and aerobic exercise participation in a prospective research design within a sample of 210 college students. Participants completed a baseline assessment of TPB variables assessing their attitude, subjective norm, perceived behavioral control, and intention towards participating in RE and aerobic exercise. A follow-up assessment of RE and aerobic exercise participation was obtained 3 months later via telephone interview using an investigator-developed measure of exercise participation. Structural equation modeling analyses revealed that all of the relationships proposed within the TPB were significant for both RE and aerobic exercise participation. Specifically, with regard to RE, attitude, subjective norm, and perceived behavioral control accounted for 67 % of the variability in intention to participate in RE. Additionally, perceived behavioral control and intention accounted 40 % of the variability in RE participation reported at the 3-month follow-up assessment. It is interesting to note that in the investigation by Bryan and Rocheleau, the TPB constructs explained considerably more variance in RE participation (40 %) relative to aerobic exercise participation (19 %).

Rhodes et al. (2007) recently examined the contributions of TPB framework in predicting participation in RE, endurance exercise, and flexibility activities in a sample of 185 undergraduate college students. The investigators also examined the potential role of specific activity-related control beliefs on exercise participation and tested if the TPB variables mediated the belief-behavior relationship. Using a passive prospective research design, measures of TPB constructs were obtained at baseline and 2-week follow-up assessments of RE, aerobic exercise, and flexibility exercise participation were collected using the “Godin Leisure Time Exercise Questionnaire” (LTEQ; Godin et al., 1985) which was modified to specifically tap each mode of exercise participation.

Results of structural equation modeling analyses demonstrated that the TPB explained greater amounts of variability in intention (46 %) and RE behavior (33 %) when compared to explained variance observed with either aerobic or flexibility exercise. Two behavioral beliefs were found to have effects on RE behavior. Both the belief that RE provides a sense of accomplishment and the belief that RE participation may take too much free time to complete had moderate-sized effects on RE behavior. Analyses also generally supported the mediational role of the TPB on belief-RE behavior relationship. RE beliefs were found to be indirectly associated with RE behavior, operating through the TPB constructs of attitude, subjective norm, perceived behavioral control each of which subsequently influenced intention to participate in RE.

Using a cross-sectional design, Dean et al. (2007) investigated the efficacy of the TPB to explain RE participation in a sample of 200 older adults. RE was assessed using a single-item index tapping self-reported frequency of typical RE participation. Results of hierarchical regression analyses demonstrated that subjective norm and perceived behavioral control explained 42 % of the variability in intention. Interestingly, intention, but not perceived behavioral control, explained 40 % of the variability in self-reported RE participation. These findings represent a departure from many prior studies examining the TPB-exercise relationship. For example, the influence of subjective norm on intention was considerably larger than documented in prior research. Additionally, in contrast to the theoretical predictions of the TPB, attitude did not significantly contribute to the explanation of intention and perceived behavioral control was not associated with self-reported RE participation. The authors suggested that augmented effect of subjective norm may indicate that social reinforcement is of particular importance in determining intention to engage in RE among older adults. Moreover, Dean et al. (2007) contended that the weak relationships observed between attitude and intention and perceived behavioral control and RE participation could be attributed to a ceiling effect resulting from the limited variability demonstrated in the measures of attitude and perceived behavioral control within the present investigation.

Although the TPB has frequently been successfully applied to explain exercise participation, recent evidence suggests that the constructs of attitude and perceived behavioral control may be multi-dimensional (Rhodes & Courneya, 2003). This proposed 2-component model of the TPB suggests that attitude is comprised of both affective and instrumental aspects whereas perceived behavioral control reflects elements of self-efficacy and controllability (Connor & Norman, 2005; Rhodes et al., 2007). Using a prospective research design we recently examined the utility of the 2-component model of the TPB in explaining both strenuous and moderate RE participation within a convenience sample of 275 college students (Focht et al., 2009). Measures of TPB constructs were obtained at baseline and a 2-week follow-up assessment of RE participation was obtained using the adapted version of the LTEQ (Godin & Shepard, 1985) used previously by Rhodes et al. (2007). Results of hierarchical regression analyses demonstrated that instrumental attitudes, subjective norm, and both the self-efficacy and controllability components of perceived behavioral control accounted for 65 % of the variance in RE intentions. In turn, intention, self-efficacy, and controllability were significant independent predictors of strenuous RE participation accounting for 32 % of the variance in RE reported at the 2-week follow-up assessment. By contrast, these proximal determinants of behavior only accounted for 16 % of the variability in moderate RE participation. These findings provide initial support for the utility of the 2-component model of the TPB for explaining RE participation. Furthermore, these results extend previous knowledge by demonstrating that the TPB may be more efficacious in predicting strenuous rather than moderate RE participation.

Building muscle and building confidence: Self-efficacy and resistance exercise participation

Bandura's (1997) "Social Cognitive Theory" proposes a complex relationship between social, behavioral, and cognitive factors influences the motivation to engage in health behaviors such as exercise. Within the context of social cognitive theory, self-efficacy (SE) beliefs are suggested to be the primary motivational determinant of behavior. SE is defined as control beliefs regarding one's capability to satisfy specific situational demands. Within the exercise domain, SE beliefs are one of the strongest, most consistent correlates of regular exercise participation (Trost et al., 2002). SE is also an important outcome variable itself which has consistently been shown to improve with regular exercise participation (McAuley & Blissmer, 2000). Furthermore, changes in SE beliefs accompanying exercise participation also have recently been demonstrated to mediate improvements in functional performance (Focht et al., 2005) and quality of life (Rejeski et al., 2001) following exercise interventions. Thus, SE beliefs represent important antecedent, outcome, and mediator variables associated with exercise participation.

Despite the well-established SE-exercise relationship, the role of SE as a determinant of RE participation has largely been overlooked in the extant literature. We recently observed that SE was a significant independent predictor of strenuous and moderate RE participation. Additionally, RE programs result in significant increases in SE for strength as well as desire for strength (Katula et al., 2006). Desire for strength has also recently been found to be an independent predictor of increases in SE observed during a 6-week RE intervention in older adults (Rejeski et al., 2005). Consistent with these findings, preliminary analyses of an ongoing study from my lab also demonstrates that desire for upper and lower body strength are significant, independent predictors of RE-related SE beliefs (Focht et al., 2009).

Taken collectively, these findings underscore the important role that SE may have in determining RE participation. Individual's beliefs regarding their RE abilities may be an integral consideration in the willingness to engage in RE. Moreover, the psychologically empowering effect of RE may be captured, at least in part, through the assessment of SE beliefs. Consequently, SE represents an important psychological construct that serves as a relevant determinant and consequence of RE participation. Given its well-established link with other modes of exercise, the potential role of SE remains woefully understudied within the context of RE and warrants considerably more attention in future inquiry addressing RE participation.

Conclusions and future directions

In summary, initial findings in the extant literature support the utility of applying social cognitive theories to explain RE behavior. Conceptual frameworks such as social cognitive theory (Bandura, 1997) and the theory of planned behavior (Azjen, 1991) represent promising foundations upon which to base future RE interventions. Clearly, in light of the alarmingly low RE participation rates currently evidenced in the adult population (Galuska et al., 2002), additional consideration should be given to these theoretical perspectives in the design and delivery of RE programs. Taken collectively, findings from research addressing social cognitive determinants of RE suggest that constructs such as attitude, subjective norm, perceived behavioral control consistently predict intentions to engage in RE. Furthermore, intention, perceived behavioral control, and self-efficacy account for significant meaningful amounts of variability in self-reported RE participation. These findings are consistent with results of studies examining these conceptual frameworks when applied to aerobic exercise as well as a variety of other health behaviors and further application of these theoretical perspectives to RE participation is warranted.

Although existing empirical evidence supports the merit of integrating social cognitive models in the design of RE programs, it should be recognized that contemporary research addressing the social cognitive factors associated with RE behavior presently remains relatively limited in both scope and depth. Consequently, additional systematic inquiry is necessary to adequately evaluate the extent to which the TPB and social cognitive theory constructs may contribute to explaining, and subsequently predicting, RE participation. I strongly believe that, in order to expeditiously advance knowledge of this important area of RE research, there are some key substantive methodological and conceptual issues that warrant targeted investigation.

From a methodological context, I believe that one of the most pressing limitations hindering progress in the study of RE behavior is the lack of a rigorously validated, psychometrically sound measure of RE participation. To date, studies addressing the social cognitive correlates of RE participation have relied on measures of aerobic exercise that have been modified to capture RE or simply employed investigator-developed scales. These measures have primarily focused upon self-reported frequency of RE participation. Accordingly, many other programatic aspects of RE such as training load, volume, and intensity are not systematically assessed by the measures which have been utilized in this research. The lack of measurement precision likely reflects the infancy of this area of study. Nonetheless, progress towards developing a more comprehensive, valid assessment of RE behavior that captures the various programmatic characteristics of RE participation is an integral consideration for future research.

The generalizability of current findings is another methodological issue of relevance given that the majority of studies to date have examined RE participation in convenience samples of young adult college students. Replicating and extending the observed findings in more diverse samples is another important future consideration. Additionally, little is known regarding individual differences that may act as moderators of social cognitive theory-RE participation relationship. For example, knowledge of differences as a function of gender, RE training experience, muscular fitness, or a host of potentially relevant cognitive and/or motivational factors remains underexamined. Exploring these differences may provide further understanding of the factors which contribute to the divergent RE participation patterns currently observed (Galuska et al., 2002). Finally, from research design perspective, longitudinal studies that concomitantly assess change in social cognitive constructs and RE participation are needed to further understanding of the prospective relationships among these variables and refine knowledge of the value that may have in promoting RE participation.

I would argue there are also several meaningful conceptual considerations for future research. There is growing empirical support for the utility of the 2-component model of the TPB for explaining exercise participation (Rhodes &

Courneya, 2003). However, to date, few studies examining the efficacy of the TPB for predicting RE participation have integrated the 2 component measurement model by examining affective and instrumental attitudes as well as the self-efficacy and controllability aspects of perceived behavioral control. Recent findings suggest that affective attitudes may be more predictive of intention for select health behaviors relative to instrumental attitudes (Lawton et al., 2007). Consequently, future research addressing RE participation should examine the multi-dimensional model. Furthermore, emerging research suggests that the stability of one's intention is a significant moderator of engaging in repetitive health behaviors such as exercise participation (Connor & Godin, 2007). Thus, future research should explore not only the formation of intention for RE but also the stability of one's intention to engage in RE participation. Finally, most studies that have examined the social cognitive theory-RE participation relationship have focused almost exclusively upon the role of self-efficacy beliefs. Additional constructs from Bandura's (1997) social cognitive theory such as the incentive value of activities, outcome expectations, social processes, and perceptions of the environment all may also play an important role in explaining RE participation. Accordingly, it is recommended that future investigations targeting the role of self-efficacy include assessments of these potentially important constructs that may help to predict RE behavior.

In summary, social cognitive theories are promising conceptual frameworks that could advance knowledge of the factors which systematically impact RE participation. Comprehensive evaluations of these theories in future RE research may aid in developing a better understanding of what factors motivate or impede regular RE participation. Additionally, as knowledge of the efficacy of applying these theoretical perspectives to RE behavior becomes more refined, these theoretical frameworks could serve as the conceptual foundation for developing more effective interventions for promoting RE participation across the lifespan.

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DARREN G. CANDOW & DARREN G. BURKE

Protein supplementation strategies on body composition, exercise performance, and muscle protein kinetics

Keywords: Protein, body composition, exercise, performance, strength

Introduction

Protein requirements for exercising individuals have gained considerable attention in recent years. It appears that individuals who engage in endurance and resistance type training may benefit from additional dietary protein (Biolo et al., 1995; Burke et al., 2001; Candow et al., 2006). The increase in amino acid oxidation from endurance exercise and breakdown of contractile protein during heavy-resistance training suggests that protein intake may exceed that of basal to supply additional amino acids for metabolic demand (Rennie & Tipton, 2000). Despite this, the current “Dietary Reference Intake” for protein (0.8 g/kg/day) does not recognize any additional protein needs for individuals engaged in endurance or resistance type training. Energy requirements increase as lean tissue mass and resting metabolic energy expenditure increase. Therefore, it is plausible to suggest that an increase in physical activity would require an increase in macronutrient consumption, especially protein, to promote the retention of lean tissue mass and maintain nitrogen balance (Lemon, 1988; Tipton et al., 2001).

It is well established that an acute bout of exercise has a large impact on muscle protein turnover (Borsheim et al., 2002; Tipton et al., 2001; Wolfe, 2002). The magnitude of the effect depends on the type, intensity, and frequency of exercise (Lemon, 2000). Several studies have shown that endurance exercise (50-70 % VO_2max, > 30 minutes) stimulates amino acid oxidation in a time dependent manner (Babij et al., 1983). For example, two hours of endurance exercise at 55 % VO_2max oxidized 80-90 % of the daily requirement for leucine in young athletes. Others have found a modest increase in urea excretion (i.e. an index of protein catabolism) in endurance trained athletes following exercise (Carraro et al., 1990). Therefore, dietary protein needs of endurance trained athletes may be greater than sedentary controls due to an increase in amino acid oxidation from exercise (Carraro et al., 1990).

In five well trained endurance athletes, nitrogen retention remained positive during a high protein intake (1.46 g/kg/day) vs. low protein intake (0.86 g/kg/day) following 75 minutes of aerobic exercise (72 % VO_2max)

(Friedman & Lemon, 1989). In examining the influence of protein intake on nitrogen balance in elite endurance athletes (> 5 years of training), Tarnopolsky et al. (1988), found that nitrogen balance was achieved at a safe protein intake of 1.37-1.65 g/kg/day. The authors suggest that the elevated protein requirements needed to achieve nitrogen balance in endurance trained athletes may be the result of increased energy expenditure, increased amino acid oxidation, and altered rates of muscle protein synthesis and breakdown in relation to the intensity, duration, and frequency of exercise. Elevated exercise intensity and duration will require more dietary protein to compensate for increased amino acid oxidation during exercise and muscle protein recovery following exercise. For example, individuals who exercise on a regular basis at high intensities (> 70 % VO_2max) for long durations (> 1 hour) will require more dietary protein (e.g. 1.65 g/kg/day) compared to individuals who exercise at low intensities (< 70 % VO_2max) for short durations (< 1 hour) (e.g. 0.9 g/kg/day). Therefore, independent of total energy intake, the intensity, duration, and frequency of exercise play a large role in determining the protein requirements for endurance trained athletes.

For many years, resistance trained athletes have consumed significant amounts of dietary protein in hope that it would lead to improvements in skeletal muscle mass, strength, and exercise performance. However, contrary to popular belief, resistance training does not have a significant effect on amino acid oxidation at rest or during exercise (Lemon, 1998; Rennie & Tipton, 2000). Despite this, there is good evidence to suggest that the protein needs of resistance trained athletes are greater than sedentary controls. Resistance training causes an increase in protein synthesis and protein breakdown (Tipton et al., 1999). Consequently, the net balance between protein synthesis and protein breakdown improves after resistance training, but in the post-absorptive state, remains negative (i.e. rate of protein breakdown exceeds protein synthesis) (Wolfe, 2001). Amino acid intake is known to be a potent stimulator of protein synthesis. Hyperaminoacidemia at rest and following exercise increases protein synthesis and attenuates protein breakdown (Tipton et al., 2001; Wolfe, 2001). Whereas resistance training can diminish the net breakdown of muscle protein in the absence of amino acids, net gain of muscle protein occurs in the presence of amino acids (Wolfe, 2001). The theory behind the greater protein requirement in resistance trained athletes involves amino acid availability and translational efficiency (Welle et al., 1994). Amino acids are selected for protein synthesis by binding with transfer RNA (tRNA). The information and order of amino acid sequence for each protein is governed by messenger RNA (mRNA) that is produced from DNA through transcription. An increase in amino acid availability through additional dietary protein could potentially increase the combination of tRNA with an amino acid for translocation to ribosomal RNA (rRNA) located on the ribosome organelle where protein synthesis occurs. Increased translation efficiency, in the presence of increased amino acid availability, could potentially increase muscle protein synthesis and maintain or increase nitrogen balance in resistance trained athletes (Welle et al, 1994).

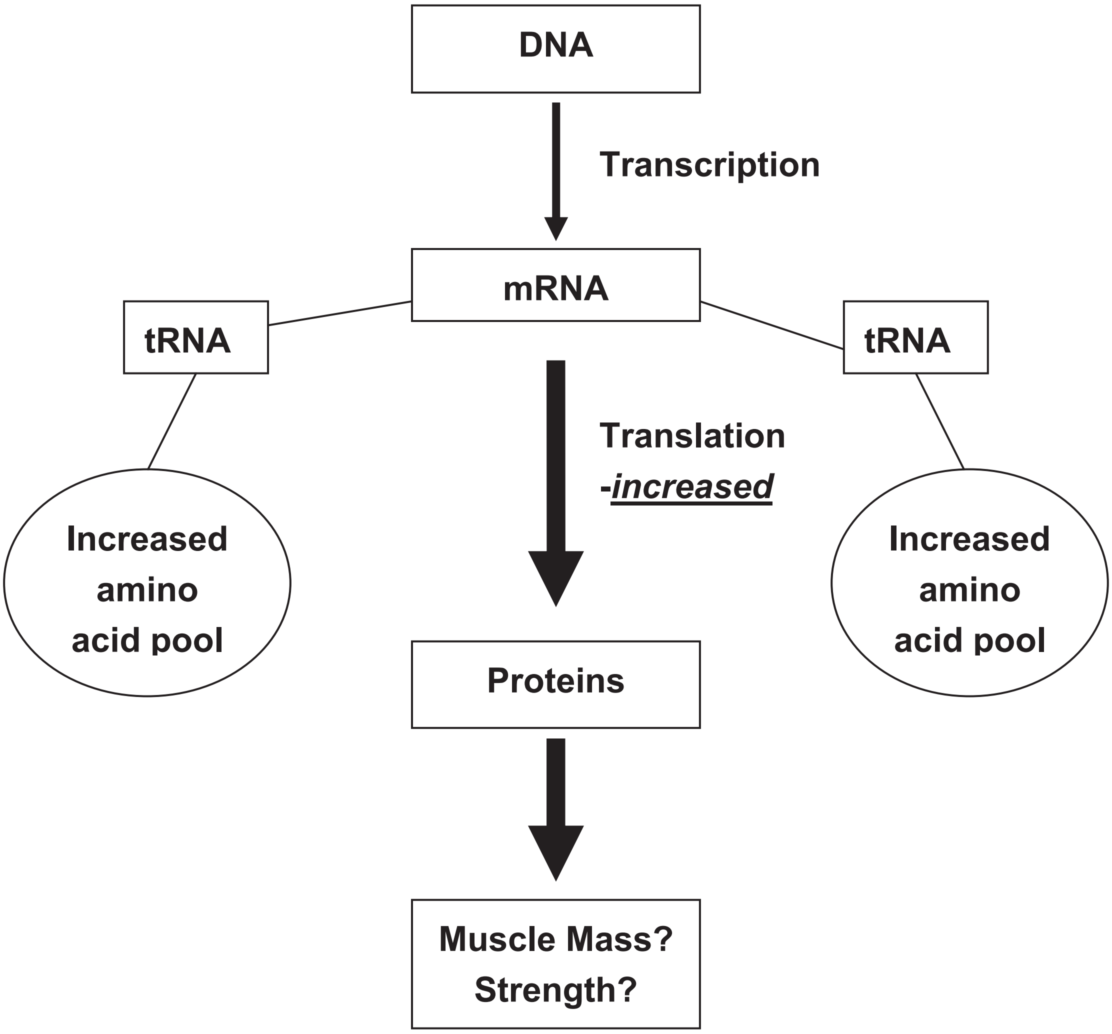

Figure 1: Schematic diagram of increased translational efficiency leading to greater muscle mass and strength

In support of this theory, resistance training in combination with 1.0 g/kg/day of protein resulted in negative nitrogen balance whereas 1.4-1.7 g/kg/day maintained nitrogen balance at the onset of training in novice bodybuilders. However, one month later, the amount of protein required to maintain nitrogen balance was reduced; suggesting a biological adaptation to resistance training (Lemon et al., 1992). Reduced amino acid availability during the initial stages of resistance training may limit muscle growth and adversely affect whole body nitrogen balance. During the initial stages of heavy resistance training, dietary protein needs are elevated for muscle protein synthesis, nitrogen balance, and recovery (Rennie & Tipton, 2000). However, chronic resistance training (e.g. months) may decrease the protein needs of resistance trained athletes (Tarnopolsky et al., 1992). It has been suggested that a continuum of training stimuli will result in a series of muscle protein turnover responses each of which is progressively reduced (Wolfe, 2002). This theoretical model is supported by the work of Farrell et al. (1999), who found that the response of muscle protein synthesis in rats following 8 weeks of resistance training was reduced compared to untrained rats. In trained vs. untrained subjects, the increase in muscle protein synthesis and breakdown was reduced by 50 % in the trained group following intense resistance training (Rennie & Tipton, 2000). Therefore, the protein needs for resistance trained individuals decrease with chronic training (i.e. down regulation adaptation), possibly due to increased net protein utilization and retention of lean tissue mass.

Research suggests that the timing of protein ingestion, not quantity, can be an effective strategy during resistance training to increase muscle mass and strength (Andersen et al., 2005; Candow & Chilibeck, 2008; Cribb & Hayes, 2006; Esmarck et al., 2001). For example, in assessing the effects of protein versus carbohydrate supplementation before (~25 g) and after (~25 g) lower body resistance training sessions for 14 weeks in young males, Andersen et al. (2005) found a significant increase in muscle cross-sectional area of type I (~18 %) and type II (~26 %) muscle fibers of the vastus lateralis in the protein group with no effect in the carbohydrate group. Therefore, protein supplementation before and after resistance training sessions induces an anabolic signal for muscle growth. In young adults, ingesting an amino acid solution (~6 g essential amino acids and 35 g of carbohydrate) immediately before a bout of acute heavy resistance training resulted in a greater increase in muscle protein synthesis compared to consuming the amino acid solution immediately after resistance training. The authors suggest that the greater increase in muscle protein synthesis from essential amino acid ingestion prior to exercise may be the result of increased amino acid delivery to working muscle from exercise induced blood flow (Tipton et al., 2001). Furthermore, in older males who ingested protein (~10 g) immediately after resistance training sessions for 10 weeks had significant increases in muscle size and strength over protein ingestion two hours post-exercise (Esmarck et al., 2001). Therefore, protein ingestion in close proximity to resistance training (i.e. before and after) may be more important for creating an anabolic environment for muscle growth (Tipton et al., 2001), with protein supplementation immediately before (Andersen et al., 2005; Tipton et al., 2001) and immediately after resistance training (Esmarck et al., 2001) appearing optimal.

Summary

It appears that endurance and resistance trained athletes benefit from additional dietary protein. Endurance and resistance trained athletes may require 1-2 g/kg/day of dietary protein to compensate for increased amino acid oxidation, alterations in muscle protein turnover during and following exercise, and recovery. However, with chronic resistance training, these protein requirements may decrease due to net protein utilization and retention of lean tissue mass. The variations in protein intake may be the result of individual training status (sedentary vs. habitual exercise), training intensity (% VO_2max), type of exercise (endurance vs. resistance), exercise duration (minutes vs. hours), energy intake, methodological limitations, and genetic endowment. The timing of protein ingestion appears critical for creating an anabolic environment for muscle growth, with protein ingestion before and after resistance training appearing optimal. However, ingestion of protein before exercise appears superior for increasing net muscle protein balance.

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BJÖRN EICHMANN, ROBERTO ADAMI & JÜRGEN GIEßING

Repetition speed and time under tension (TUT) in single-set vs. multiple-set training programs

Keywords: Time under tension, repetition speed, single-set training, multiple-set training, training methods

Introduction

Although the exact mechanisms that are responsible for muscular hypertrophy have not yet been entirely identified, there is a consensus that certain training methods are superior for inducing muscular hypertrophy and strength gains. It is generally accepted that lifting weights of 6-RM to 20-RM are very likely to induce increases in muscle mass and strength, especially when sets are not terminated before reaching the repetition maximum or even the point of momentary muscular failure (Allmann, 2001; Buchbauer, 1999; Bührle, 1985, 1995; Bührle & Werner, 1985; Ehlenz et al., 1998; Gießing, 2006; Güllich & Schmidtbleicher, 1999; Harre, 1990, 1997; Hartmann & Tünnemann, 1988, 1990; Radlinger et al., 1998; Schmidtbleicher, 1985, 1987; Verchoshanskij, 1995; Weineck, 2000; Zatsiorsky, 2000).

However, according to Boeckh-Behrens and Buskies (2003) most training methods applied today are based on the experiences of athletes and coaches concerning strength training rather than on training science. According to Greiwing (2006) most suggestions on how to train for muscle mass and strength have their origin in an attempt to copy the training methods of successful athletes. As a consequence of this, there is a wide range of suggestions on which training method is the most effective one. One aspect in this context is the controversy concerning multiple-set training (MST) vs. single-set training (SST). Apart from the number of sets there are other training parameters that need to be taken into consideration, such as: Relative intensity, training intensity, eccentric, concentric and isometrical contractions, the number of repetitions and time under tension (TUT). The following study focuses on two of these parameters, namely repetition speed and time under tension.

Time under tension (TUT) and repetition speed

In strength training programs TUT is generally determined by the number of repetitions in a set. There is a wide range of suggestions concerning the optimum number of repetitions for inducing increases in muscle mass and strength (Table 1).

Table 1: Recommended ranges of repetitions for muscle hypertrophy

Authors	Recommended range of repetitions for hypertrophy training
Allmann (2001) Letzelter & Letzelter (1986)	6-10
Boeckh-Behrens & Buskies (2003)	4-20
Buchbauer (1999)	6-12
Castellano (2000)	6-30
Ehlenz et al. (1998)	3-18
Fröhlich (2003) Güllich & Schmidtbleicher (1999) Poliquin (1997)	6-20
Harre (1990)	4-10
Hartmann & Tünnemann (1988)	5-12
Hohmann et al. (2002) Bührle (1985) Martin et al. (1993) Pampus (2001)	5-20
Verchoshanskij (1995)	3-20

Apart from focusing on the number of repetitions in a set attention should be paid to the length of time that the muscle is under tension during a set. The TUT can be calculated by adding the amount of time that it takes to complete the positive, the negative, and the isometrical part of each repetition. However, counting repetitions is still the most common way to determine the contraction time of a muscle during a set:

> "Counting the repetitions has been a mainstay of strength training for decades. However, the time that the muscles are loaded within a set is actually more important than the number of repetitions." (Castellano, 2000, p. 219)

Recommendations concerning the ideal TUT for hypertrophy training vary considerably (Table 2). Radlinger et al. (1998) recommend not surpassing a TUT of more than 30 seconds in order to keep lactic acid concentrations to a minimum whereas other authors recommend considerably longer times under tension (Castellano, 2000; Fröhlich, 2003; Poliqiun, 1997).
Castellano (2000, p. 219) recommends longer times under tension for individuals with a higher percentage of slow-twitch muscle fibers:

> "Someone who has a high percentage of st-fibers should train for a slightly longer duration. For instance, more appropriate time frames might be about 120-180 seconds for the hips/gluteals, 90-120 for the legs, and 60-90 for the upper torso."

Table 2: Recommended times under tension for hypertrophy training

Author(s)	Time under tension
Castellano (2000)	40-180 s
Denner (1998)	20-50 s
Ehlenz et al. (1998)	20-30 s
Fröhlich (2003)	20-50 s
Gießing (2004)	30-40 s (60) s
Güllich & Schmidtbleicher (1999);	30-45 s
Poliquin (1997)	20-70 s
Harre (1990)	20-25 s
Hartmann & Tünnemann (1988)	20-30 s
Radlinger et al. (1998)	6-30 s

Philipp (1999) emphasizes that single-set training results in longer times under tension per set due to the lower repetition speed commonly applied in single-set training. Heiduk et al. (2002) report a time under tension of an average of 82 seconds for chin-ups in a single-set training program whereas Gießing (2004) suggests not to surpass a time under tension of considerably more than one minute because of the accumulation of lactic acid that goes along with longer contraction times and high degrees of training intensity. On the other hand this accumulation of lactic acid may even reinforce the hypertrophy stimulus and result in an even greater amount of muscular hypertrophy.

Therefore recommendations concerning repetition speed and time under tension should contain a certain range of repetitions and TUT respectively rather than an exact figure to be applied to all exercises and all training goals:

> "To develop maximum muscle mass, the optimal time a muscle should contract during a set should fall between 20-70 seconds. This allows for a lot of variation, from sets consisting of one rep and lasting 70 seconds to sets involving 15 reps and lasting 70 seconds." (Poliquin, 1997, p. 24)

The reason for this wide spectrum of different possible TUT and repetition schemes is the large variety of repetition speeds commonly applied in hypertrophy training with repetitions that are supposed to be „deliberately slow" or "controlled" or "moderate-to-slow" respectively (Bührle, 1985; Boeckh-Behrens & Buskies, 2003; Ehlenz et al., 1998, Güllich & Schmidtbleicher, 1999; Hartmann & Tünnemann, 1988; Radlinger et al., 1998). In this context Greiwing (2006) quotes a publication of the American College of Sports Medicine (1998, p. 983) in which the following is recommended:

> "Resistance Training for the average participant, should be rhythmical, performed at a moderate-to-slow controlled speed, through a full ROM, and with a normal breathing pattern during the lifting movements."

Poliquin (1997) emphasizes the importance of a slow and controlled execution of all repetitions in a hypertrophy training program and recommends different contraction times for the concentric, eccentric and isometric parts of each repetition:

> "For a bodybuilder, one secret to success is to manipulate training speeds to create maximum adaptation. In this regard, slow-speed exercises should be emphasized over fast speeds, because they make the muscle work harder by eliminating the use of momentum." (Poliquin, 1997, p. 29)

According to Preuss et al. (2006) a typical repetition in a single-set training program lasts between five and seven seconds with an emphasis on a slow execution of the eccentric part of each repetition. The authors also agree with Pereira und Gomes (2003) who point out that there is a lack of empirical evidence concerning optimum repetition speed for multiple-set training programs.
Summing up, it can be stated that despite of several recommendations concerning repetition speeds and TUT there is still a lack of empirical data in which repetition speeds and TUT are actually applied in training practice. Another aspect that needs to be looked at is the question whether or not there is a difference between single-set training and multiple-set training.

Methods

In a study at the University of Landau, Germany, the training programs of 100 subjects were observed and evaluated with a special interest in the factors repetition speed and TUT in single-set vs. multiple-set training programs. Subjects were recreational athletes, sports students, and recreational powerlifters. Prior to the study subjects had to fill in a questionnaire in which they gave detailed information about their training programs regarding the most important parameters like training goals, training volume, training frequency, number of exercises and sets per exercise, number of repetitions etc. Subjects were asked to apply their usual training patterns and were not told what the study was looking at in order not to influence the procedure of the subjects´ training. TUT and repetition speed was tested for the following exercises: Bench press (free weight or machine), lat pulldowns, butterfly, rows, leg extensions, leg curls, biceps curls, triceps extensions, crunches.
The following data was collected: The number of repetitions in each set, duration of each set (time span in seconds including intra-serial breaks), TUT (in seconds, duration of the set minus possible intra-serial breaks), and the average duration of each repetition (TUT divided by the number of repetitions).

Results

100 subjects (76 men, 24 women) took part in the study. Subjects were 28.72 years of age on average and had an average strength training experience of 2.66 years. Subjects were asked about their main training goal and could choose from the items muscle hypertrophy, weight loss, strength increases, health improvements, overall fitness, and improvements in a different kind of sport. These goals had to be ranked by the subjects from 0 (not important at all) to 5 (very important). Male and female subjects ranked health and fitness as their most important training goals. One very obvious difference between male and female subjects is the ranking of the training goal weight loss which is much more important to the female subjects (Table 3).

Table 3: Ranking of training goals

	Hypertrophy	Weight loss	Strength	Health	Fitness	Diff. sport
Total	3.47	1.85	3.72	3.90	4.05	2.47
Male	3.50	1.49	3.86	3.87	4.07	2.46
Female	2.58	3.00	3.29	4.00	4.00	2.50

Results concerning the number of repetitions, time under tension, and the duration of the sets are shown in tables 4 to 6. AV stands for the average number of repetitions or sets or time under tension respectively, MIN stands for the minimum and MAX for the maximum.

Table 4: Number of repetitions

	MIN	MAX	AV number of repetitions
Total number (N = 354)	5	50	15.89
MST program (N = 171)	5	50	16.49
SST program (N = 183)	7	50	15.33

On average 15.89 repetitions were performed per set (Table 4). The longer duration of each repetition in SST programs results in a longer TUT despite the fact that in MST programs the average number of repetitions is higher.

Table 5: Time under Tension (one set)

	MIN	MAX	AV time under tension
Total number (N = 354)	13	145	44.59
MST program (N = 171)	13	84	36.15
SST program (N = 183)	18	145	52.48

The average TUT of all analyzed sets is 44.59 seconds, however, there is a remarkable difference concerning TUT between MST and SST. Despite the fewer number of repetitions in SST programs TUT is considerably higher in

SST than in MST (52.48 seconds per set vs. 36.15 seconds per set for MST), which is due to the longer TUT of each repetition in SST programs than in MST programs (3.64 seconds for each repetition vs. 2.33 seconds per repetition for MST).

Table 6: Duration of one repetition (seconds)

	MIN	MAX	AV duration of one repetition
Total number (n = 354)	0.51	6.91	3.00
MST program (n = 171)	0.51	5.60	2.33
SST program (n = 183)	1.42	6.91	3.64

Discussion

The study at hand analyses the relationship between the number of repetitions, time under tension and duration of repetitions in strength training. The durations of repetitions vary considerably which results in different TUT, even when the exact same number of repetitions is performed.

The average TUT for SST is significantly greater than the average TUT for MST: The TUT per repetition is found to be 2.33 seconds for MST, whereas the average TUT for SST is 3.64 seconds per repetition which is still far from the 5 to 7 seconds generally recommended for SST (Gießing, 2010).

Heiduk et al. (2002) found almost identical TUT for SST and for MST due to the fact that the TUT of SST were approximately 300 % of the TUT in MST which consisted of three sets per exercise. The study at hand indicates that the TUT per exercise is greater for MST since MST programs consist of at least two sets per exercise. Two sets of a certain exercise which last 2.33 seconds each, add up to a total TUT of 4.66 seconds and three sets would add up to 6.99 seconds per exercise, interrupted by one or two inter-serial breaks.

The longer TUT of SST per set is likely to result in a greater accumulation of lactic acid. Whether higher levels of lactic acid are a favorable influence on muscle hypertrophy is still being debated (Tesch, 1994; Kawada & Ishii, 2005). Another consequence of different TUT is that different muscle fiber types may be recruited during the execution of a particular exercise (Castellano, 2000). Faster repetitions are more likely to result in recruiting a higher percentage of fast-twitch fibers whereas slower repetitions are supposed to predominantly activate slow-twitch fibers. TUT, however, is not the only factor that influences how many fibers and which fiber types are activated. Another decisive factor in this regard is training intensity. During the first repetition of a set relatively few motor units and muscle fibers are sufficient to finish the repetition. The more muscle fibers become fatigued during the further execution of the set, the more previously inactivated fibers become activated. Once the point of momentary muscular failure has been reached, a near-maximum number of muscle fibers are recruited which comprises a large number of muscle fibers of both fiber types.

Training programs are usually geared at a certain number of repetitions. This approach has been criticized in the past as being insufficient (Denner, 1998). The results of the present study suggest considering further parameters and factors as well, such as: Repetition tempo/duration of each repetition and TUT. In order to exactly determine TUT, it is necessary to take into account that a certain number of repetitions does not necessarily result in the same TUT for every athlete as often suggested. Especially when comparing MST to SST the differing durations of repetitions have to be taken into account since they inevitably result in different TUT.

As a consequence of these findings, TUT should be added to the list of parameters that are taken into consideration when designing resistance training programs.

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JÜRGEN GIEßING & MANUEL SCHOHL

Muscle conditioning and improvements in soccer player performance

Keywords: Soccer, performance, pre-season conditioning phase, strength training, endurance training

Introduction

Various statistics confirm that soccer is the world's most popular sport. Game performance is determined by technical, tactical and coordination skills as well as physical constitution. Maximum success requires a customized fitness profile for every soccer player which is shaped by training and must be explicitly optimized. The basic foundation for physical parameters of the player such as strength and endurance is laid during pre-season conditioning. It was widely believed in the past that muscle conditioning is not necessary because it does not meet the requirements of a soccer player and is even counterproductive because it produces physical reactions which conflict with those of endurance training. There was concern that soccer players would lose speed and flexibility and forfeit endurance.

Meanwhile, however, a good deal of evidence suggests that the opposite is true, namely that specialized muscle conditioning optimizes the physical parameters for exceptional soccer-relevant skills.

For an ambitious soccer trainer even the supposedly prohibitive time factor is not an issue if high intensities and correspondingly low work units are used based on the principle of High-Intensity fitness-Training (Gießing, 2010). The HIT work-out with just one set per exercise is only about 30 minutes duration twice a week and therefore not a significant time loss in the training plan.

The following analysis will examine how physical parameters and performance capabilities of soccer players are affected by two short soccer-specific muscle conditioning sessions integrated in soccer training during the pre-season conditioning.

Methodology

A well-planned pre-season conditioning phase is an important element in the yearly training cycle and should optimize the player for the stress of the upcoming season. To this end a muscle conditioning program, especially designed for the pre-season conditioning phase, was integrated in the training plan of a soccer team on ambitious amateur level. The muscle conditioning program was executed twice a week during the pre-season conditioning phase in the form of drill training. The study period lasted six weeks. The ideal ratio of stress to recovery is especially relevant to success. Tests were carried out at the beginning and end of pre-season training to make any changes in endurance, strength and muscle cross-section tests transparent. A control team with virtually identical training plan during the pre-season conditioning phase but with no muscle training was incorporated. Identical tests were conducted at the beginning and end of the pre-season conditioning phase for direct comparison of teams. The teams play in the same league but in different districts. Both teams underwent a cooper-test during the study period at the beginning and end of the pre-season conditioning phase as an endurance indicator. Three more tests were conducted to check current strength levels (standing long jump, maximum number of push-ups, maximum number of pull-ups). Furthermore a so-called bio-electrical impedance analyzer measured body composition, specifically fat and muscle mass before and after the pre-season conditioning phase.

To effectively analyze the effects of muscle conditioning appropriate exercises must be set in advance which will trigger physical changes in the trainees. The program was set up to give the test team one weekly muscle conditioning training session on the soccer field and one in the gym. If required both training sessions can also be completed on the soccer field. An additional gym unit can act as a supplement for variety but is not essential. For muscle conditioning, too, the focus of the training work-out is laid on the soccer field.

The frequency of muscle training was twice a week because this frequency has proven to be particularly favourable for the ratio of training effort to training progress (Gießing, 2010). The high efficiency of the HIT work-out with only one intense set per exercise allows seamless integration of muscle conditioning into soccer training. Both on the soccer field and in the gym a pre-season conditioning set was carried out first, followed by a training set to the point of muscle failure, i.e. as many repetitions as possible were performed until another complete repetition was not possible.

Table 1 shows the test persons participating in the study and their average age, height and weight at the beginning of the pre-season conditioning phase.

Table 1: Persons tested

	Test Team (N = 13)	Control Team (N = 11)
Age (years)	23.6 ± 10	21.3 ± 6
Height (cm)	183.5 ± 20	176.8 ± 21
Weight (kg)	77.2 ± 25.2	76.5 ± 37.2

During the six weeks of the pre-season conditioning phase in which the coaches of both teams pursued almost identical course content and goals the test team completed 32 and the control team 29 training sessions. Strength training was included in 14 of the test team's 32 sessions. At least twice a week, strength was targeted specifically as a physical skill.
The following chart lists different exercises integrated in the muscle conditioning specially chosen for this study, both for the gym and for the soccer field. The exercises for the soccer field are such that can be carried out on a standard soccer field without any further accessories.

Table 2: Training exercise

On the soccer field	In the gym
chin-ups	bench press
Push-ups	incline press
squat	peck-deck
situps	Lat pulldowns
back extensions	dumbell schoulder laterals
flies	situps
calf-raise, one leg at a time	biceps curls
hurdle jumps	triceps extensions
running upstairs, one leg at a time	chin-ups
medicine ball throws with legs	
rope pulls	

Results

Comparison of initial and final values of the two teams

A comparison of the initial and final results of both teams reveals a definite correlation to muscle conditioning. The test team that trained for strength was able to achieve a significant increase in all implemented tests. For example the cooper-test at the end of the pre-season conditioning phase showed an average of additional 219 running meters. In addition the players were able to complete an average of four additional push-ups. They were also able to do about two more pull-ups than in the first test. The distance reached in the standing long jump increased by an average of 3 cm (Figure 1).
Figure 2 compares the initial and final test results of the control team. In only two of the four tests better results were achieved. The results of the final test reflect the lack of muscle conditioning. Muscles which are less strained during

soccer training but needed to perform push-ups or pull-ups were not integrated in the training of the pre-season conditioning phase, which explains the suboptimal test results. The players of the control team achieved an average of only 48 push-ups in the final test although they had already accomplished an average of 51 push-ups in the initial test. Also the number of pulls-ups deteriorated. Instead of the 11 repetitions in the initial test the players could only complete ten repetitions to the point of sudden muscular failure. In the case of the standing long jump the increase again was not as pronounced as that of the test team. Jumps showed an average increase of only one centimeter.

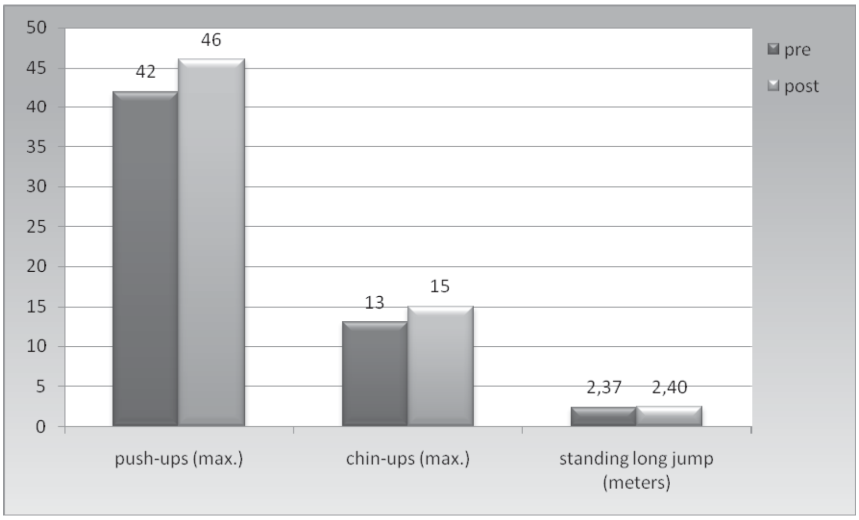

Figure 1: Test Team (average initial and final measurements)

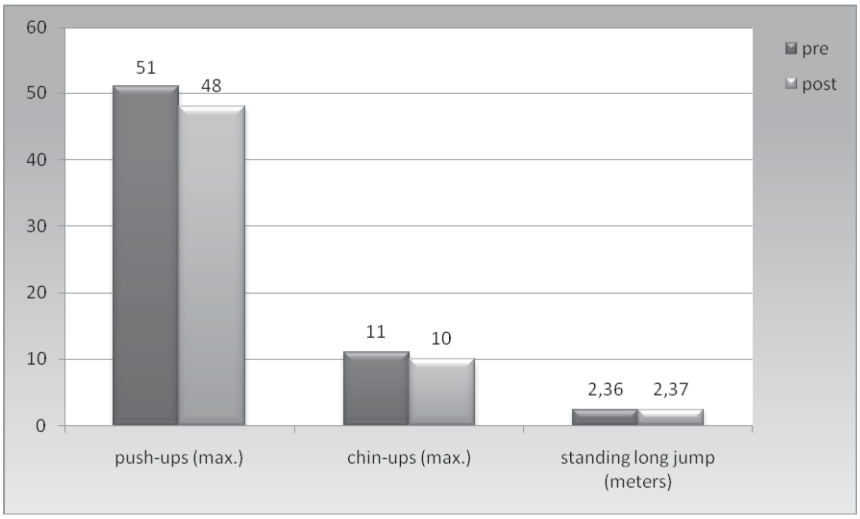

Figure 2: Control Team (average initial and final measurements)

Endurance training played a major role in both training plans and improvement was expected in the cooper-test. The control team, however, did not even come close to the impressive increase of the test team. They were able to run an average of only 55 meters more than at the beginning of the pre-season conditioning phase. Interestingly, the test team not only gained strength but also endurance, which clearly shows that muscle training condition did not degrade the endurance values.

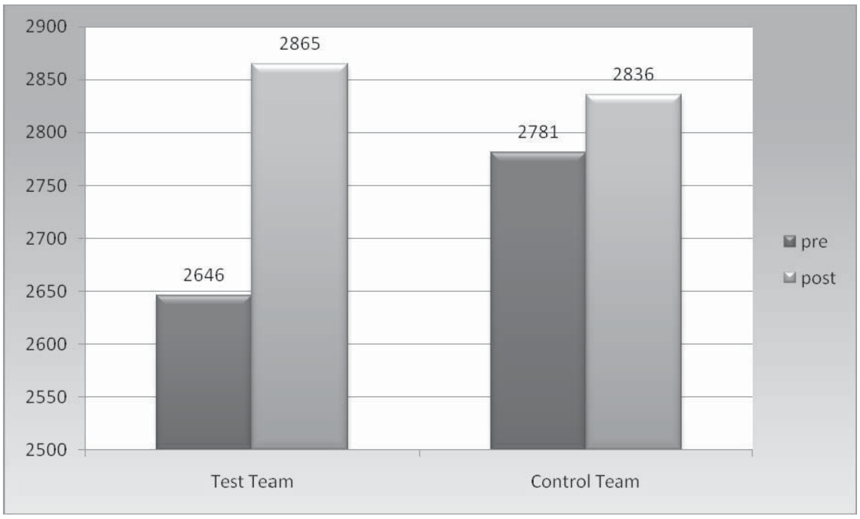

Figure 3: Results of the cooper-test (test team and control team)

Body composition

Despite enormous improvement in the strength tests the test team players did not gain muscle mass in trunk and arms. The strength increase obviously results from the improved intra- and intermuscular coordination. The muscles of the trunk and arms, used comparatively less than the leg muscles, would have required a few more weeks of muscle training for muscle growth. However, a significant growth of muscle mass was noted in the leg muscles which were used intensively over a long period. The muscle gain was not noticeable on the scale because the players lost as much as body fat as they gained muscles and total body weight remained unchanged. The control group which did not do specific muscle conditioning in their soccer training reacted much differently. During the pre-season conditioning phase they lost muscle mass not only in trunk and arms but also in the legs.

Figure 4 shows the percentage change in values for body composition after the pre-season conditioning phase. It is very evident that the test team players built up more muscle mass (0.5 %) than those in the control team who actually lost muscle mass by an average of 0.3 %. In addition, the players of the “muscle training team” were able to reduce their fat more drastically than those of the control team.

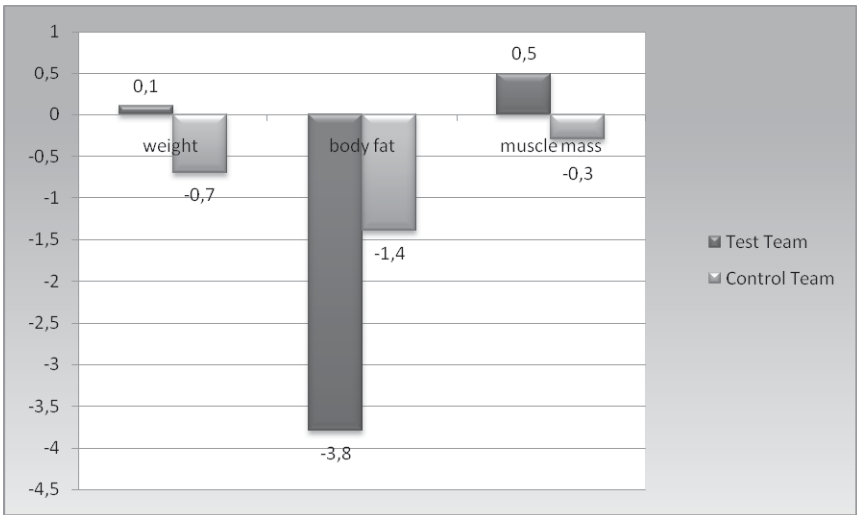

Figure 4: Percentage change of weight, body fat and muscle mass in both teams

A striking difference is evident in the leg muscles. While the test team players increased their leg muscle mass by an average of 3.2 % the control team players lost an average of about 0.5 %. As a result the leg muscles, which are used heavily in both strength and conventional soccer training, show clear signs of hypertrophy whereas the control team players showed loss of muscle mass due to lack of muscle excitement in the pre-season conditioning phase. The values of the control team players dropped not only in the strength tests but also in the analysis of physical condition. The most prominent examples in both teams produce a definite trend by attending training regularly and undergoing high stress levels in each exercise. Two test team players achieved tremendous hypertrophy effects. Even the control team players who gained muscle mass and attended regularly were not able to gain as much as muscle cross section as these control team examples.

Discussion

The results prove the importance of strength training during the pre-season conditioning phase. The loss of strength, especially in the less stressed trunk muscles, is immense. Figure 5 shows the percentage change in the values of both teams after the pre-season conditioning phase. Clearly, the strength training team, i.e. the test team, in spite of similar type and number of work-outs in the pre-season conditioning phase, achieved more improvements in all test areas. Thus the players improved around 8.3 % in the cooper-test. The control team players could only improve by 2 %. Even in the standing long jump, where the improvements were not unusually great, the test team achieved a three times higher increase over the control team.

If we look at the value changes in push-ups and chin-ups the importance of strength training during the pre-season conditioning phase becomes very clear. These two tests in particular reveal dramatic differences. The test team players improved by 9.5 % whereas the control team players worsened by 5.9 %. The percentage difference was even more significant in the pull-ups. The players of the muscle training team improved by an average of 15.4 % the control team players deteriorated by 9.1 %.

A muscle training program integrated in the pre-season conditioning phase therefore produces significant gains in strength in the majority of players. In spite of identical training types and methods in both clubs the players in the test group improved more than four times as much as the control team, even in the cooper-test.

This indicates that muscle training incorporated in the training plan does not degrade the endurance values at all, but rather has a positive effect. The notable increase in push-ups and chin-ups is more unmistakable evidence of the effectiveness of strength training during the pre-season conditioning phase. Even more, so when the absence of muscle conditioning in the pre-season conditioning phase and with the focus on other types of stress results in a very obvious loss of strength in the upper body muscles.

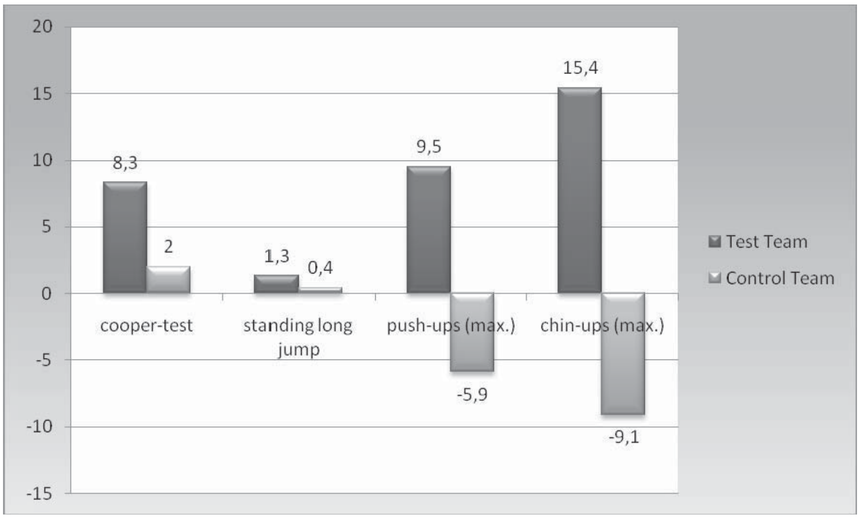

Figure 5: Percentage changes in test results of both teams

The current results as a whole show the superiority of the pre-season conditioning phase which included strength training. After evaluating the test results we must assume that skipping any form of strength training during the pre-season conditioning phase leads to an enormous decline in muscle mass and a correspondingly great loss of strength. Moreover, it is also obvious that even the leg muscles must be specifically targeted with individual strength exercises if progress is to be expected. The test team players clearly achieved better results in all tests than the players of the control team. They definitely appear to be in better shape, mentally stronger and physically more robust as shown by the changes in test results in particular the enormous improvement in the cooper-test. It appears this is an ideal method of increasing strength during the pre-season conditioning phase of soccer teams whether they play on the lower, middle or higher amateur level. This study reveals impressively through the example of the control team that leaving out strength training in the pre-season conditioning phase leads to enormous loss of strength and muscle mass decline in all muscle groups tested.

Does muscle conditioning influence endurance?

A closer look at the test results reveals that the strength-trained test team did not only do much better in the strength tests but also achieved strikingly high improvements in the cooper-test during the pre-season conditioning phase. The test team players ran an average of 219 meters more than in the beginning of the pre-season conditioning phase: The control team gained only about 55 meters. The common concern that muscle conditioning has a negative impact on endurance is disproved by this study. Figure 6 shows that the test team members improved in the cooper-test by about 8 %; the members of the control team improved by only 2 %. This would indicate that muscle conditioning in fact might be beneficial for endurance values and by no means degrades them.

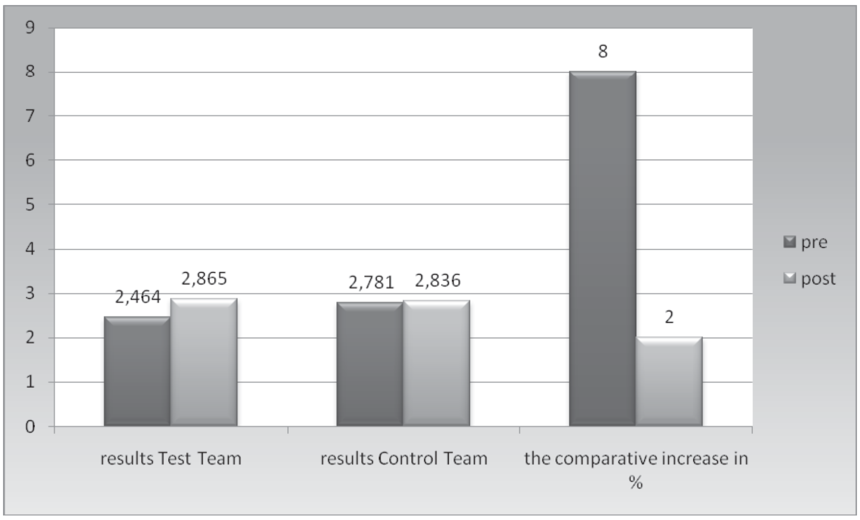

Figure 6: Cooper-test results (absolute) and comparative improvements (percent)

Conclusion

The early wide-spread concern that muscle training makes soccer players slow, inflexible and degrades their endurance can no longer be supported. As Weineck pointed out as early as 2004 (p. 203) “top players not only possess a higher aerobic and anaerobic capability but also have more pronounced muscular strength characteristics”. The present study confirms that the skills attained by special muscle conditioning can effectively support improvement in physical condition. In addition, it was shown that in periods of increased physical stress leg muscle strength can worsen as seen in the pre-season conditioning phase. Not only can this muscle decline be prevented by specialized soccer-relevant muscle training – it can also be reversed so that in the end of the pre-season conditioning phase the scope and performance skills of leg muscles actually increase.

To this end only two short muscle conditioning sessions, which are easily incorporated in the training program, are required. One pre-season conditioning set and one intensity set per exercise will suffice.

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MICHAEL MAC MILLAN & JÜRGEN GIEßING

Eccentrics and high intensity training

Keywords: High intensity training (HIT), eccentric training, degrees of training intensity, muscular fatigue, speed of movement

Introduction

The word “intensity” is derived from the word “tense” or “tension”. Although intensity has general meanings regarding mental stress or the impact of an event, in a physical sense, intensity refers to the magnitude of a physical action. Thus a “low intensity” event is interpreted as a relatively low level of mechanical tension, while “high intensity” suggests a high level of tension. In terms of physical exercise, intensity relates to the amount of effort. The highest value of intensity is when maximum effort is exerted and a single burst of force is measured; such as the distance thrown, the speed attained, or the weight lifted. If effort is exerted for longer periods of time or over greater distances the level of force must be controlled to ensure that it continues throughout the specified time or distance. Marathoners do not run at top speed for the whole race, nor would a lifter try to do ten repetitions with his or her one repetition maximum. As the time or distance over which the exercise lasts gets longer the amount of force generated becomes less. Thus intensity training, as it is practiced is time dependent. When a muscle generates a low level of continuous tension for as long as possible, the amount of time during which the muscle is under tension is relatively long, whereas when resisting a high level of continuous tension the time period is relatively short.
As it applies to strength training, applying resistance against the trunk or limbs while the lifter raises and lowers the weight by bending and extending the involved joints creates intensity. A generally accepted concept is to perform an exercise until no further repetitions can be performed. This stopping point is called “The point of momentary muscular failure (PMF)” and is relative to the amount of weight being lifted (Table 1). Thus if you knew the maximum strength or force capacity of a limb movement and supplied a resistance that was 50 to 70 percent of that maximum, you could expect the lifter to be able to perform serial, uninterrupted repetitions for about 60 seconds. As you decrease the amount of weight applied, the number of predicted repetitions, and length of time, would increase, as the resistance increases the number of predicted repetitions decreases.

Table 1: Overview of the different degrees of training intensity (Gießing et al., 2005)

Degrees of training intensity (DTI)	
n-RM	non repetition maximum Terminating a set at a fixed number of repetitions or a certain rate of perceived exertion whereas additional repetitions are possible.
RM	repetition maximum Terminating a set after the final repetition that can be completed in proper form.
PMF	point of momentary muscular failure Terminating a set when concentric failure has been reached, i. e. the final repetition cannot be fully completed due to fatigue.
PMF+	point of momentary muscular failure plus HITM Training beyond failure by applying high intensity training methods (HITM) like forced repetitions, drop set, cheating etc.

Another generally accepted truism is that the highest training response to exercise occurs when maximum effort is applied. More precisely, muscle has a certain reproducible, predictable training response for an exercise that is a low intensity exercise and different adaptation to an exercise that creates maximal high intensity. Physiologically, muscle adapts to the duration of time it is under load and to the magnitude of the applied load (Tabata et al., 1996). The adaptation to the length of time under load is an alteration in the energy metabolism, quality of the contractile proteins and the micro-circulation within the muscle. In contrast, the adaptation to the magnitude of the load occurs through the quantity of contractile proteins and the organization of musculotendinous tissues (Hather et al., 1991). Generally, magnitude and duration are inversely proportional; meaning that the higher the magnitude of the load the shorter the duration of time that the lifter can support it, and vice versa.

When a lifter does a maximal number of repetitions the exercise stops because of reaching the PMF secondary to fatigue exhaustion. The heavier the weight the shorter the amount of time it takes to fail. Generally speaking, for an exercise to be considered “high intensity” the number of continuous repetitions should be relatively low. A muscle subjected to heavy resistance for a short period of time will adapt differently than a muscle exposed to long duration, low resistance exercise. This is analogous to a car having different fuel efficiencies for city than for highway driving. Thus one response of muscle to exhaustive exercise is to increase its “fuel efficiency” under the specific conditions under which it is exercised.

There is however an entirely different physiologic response related uniquely to the magnitude of the applied load. In addition to the metabolic response mentioned above there is also a structural response. This is analogous to increasing the “horsepower” of the muscle. Muscle has two physiological processes to change its effective cross sectional area. One is the routine process of ho-

meostasis in which muscle proteins are in a constant state of turnover. Protein anabolism produces and incorporates contractile and supportive proteins into the muscle and protein catabolism constantly breaks down and removes proteins from the muscle. These two processes are in balance and are influenced by a number of factors. Although, neurologic, endocrine, and metabolic factors have been shown to have an influence on anabolism and catabolism, the dominant effect of resistance training is the level of mechanical tension transmitted through the musculotendinous tissue. Through its cytoskeletal system of large non-contractile proteins, force applied through the muscle is detected by the nuclei of the contained cells (Lieber et al., 2002). In conditions of inactivity, where little or no force is being transmitted through the muscle, the homeostatic process tips in favour of catabolism and muscle structure is reduced; with high force transmission the anabolic enzymes dominate and muscle density and cross sectional area increases.
Thus if increased power production is the desired goal of the weight training program, using higher levels of resistance would best achieve this result. Increased resistance results in increased muscle mass, reduced resistance results in reduced muscle tissue.

The physics of "forcibly lengthening a muscle"

There is however another physiological process that creates greater cross sectional area in the muscle than simply influencing the homeostatic balance of anabolism and catabolism. This is the much more robust system of muscular repair and regeneration. To understand how repair and regeneration can be utilized for training, a simple, basic law of physics has to be understood first. It basically is Newton's third law of physics that states that energy is neither lost nor gained in any physical action. In terms of weight lifting this means that when you lift a weight, energy is transferred from the muscle and is transformed into the potential energy by increasing the height of the weight relative to the ground. Simply put, when you lift a weight you transfer energy from the muscle into the weight. But what is not widely appreciated is that when the weight is being lowered energy is transferred as the weight lowers. The energy in this case is transferred from the potential energy of the elevated weight and converted into kinetic energy and (by decelerating the weight through muscle activity) it is then converted into strain energy within the muscle. Strain energy is the same mechanism whereby elastic materials (i.e. rubber bands) can accumulate force.

This is where a clear definition of an eccentric muscle action is helpful. It is a "forced lengthening" of a muscle that is being stimulated to maximally contract. More precisely, it is not the muscle just letting the weight lower; it is the weight forcing the muscle to lengthen while the muscle is trying to shorten. Therefore by definition, the amount of weight that can force a muscle to lengthen is a value that exceeds the maximum voluntary contraction force that the muscle can generate. Knowing this, it is possible to understand why true eccentric resistance can effectively stimulate repair and regeneration. The weight exceeds the force capacity of the muscle and compels it to lengthen. This is a true overload (Heinemeier et al., 2007).

The strain seen by the muscle during forcible lengthening is entirely dependent on the level of the applied resistance. As the applied external resistance is increased the muscle has to absorb more and more strain energy until there is actual disruption of the contractile proteins. There is a relationship between the magnitude of the eccentric resistance and the extent of the micro-trauma seen within the muscle. This relationship is an opportunity to "dose" the exposure of the muscle to the micro-trauma. When the resistance just exceeds the one repetition maximum (1-RM) it is in fact the minimum "safe and effective" dose of eccentric resistance. It is "effective" because it is intense enough to create the forced lengthening required to stimulate growth. It is "safe" because at the 1-RM level the muscle has demonstrated its ability to withstand this load during maximal testing.

Thus, the 1-RM is a safe and effective starting amount for eccentric loading. By having the lifter lower a weight that is at or just exceeds his 1-RM, powerful physiological processes of repair and regeneration can be invoked to stimulate increased contractile protein production and hence hypertrophy. It is not recommended to give lifters resistances that significantly exceed their maximum capacity, because of the possibility of causing "macro-damage", i.e. muscle injury.

How is "eccentric PMF" defined?

If the eccentric application of the 1-RM induces muscular repair and regeneration, what is the length of time over which that should be applied, i.e. what is the duration of application? To apply the HIT philosophy to the application of eccentric resistance, the resistance should be applied until failure is achieved. Failure is easily observed and documented with concentric exercise. When fatigue reduces the force generating capacity of the muscle so that it drops be-

low the level of the applied resistance, failure occurs relative to that level of resistance. Failure of the eccentric lowering of a resistance is more difficult to assess and related to the load velocity curve of eccentric muscular lengthening. By definition, once an eccentric weight begins lengthening the muscle, it travels in a direction opposite to the concentric raising of the weight. By definition, the concentric direction is considered “positive” and the eccentric direction is considered “negative”. This has significant implications on how we define “power” of a lift. Typically, in concentric lifting, power is the product of load and velocity; the faster the weight moves, the higher the power generated. But eccentrically, the relationship of load to velocity is inverse; the higher the load, the higher the velocity. Eccentrically, as the lifter is placed under heavier and heavier loads, the velocity of descent increases, but the product of the load and a negative velocity is a large negative value. Intuitively this makes sense; if you are asked to slow the descent of a heavy cart down a hill, the weaker individual lets the cart roll down quickly, the stronger one can prevent runaway acceleration of the cart. Thus eccentrically, the faster a weight forces the muscle to lengthen the greater the negative value of the power produced; the power decreases with speed of movement.
You therefore want to control the weight during the eccentric lowering of an exercise and prevent increasing the speed with which the weight descends. Failure to control the speed of descent of the eccentric weight means that eccentric failure at that level of resistance has been reached. The duration of application is the number of serial repetitions that can be performed without allowing the speed of descent to increase.

When does eccentric PMF occur?

The question arises as to how many repetitions can typically be done with the 1-RM before rapid increases in descent indicate eccentric failure. It is well documented that eccentric lengthening of a muscle is extremely resistant to fatigue (Abbott, 1952; Lindsteth et al., 2001). During serial repetitions concentric force production capabilities of the muscle drops off quickly for the concentric stroke of the lift, but even when complete concentric exhaustion is reached, the lifter can still control and lower the resistance during the eccentric stroke of the lift. There is inevitably a point at which fatigue prevents controlled descent of the eccentric resistance. Although further study is needed, it appears anecdotally from our practical experience and from dynamometer data that eccentric failure with a 1-RM resistance does not occur until true momentary muscu-

lar failure is achieved of the concentric phase. True momentary muscular failure is complete exhaustion of the force producing system of the muscle, not just at one resistance level. This means that some type of stepwise decline in concentric resistance is necessary to completely exhaust the muscle's concentric strength before you reach "eccentric failure". Even if the eccentric load is reduced as well, at the point of momentary muscular failure (PMF), the muscle cannot generate any meaningful resistance to even a fraction of the 1-RM in the eccentric phase.
This means that the perfect, "ideal" set of repetitions that would maximally stimulate muscle growth and endurance would use a concentric resistance that would decrease with successive repetitions until it was virtually "zero", and the eccentric resistance would be the 1-RM that would be used until the lifter could no longer control its descent. Advanced technology is required to apply this sequence of resistance.

Advanced resistance technology

To ensure that each individual exercise provides the most effective stimulus possible during one particular session, each and every repetition must satisfy a very specific set of conditions. The following seven conditions will predictably lead to maximal structural growth and anaerobic stamina of the exercised muscle, while providing safe loading conditions:

1. Maximal voluntary effort should be exerted during both lengthening and shortening for each and every repetition (Maximum Effort).
2. The level of resistance must be proportionate to the force capacity of the muscle throughout the range of motion (Variable Resistance).
3. The resistance must be applied through the full range of movement allowed by the involved joints (Full Range of Motion).
4. The concentric resistance should be adjusted to maintain a velocity that approximates the peak power of the movement (Isokinetic).
5. The eccentric resistance should be at or just above the one repetition maximum (Iso-eccentric).
6. The set is continued until true, complete concentric failure (PMF+).
7. Decreasing the eccentric resistance should be done rapidly and increasing the concentric resistance should be done without impulse forces (Transitions).

A set of repetitions performed under the above conditions will stimulate increased strength and power of the trained muscle even when performed only one time per week. The rationale for each of these conditions is explained below.

Maximum effort

By assuming full, concentric effort, it is possible to control the speed of movement. If full effort causes the weight to travel too quickly, simply increase the starting concentric resistance and this will slow the speed of the lift without consciously slowing down. As fatigue affects the lifter, each maximum effort results in successively slower speeds. Before fatigue causes the set to end, it is possible to lower the resistance to permit further repetitions to be done. Lifting a resistance that is sequentially, incrementally lightened will lead to complete anaerobic failure. If you cannot assume full effort, it is impossible to know if the number of repetitions performed actually represents the capabilities of the athlete, and hence decisions made about weight increases will be inaccurate. Thus, an important dictum of truly effective training is that a full effort is exerted throughout the exercise.
On the eccentric side, true eccentric loading requires a resistance that “forcibly lengthens” the muscle. Two useless events can occur if the lifter is not giving full effort. The first is that the lifter is not being “forced” to lower the weight, but rather he is just letting the weight to descend. Voluntarily lowering a weight does not result in any meaningful training stimulus. Secondly, if the weight is heavy enough to give effective resistance, but the lifter does not give full effort and the weight simply falls down, no meaningful training occurs. Full effort during the eccentric part of the movement is mandatory to receive full benefit.

Variable resistance

Although not specific to eccentric resistance, variable resistance ensures that the muscle is stimulated maximally at each point along its range of motion. When resistance is preferentially applied at some points along the range of motion and not at others, the muscle can develop disproportionate strength in limited portions of the strength curve. Muscle architecture dictates that when exercises are performed in different positions, that different regions of the muscle are preferentially affected. This concept is discussed under workout design. Thus, variable resistance transmits signals to largest number of nuclei within the muscle.

Variable resistance can be achieved by using a single resistance and varying the leverage it has over the range of motion to approximate the strength curve of the muscle. Alternatively, resistance can be modified by varying the resistance itself as seen when chains are used to increase the amount of weight applied or elastic bands are used to decrease the amount.

Full range of motion (FROM) training

The purpose of full range of motion training is to preserve joint motion. Ultimately, the goal is to increase the ability of the muscle to generate an increased level of force throughout the entire length of the muscle. Another justification for performing full range of motion exercise relates to the leverage system through which muscles exert their action. In a multi-axial movement such as the bench press, the weight is loaded initially onto the shoulder through the locked elbow that is positioned almost straight up and down. The joint structures are bearing almost all the load and very little muscle force is required. As the weight descends the arm angles outward away from the body and more muscular effort is required to support the weight. The practical application of this, again, concerns going through the full range of motion. The lifter who only brings the bar down half way may be handling a heavy weight but the actual force generated by the muscle is relatively small. Therefore, the lifter who lowers a weight less than the full range of motion is actually reducing the effectiveness of the exercise in two different ways. Not only is a small portion of the muscle being exercised but also the actual amount of force the muscle is generating may be inadequate to stimulate muscular growth.

Isokinetic concentric speed of movement

The usual application is to apply a known resistance that results in a certain speed of exercise movement. This of course is the conventional method of resistance training. The standard strategy in this method is to control the applied resistance, and let the user exert some arbitrary level of effort to achieve a predetermined speed, i.e. 2 seconds up 4 seconds down, etc. The ideal situation would be for the lifter to exert a maximum effort and to manipulate the resistance to create the desired speed of movement. Given that lifters are exerting a maximal effort, the speed at which the muscles contract depends on the amount of the load that is being handled. At maximum effort, a light resistance will allow the muscle to contract rapidly, and then as the resistance is increased, the speed at which the muscle contracts will decrease. Therefore, to

adjust the time or duration that the muscle is under load, you need only to adjust the magnitude of the load. In other words, lifting speed is a by-product of a maximum effort by the athlete exerted against a known resistance. Therefore, the "right" lifting speed is achieved by applying the "right" resistance.
One of the best known relationships in muscle physiology is the change in the shortening speed of a muscle depending on the amount of load applied. This load-velocity curve comes from exposing a contracting muscle to many different levels of isotonic resistance. This collection of points describes a curve which is inversely proportional, meaning that the lighter the weight, the faster the speed of contraction (i.e. movement) and the heavier the weight the slower the speed of contraction. The relationship is also not a straight line; in fact it is a hyperbolic curve. This curve means that there is a large increase in velocity with relatively small reductions in weight. With this curve you can estimate how fast a load will travel when it is acted upon by a maximally contracting muscle. What then is the optimal speed? The answer comes from the analysis of power. If you are riding a bicycle with multiple gears there is usually one gear selection that gives you maximal power output. If you choose a gear level that is too "light", you may be able to travel at the speed you choose but the pedals will spin rapidly and inefficiently. Likewise, choosing a gear level that is too hard, the pedals will move slowly and clumsily. There will be one gear level for the speed and inclination you wish to travel that will be most efficient; too little or too much resistance makes you less effective.
The relationship of load to velocity can indicate the optimal speed of movement by determining the power curve for each specific load-velocity curve. Power is the rate of doing work. It can be expressed as the amount of work (force × distance) done per unit time. Since the amount of distance covered in a unit of time is velocity, i.e. miles per hour, power is equal to force times velocity. It is this last relationship that can be derived from the load-velocity curve. In fact, load-velocity is synonymous with force-velocity. The product of load and velocity can be calculated for each point on the curve. The power value is low at either end of the curve, because the velocity approaches zero at one end, and the load approaches zero at the other. However, in the middle there is a dome-like curve where work is being produced at significant rates. Depending on the muscle and movement involved, peak power occurs between 30 % and 70 % of peak velocity.
Therefore, the optimal concentric lifting speed is actually a range of loads that lie under the power curve for load-velocity. The range will also be specific for

the activity being performed. For example, Zink in 2006, found the force at peak power production in the barbell squat to lie somewhere between 60 and 80 % of the 1-RM. Likewise, Baker et al. in 2001 found the maximum power output in bench press to occur between 46-62 % of the 1-RM. Thus, there appears to be a relatively wide range of loads, usually above 50 % of the 1-RM, that are an appropriate starting resistance for the concentric portion of the repetition. However, as we will see next, even after one repetition, the relationship of the external load to the force production capacity of the muscle begins to change and demands further modification.

Eccentric speed of movement

Eccentric contractions are critical to achieving muscular hypertrophy. Simply put, muscle adapts to the amount of weight applied. As we have seen, it is only by loading a muscle during eccentric lengthening that energy is transferred into the muscle. This energy transference to achieve structural change however, needs to be done under careful control with verifiable, quantifiable resistance. Whereas the muscular force created during concentric resistance will never exceed the structural capacity of the muscle.

As was described for concentric shortening, the speed at which the muscle shortens is dependent on the amount of applied resistance, the amount of effort exerted, and the force producing capability of the muscle. This relationship holds true also for the lowering or eccentric phase as well, although the effect is opposite. If the lifter is exerting a strong effort against a descending weight and this weight just slightly exceeds the 1-RM, the weight will descend relatively slowly. As the weight increases over the lifter's maximum, it will certainly come down a greater rate of speed. The load-velocity curve for eccentric contractions is very simple. The heavier the weight the faster it travels, but it travels in the opposite, or negative, direction of the concentric movement.

Therefore, the power curves generated by the load and velocity of eccentric lengthening have a "negative" value. The highest power value is therefore the slowest movement which for the eccentric phase is the 1-RM. The ability to control the speed of lowering of the 1-RM continues as the muscle tires until complete failure occurs, at which point the lifter can no longer control the descent of the weight. When then, does "eccentric failure" occur? In order to continue concentric repetitions until true anaerobic failure occurs, there must be stepwise reductions in the concentric resistance to match it to the relative force capacity of the muscle at that point in time. Incredibly, repeated observations have shown that as long as there are any energy reserves to perform the concentric movement, the eccentric load can be lowered under control, even if it is set at the 1-RM. The fatigue resistance of eccentric muscular force is such that an initial eccentric load equal to the absolute 1-RM, can be successfully resisted until true, complete failure is reached. It is a built in "safety mechanism" that the concentric muscular force that loads the skeleton fails before the eccentric muscular force that unloads it. An eccentric resistance level equal to the 1-RM, when performed for several consecutive repetitions represents an effective true overload for the involved muscle. In fact it satisfies the basic requirements as the "Minimum Effective Dose" for structural transformation. This level of eccentric resistance is both safe and effective. It is safe in that by being the 1-RM the targeted muscle has demonstrated that it can resist this load without sustaining injury. It is effective because it is a level of resistance that the muscle is unaccustomed to bearing and therefore the muscle is stimulated to adapt.

True momentary muscular failure (PMF+)

By simply using a muscle, you change its capabilities. In the process of contracting a muscle you not only reduce the amount of energy available to perform further contractions, but you also create metabolic by-products that reduce the ability of the muscle to function optimally. Virtually all of what we consider "fitness" or "conditioning" is simply improving the capability of our muscles to maintain force even with limited energy available or high levels of local metabolic waste. True anaerobic failure occurs when a muscle has exhausted its fuel reserves or is "poisoned" by high levels of metabolic waste products.

As was previously stated, when a muscle applies force to a resistance that is between 50 % and 70 % of its maximum force production, the movement has high power output and therefore is a good source of constant resistance for muscle training. However, since this is a relatively heavy weight, the length of time that the muscle is under load is not sufficient to completely exhaust the energy stores of the muscle. This means that the exercise stops when the muscle can no longer raise the 50-70 % 1-RM, even though the muscle is capable of considerably more work. For example, if a lifter has a 1-RM in the standing arm curl of 100 lbs, he or she may be able to do six repetitions with 60lbs. The reason why the exercise stops after six repetitions is because the fatigued lifter can no longer lift 60 lbs. But, the lifter could lift 40 lbs. If the resistance could be reduced without stopping the exercise, further repetitions could be done and higher stress on the internal metabolism of the muscle would be possible. In fact, the ideal situation would be to introduce further stepwise reductions in the applied resistance until complete and total internal muscular exhaustion is achieved. This is true anaerobic failure and training to this level greatly improves the “fitness” or “conditioning” of the muscle.

In actuality on the last repetition of a set, at the point that the muscle fails, whatever resistance is being applied at that time is by definition, the Point of Momentary Muscular Failure (PMF). It is in fact, the maximum resistance that the muscle can create at that moment. If the lifter attempts one additional repetition, it will not be lifted. The only way for any further repetitions to be performed is to lessen the amount of applied resistance. At this point, to maintain the speed of travel where it is consistent with the previous repetitions, the new, lower resistance should be 50-70 % of the PMF. In the example above, when the lifter fails at 60 lbs, the resistance is changed to 40 lbs, which is about 60 % of the PMF (actually 66 %), and the lifter can continue the exercise at about the same speed of movement. This strategy represents a new paradigm for resistance training, i.e. the ability to change the resistance during the set without stopping the exercise and unloading the muscle. This process of lowering the resistance and allowing the exercise to continue beyond where failure would typically occur increases the anaerobic endurance of the muscle.

The only other means of achieving total internal muscular exhaustion is to simply apply a very low resistance at the outset of the exercise. There are three disadvantages with this method. The first is that the lifter will have to volitionally control the speed of lifting so that rapid accelerations and decelerations of the weight do not occur. The second is that the duration of the exercise is overly long. However, lastly and most importantly, it appears that the muscle has the capability to adapt to various levels of work intensity. In other words, there is specificity to the intensity of anaerobic work.

The adaptation of muscle occurs through altering the myosin molecule in response to the demands placed on the muscle. The best examples of this are sprinters, middle distance runners and long distance runners. Although they all performing maximally during their respective races, they do not perform as well when they try to run either longer or shorter distances. For maximal performance they have to train at the distance that they intend to race.

The advantage of controlling the concentric load is that the athlete continuously trains at levels of peak power, even when fatigue sets in. Since resistance training is done to increase strength and power, it should, therefore, be performed at maximal intensity, such as what is experienced at 50-70 % of the 1-RM. In traditional weightlifting, this however results in a short bout of exercise because of the inability to raise the heavy resistance after just a few repetitions. To prolong the period of exercise while simultaneously maintaining a high level of intensity a new, lower, level of resistance has to be introduced.

Transitions

Concentric muscle shortening goes in one direction; eccentric lengthening goes in the other. What happens, when the weight changes direction from raising to lowering, and vice versa, also has significant impact on the effect of the exercise. The two major factors at these reversal points are the reperfusion of oxygenated blood into the muscle and the release of stored elastic energy.
A muscle contracting with as little a force as 25 % of its 1-RM, essentially squeezes the blood vessels in the muscle belly and prevents perfusion of blood into the muscle. The lack of fresh blood from the systemic circulation forces the muscle into anaerobic metabolism. The declining oxygen levels along with the increasing lactic acid production create that well-known muscle ‘burn’. This metabolic stress is a desirable training goal, stimulating the muscle to function well during anaerobic conditions. To create a near maximal anaerobic stress, the muscle must be performing work, consuming oxygen, and excluding external blood flow for about 60 seconds. To prohibit arterial blood from perfusing into the muscle during exercise the muscle must be under constant tension for the full duration of the set. This specifically means that the lifter cannot rest between or during repetitions. Resting and allowing blood to re-perfuse the muscle would change the training concept into interval training, which would be a different kind of training method.
It has been stated that it is almost impossible to structurally enhance muscle and bones with concentric muscle contractions alone and that virtually every resistance exercise is concentric. This implies that no one should be able to build muscle yet clearly hypertrophy occurs with the use of standard equipment. The use of performance enhancing drugs aside, the key concept is applying overloads “safely”. One “unsafe” application of resistance training is to rapidly accelerate a weight. It is not that the acceleration is dangerous, but it is dangerous to use your muscles, bones and joints to stop a rapidly moving weight. This concept of moving a weight rapidly has been advocated because the present training philosophies only consider the concentric lift. If you rapidly accelerate a weight concentrically, whether in a machine or a free weight, typi-

cally the huge spike in kinetic energy created by rapid acceleration is either mechanically absorbed by the exercise device or, since the weight moves opposite from gravity, it is slowed by gravity.

None of this is true with a rapidly decelerating or falling weight. When you let a 100 lb curl bar drop rapidly and “catch” it at the bottom, that weight can transfer the equivalent of 300 lbs of impulse energy to the body; the “sling shot”-effect. As has been shown, exposing the muscles to supramaximal levels of force can stimulate structural growth; but, uncontrolled, rapid decelerations are dangerous, highly variable, and non-reproducible. Letting a weight essentially drop and catching at the bottom may unintentionally lead to structural growth, but is dangerous and contraindicated as a means of applying eccentric resistance.

This ‘sling shot’ effect basically uses the elastic components of the muscle to ‘catch’ the falling weight and generate a stretch-shortening contraction (SSC), which slows the descending weight, stores the energy, and then helps to propel the weight back in the opposite direction. The major drawback to the SSC is the unintended, high strain forces encountered by the muscular tissue. The peak strains can easily exceed the structural integrity of the muscle and cause frank tissue disruption. The potential for “macrodamage” and muscular dysfunction is high.

Thus the transitions between the concentric shortening and eccentric lengthening have stringent requirements to provide an effective training stimulus. First, there shouldn´t be a relaxation of the muscle at the reversal points that could allow reperfusion of the muscle. This would essentially destroy any training effect derived from exposing the muscles to low oxygen and high lactic acid levels. Secondly, the speed of the weight must be carefully managed when reversing directions to avoid sudden spikes of potentially injurious force.

Practical approximations of eccentric high intensity training

In order to achieve the ideal set, each and every repetition would have to split into an eccentric maximum stroke and decreasing amounts of concentric resistance. Basically, this is not possible with existing strength technology. To approximate the training effect of the ideal set, the eccentric portion can be done separately from the concentric portion. In order to get the maximum benefit and safety of this training program, the principals of the “ideal set” will need to be followed; but rather than following the principals concurrently during one set, they can be approximated by performing two or more consecutive sets.

The first step is to work the target muscle to exhaustion or concentric failure. This is in fact a commonly practiced technique of “drop sets” or “strip sets”. Although strict definitions of these terms do not exist, generally in drop sets the lifter uses a consecutive series of weights, each lighter than the previous, to reach concentric exhaustion. A solitary weight lifter without assistance can do drop sets. A common example is to begin at the end of the dumbbell rack with the heavier dumbbells and do as many repetitions as possible. After the heavier dumbbell set is completed, then switch to a lighter set of dumbbells and repeat. For barbells, the lifter would have to prearrange two, three, or even four different lifting stations of the same movement but with progressively lighter weights at each.

Another way to achieve concentric exhaustion is to do “strip sets”. Again, there are different interpretations of this term, but generally this means using a single barbell and “stripping” the weights off it during the set. This would require two assistants to remove plates off the barbell after the completion of one or more repetitions.

There are different strategies used to apply heavy eccentric overloads. Clearly the most common method is “cheating”. This means, particularly in the standing barbell curl, that the lifter uses a weight that is heavier than he or she can lift with strict form, so the weight is “cheated” up by swinging it up to the top position. The “heavier” weight is then lowered eccentrically with strict form. Similarly, the clean and jerk, an Olympic lift, can be used to position a relatively heavy weight above the head. However, once in position with the arms fully extended, the weight can be deliberately lowered as the eccentric stroke of a military press. One major disadvantage of “cheating” is the fact that it is potentially dangerous in terms of muscle, tendon and/or bone injuries and that it requires years of training experience to be applied effectively and safely.

One of the most common means of eccentric training without the use of assistants is done on selectorized weight training equipment. This is the “two up, one down” technique. As the name implies, exercises such as the arm curl are performed concentrically in the traditional two-arm movement, but then at the top of the movement, one arm is released, leaving the lifter to lower the now relatively heavy resistance with just one arm. This can be done with any machine that has a fixed axis, rigid movement arm for a bilateral exercise. Typically it is done for the quadriceps, the hamstrings, the biceps, and calf muscles.

There are a few unique movements that can be done independently to apply enhanced negative resistance. One is the so-called "Zottman Curl" where a dumbbell curl is performed with the hand in the supinated position and then rotating into the relatively weaker pronated position at the top of the movement. Lowering the heavy dumbbell in the reverse curl position applies a heavier than normal eccentric load to the brachioradialis muscle. Another fairly useful method has been promoted by the Scandinavians for the hamstrings. This involves kneeling down and locking the ankles under a fixed bar. The lifter can then simply let the body lean forward, and use the eccentric lengthening of the hamstrings brake the descent of the body towards the floor. Once completely face down on the floor, the lifter can use his or her arms to get back to the upright kneeling position so that the movement can be repeated. The most effective means of using eccentric resistance is to simply have two spotters. Obviously, the lifter would lower the heavy eccentric resistance and the spotters would raise it back to the top position.
To create the maximally effective set that combines anaerobic endurance and eccentric overload, each component would have to be performed in sequence. For example, in the bench press the lifter would start with 60-80 % of the 1-RM and the spotters would manually strip off weights until a resistance as low as 25 % of the 1-RM could not be completed. The bar would then be re-racked and the weight re-loaded to approximately the 1-RM. The spotters would then assist the lifter in slowly and carefully lowering the weight for at least 6 repetitions. It is highly recommended in performing eccentrics in the bench press and squat exercise, that the movement be done in a rack that provides side safety bars to prevent full descent of the bar.

New technologies for eccentric resistance

Because of the difficulty of safely and reproducibly "splitting the rep" into its concentric and eccentric components with manual methods, automatic systems of providing this have emerged. One system that we have employed for many years involves the use of a counterbalance weight stack (Kaminski et al., 1998).

Figure 1: Photo Maxout

This counterweight stack is locked in the raised position and is connected by a cable to the main weight. In the case of the bench press the cable courses from the middle of the bar to a small empty carriage plate underneath the raised counterbalance weight stack. For example, as the lifter lowers the heavy 150 kilo barbell the cable from the barbell pulls the carriage plate up along the guide rods underneath the counterbalance weight stack until the 150 kilo bar is fully lowered. At this point, the carriage plate is underneath the weight stack and it triggers the release of the counter balance weight stack. If the released counterbalance weighs 50 kilos, it exerts a "helping" assistance to effectively convert the barbell weight to only 100 kilos when it is supported by the carriage plate. The lifter can then raise the entire barbell back up to the fully raised position, the 50 kilo counterweight assisting the lifter. The counterbalance is manipulated by a small motor which senses that the lift is completed and raises the counterweight back to the top position. Once this happens, the lifter is again solely supporting the full 150 kilos in the top position and is ready to lower the heavy weight back down in an eccentric repetition. This can be repeated for as many repetitions as required.

Since the counterweight which assists in the concentric lift is a weight stack, the amount of the counterweight can be manipulated as well. Thus, it is possible to change the pin selection in the counterweight while it is being held in the fully raised position during the eccentric part of the lift. Adding more counterweights, creates more assistance and effectively lightens the resistance felt by the lifter. This creates a very beneficial effect of reducing the concentric resistance at any time during the set to accommodate fatigue. In the example above, once the lifter has difficulty in concentrically raising the barbell with 100

kilos of effective resistance, 10 more kilos of counterweight could be applied. Now the lifter only has to raise 90 kilos, which allows the set to continue despite the onset of fatigue.
There is another eccentric-capable system available which works by changing the angle over which the main weight stack travels, to change the amount of resistance needed to move the weight stack. Thus, when raising the weight stack it may be tilted backwards to reduce the amount of force needed to raise the weights. Once the weights have travelled the full distance up the guide rods, the angled weight stack is tilted back into the fully upright and locked position. The weight stack now exerts its full weight, vertically against the lifter who can lower it in a controlled manner. Before the weight stack is raised again, it can be tilted back to make it easier for the lifter to move it. Presumably, by manipulating the degree and timing of the tilt, various combinations of resistance can be applied.

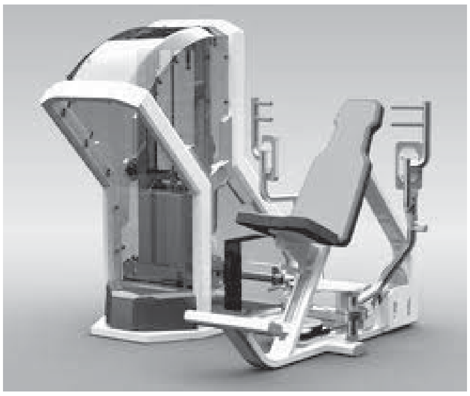

Figure 2: Photo X-Force

Other eccentric systems simply apply motorized resistance against the muscle. Although simple motors are probably safe and effective for concentric muscle actions, it is potentially dangerous to use this for eccentric force application. This is because a motorized movement arm exerting force against a contracting muscle will keep applying force even as the lifter resists. This causes the force levels to rise to very high levels within the muscle. Since there is no external control the amount of force the muscle sees, it is quite possible that a single maximal effort could cause muscle tearing. Any reasonable technology must control the maximal force the muscle can be exposed to during the eccentric portion of the lift.

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THOMAS KORFF

Children are not miniature adults – insights gained from kinematic and kinetic analyses of movement

Keywords: Children, anthropometry, growth, force, maximum power

Introduction

The notion that children are not just miniature adults when performing motor tasks is widely accepted. While it is intriguing to think that children perform motor tasks in an adult-like fashion – just less controlled, research has shown that the mechanisms underlying age-related differences in the execution of motor tasks are multi-factorial and cannot always be attributed to an immature nervous system. The maturation of the nervous system is undoubtedly a factor leading to improvements in the execution of motor tasks (Vaughn et al., 2003; Zelazo, 1984). However, it is the interaction between many factors that ultimately leads to age-related changes in motor behaviour. These factors include (but are not limited to) maturation of the nervous and musculo-skeletal systems, segmental growth and psychological factors (Clark, 1994; Jensen, 2005; Thelen, 1995). Age-related changes in these factors occur simultaneously, and it is important to acknowledge the relevance of each within the context of motor development.

Biomechanical analyses can give us unique insights into the multi-factorial nature of motor development. In this chapter, it is discussed how kinematic and kinetic analyses of movement provide us with different levels of understanding about the mechanisms underlying motor development.

Kinematics, kinetics and redundancy – implications for motor development

Kinematic analyses are concerned with the description of movement in terms of positions, velocities and accelerations. Kinetic analyses are concerned with the forces and torques that cause movement. Kinematic analyses are useful to describe developmental changes in the execution of movement on a behavioural level. Kinetic analyses provide us with information about the mechanisms that underlie such changes (Winter & Eng, 1995). In a developmental context, the different levels of biomechanical analysis allow us to investigate different aspects of the acquisition of motor skills (Jensen & Korff, 2005). One example that illustrates the usefulness of the different levels of biomechanical analyses comes from the developmental walking literature. Forssberg (1985) quantified differences in kinematic characteristics in walking patterns between toddlers and adults and found that toddlers demonstrate exaggerated levels of hip and knee flexion during the swing phase of gait. While it is intuitive to speculate that the exaggerated levels of joint flexion are due to an increased tone of the corresponding muscles, the kinetic analysis by Jensen et al. (1994a) gave us more differentiated insights. These authors found that the exaggerated joint flexions in children are not only due to exaggerated muscular flexor torques about the corresponding joints, but also to the complex interplay between muscular, gravitational and motion-dependent influences. In a similar fashion, kinetic analysis of movement have helped us to gain a more differentiated understanding of the development of other gross motor tasks, such as kicking (Jensen et al., 1994b), reaching (Konczak et al., 1995, 2003), cycling (Korff & Jensen, 2007; Korff et al., 2009b), and postural control (Roncesvalles et al., 2001, 2004).

When performing kinetic analyses of movement, it is important to understand that the human body is a redundant mechanical system (Bernstein, 1967) and that the same (kinematic) outcome can be achieved using a number of (kinetic) strategies. For developmentalists, this mechanical redundancy is important to acknowledge as it implies that children can perform the same (kinematic) task using different (kinetic) inter-muscular coordination patterns when compared to adults. For example, Jensen and Korff (2004) used a submaximal cycling task to test children's and adults' adaptability in response to changes in movement speed in terms of kinematic variability. By adjusting the bicycle to the children's body dimensions, they ensured that children and adults were performing the same (kinematic) task. They found that on a kinematic level, children respond in an adult-like fashion to changes in movement speed. Expanding on this finding, a similar experimental paradigm was used to test children's adaptability in terms of (kinetic) inter-muscular coordination (Korff & Jensen, 2007). Again, the authors ensured that the kinematics of the movement were similar across all participants. However, they found differences in inter-muscular coordination patterns between children and adults – particularly at the higher movement speeds. Together these findings provide an example of children adapting adult-like on a kinematic level but not on a kinetic level. They thereby emphasize the importance of the different levels of biomechanical analyses of movement. Such an understanding is important for teachers and youth coaches who are most often limited to the use of kinematic information.

Age-related changes in anthropometry

It is well known that children's segments are not miniature versions of those of adults. In humans, relative segment lengths change dramatically between infancy and adulthood. For example, the relative leg length of a newborn is significantly shorter (relative to whole body size) than that of an adult (Prader et al., 1989; Timiras, 1972). During childhood and adolescence, relative segment lengths become more and more similar to those of adults (Figure 1).

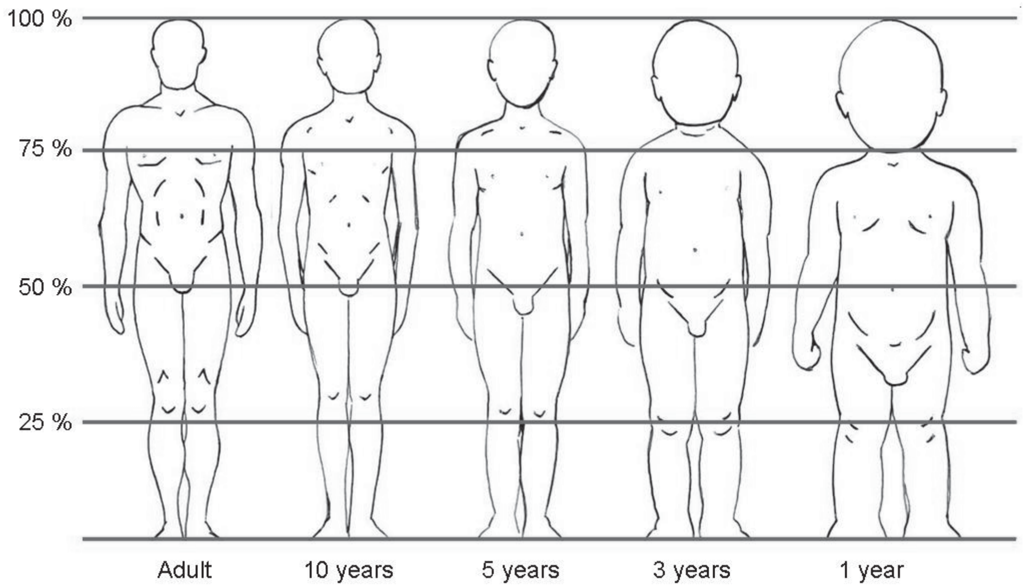

Figure 1: Age-related changes in segment lengths (adapted from Timiras, 1972)

However, not all segments grow at the same rate. In addition to age-related changes in relative segment lengths, the inertial segmental properties change in a non-linear fashion during infancy (Schneider & Zernicke, 1992) and childhood (Ganley & Powers, 2004; Jensen, 1986, 1988, 1989). Jensen (1989), for example, demonstrated that the mass proportion of the thigh segment (relative to total body mass) increases from 8 to 12 percent between 4 and 20 years of age (Figure 2). Furthermore, relative segmental centre of mass locations as well as segmental radi of gyration change in a non-linear fashion during childhood (Jensen, 1989). Together, these findings make it obvious that from a purely anthropometric perspective, children are not miniature adults.

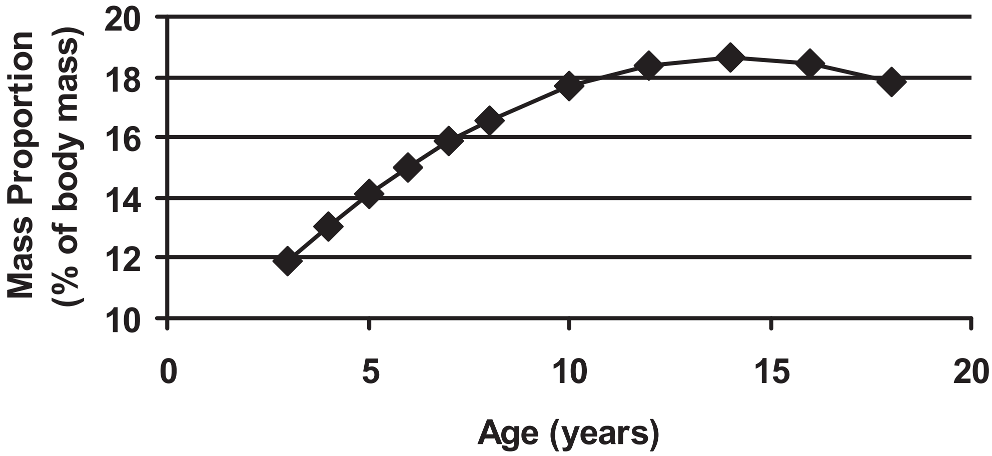

Figure 2: Age-related changes in the relative mass proportion of the thigh between 4 and 20 years of age (adapted from Jensen, 1989)

Effect of age-related differences in anthropometry on movement kinematics and kinetics

An understanding of developmental changes in anthropometry is important as these may result in differences in movement kinematics between children and adults. One obvious example comes again from the walking literature. Sutherland (1997) showed that during the acquisition of walking, children increase their walking stride length between 1 and 4 years of age. An obvious explanation is the mathematical dependency of stride length on leg length: Age-related increases in stride length are directly due to an increase in leg length (at least partially). It is worthwhile noting, however, that even after eliminating the influence of leg length, younger children exhibit smaller (normalised) step lengths when compared to their older peers, which is due to an increased demand for stability in new walkers (Sutherland, 1997).

A less obvious but perhaps more intriguing consequence of age-related differences in anthropometry during childhood is their effect on the forces and torques that cause movement. Within the context of human movement, mechanical forces and torques can be divided into non-muscular and muscular. Muscular forces and torques are a consequence of cross bridge formation and myofilament movement within the muscle's sarcomeres (Huxley, 1975). Their biomechanical analysis gives us important insights into the strategies of the central nervous system (Winter & Eng, 1995). Non-muscular forces and torques include gravitational, motion-dependent and external forces and torques. Gravitational and motion-dependent forces are directly influenced by body anthropometry, which has important implications for movement. The importance of the interaction between developmental changes in anthropometry and gravitational and muscular torques can be illustrated by the simplified example of a person holding their leg (assumed to be one rigid segment) in a horizontal (static) position as indicated in Figure 3. The torque induced by gravitational forces about the hip joint (T_{GRA}) is equal to the product of the weight of the leg ($W_{LEG} = m_{LEG} \times g$) and the perpendicular distance (d) between the leg's centre of mass and the centre of rotation (i.e. the hip joint):

$$T_{GRA} = -m_{LEG} \times g \times d = -W_{LEG} \times d \qquad (1)$$

Where T_{GRA} is the gravitational torque, g is the gravitational acceleration of 9.81 m/s^2, m_{LEG} is the segmental mass of the leg, W_{LEG} is the segmental weight of the leg and d is the perpendicular distance between the centre of mass of the leg and the hip joint.

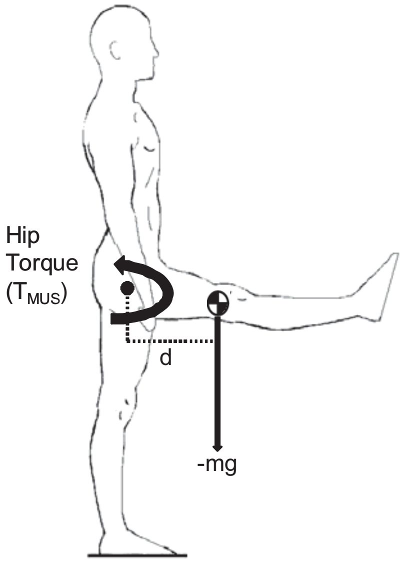

Figure 3: Muscular and gravitational torques required for static equilibrium

According to Newton's third law, the person is required to apply a muscular torque (T_{MUS}) that is equal in magnitude and opposite in direction to the gravitational torque ($+m_{LEG} \times g \times d$) to hold the leg in static equilibrium. From equation (1) it is evident that the above-mentioned developmental changes of segmental mass proportions (which are contributing to m_{LEG}) or segmental centre of mass locations (which are contributing to the distance d) have direct implications for the muscular torque that is required to hold the leg in static equilibrium (i.e. an increase in the segmental mass of the leg requires a greater muscular torque to hold the leg in static equilibrium). This simple example illustrates that developmental changes in anthropometry can directly influence the application of muscular forces and torques via their effect on non-muscular influences.

During dynamic movements, differences in anthropometry can have even more complex effects on the production of muscular forces or torques. Due to the presence of motion-dependent (centripetal and centrifugal) forces and torques, muscular forces have to be matched to both gravitational and motion-dependent influences to produce a resultant force or torque that causes the desired movement. A simplified mathematical equation (2) illustrates these interactions.

$$T_{RES} = T_{MUS} + T_{GRA} + T_{MDT} + T_{EXT} \qquad (2)$$

Where T_{RES} is the resultant torque, T_{MUS} represents muscular torques, T_{GRA} represents gravitational torques, T_{MDT} represents motion-dependent torques and T_{EXT} represents external torques.

Both T_{GRA} and T_{MDT} are directly influenced by the anthropometrics of the performer. If a motor task requires a certain resultant torque to be applied, muscular torques have to be matched to non-muscular and external torques to satisfy equation (2). If non-muscular torques change (i.e. as a result of age-related changes in anthropometrics), muscular torques must be adjusted to keep the resultant torque constant.

Experimental evidence for the interactions between anthropometry, gravitational, motion-dependent and muscular forces/torques during dynamic movements has been provided using a cycling paradigm, a kinematically controlled task. Brown and Jensen (2003) observed differences in the application of muscular forces during cycling between children and adults, which suggested anthropometry-driven age-related differences in the distribution between muscular and non-muscular forces. In a second experiment, these authors added mass to children’s legs, which then resulted in a more adult-like distribution between muscular and non-muscular forces in children (Brown & Jensen, 2006). Results from this second study confirmed the initial speculation that observed differences in muscular force application are due to anthropometry-driven differences in non-muscular forces and a resulting need to match muscular forces differently. Brown and Jensen's results were extended by Korff and Jensen (2008) who used a biomechanical simulation to demonstrate that age-related changes in relative anthropometrics (i.e. relative segmental masses, centre of mass locations and radii of gyration) can affect muscular power production. Together, these findings demonstrate that differences in muscular force, torque or power production in children (when compared to adults) are not necessarily immature, but can be functional muscular adjustments to anthropometry-driven age-related differences in non-muscular forces.

Determinants of maximum power production during complex motor tasks

Another example of kinetic analysis giving us differentiated insights into the mechanisms underlying motor development is the age-related increase in maximum muscular power production during complex motor tasks. It is well documented that the ability to produce maximum power during complex motor tasks such as jumping or cycling increases as children grow older (De Ste Croix et al., 2001; Feretti et al., 1994; Korff et al., 2009a; Martin et al., 2000). Within this context, it is intuitive to hypothesise that children become more powerful because of increases in muscle mass. Indeed, increases in muscle mass (Blimkie, 1989; Kanehisa et al., 1995) are undoubtedly a major factor contributing to age-related changes of maximum power production. However, it has been consistently shown that changes in muscle size cannot account for all these changes. For example, Martin et al. (2000) showed that only 76 % of age-related changes in maximum power production during cycling can be attributed to differences in muscle mass. Similarly, Feretti et al. (1994) and Korff et al. (2009a) demonstrated that during maximum vertical jumping, not all age-related differences in maximum power production can be attributed to differences in muscle or body size.

From these results, the question arises as to which additional factors contribute to age-related increases in maximum power production. Again, the answer to this question is multi-factorial. Potential contributors to the development of maximum power during multi-joint tasks include age-related changes in inter-muscular coordination (Korff et al., 2009b), motor unit recruitment (Kanehisa et al., 1995), antagonistic co-activation (Keefer et al., 2004; Lambertz et al., 2003), and a muscle or joint specific development of muscular strength (Asmussen & Heeboll-Nielsen, 1954; Denis & Korff, 2009). Recently, we also found developmental differences in the relationship between leg stiffness and maximum power production during vertical jumping (Korff et al., 2009a), suggesting that the ability to store and release elastic energy could be an additional factor, which contributes to the development of maximum power production. While each of the above factors has been investigated individually, little is known about their relative importance with respect to the development of maximum power production. To understand the development of maximum power production more holistically, future research should be designed to take several potential contributors into consideration.

Conclusion

In summary, kinematic and kinetic analysis of movement give us insights into the multifactorial nature of the mechanisms underlying motor development. Specifically we have learnt that:

- Children may perform the same (kinematic) motor task as adults but use different inter-muscular coordination patterns. This is due to the redundancy of the mechanical (human) system.
- From an anthropometric perspective, children are not miniature adults, as segmental growth is non-linear.
- Developmental differences in anthropometry affect muscular force production during isometric and dynamic tasks via the interaction of muscular and non-muscular forces.
- As a result, observed differences in (kinematic) movement behaviour and muscular force, torque or power production are not necessarily immature, but can be functional adjustments in response to age-related differences in anthropometry.
- Not all age-related differences in maximum power production during complex motor tasks can be attributed to differences in muscle or body size. The development of maximum power production is multifactorial, but more research is needed to understand it more holistically.
- Results from developmental biomechanical analyses reinforce the notion that children are not miniature adults, which has implications for teachers and youth coaches.

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WOLFGANG RAUBUCH, DOMINIK HABERECHT, MICHAEL FRÖHLICH & JÜRGEN GIEßING

Outcome-effects of high intensity pre-exhaustion vs. post-exhaustion in muscle hypertrophy training

Keywords: High-intensity training methods, exhaustion, strength, pre-exhaustion, post-exhaustion (priority system)

Introduction

It is generally accepted that inducing muscular hypertrophy requires a certain time under tension (TUT) as well as training intensities that surpass a certain threshold.

Times under tension that translate into six to twelve repetitions (depending on repetition speed) and relative intensities of about 70 to 85 % of 1-RM are likely to result in physiological consequences associated with myogenetic expressions (Adams, 2010; Eleftheriou & Montgomery, 2008; Schoenfeld, 2010; Spurway & Wackerhage, 2006). Regardless of the controversy concerning the optimum number of sets per exercise (Fröhlich et al., 2010), several high intensity training methods (HITM) are commonly applied in order to increase training intensity and TUT of a given set (Gießing et al., 2005). Although training to muscular failure is not necessary for muscular hypertrophy to occur, especially in beginners – it is generally accepted and well documented that training near or even beyond muscular failure is likely to result in greater muscular hypertrophy than lower levels of training intensity (Bührle & Werner, 1984; Müller, 2003; Richmond & Godard, 2004; Zatsiorsky & Kramer, 2008). Therefore a variety of HITM is commonly applied in hypertrophy training with the goal of taking training intensity to the point of momentary muscular failure (PMF) or beyond (PMF+) which means that the training stimulus is kept up at an adequate level of muscular tension (mechanical stimulus) over an extended time span (metabolic stimulus). Therefore, TUT is extended without sacrificing muscular tension. The following study compares the effects of pre-exhaustion vs. post-exhaustion as methods of high intensity training (HITM).

Pre-exhaustion

The basic consideration that led to developing pre-exhaustion as a high intensity training method is that when large muscle groups are trained using compound exercises such as the squat, the bench press or chin ups muscular failure occurs before the target muscle has been stimulated optimally because the smaller and therefore weaker muscles which contract synergistically during that exercise will fatigue before the actual target muscle does. Through pre-exhausting the target muscle by doing a single-joint exercise (like flies) immediately before a compound multiple-joint exercise (like the bench press) the target muscle is already fatigued to a certain extent when the compound exercise is performed whereas the auxiliary muscles are less exhausted and thereby relatively stronger than without the pre-exhaustion.

Post-exhaustion

When applying post-exhaustion as a high intensity training method the same exercise combinations are used. The decisive difference between post- and pre-exhaustion is that the order in which the exercises are performed is reversed. Post-exhaustion means that a multiple-joint compound exercise is immediately followed by a single-joint exercise (Fröhlich & Gießing, 2006). The idea behind this approach is that by doing the multiple-joint exercise first, it should be possible to increase the workload and then continue to fatigue the target muscle by immediately doing a single-joint exercise (Fröhlich et al., 2007, Spreuwenberg et al., 2006).

Research on pre- vs. post-exhaustion as high intensity training methods and exercise order in strength training

In 1996 Sforzo and Touey studied the relevance of the order of exercises when multiple-joint exercises were either done before or after single-joint exercises for the same target muscles in the same workout and analyzed “Total Force” (TF) and “Fatigue Rate” (FR). The study showed that when multiple-joint exercises were done before single-joint exercises physical total work was 13.6 % greater than when workouts were begun with single-joint exercises (Sforzo & Touey, 1996).

> “Cumulative TF was greater when structural exercises (multi-jointed) were done first. Fatigue rate and TF for the bench press were substantially decreased when single-jointed exercises preceded structure ones.” (Sforzo & Touey, 1996, p. 20)

Similar results were found by Simão et al. (2005) and Spreuwenberg et al. (2006). Kraemer and Fleck (2007, p. 46) explain the reason for these findings:

> “The rationale for this order of exercise is that by performing the multijoint exercise first or early in a training session, a superior training stimulus is presented to the muscles involved in the multijoint exercises. This is thought to be mediated by a greater neural, metabolic, hormonal, and circulatory response, which may augment training of muscles or exercises later in the training session.”

Research that focuses on pre-exhaustion as a method of high intensity training was conducted by Maynard and Ebben (2003) and Augustsson et al. (2003). Both research teams concentrated on leg exercises. Maynard and Ebben analyzed the effects of antagonistic pre-exhaustion. They had 20 male wrestlers perform a set of leg extensions (5-RM) immediately followed by a set of leg curls (5-RM). Contrary to what they had expected, EMG-analyses showed that antagonistic supersetting did not result in increased muscle activation of the target muscles (musculus quadriceps femoris) which led the authors to the conclusion:

> “This study demonstrates that antagonist /agonist superset training may not be the most effective system of weight training as evidenced by a reduction of torque, time to peak torque, and power during subsequent agonist sets.” (Maynard & Ebben, 2003, p. 473)

Kraemer and Fleck (2007, p. 47) point out that the aspect of neural coordination should be taken into consideration: “Multijoint exercises also require greater neural coordination than single-joint exercises.”
Augustsson et al. (2003) studied the effects of pre-exhaustion for compound sets consisting of the exercises leg extensions and leg press expecting this compound set to result in an improved activation of the target muscles:

> “Weight trainers using this method believe pre-exhaustion exercise would result in greater muscle activation for the subsequent multijoint exercise because presumably the pre-exhausted muscle is engaged in both exercises.” (Augustsson et al., 2003, p. 412)

Their study, however, showed a reduced activation in the target muscles (musculus rectus femoris and musculus vastus lateralis) so that the authors concluded:

> “Future Research in this area should address the effect of a reversed pre-exhaustion strategy, as our data support the notion of pre-exhausting small synergistic muscles, rather than prime mover agonistic muscles.” (Augustsson et al., 2003, p. 415)

Gentil et al. (2007) studied maximum load for the 10-RM test (total repetition) as well as “Total Work” during sets using either pre-exhaustion or post-exhaustion. They also used EMG-analyses for musculus triceps, musculus deltoideus and musculus pectoralis major. 13 subjects with an average training experience of 7.4 years took part in the study using a cross-over design. All exercises were taken to the point of momentary muscular failure. Gentil et al. (2007) found an increased activation of smaller synergistic muscles once the primary target muscle reached a certain level of exhaustion. In contrast to the results of studies by Sforzo and Touey (1996), Fröhlich and Gießing (2006), Fröhlich et al. (2007), Spreuwenberg et al. (2006) and Bellezza et al. (2009) they did not find differences between pre-exhaustion and post-exhaustion concerning total repetitions or total work.

Brennecke et al. (2009) compared one pre-exhaustion compound set to a regular hypertrophy program. The compound set consisted of the exercise flying motion (isolation exercise) and bench press (multi-joint exercise). Twelve male subjects with an average training experience of 8.8 years performed both exercises of the compound set using their 10-RM for each respective exercise. The neural activity of the musculus pectoralis major, musculus deltoideus anterior and triceps brachii were studied using EMG. As a result of their study the authors reported that applying pre-exhaustion did not result in an increased activation of the target muscle (musculus pectoralis major) but activation of the musculus triceps brachii was slightly increased (Brennecke et al., 2009). Because of these nonuniform results (Augustsson et al., 2003; Brennecke et al., 2009; Gentil, 2007; Maynard & Ebben, 2003; Simão et al., 2005; Fröhlich & Gießing, 2006; Fröhlich et al., 2007) the need for longitudinal studies becomes obvious.

Methods

Study design and treatment

29 male subjects with a training experience of at least six months took part in this study. 42.9 % of the subjects had a training experience of six or more months and 57.1 % of the subjects had been training for twelve months or more. The 1-RM for each of the exercises used in this study was determined and subjects were then assigned to one of the three groups: Pre-exhaustion group (11 subjects), post-exhaustion group (11 subjects), and control group (7 subjects). There were no significant differences in pre-test performances (between the three groups). Table 1 shows the anthropometrical data. Depending variables were 1-RM, 12-RM, physical work performed (W), and rate of perceived exertion ([RPE] using the Borg CR 10 scale). Due to the circumstance of the point of momentary muscular failure the eccentric and concentric distance were incorporated individually into the calculation of the physical work performance [$w = m \times g \times (2 \times \text{distance}) \times \text{repetitions}$]. Training and test exercises were the smith machine chest press and the peck deck. Control variables were age, body weight, TUT, number of repetitions, range of motion, load, training experience, and motivation.

Table 1: Anthropometrical data of the subjects

Parameter	Post-exhaustion (N = 10)	Pre-exhaustion (N = 11)	Control group (N = 7)	Total (N = 28)
Age (years)	23.50 ± 1.65	23.64 ± 1.50	25.00 ± 1.91	23.93 ± 1.72
Height (cm)	180.40 ± 5.29	179.77 ± 8.40	182.07 ± 8.31	180.57 ± 7.19
Bodyweight (kg)	78.02 ± 7.43	76.87 ± 9.96	85.90 ± 20.67	79.54 ± 12.82
Range of motion	39.90 ± 3.63	38.14 ± 4.43	40.00 ± 3.65	39.23 ± 3.93

In order to exclude the possible learning or habituation effects a habituation phase of one week was included in the study (Fröhlich & Marschall, 2001) followed by a training phase of six weeks and a detraining phase of one week. Four strength tests were undertaken during the study, each time the 1-RM and the 12-RM for the smith machine chest press was tested. Subjects trained twice a week for six weeks. Including the habituation phase and the detraining phase and the tests, the study took nine weeks to be conducted (Figure 1).

T1	Habituation phase	T2	Training phase	T3	Detraining phase	T4
	1 week		6 weeks		1 week	
familiarization-test		pre-test		post-test		retension-test

Figure 1: Study design

Both treatment groups trained twelve times, each time performing three sets to the point of momentary muscular failure (PMF), resting three minutes between sets (Gentil et al., 2007; Richmond & Godard, 2004). Training sessions were followed by at least 48-72 hours of regeneration time. Subjects in the control group took part at all the tests but did not participate in any kind of strength training.

Results

1-RM-tests and 12-RM-tests

Both methods of high intensity training, pre-exhaustion as well as post-exhaustion, resulted in significant increases in strength as shown in the 1-RM-test and 12-RM-test respectively. Mean and standard deviation of the three groups are shown in Table 2. The 1-RM test showed significant higher increases of performance ($p < 0.05$) of the post-exhaustion than of the pre-exhaustion, from pre-test to post-test, and from pre-test to retension-test. The 12-RM-test did not show significant difference between the two methods from pre-test to post-test and from post-test to retension-test. The control group showed no significant changes for any of the test periods.

Table 2: Results of 1-RM-tests and 12-RM-tests

Group	Pre-test (T2)	Post-test (T3)	Retension-test (T4)
	1-RM (kg)	1-RM (kg)	1-RM (kg)
Pre-exhaustion (N = 11)	82.68 ± 14.37	86.55 ± 15.03	87.45 ± 14.05
Post-exhaustion (N = 10)	75.50 ± 09.66	81.75 ± 09.39	82.25 ± 09.24
Control group (N = 7)	80.93 ± 19.41	81.64 ± 19.55	83.07 ± 17.92
	12-RM (kg)	12-RM (kg)	12-RM (kg)
Pre-exhaustion (N = 11)	53.14 ± 07.86	57.00 ± 07.61	57.23 ± 07.94
Post-exhaustion (N = 11)	49.45 ± 07.73	54.25 ± 07.21	55.25 ± 06.46
Control group (N = 7)	47.71 ± 11.16	46.64 ± 11.29	49.50 ± 11.99

Physical work

When post-exhaustion was applied, physical work was reduced by 12.2 % from set 1 to set 2 and 8.1 % from set 2 to set 3, which represents a fatigue rate (FR) of 19.3 %. The respective results for the pre-exhaustion group were 16.5 % and 10.1 % and a total fatigue rate (TFR) of 24.9 % (Figure 2). A significant reduction of physical work was found for pre-exhaustion as well as for post-exhaustion ($p < 0.05$).

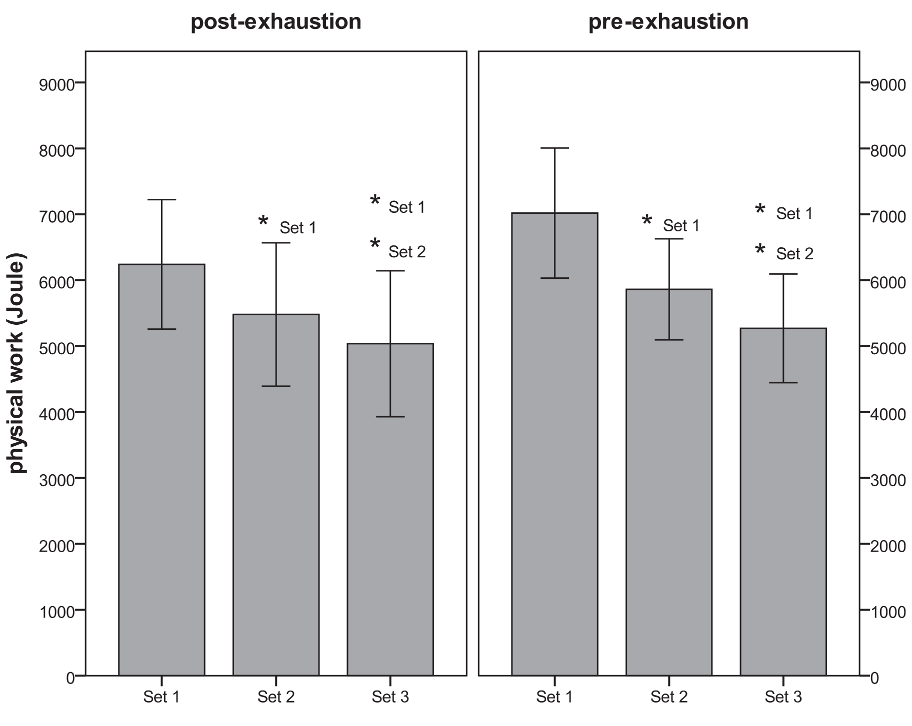

Figure 2: Physical work during compound sets using post-exhaustion or pre-exhaustion

Over the course of 12 training sessions the pre-exhaustion group increased physical work by 20.5 % whereas the subjects in the post-exhaustion group increased physical work by 11.5 % (Figure 3). The main effect (test dates) shows significant results ($F = 12.57$; $p < 0.05$; $d = 0.87$). There are no significant differences between treatment groups ($F = 1.05$; $p = 0.32$).

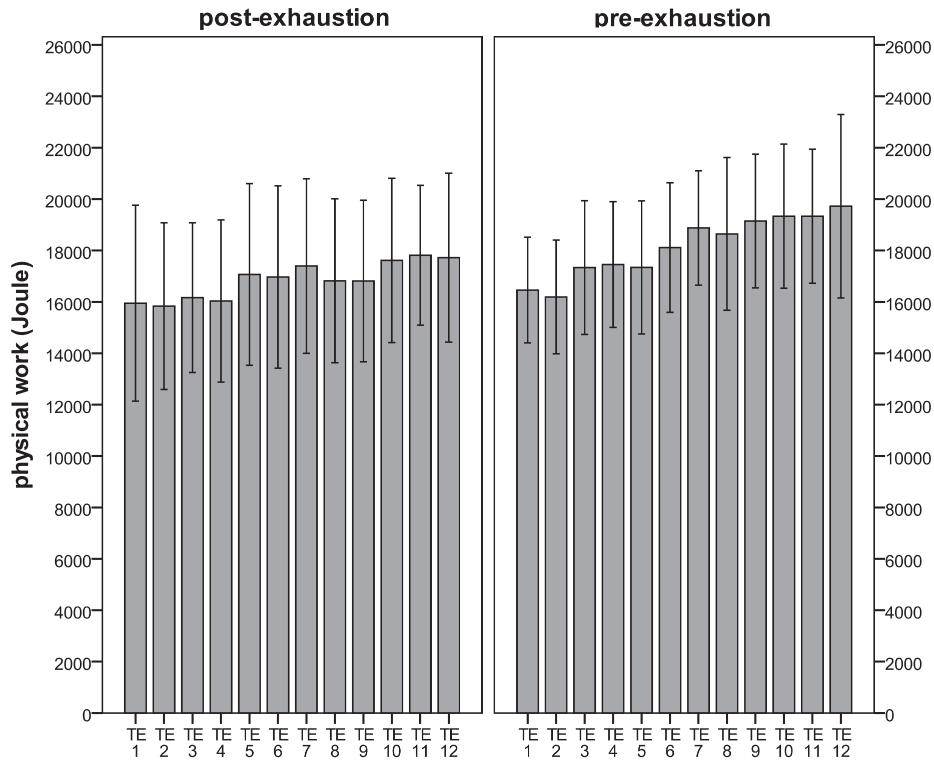

Figure 3: Changes of physical work over the course of 12 training sessions for the treatment groups post-exhaustion and pre-exhaustion

Rate of perceived exertion (RPE)

On average post-exhaustion increased RPE by 7.1 % from set 1 to set 2 and by 1.6 % from set 2 to set 3, which means an increase of 8.8 % over the course of all three sets. Pre-exhaustion increased RPE by 16.1 % from set 1 to set 2 and by 11.0 % from set 2 to set 3, which means an increase of 28.0 % for all three sets with a significant main effect ($F = 35.39$; $p < 0.05$; $d = 1.33$). RPE is lower for pre-exhaustion at set 1, whereas post-exhaustion produces higher RPE for sets 2 and 3. Determining an average RPE for all three sets shows no significant differences between pre-exhaustion and post-exhaustion ($t = -0.24$; $p = 0.82$).

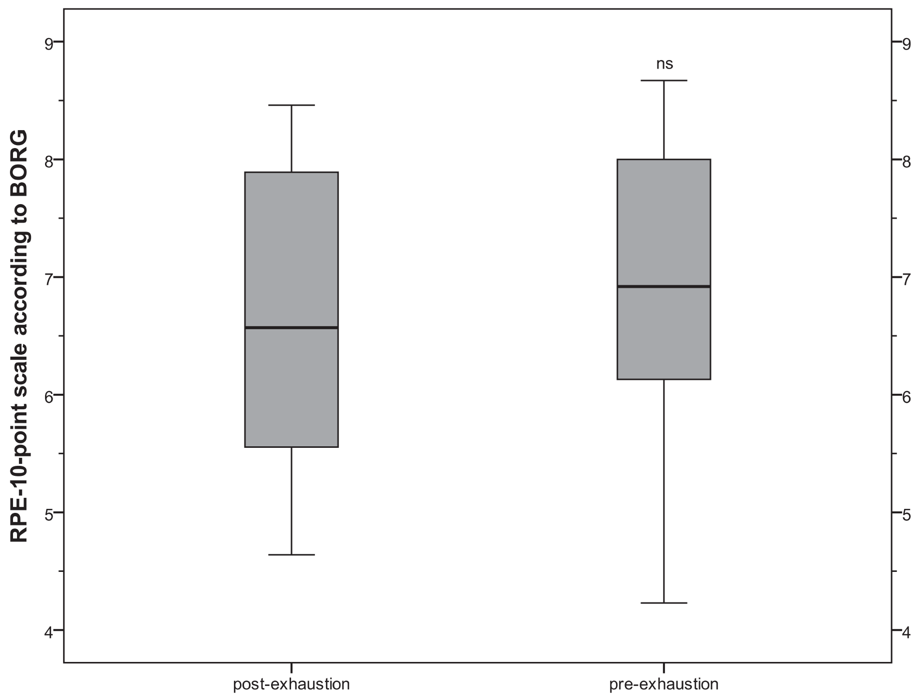

Figure 4: Boxplot of the average RPE of all twelve training sessions for post-exhaustion and pre-exhaustion

Discussion

Both training methods resulted in a considerable increase of maximum strength after six weeks of training. Based on the findings of other training studies such an increase can be expected (Spineti et al., 2010). However, post-exhaustion produced higher outcome effects than pre-exhaustion, especially in terms of temporarily delayed effects (Schlumberger & Schmidtbleicher, 1998). The results of the 12-RM test are more difficult to be interpreted since there were enormous fatigue rates between the tests which suggest that the first test of each test date is the most relevant one.

The results concerning physical work show slightly higher levels for pre-exhaustion that do not reach a statistically significant level. The results at hand are in agreement with those by Gentil et al. (2007), who could not find significant differences of physical work between pre-exhaustion and post-exhaustion. Bellezza et al. (2009, p. 208) suggest to train smaller muscles before larger muscles for trainees with limited exercise tolerance:

> "Applying the results to exercise prescription, a small to large muscle group order might be more beneficial for sedentary, elderly, or obese individuals when trying to improve health."

Fröhlich and Gießing (2006), too, found no significant difference for a compound set (targeting musculus pectoralis major) between pre-exhaustion and post-exhaustion but did find levels of physical work that were 4.5 % higher during the third set of post-exhaustion than for the third set of pre-exhaustion.
The longitudinal study at hand shows levels of physical work that are 7.3 % higher for pre-exhaustion over all three sets, not reaching a statistically significant level.
The inconsistent results of several studies conducted in this context are most likely due to the different experimental and test settings (single-set training in the study by Gentil et al., 2005; determining training load by using 12-RM in the study by Fröhlich and Gießing, 2006). The present study used training loads of 6-RM to 8-RM for each one of the exercises.
Not only FR but also RPE increases gradually from set to set. It can be stated that RPE increases similarly to FR as can be shown using the Borg scale showing no significant differences between both groups. These results are in agreement with those by Bellezza et al. (2009), Simão et al. (2005) and Spreuwenberg et al. (2006) who also did not find any significant differences. Neither did Fröhlich et al. (2007).

Methodological limitations and practical application

Methodological limitations of the present study result from the rather limited number of subjects and the limited number of training sessions (two sessions per week for six weeks).
The study cannot answer the question whether or not pre-exhaustion or post-exhaustion may produce higher outcome effects than conventional strength or hypertrophy training programs using similar TUT.
However, it can be concluded that post-exhaustion may be a beneficial alternative for experienced trainees looking for ways to increase training intensity (Fröhlich & Gießing, 2006; Fröhlich et al., 2007). Some subjects show enormous strength increases of up to 12 kilograms by using post-exhaustion as a method of high intensity training. Therefore, more studies should be conducted concentrating on the effects of post-exhaustion in experienced athletes. Another aspect that should be looked at is the combination of post-exhaustion and drop sets in order to further extend TUT and increase training intensity for experienced athletes.

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Directory of the authors

Adami, Robert, M.A., Institut für Sportwissenschaft, Universität Koblenz-Landau, Campus Landau, Fortstraße 7, 76829 Landau, **Germany**
Email: robertoadami70@googlemail.com

Babraj, John A., PhD, Translational Biomedicine, School of Engineering and Physical Sciences, Heriot-Watt University Edinburgh, Scotland, **UK**
Email: j.babraj@hw.ac.uk

Burke, Darren G., PhD, Assistant Professor, Department of Human Kinetics, St. Francis Xavier University, Antigonish, NS, **Canada**
Email: dburke@stfx.ca

Candow, Darren G., PhD, Associate Professor, Faculty of Kinesiology & Health Studies, Aging Muscle and Bone Health Laboratory, Centre on Aging and Health, 3737 Wascana Parkway, University of Regina, **Canada**
Email: Darren.Candow@uregina.ca

Clarke, Neil, Dr., Department of Biomolecular and Sport Science, Faculty of Health and Life Sciences, Coventry University, Priory Street, Coventry, CV1 5FB, **UK**
Email: neil.clarke@coventry.ac.uk

Cottrell, Greg, Translational Biomedicine, School of Engineering and Physical Sciences, Heriot-Watt University Edinburgh, Scotland, **UK**
Email: gc29@hw.ac.uk

Delextrat, Anne, Dr., Faculty of Life Sciences, London Metropolitan University, 166-220 Holloway road, London N78DB, **UK**
Email: a.delextrat@londonmet.a.uk

Eichmann, Björn, M.A., Institut für Sportwissenschaft, Universität Koblenz-Landau, Campus Landau, Fortstraße 7, 76829 Landau, **Germany**
Email: eichmann@uni-landau.de

Focht, Brian C., PhD, Assistant Professor, Health and Exercise Science & The OSU Comprehensive Cancer Center & Solove Research Institute School of PAES, The Ohio State University, 305 W. 17th Avenue, Columbus, **USA**
Email: bfocht@ehe.osu.edu

Fröhlich, Michael, Priv.-Doz. Dr., Sportwissenschaftliches Institut der Universität des Saarlandes, Universität Campus Geb. B8 1, 66123 Saarbrücken, **Germany**
Email: m.froehlich@mx.uni-saarland.de

Gießing, Jürgen, Prof. Dr. Dr., Institut für Sportwissenschaft, Universität Koblenz-Landau, Campus Landau, Fortstraße 7, 76829 Landau, **Germany**
Email: giessing@uni-landau.de

Guppy, Fergus M., Translational Biomedicine, School of Engineering and Physical Sciences, Heriot-Watt University Edinburgh, Scotland, **UK**
Email: fmg1@hw.ac.uk

Haberecht, Dominik, Diplomsportlehrer, Sportwissenschaftliches Institut der Universität des Saarlandes, Universität Campus Geb. B8 1, 66123 Saarbrücken, **Germany**
Email: dominikhaberecht@web.de

Keast, Cameron, Translational Biomedicine, School of Engineering and Physical Sciences, Heriot-Watt University Edinburgh, Scotland, **UK**
Email: ck51@hw.ac.uk

Korff, Thomas, PhD, Senior Lecturer, Centre for Sports Medicine and Human Performance Brunel University Uxbridge UB8 3PH, **UK**
Email: Thomas.Korff@brunel.ac.uk

Mac Millan, Michael, M.D., Associate Professor, Orthopaedic Surgery, Department of Orthopaedics and Rehabilitation, University of Florida, **USA**
Email: macmim@ortho.ufl.edu

Raubuch, Wolfgang, Diplomsportlehrer, Sportwissenschaftliches Institut der Universität des Saarlandes, Universität Campus Geb. B8 1, 66123 Saarbrücken, **Germany**
Email: wolfgang.raubuch@sportbund-pfalz.de

Schohl, Manuel, Institut für Sportwissenschaft, Universität Koblenz-Landau, Campus Landau, Fortstraße 7, 76829 Landau, **Germany**
Email: gsmschohl@aol.com

Timmons, James A., PhD, Professor, Chair of Ageing Biology, MRC ARUK Centre of Excellence in Musculo-Skeletal Ageing, The Medical School University of Birmingham, 07878828117, **UK**
Email: jamie.timmons@gmail.com

Vollaard, Niels B. J., PhD, Lecturer, Translational Biomedicine, School of Engineering and Physical Sciences, Heriot-Watt University Edinburgh, Scotland, **UK**
Email: n.vollaard@hw.ac.uk