Periodisation of Eccentrically-Integrated Resistance Training during a National Rugby League Pre-Season

Ryan Whitley1, Patrick M. Holmberg2, David G. Jenkins3, 4, 5 & Vincent G. Kelly2, 3

1Sydney Roosters Rugby League Football Club, New South Wales, Australia, 2School of Exercise and Nutrition Sciences, Queensland University of Technology, Brisbane, Queensland, Australia, 3School of Human Movement and Nutrition Sciences, The University of Queensland, Saint Lucia, Queensland, Australia, 4School of Health and Sport Sciences, University of the Sunshine Coast, Sippy Downs, Queensland, Australia, 5Applied Sport Science Technology and Medicine Research Centre, Swansea University, Swansea, Wales

ABSTRACT

Successful performances in rugby league require the ability to engage in repeated contact efforts with minimal recovery while maintaining a high running intensity. The capacity to express high levels of time-limited force appears to underlie many important physical attributes required to meet the repeated-effort demands of rugby league play. If appropriately periodised and integrated into the training plan, resistance exercise that sufficiently loads the eccentric phase of movement may provide a beneficial stimulus to improve players’ force-generating capacity. Comprehensive reviews relating to the adaptive effects of eccentric training and the methods most commonly prescribed in practical environments are available and may provide context for applying these strategies. However, no literature to date has specifically discussed the planning and programming of eccentric resistance exercise to enhance force production characteristics in elite athletes. Therefore, this narrative review focuses on the periodisation of eccentrically-integrated resistance training during a 17-week National Rugby League pre-season phase. To help guide programming during the pre-season period, the 17-week timeline is divided into several phases (i.e., general preparation, special preparation, active rest, and pre-competition). Within the periodised model, eccentric exercise parameters (i.e., volume, load [% 1RM]) are manipulated to progressively increase the rate of muscle lengthening velocity over the pre-season phase and sequentially elicit changes in muscle-tendon properties and neural function that culminate in improving muscular strength expression.

Keywords: eccentric training, neuromuscular adaptation, periodisation, rugby league

INTRODUCTION

Well-developed physical capacities (e.g., muscular strength and power, maximal running speed, change of direction, aerobic power) are required to meet the high-intensity activity demands of rugby league competition (Johnston, Gabbett, & Jenkins, 2014). Players generally travel ~85-100 m per minute and total distances of ~5,000-8,500 m, with 250-750 m of this at high-speed (≥ 5.5 m.s−1) and completing 1.1 ± 0.56 accelerations·min−1 (≥ 2.78 m.s−2) while involved in an average of 0.67 collisions per minute during match-play (Austin & Kelly, 2013; Gabbett, 2015; Gabbett, Jenkins, & Abernethy, 2012; Varley, Gabbett, & Aughey, 2014). Additionally, repeated high-intensity effort bouts (3 maximal accelerations, high-speed or contact efforts with 21 seconds of
recovery between efforts) involving an average recovery period of 5.9-7.0 sec between bouts over a duration of 49-64 sec are common (4.8-9.1 min) during peak periods of match-play (Austin, Gabbett, & Jenkins, 2011; Gabbett, 2011; Gabbett et al., 2012; Gabbett, Jenkins, & Abernethy, 2011a; Johnston et al., 2014). As such, training that improves players’ ability to engage in repeated contact efforts with minimal recovery while maintaining a high running intensity during competition has important implications for performance (Johnston & Gabbett, 2011; Johnston et al., 2014).

The capacity to express high levels of strength (i.e., the ability to produce force [Stone, Moir, Glaister, & Sanders, 2002]) is particularly important for success in rugby league (Hulin, Gabbett, Kearney, & Corvo, 2015; Johnston et al., 2014; McMaster, Gill, Cronin, & McGuigan, 2013). Considerable evidence highlights the association between greater muscular strength and many physical and performance attributes (Johnston et al., 2014; McMaster et al., 2013); improved technical and tactical skills (Gabbett et al., 2011a; Redman, Wade, Kelly, Connick, & Beckman, 2022; Redman, Wade, Whitley, et al., 2021); a lower chance of injury (Gabbett, Jenkins, & Abernethy, 2011b); and a higher standard of play (Baker & Newton, 2008). Considering that most activities in rugby league require players to repeatedly produce large amounts of force within a limited time period (Redman, Wade, Kelly, et al., 2021; Redman, Wade, Whitley, et al., 2021) and understanding that strength gains through resistance exercise positively influence the force-time characteristics of an individual (Andersen & Aagaard, 2006; Andersen, Andersen, Zebis, & Aagaard, 2010), training strategies that improve muscular strength will likely result in improved play.

Eccentric muscle actions can produce greater peak force (10-35%) than concentric muscle actions of equivalent velocity (Aagaard et al., 2000; Babault, Pousson, Ballay, & Van Hoecke, 2001; Beltman, Sargeant, Van Mechelen, & De Haan, 2004; Seger & Thorstensson, 2000; Westing, Cresswell, & Thorstensson, 1991). As such, traditional resistance exercise involving the prescription of loads constrained by concentric force may not sufficiently load the eccentric phase of movement (Douglas, Pearson, Ross, & McGuigan, 2017a) and therefore may limit the potential for strength development (Vogt & Hoppeler, 2014; Roig et al., 2009). In contrast, resistance training that sufficiently loads the eccentric phase of movement can induce novel stimuli to elicit morphological and neural changes that improve players’ capacity to generate high levels of time-limited force (Cormie, McGuigan, & Newton, 2011a; Douglas et al., 2017a). The magnitude of mechanical tension induced by eccentric training, particularly involving loads near (≥ 85% 1 repetition maximum [RM]) or above maximal concentric strength (e.g., ≥ 1RM), has been shown to increase muscle cross-sectional area (CSA) and architecture (English, Loehr, Lee, & Smith, 2014; Potier, Alexander, & Seynnes, 2009), induce preferential recruitment of type II muscle fibres (Nardone, Romano, & Schieppati, 1989), reduce neural inhibition (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002), increase muscle activation (Tallent, Goodall, Gibbon, Hortobagyi, & Howatson, 2017), enhance task-specific gains in eccentric strength (Paddon-Jones, Leveritt, Lonergan, & Abernethy, 2001), and produce changes in tendon structure and function (Malliars et al., 2013). Collectively, these adaptive responses can raise the potential for muscular strength development (Harden, Wolf, Haff, Hicks, & Howatson, 2019; Suchomel et al., 2019a) and therefore also improve rugby league performance (Baker & Newton, 2008; Johnston et al., 2014).

A systematic approach to training is generally applied in most sporting environments to elicit the physiological adaptations underlying the expression of muscular strength (Baker, Wilson, & Carlyon, 1994; Suchomel, Nimphius, Bellon, & Stone, 2018). If appropriately periodised and integrated into the resistance training plan, eccentric exercise may be particularly beneficial in enhancing maximal and time-limited force expression (Suchomel et al., 2019a). Comprehensive reviews relating to the adaptive effects of eccentric training (Douglas et al., 2019a,b; Handford et al., 2022) and the methods most commonly prescribed in practical environments (Suchomel et al., 2019a,b) are available and may provide context for applying these strategies. However, no literature to date has specifically discussed the planning and programming of eccentric training methods to enhance force production characteristics in elite athletes. Therefore, this narrative review focuses on the periodisation of eccentrically-integrated resistance training during a National Rugby League (NRL) pre-season phase.

**PERIODISED MODEL FOR ECCENTRIC TRAINING DURING AN NRL PRE-SEASON**

Periodisation strategies in rugby league often involve dividing the annual training plan into three
primary macrocycles (i.e., pre-season, competition, and off-season phases) (Kelly & Coutts, 2007). Pre-season rugby league training typically spans 17 weeks (November-February) and generally involves frequent bouts of resistance exercise that aim to develop the muscular strength required to meet the physical demands of competitive match-play (Baker et al., 1994; de Lacey et al., 2014; McLean, Coutts, Kelly, McGuigan, & Cormack, 2010). To help guide programming during the pre-season period, the 17-week timeline is divided into several phases (i.e., general preparation, special preparation, active rest, and pre-competition). Within the periodised model, eccentric exercise parameters (i.e., volume, load [%1RM]) (Table 1) are manipulated to progressively increase the rate of muscle lengthening velocity over the pre-season phase and sequentially elicit changes in muscle-tendon properties and neural function that culminate in improving muscular strength expression (Figure 1). The following sections discuss the implementation of eccentric resistance training within an NRL pre-season based on the available evidence.

GENERAL PREPARATION PHASE

The primary aim of the 4-week general preparation phase (GPP) is to increase muscle hypertrophy and raise work capacity (i.e., force production capacity [O’Bryant, Byrd, & Stone, 1988]) in order to improve the potential for players to repeatedly express large amounts of time-limited force (Stone, Sands, & Stone, 2007). Exercise parameters (e.g., 70-75% 1RM) are manipulated to slow (5 sec [Krzysztofik, Wilk, Wojdala, & Golas, 2019]) the eccentric phase of movement and therefore augment time under tension (i.e., the time a muscle is held under tension or strain during an exercise set [Handford et al., 2022]) and elicit high resistance training volumes.

Metabolic stress within a muscle through a resistance exercise stimulus of sufficient magnitude results in the upregulation of muscle protein synthesis and, subsequently, protein accretion and changes in muscle size (Schoenfeld et al., 2021). Increases in muscle protein synthesis rates within the day following lower-body resistance exercise involving submaximal intensities performed with a 6-sec lowering phase until volitional fatigue have been reported (Burd et al., 2012). This suggests that maximal fibre activation may not exclusively drive muscle protein synthesis rates (Burd et al., 2012). Increasing exercise volume, through increasing time under tension during the eccentric phase of movement, may also stimulate protein accretion and lead to muscle growth despite lower resistance exercise loads (Burd et al., 2010; Schoenfeld, 2010; Terzis et al., 2010). Greater time under tension during muscle lengthening actions with moderate loads can result in larger accumulations of blood lactate, growth hormone, and testosterone when compared to volume-matched eccentric exercise involving faster tempos (Kraemer & Castracane, 2015). With repeated exercise bouts, these acute hormonal responses can produce increases in muscle size (Godfrey, Whyte, Buckley, & Quinlivan, 2009; Kraemer & Castracane, 2015). This may explain the increases in muscle hypertrophy following 12 weeks of resistance exercise involving a 4-sec eccentric phase of movement with moderate loads (~81% CON 1RM) in resistance-trained males (Pereira et al., 2016). The improvements in muscle size were attributed to the prolonged eccentric phase of movement and therefore a heightened time under tension (Schoenfeld, 2010) that may have elicited substantial metabolic stress (Lieber & Friden, 1988; Stauber, 1988) and subsequent increases in muscle size following the training intervention (Schoenfeld et al., 2021).

Evidence suggests that sarcoplasmic hypertrophy (i.e., an increase in sarcoplasmic volume and its constituents [e.g., fluid, enzymes, organelles] [Roberts, Haun, Vann, Osburn, & Young, 2020]) contributes to increases in muscle size following higher volume resistance training (Haun et al., 2019a) and that these changes support subsequent myofibrillar hypertrophy (Roberts et al., 2020). Data show that increasing the time under tension during the eccentric phase of movement (~6 sec) increases the amplitude of sarcoplasmic protein synthesis within 6 h of the exercise bout and results in a delayed simulation of myofibril accretion 24-30 h post-training (Burd et al., 2012). Myofibrillar protein synthetic rate was also shown to be associated with p70S6K phosphorylation within this time frame following the training session (Burd et al., 2012). Previous findings have demonstrated that the increase in p70S6K 6 h following resistance exercise involving high-resistance muscle lengthening actions is almost perfectly correlated to the percent change in muscle mass after 6 weeks of training (Baar & Esser, 1999). As such, transient increases in sarcoplasmic protein synthesis rates following slow eccentric resistance exercise with relatively higher exercise volumes and submaximal loads may support subsequent increases in myofibril hypertrophy (Haun et al., 2019b; Roberts et al., 2020) and thus long-term increases in muscle size (Baar & Esser, 1999),
## Table 1. Eccentric resistance exercise parameters during the 17-week pre-season period.

### Eccentric Resistance Exercise Parameters

| GPP 1 | GPP 2 |
|-------|-------|
| **Week 1** | **Week 2** | **Week 3** | **Week 4** |
| **Back Squat** | 50%/60%/5, (70%/5[5sec])3 | 50%/60%/5, (75%/5[5sec])2 | 50%/60%/5, (75%/5[5sec])2 | 50%/60%/5, (75%/5[5sec])2 |
| **Bench Press** | 50%/60%/5, (75%/5[5sec])3 | 55%/65%/5, (75%/5[5sec])2 | 55%/65%/5, (75%/5[5sec])2 | 55%/65%/5, (75%/5[5sec])2 |
| **Week 5** | **Week 6** | **Week 7** |
| **Back Squat** | 60%/75%/5, (85%/4[3sec])2*, 90%/3[3sec] | 60%/75%/5, (85%/4[3sec])2*, 90%/3[3sec]*, 95%/3[3sec]* | 85%/3[3sec]*, 95%/3[3sec]*, 100%/2[3sec]*, 105%/2[3sec]* |
| **Bench Press** | 60%/70%/75%/5, (85%/4[3sec])2*, 90%/3[3sec]*, 95%/3[3sec]* | 60%/70%/75%/5, 80%/3, 90%/3[3sec]*, 95%/3[3sec]*, 100%/3[3sec]* |
| **Week 8** | **Week 9** |
| **SPP** | **Week 10** | **Week 11** | **Week 12** | **Week 13** |
| **Back Squat** | 60%/5, 75%/3, 85%/1, 90%/3[<1sec])3* | 60%/5, 75%/3, 85%/1, 90%/3[<1sec]*, 95%/3[<1sec]*, 100%/3[<1sec]* | 60%/5, 75%/3, 85%/1, 95%/3[<1sec]*, 100%/2[<1sec]*, 105%/2[<1sec]* | 60%/5, 75%/3, 85%/1, 95%/2[<1sec])3* |
| **Bench Press** | 60%/70%/5, 80%/3, (90%/4[<1sec])3* | 60%/70%/5, 80%/3, (90%/3[<1sec]2*, 95%/3[<1sec]*, 100%/3[<1sec]* | 60%/5, 70%/3, 80%/3, 90%/2[<1sec]*, 95%/2[<1sec]*, 100%/2[<1sec]* | 60%/5, 70%/3, 80%/3, 90%/3[<1sec]*)*, 95%/3[<1sec]*, 100%/2[<1sec]* |
| Exercise       | PCP                                      | Week 14                                      | Week 15                                      | Week 16                                      | Week 17                                      |
|---------------|------------------------------------------|----------------------------------------------|----------------------------------------------|----------------------------------------------|----------------------------------------------|
| Back Squat    | 60%/70%/5, 80%/3,                       | 60%/70%/5, 80%/3,                           | 60%/70%/5, 80%/3,                           | 60%/70%/5, 80%/3,                           | 60%/70%/5, 80%/3,                           |
|               | 85%/2[<1sec]*, 90%/2[<1sec]*,            | 85%/2[<1sec]*, 90%/2[<1sec]*,                | 90%/2[<1sec],                               | 90%/2[<1sec],                               | 90%/2[<1sec],                               |
|               | 95%/1[<1sec]*                           | 95%/1[<1sec]*                                | 95%/1[<1sec]*                               | 95%/1[<1sec]*                               | 95%/1[<1sec]*                               |
| DJ            | (X/3)3                                   | (X/3)4                                       | (X/3)2                                       | (X/3)2                                       | (X/3)2                                       |
| Bench Press   | 60%/70%/5, 80%/3,                       | 60%/70%/5, 80%/3,                           | 60%/70%/5, 80%/3,                           | 60%/70%/5, 80%/3,                           | 60%/70%/5, 80%/3,                           |
|               | (85%/2[<1sec])2*, 90%/2[<1sec]*         | (85%/2[<1sec])2*, 90%/2[<1sec]*             | (85%/2[<1sec])2*                            | (85%/2[<1sec])2*                            | (85%/2[<1sec])2*                            |
| Lying MB Rebound | (X/5)3                                 | (X/5)2                                       | X/5                                          | X/5                                          | X/5                                          |
| Chest Pass    |                                         |                                              |                                              |                                              |                                              |

Notes: Italic = eccentric exercise working sets; [ ] = duration of the eccentric phase of movement; *partner assisted during the concentric phase of movement; postactivation potentiation enhancement complexes are performed with ≥ 3 min rest between the conditioning stimulus and plyometric exercise (Seitz & Haff, 2016); exercise loads are based on concentric 1 repetition maximum; drop jump height is based on the vertical height that maximised a player’s power output during pre-testing.

DJ drop jump; GPP general physical preparation; MB medicine ball; PCP pre-competition phase; SPP special physical preparation

**Figure 1.** Periodisation of eccentrically-integrated resistance training during a pre-season phase. Adapted from Stone et al., 2007; Suchomel et al., 2018 CSA cross-sectional area, GPP general preparation phase, SPP special preparation phase.
which should result in improved force output (Taber, Vigotsky, Nuckols, & Haun, 2019). Accordingly, increases in muscle size and strength were found after 12 weeks of moderate-load resistance exercise involving slow lengthening actions (Pereira et al., 2016), which may support prolonging the eccentric phase of movement to induce morphological changes and improvements in force production.

Exercise-induced increases in the protein expression of sarcoplasmic enzymes responsible for generating ATP (Haun et al., 2019a,b; Roberts et al., 2020) also have implications for improving work capacity. Greater time under tension elicited by a 6-sec eccentric movement phase performed to volitional fatigue has been shown to increase sarcoplasmic and mitochondrial protein synthesis rates following a bout of resistance exercise completed on the same day in resistance-trained individuals (Burden et al., 2012). Same-day increases in peroxisome proliferator-activated receptor-gamma coactivator (PGC-1α) expression were also observed following the training session (Burden et al., 2012). Given its central role in the regulation of cellular energy metabolism and the remodelling of muscle tissue that is metabolically more oxidative (Liang & Ward, 2006), increases in PGC-1α together with the heightened protein expression of sarcoplasmic enzymes responsible for generating ATP could result in enhanced work capacity (Haun et al., 2019a,b; Roberts et al., 2020). These responses to eccentric exercise involving a longer time under tension and subsequently higher volumes may occur early in the training process to prepare muscle cells spatially and energetically for subsequent myofibrillar hypertrophy (Roberts et al., 2020). This may have implications for professional rugby league athletes as there is evidence to suggest that sarcoplasmic hypertrophy may result from a myofibrillar protein accretion threshold being reached in individuals with years of resistance training experience (Roberts et al., 2020). To accumulate more myofibrillar proteins, increases in intracellular space generated by sarcoplasmic hypertrophy may be required (Roberts et al., 2020). The subsequent replacement of sarcoplasmic space with contractile components (Roberts et al., 2020) should result in increased force output (Taber et al., 2019) and improved play (Gabbett et al., 2011a; Johnston et al., 2014; McMaster et al., 2013; Redman et al., 2022; Redman, Wade, Whitley, et al., 2021).

Despite these potential benefits, there may be disadvantages to prolonging the eccentric phase of movement (Suchomel et al., 2019a). Increasing the time under tension has been shown to limit the contribution of the stretch-shortening cycle (SSC) during resistance exercise repetitions, resulting in decreased average (e.g., ~18%) and peak (e.g., ~20%) concentric power output during training bouts (Wilk, Goals, Krzysztofik, Nawrocka, & Zajac, 2019). Additionally, slow eccentric muscle actions may result in higher acute fatigue and perceived exertion during resistance training sessions (Diniz, Martins-Costa, Machado, Lima, & Chagas, 2014; Martins-Costa et al., 2016). Chronic fatigue with higher volume training may activate the AMP-activated protein kinase pathway to reduce protein turnover for type II muscle fibre growth and subsequently decrease the II:I fibre CSA ratio (Kristensen et al., 2015), which can result in decreases in the rate of force development (RFD) (Mike, 2015; Stasinaki, Zaras, Methenitis, & Bogdanis, 2019). Training strategies that have the potential to decrease time-limited force expression in rugby league players may be untenable. However, increasing muscle size and work capacity initially may improve the ability to maximise muscular strength development in later phases of training (Minetti, 2002; Stone et al., 2007; Zamparo et al., 2002).

**GENERAL PREPARATION PHASE 2**

The subsequent 3-week GPP aims to elicit changes in muscle-tendon properties and neural function through slow (3 sec [Krzysztofik et al., 2019]) eccentric tempos and high-load (85-105% 1RM) muscle lengthening actions.

Increases in resistance exercise volume and load have been shown to influence muscle growth and changes in fascicle length (Duclay, Martin, Duclay, Cometti, & Pousson, 2009; Franchi et al., 2014; Pereira et al., 2016). The potential for high levels of mechanical tension with eccentric resistance exercise may be particularly beneficial for increasing muscle size (Eliasson et al., 2006). Eccentric exercise involving high loads induces large amounts of mechanical tension per motor unit (Hollander et al., 2007) and may influence the magnitude of muscle damage post-exercise (Chen et al., 2019). This may upregulate anabolic and cellular activity within muscle fibres to elicit a potent signal for protein synthesis (Eliasson et al., 2006). These observations may explain the increases in muscle hypertrophy following 6-weeks of heavy (90% CON 1RM) eccentric training involving a squating movement performed with a slow lengthening phase (Stasinaki et al., 2019). High-load eccentric training appears...
to promote increases in muscle CSA by adding sarcomeres in series, as inferred from changes in fascicle length (Blazevich, Cannavan, Coleman, & Horne, 2007; Douglas et al., 2017a; Franchi et al., 2014). Notably, most studies investigating changes in fascicle length following eccentric training have involved untrained participants (Baroni et al., 2013; Blazevich et al., 2007; Duclay et al., 2009; Franchi et al., 2014; Potier et al., 2009; Seynnes, de Boer, & Narici, 2007; Stasinaki et al., 2019). As such, how the findings may translate to highly-trained athletes is unclear, although it has been suggested that adaptive processes may be similar but of a lesser magnitude (Vogt & Hoppeler, 2014). Nevertheless, greater fascicle length may affect muscle power by allowing fibres to produce forces at more optimal lengths and shortening velocities (Azizi & Brainerd, 2007; Kaufman, An, & Chao, 1989; Wickiewicz, Roy, Powell, Perrine, & Edgerton, 1984), which may increase the potential for improvements in physical capacities (e.g., maximal running speed [Abe, Fukashiro, Harada, & Kawamoto, 2001]) required for successful performances in rugby league (Johnston & Gabbett, 2011; Johnson et al., 2014).

High-load eccentric training may uniquely influence fibre type composition (Raue, Terpstra, Williamson, Gallagher, & Trappe, 2005). The predisposition for type II fibre growth may be associated with the tension-generating capacity and subsequent damage of these fibres due to increased recruitment with heavy eccentric exercise (Friedmann-Bette et al., 2010). Accordingly, increases in type II fibre size and a shift towards a faster phenotype have been shown following an 8-week training intervention involving slow muscle lengthening actions and maximal resistive loads in untrained participants (Shepstone et al., 2005). In resistance-trained males, an increase in the relative CSA occupied by type II fibres was similarly found after slow eccentric exercise with progressively heavier loads (~94% ECC 1RM) over a 12-week training intervention (Vikne et al., 2006). Type II fibre type area is associated with percent fibre type area (Fry, Allemear, & Staron, 1994) and most likely represents an important contractile variable for repeatedly expressing large amounts of time-limited force (Fry, Schilling, et al., 2003; Tesch & Karlsson, 1985). However, type II fibre composition increases may be evident only after several weeks of eccentric training (Hortobagyi et al., 2000; Seynnes et al., 2007). Performance outcomes may similarly reflect muscle fibre alterations only after adequate recovery (~6-8 weeks) (Leong, McDermott, Elmer, & Martin, 2014; Shepstone et al., 2005). As such, these time frames should be considered when planning pre-season training.

Heavy eccentric training may take advantage of unique neural activation strategies to raise volitional muscle activation (Aagaard, 2003; Vangsgaard, Taylor, Hansen, & Madeleine, 2014) through increases in motor unit firing rates (Higbie, Cureton, Warren, & Prior, 1996), downregulation of inhibitory pathways (Aagaard et al., 2002), and greater central descending motor drive (Fang, Siemionow, Sahgal, Xiong, & Yue, 2004, 2001). Motor unit firing rates appear to be the primary inhibitory mechanism limiting voluntary activation (Duchateau & Baudry, 2014). As such, it may play a significant role in increasing force production characteristics after high-load eccentric training (Aagaard, 2003; Douglas et al., 2017a). Decreased neural inhibition has been shown following slow eccentric training with progressively higher loads (~90% CON 1RM) in previously untrained males (Aagaard et al., 2002). This was paralleled by substantial increases in neuromuscular activation and maximal strength following the 14-week training intervention (Aagaard et al., 2002). Supraspinal and spinal adaptation mechanisms (i.e., greater central descending motor drive, increased motoneuron excitability, decreased presynaptic inhibition) were similarly shown following heavy (120% CON 1RM) eccentric training involving slow lengthening actions in recreationally-trained participants (Duclay et al., 2009). Neural mechanisms have been shown to underpin training-induced increases in strength in novice trainees (Aagaard, 2003; Seynnes et al., 2007). Although it is less clear whether a similar magnitude of improvement occurs in highly-trained individuals, evidence suggests that neural plasticity exists in participants with highly augmented neural function (Aagaard, 2003). As such, slow, heavy eccentric training may provide a beneficial stimulus to elicit neural changes that improve players’ force output. Nevertheless, considerable fatigue can occur with heavy eccentric exercise (particularly involving slower movement speeds) and this may attenuate force-time characteristics (Mike, 2015; Stasinaki et al., 2019) and affect motor control for several weeks following the cessation of training (Leong et al., 2014). Thus, improvements in neural function and therefore heightened maximal and time-limited force expression may be a delayed response to high-load eccentric training involving prolonged lengthening actions (Baroni et al., 2013). Performance outcomes may parallel this delayed neuromuscular response and should, therefore, be taken into consideration.

Changes in tendon structure and function have been
reported following slow, heavy eccentric training, possibly due to the large magnitude of mechanical tension induced (Farup et al., 2014; Malliaras et al., 2013). Maximal eccentric exercise was found to elicit large amounts of tendon force and stress and produce improvements in tendon CSA and stiffness following 12 weeks of high-load (80% ECC 1RM) training involving slow muscle lengthening actions (Malliaras et al., 2013). Increases in maximal voluntary contraction and RFD were also observed following the training intervention (Malliaras et al., 2013). Findings suggest that changes in tendon properties after high-load eccentric training with longer time under tension increase the use of elastic energy during SSC actions (Bojsen-Moller, Magnusson, Rasmussen, Kjaer, and Aagaard, 2005), which may raise the potential for improvements in motor control and time-limited force expression (Cormie, McGuigan, & Newton, 2010; Elmer, Hahn, McAllister, Leong, & Martin, 2012; Liu et al., 2013; Papadopoulos et al., 2014). Decreases in ankle, knee, and hip joint angles during the eccentric phase of a drop jump assessment were observed following 8 weeks of slow eccentric training involving progressively heavier loads (90% ECC 1RM) (Papadopoulos et al., 2014). This was associated with large improvements in maximal eccentric and concentric force output and RFD and drop jump performance (Papadopoulos et al., 2014). Variables associated with SSC performance are associated with many important physical attributes and technical and tactical skills required for successful performance in rugby league (Gabbett et al., 2011a; Johnston et al., 2014; McMaster et al., 2013; Redman, Wade, Kelly et al., 2022; Redman, Wade, Whitley, et al., 2021).

Prolonging the lowering phase during eccentric resistance exercise can decrease the number of repetitions completed and reduce the potential for muscle growth (Nobrega et al., 2018; Pryor, Sforzo, & King, 2011). Yet, if overall time under tension is emphasised, lengthening the eccentric phase of movement during the early pre-season period may provide a beneficial stimulus to improve muscle-tendon structure and function (Pereira et al., 2016; Stasinaki et al., 2019) and, subsequently, force output (Liu et al., 2013). Increasing eccentric time under tension can also induce considerable fatigue and attenuate performance (Baroni et al., 2013; Leong et al., 2014; Mike, 2015; Shepstone et al., 2005; Stasinaki et al., 2019). Nevertheless, training that elicits improvements in muscle-tendon properties and neural function while raising work capacity during the early pre-season period may maximise force production characteristics with later training (Minetti, 2002; Stone et al., 2007; Zamparo et al., 2002). This may have important implications for rugby league play in which competition is characterised by many repeated high-intensity effort bouts (Gabbett & Wheeler, 2015; Johnston et al., 2014).

ACTIVE REST

The 2-week active rest period occurs over the holiday season and aims to promote recovery following previously strenuous training through substantially lower resistance training volume-loads compared to the other pre-season phases (Bompa & Haff, 2009). Eccentric training is not programmed during this period so that neuromuscular fatigue is minimised. A supercompensatory effect whereby improvements in psychophysiological state and performance occur has been reported following active rest periods (Bompa & Haff, 2009; Brannstrom & Rova, 2013), which may have positive implications for subsequent training.

SPECIAL PREPARATION PHASE

The primary aim of the 4-week special preparation phase (SPP) is to elicit the physiological adaptations underlying improvements in neuromuscular function. Compared to previous training phases, the SPP involves reduced exercise volumes, high-loads (≥ 90% 1RM), and fast (< 2 sec [Krzysztofik et al., 2019]) muscle lengthening actions.

High force outputs may be achieved with fast lengthening actions given that muscle force production is not constrained by lengthening velocity during the eccentric phase of movement (Edman, 1988). As such, muscle size and strength gains, which are generally proportional to the degree of overloading (Martino, Perestrello, Vinarsky, Pagliari, & Forte, 2018), may be elicited through heavy resistance exercise involving fast eccentric actions (Douglas et al., 2017a). Greater muscle growth has been reported following maximal eccentric exercise involving a fast compared to a slow lengthening speed (English et al., 2014; Farthing & Chilibeck, 2003; Shepstone et al., 2005). This may be due to the larger magnitude of muscle damage and subsequent anabolic response produced with fast eccentric training when compared to load-matched slow eccentric training (Chapman, Newton, Sacco, & Nosaka, 2006; Prose & Morgan, 2001). Studies
have also largely found greater improvements in muscle strength following eccentric training involving a faster versus slower eccentric phase of movement (Handford et al., 2022), which may not be surprising given the relationship between muscle size and strength (Taber et al., 2019). Nevertheless, research suggests that force production characteristics may be decreased for longer periods following fast, heavy eccentric training (Shepstone et al., 2005). Shepstone et al. (2005) showed decreases in weekly peak torque production that only exceeded pre-training measures in the last week of the 8-week eccentric training intervention involving maximal resistive loads and following 4 days of complete rest. Given that heavy eccentric exercise with faster speeds can induce large amounts of muscle damage and heightened neuromuscular fatigue (Chapman et al., 2006; English et al., 2014; Farthing & Chilibeck, 2003; Mike, 2015; Shepstone et al., 2005), moderate- and high-load eccentric training involving a slow eccentric phase of movement are programmed in prior phases to elicit a progressive overload over the pre-season period.

Stretch-induced strain from fast lengthening actions under high loads can increase the number of sarcomeres in series (Goldspink & Harridge, 2003; Sharifnezhad, Marzilger, & Arampatzis, 2014). This may explain the reported changes in fascicle length and subsequent increases in muscle CSA, force production, and shortening velocity following similar eccentric training protocols (Potier et al., 2009; Seynnes et al., 2007; Sharifnezhad et al., 2014). Following 10 and 12 weeks of fast eccentric training involving maximal loads, fascicle length was shown to be increased by 10% and 14%, respectively (Baroni et al., 2013; Sharifnezhad et al., 2014). In the latter study, significant improvements in fascicle length were only observed in the condition involving the leg that was exercised using a higher lengthening velocity (240 deg·s⁻¹ versus 90 deg·s⁻¹) through a larger range of motion (25° to 100° versus 25° to 65°) (Sharifnezhad et al., 2014). The increases in fascicle length may be attributed to the rapid lengthening of the muscle fibres in the descending part of the force-length relationship that can induce a high magnitude of strain, resulting in sarcomerogenesis (Butterfield & Herzog, 2005) and subsequent improvements in time-limited force expression (Baroni et al., 2013; Blazevich et al., 2007; Sharifnezhad et al., 2014). This may support previous findings suggesting that exercise range of motion is the strongest influencing factor for fascicle length adaptations (Blazevich et al., 2007) and provide a rationale for including fast, heavy squats performed to full depth in the mid-pre-season period.

A shift in fibre type composition towards a more fatigue-resistant phenotype generally occurs with resistance training (Fry, Webber, et al., 2003). However, eccentric training may uniquely influence fibre type composition to maintain or increase type IIx fibre composition (Colliander & Tesch, 1990; Hortobagyi et al., 1996; Paddon-Jones et al., 2001; Vikne et al., 2006). Following a 10-week training intervention involving fast eccentric exercise with high loads, type I and IIx composition were decreased and increased by ~14% and ~7%, respectively (Paddon-Jones et al., 2001). This study also reported substantial increases in eccentric, concentric, and isometric force production characteristics post-training (Paddon-Jones et al., 2001). In contrast, muscle fibre composition and maximal force expression (irrespective of contraction type) were generally unchanged with the same protocol involving slow lengthening actions (Paddon-Jones et al., 2001). Shepstone et al. (2005) also showed greater increases in force generation following similar eccentric training interventions over 8 weeks. Type I and type IIx fibre composition, however, were reportedly increased and decreased, respectively, following both the slow and fast eccentric training protocols (Shepstone et al., 2005). Nevertheless, the total area occupied by type IIa fibres was increased following the fast but not slow eccentric protocol (Shepstone et al., 2005). Previous findings have shown increases in type IIa fibre CSA and percent following resistance training (Fry, Webber, et al., 2003). Although type IIa fibres have a lower peak force-generating capacity compared to type IIx fibres, type IIa fibres have a greater oxidative capacity and are generally more resistant to fatigue than type IIx fibres (Schiaffino et al., 2019). As such, type IIa fibres may have a greater capacity to incur muscle damage, which can elicit larger increases in muscle CSA (Friedmann-Bette et al., 2010; Schiaffino et al., 2019). This may explain the greater increases in muscle hypertrophy and force production following fast versus slow eccentric training despite the shift in fibre composition from type IIx to type IIa reported by Shepstone et al. (2005). Furthermore, the shift toward a more fatigue-resistant phenotype generally occurs with greater volume-loads (Andersen & Aagaard, 2000). As such, the differences in average weekly (3.14 rad·s⁻¹ x 24 repetitions versus 3.66 rad·s⁻¹ x 32.5 repetitions) and total volume-load between the studies of Paddon-Jones et al. (2001) and Shepstone et al. (2005) may explain the conflicting findings related to changes in type IIx fibre composition. Findings
suggest that there may be a pattern of decreased force production due to fibre remodelling that subsequently improves the type II:I fibre ratio and increases muscle hypertrophy following fast, heavy eccentric training (Shepstone et al., 2005). This may provide an explanation of the delayed training effects often observed following similar training protocols (Baroni et al., 2013; Leong et al., 2014) and support for high-load exercise prescription involving a faster eccentric phase of movement in the mid-pre-season period.

Neural adaptations may influence the reported increases in maximal and time-limited force expression following high-load eccentric training involving fast lengthening actions (Oliveira, Corvino, Caputo, Aagaard, & Denadai, 2016). Following 8 weeks of fast, maximal eccentric training, peak force production and early-phase (100 ms) RFD increased by 28% and 30%, respectively (Oliveira et al., 2016). Increases in volitional supraspinal drive and spinal reflex disinhibition have been shown to positively influence early-phase RFD (Michaut, Babault, & Pousson, 2004; Pensini, Martin, & Maffiuletti, 2002) and may explain the findings of Oliveira et al. (2016). In contrast, improvements in late-phase (> 100 ms) RFD generally occur in parallel with increases in strength and may be related to muscle CSA and mechanical stiffness (Andersen & Aagaard, 2006). Interestingly, Oliveira et al. (2016) showed no changes in late-phase RFD despite increases in maximal force production. This may further indicate that neural adaptations largely influence increases in early-phase RFD following fast, heavy eccentric training (Andersen et al., 2010; Oliveira et al., 2016). However, Oliveira et al. (2016) did not investigate changes in muscular properties (i.e., fibre composition), which are associated with early-phase RFD (Bottinelli, Pellegrino, Canepari, Rossi, & Reggiani, 1999). Additionally, the study participants were recreationally-trained. As such, the substantial improvements in force-generating capacity may be due to their training status (Aagaard, 2003; Seynnes et al., 2007). Although a similar increase may not occur in professional rugby league players, neural plasticity is evident in individuals with highly augmented neural function (Aagaard, 2003). These results suggest that increasing the speed of high-load lengthening actions may elicit improvements in neural function that subsequently increase RFD at the early phase of rising torque.

Findings suggest that improvements in force-time characteristics are more evident when the testing velocity matches that generally used in training (Roig et al., 2009). Studies have shown that high-load eccentric training with slow lengthening actions can improve sprint and jump performance (Cook, Beaven, & Kilduff, 2013; Stasinaki et al., 2019). Increases in upper- and lower-body maximal strength and countermovement jump performance were found following 3 weeks of heavy (120% CON 1RM) eccentric training in semi-professional rugby players (Cook et al., 2013). However, 40 m sprint performance was only improved when fast, unloaded eccentric exercises (i.e., assisted countermovement jumps and downhill running) were added to the protocol (Cook et al., 2013). Training that progressively exposes players to faster lengthening actions may improve motor control and time-limited force expression to a greater degree compared to training involving slower lengthening actions (Handford et al., 2022; Suchomel et al., 2018). This may elicit a large transfer of training effect (particularly after training-induced changes in muscle-tendon and neural function have occurred [Cormie et al., 2010]) that subsequently enhances many physical attributes associated with a broad range of technical and tactical skills (Gabbert et al., 2011a; Johnston et al., 2014; Liu et al., 2013; McMaster et al., 2013; Redman, Wade, Kelly, et al., 2021; Redman, Wade, Whitley, et al., 2021).

PRE-COMPETITION PHASE

The realisation of delayed training effects following eccentric training may require considerable time (Baroni et al., 2013; Coratella & Schena, 2016; Leong et al., 2014; Shepstone et al., 2005). As such, high-load eccentric training with fast lengthening actions is prescribed with lower volumes during the 4-week pre-competition phase to allow for adequate recovery while maintaining high levels of force production. Plyometric training involving high rates of muscle lengthening is performed subsequent to fast, heavy eccentric exercise during training sessions to further elicit the morphological and neural adaptations underlying improvements in time-limited force expression and enhance motor control (Golas, Maszczysz, Zajac, Mikolajec, & Stastny, 2016; Markovic & Mikulic, 2010; Suchomel et al., 2018) while maximising training economy.

The performance benefits of plyometric training are well documented (Markovic & Mikulic, 2010). Studies have demonstrated changes in muscle-tendon properties (e.g., muscle size and architecture, type II fibre CSA, type II:I ratio, tendon CSA and stiffness) (Kubo et al., 2017; Malisoux, Francaux,
Nielens, & Theisen, 2006; Potteiger et al., 1999) and neural function (e.g., voluntary activation) (Behrens, Mau-Moeller, & Bruhn, 2014; Behrens et al., 2016) underpinning force-time characteristics following plyometric training (Markovic & Mikulic, 2010). Nevertheless, improvements in performance outcomes involving an SSC component may not be maximised only through increases in force production (Bobbert & Van Soest, 1994; Toumi et al., 2001). Changes in muscle activation strategies (i.e., intermuscular coordination) subsequent to plyometric training may be particularly important for enhancing motor control (Kyrolainen, Komis, & Kim, 1991; Markovic & Mikulic, 2010) and thus the expression of skilled movement (Bobbert & Van Soest, 1994; Cormie et al., 2010; Toumi et al., 2001). This may support the findings of Cook et al. (2013) who observed increases in sprint and jump performance only after sprinting and jumping activities were included in the eccentric training intervention. Thus, improvements in motor control that occur with plyometric exercise may actualise the muscle-tendon and neural adaptations elicited through previous eccentric training.

Considering the large amount of sport-specific training that typically occurs during the late pre-season period, maximising training economy is important. Fast, heavy eccentric exercise has been shown to acutely improve jumping, throwing, and pushing performance in well-trained athletes (Golas et al., 2016). Findings suggest that high-load exercise involving a lengthening action may be particularly beneficial for eliciting a postactivation potentiation (PAPE) effect given the large amount of mechanical tension for a low metabolic cost associated with these exercises (English et al., 2014; Golas et al., 2016; Horstmann et al., 2001; Krzysztofik et al., 2020; Ong, Lim, Chong, & Tan, 2016). Increases in bar velocity and peak power during a bench throw were found within 5 minutes following an upper-body stimulus involving 2-3 x 2-3 at 110% and 130% CON 1RM with a fast eccentric phase of movement in strength-trained athletes (Golas et al., 2016; Krzysztofik et al., 2020). Countermovement jump peak power was similarly improved within 6 minutes following a lower-body eccentric exercise stimulus (1 x 5-6 at 105% and 125% CON 1RM) in trained participants (Ong et al., 2016). Research has demonstrated that the magnitude of PAPE effects may be related to the strength level and resistance training experience of the individual (Seitz & Haff, 2016). As such, previous eccentric training that improves force output may be important to maximise PAPE effects following stimuli involving fast muscle lengthening actions under high-loads. While plyometric exercise can provide a beneficial stimulus for improving motor control (Kyrolainen et al., 1991; Markovic & Mikulic, 2010; Suchomel et al., 2018), training that develops a high level of muscular strength initially may enhance the magnitude of potential adaptations to subsequent plyometric training (Cormie et al., 2010, 2011b). This may have implications for enhancing muscular strength expression when training to improve rugby league performance (Gabbett et al., 2011a; Johnston et al., 2014; Redman, Wade, Kelly, et al., 2021; Redman, Wade, Whitley, et al., 2021).

CONSIDERATIONS AND LIMITATIONS

Although eccentric training appears to be a beneficial strategy to improve rugby league performance, several factors need to be considered. First, eccentric exercise should be integrated (i.e., not prescribed exclusively) into the resistance training plan (Suchomel et al., 2019b). Second, the planning of eccentric training should take into consideration the time course of adaptive responses (Suchomel et al., 2019a). Although eccentric exercise may elicit a protective effect that decreases muscle damage after subsequent training bouts (Chen et al., 2019; Nosaka, Newton, & Sacco, 2005), performance may be attenuated for a period of time (Hesselink, Kuipers, Geurten, & Van Straaten, 1996; Linnamo, Bottas, & Komi, 2000). Therefore, it may be beneficial to schedule adequate rest periods following training sessions involving eccentric exercise (≥ 72 h) (Table 2). Third, the realisation of delayed training effects following eccentric training may require considerable time (Baroni et al., 2013; Coratella & Schena, 2016; Leong et al., 2014; Shepstone et al., 2005). Monitoring systems may provide important information related to athletes’ psychophysiological state (DeWeese, Hornsby, Stone, & Stone, 2015) in response to eccentric training. A fourth consideration is the assignment of eccentric exercise loads. As force output is task-specific, prescribing eccentric loads based on tasks limited by concentric strength may not take advantage of the high levels of mechanical tension that can be elicited by eccentric exercise (Harden et al., 2019). Nevertheless, specialised equipment that may not be available in most practical environments is likely needed to establish maximal eccentric strength levels (Harden et al., 2018). Fifth, the training age and technical proficiency of players should be considered when prescribing eccentric training to reduce the chance of maladaptive outcomes (Suchomel et al., 2019b). Sixth, the decision to
### Table 2. Typical weekly resistance training schedule during the 17-week pre-season period

| Pre-season Calendar | Training phase | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Sunday |
|---------------------|----------------|--------|---------|-----------|----------|--------|----------|--------|
| Weeks 1-7           | GPP 1-2        | Full body (60 min) | Upper-body (45 min) | Lower-body (60 min) | Individualised extras** (45 min) | Full-body Eccentric exercise* (60 min) | OFF | OFF |
| Weeks 8-9           | Active Rest    | OFF    | Full-body (45 min) | OFF | OFF | Full-body (45 min) | OFF | OFF |
| Weeks 10-13         | SPP            | Full body (60 min) | Upper-body (45 min) | Lower-body (60 min) | Individualised extras** (45 min) | Full-body Eccentric exercise* (60 min) | OFF | OFF |
| Weeks 14-17         | PCP            | Full-body Eccentric exercise* (45 min) | Upper-body (45 min) | OFF | Full-body (45 min) | Captain’s run | Trial Game | OFF |

**Notes:**
*Session includes upper- and lower-body eccentric exercise (i.e., back squat, bench press); **resistance exercise parameters are selected based on a player's identified physical deficiencies and positional requirements.

*GPP* general physical preparation; *PCP* pre-competition phase; *SPP* special physical preparation.
Figure 2. Volume-load (sets x repetitions x load [%1RM] x eccentric time under tension [sec]) of eccentrically-integrated resistance training during a pre-season phase. GPP general preparation phase, PCP pre-competition phase, RM repetition max, SPP special preparation phase.
prescribe eccentric training should be informed by the physical demands of competition together with an individualised approach that addresses movement deficiencies and consideration of other sport-related training. Importantly, the pre-season programme illustrated is a general representation and does not reflect possible modifications due to changes in player health and performance and positional requirements that will ultimately guide resistance training prescription. Lastly, eccentric resistance training should be appropriately periodised to elicit a systematic and progressive overload over the pre-season phase (Figure 2).

**CONCLUSION**

Successful performances in rugby league require the ability to engage in repeated contact efforts with minimal recovery while maintaining a high running intensity (Johnston & Gabbett, 2011; Johnston et al., 2014). The capacity to express high levels of time-limited force appears to underlie many important physical attributes that are required to meet the repeated-effort demands of rugby league play (Gabbett et al., 2011a; Johnston et al., 2014; McMaster et al., 2013; Redman, Wade, Kelly et al., 2021; Redman, Wade, Whitley, et al., 2021). If appropriately periodised and integrated into the training plan, resistance training that sufficiently loads the eccentric phase of movement and progressively increases the rate of muscle lengthening velocity over the pre-season phase can provide a beneficial stimulus to elicit morphological and neural changes that culminate in improving muscular strength expression.

**REFERENCES**

1. Aagaard P. Training-induced changes in neural function. Exerc Sport Sci Rev, 31(2): 61-67, 2003. doi: 10.1097/00003677-200304000-00002
2. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P. Neural adaptation to resistance training: changes in evoked V-wave and H-reflex responses. J Appl Physiol, 92(6): 2309-2318, 2002.
3. Aagaard P, Simonsen EB, Andersen JL, Magnusson SP, Halkjaer-Kristensen J, Dyhre-Poulsen P. Neural inhibition during maximal eccentric and concentric quadriceps contraction: Effects of resistance training. J Appl Physiol, (89): 2249-2257, 2000. doi: 10.1152/ jappl.2000.89.6.2249
4. Abe T, Fukashiro S, Harada Y, Kawamoto K. Relationship between sprint performance and muscle fascicle length in female sprinters. J Physiol Anthropol, 20(2): 141-147, 2001.
5. Andersen LL, Aagaard P. Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development. Eur J Appl Physiol, 96: 46-52, 2006. doi: 10.1007/s00421-005-0070-z
6. Andersen JL, Aagaard P. Myosin heavy chain IIX overshoot in human skeletal muscle. Muscle Nerve, 23: 1095-1104, 2000. doi: 10.1002/1097-4598(200007)23:73.3.CO;2-F
7. Andersen LL, Andersen JL, Zebis MK, Aagaard P. Early and late rate of force development: Differential adaptive responses to resistance training? Scand J Med Sci Sports, 20: 162-169, 2010. doi: 10.1111/j.1600-0838.2009.00933.x
8. Austin DJ, Gabbett TJ, Jenkins DJ. Repeated high-intensity exercise in a professional rugby league. J Strength Cond Res, 25: 1898-1904, 2011. doi: 10.1519/JSC.0b013e3181e83a5b
9. Austin DJ, Kelly SJ. Positional differences in professional rugby league match play through the use of global positioning systems. J Strength Cond Res, 27: 14-19, 2013. doi: 10.1519/JSC.0b013e31824e108c
10. Azizi E, Brainerd EL. Architectural gear ratio and muscle fibre strain homogeneity in segmented musculature. J Exp Zool, 307A: 145-155, 2007.
11. Baar K, Esser K. Phosphorylation of p7OS6k correlates with increased skeletal muscle mass following resistance exercise. Am J Physiol Cell Physiol, 276(1): C120-127, 1999. doi: 10.1152/ajpcell.1999.276.1.C120.
12. Babault N, Pousson M, Ballay Y, Van Hoecke J. Activation of human quadriceps femoris during isometric, concentric, and eccentric contractions. J Appl Physiol, 91(6): 2628-2634, 2001.
13. Baker DG, Newton RU. Comparison of lower body strength, power, acceleration, speed, agility, and sprint momentum to describe and compare playing rank among professional rugby league players. J Strength Cond Res, 22: 153-158, 2008. doi: 10.1519/JSC.0b013e3181f5915.
14. Baker D, Wilson G, Carlyon R. Periodization: The effect on strength of manipulating volume and intensity. J Strength Cond Res, 8: 235-242, 1994.
15. Baroni BM, Geremia JM, Rodrigues R, De Azevedo Franke R, Karamanidis K, Vaz MA. Muscle architecture adaptations to knee extensor eccentric training: Rectus femoris vs. vastus lateralis. Muscle Nerve, 48: 498-506, 2013. doi: 10.1002/mus.23785.
16. Babault N, Pousson M, Ballay Y, Van Hoecke J. Activation of human quadriceps femoris during isometric, concentric, and eccentric contractions. J Appl Physiol, 91(6): 2628-2634, 2001.
17. Behrens M, Mau-Moeller A, Bruhn S. Effect of plyometric training on neural and mechanical properties of the knee extensor muscles. Int J Sports Med, 35(2): 101-109, 2014. doi: 10.1055/s-0033-1343401
18. Behrens M, Mau-Moeller A, Mueller K, Heise S, Gube M, Beuster N, Herlyn PK, Fischer DC, Bruhn S.
Plyometric training improves voluntary activation and strength during isometric, concentric and eccentric contractions. J Sci Med Sport, 19: 170-176, 2016. doi: 10.1016/j.jsms.2015.01.011

19. Beltman JM, Sargeant AJ, Van Mechelen W, De Haan A. Voluntary activation level and muscle fibre recruitment of human quadriceps during lengthening contractions. J App Physiol, 97(2): 619-626, 2004.

20. Blazevich AJ, Cannavan D, Coleman DR, Horne S. Influence of concentric and eccentric resistance training on architectural adaptation in human quadriceps muscles. J Appl Physiol, 103(5): 1565-75, 2007. doi: 10.1152/japplphysiol.00578.2007

21. Bobbert MF, Van Soest AJ. Effects of muscle strengthening on vertical jump height: A simulation study. Med Sci Sports Exerc, 26: 1012-1020, 1994. doi: 10.1249/00005768-19940800-00013

22. Bojsen-Moller J, Magnusson SP, Rasmussen LR, Kjaer M, Aagaard P. Muscle performance during maximal isometric and dynamic contractions is influenced by the stiffness of the tendinous structures. J Appl Physiol, 99(3): 986-994, 2005. doi: 10.1152/japplphysiol.01305.2004

23. Bompa TO, Haff G. Peaking for competition. In: Periodization: Theory and Methodology of Training. Champaign: Human Kinetics, 2009. pp. 187-202.

24. Bottinelli R, Pellegrino MA, Canepari M, Rossi R, Reggiani C. Specific contributions of various muscle fibre types to human muscle performance: An in vitro study. J Electromyogr Kinesiol, 9: 87-95, 1999. doi: 10.1016/S1050-6411(98)00040-6

25. Brannstrom A, Rova A, YuJG. Effects and mechanisms of tapering in maximizing muscular power. Sport Art, 1: 18-23, 2013. doi: 10.13189/saj.2013.010103

26. Burd NA, Andrews RJ, West DW, Little JP, Cochran AJ, Hector AJ, Cashaback JG, Gibala MJ, Potvin JR, Baker SK. Muscle time under tension during resistance exercise stimulates differential muscle protein sub-fractional synthetic responses in men. J Physiol, 590(2): 351-362, 2012. doi: 10.1113/jphysiol.2011.221200

27. Burd NA, West DW, Staples AW, Atherton PJ, Baker JM, Moore DR, Holwerda AM, Parise G, Rennie MJ, Baker SK, Phillips SM. Low-load high volume resistance exercise stimulates muscle protein synthesis more than high-load low volume resistance exercise in young men. PLoS One, 5: e120330, 2010. doi: 10.1371/journal.pone.0012033

28. Butterfield TA, Leonard TR, Herzog W. Differential serial sarcomere number adaptations in knee extensor muscles of rats is contraction type dependent. J Appl Physiol, 99(4): 1352-1358, 2005.

29. Chapman D, Newton M, Sacco P, Nosaka K. Greater muscle damage induced by fast versus slow velocity eccentric exercise. Int J Sports Med, 27: 591-598, 2006. doi: 10.1055/s-2005-865920

30. Chen TC, Yang TJ, Huang MJ, Wang HS, Tseng KW, Chen HL, Nosaka K. Damage and the repeated bout effect of arm, leg, and trunk muscle induced by eccentric resistance exercise. Scan J Med Sci Sports, 29: 725-735, 2019. doi: 10.1111/sms.13388

31. Collie EB, Tesch PA. Effects of eccentric and concentric muscle actions in resistance training. Acta Physiol Scand, 140: 31-39, 1990. doi: 10.1111/j.1748-1716.1990.tb08973.x

32. Cook CJ, Beaven CM, Kiduff LP. Three weeks of eccentric training combined with overspeed exercises enhances power and running speed performance gains in trained athletes. J Strength Cond Res, 27(5): 1280-1286, 2013. doi: 10.1519/JSC.0b013e3182679278

33. Coratella G, Schena F. Eccentric resistance training increases and retains maximal strength, muscle endurance, and hypertrophy in trained men. Appl Physiol Nutr Metab, 41(11): 1184-1189, 2016. doi: 10.1139/apnm-2016-0321

34. Cormie P, McGuigan MR, Newton RU. Changes in the eccentric phase contribute to improved stretch-shorten cycle performance after training. Med Sci Sports Exerc, 42(9): 1731-1744, 2010. doi: 10.1249/MSS.0b013e3181d392e8

35. Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power: Part 1. Biological basis of maximal power production. Sports Med, 41: 17-38, 2011a. doi: 10.2165/11537690-000000000-00000

36. Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power: Part 2. Biological basis of maximal power production. Sports Med, 41: 17-38, 2011b. doi: 10.2165/11538500-000000000-00000

37. de Lacey J, Brughelli M, McGuigan M, Hansen K, Samozino P, Morin, JB. The Effects of tapering on power-force-velocity profiling and jump performance in professional rugby league players. J Strength Cond Res, 28: 3567-3570, 2014. doi: 10.1519/JSC.0000000000000572

38. DeWeese BH, Hornsby G, Stone M, Stone MH. The training process: Planning for strength-power training in track and field. Part 2: Practical and applied aspects. J Sport Health Sci, 4(4): 318-324, 2015. doi: 10.1016/j.jshs.2015.07.002

39. Diniz RC, Martins-Costa HC, Machado SC, Lima FV, Chagas MH. Repetition duration influences ratings of perceived exertion. Percept Motor Skills, 118, 261E-273E, 2014. doi: 10.2466/03.06.PMS.118k11w6

40. Douglas J, Pearson S, Ross A, McGuigan MR. Chronic adaptations to eccentric training: A systematic review. Sports Med, 47: 917-941, 2017a. doi: 10.1007/s00025-016-0628-4

41. Douglas J, Pearson S, Ross A, McGuigan MR. Eccentric exercise: Physiological characteristics and acute responses. Sports Med, 47(4): 663-675, 2017. doi: 10.1007/s40279-016-0624-8

42. Duchateau J, Baudry S. Insights into the neural control of eccentric contractions. J Appl Physiol, 116(11): 1418-1425, 2014. doi: 10.1152/japplphysiol.00022.2013

43. Duclay J, Martin A, Duclay A, Cometti G, Pousson M. Behavior of fascicles and the myotendinous junction
of human medial gastrocnemius following eccentric strength training. Muscle Nerve, 39: 819-827, 2009. doi: 10.1002/mus.21297

44. Edman KAP. Double-hyperbolic force-velocity relation in frog muscle fibres. J Physiol, 404: 301-321, 1988. doi: 10.1113/jphysiol.1988.sp01729

45. Eliasson J, Elfegoun T, Nilsson J, Kohrke R, Ekblom B, Blomstrand E. Maximal lengthening contractions increase p70S6K phosphorylation in human skeletal muscle in the absence of nutritional supply. Am J Physiol Endocrinol Metab, 291: E1197-205, 2006. doi: 10.1152/ajpendo.00141.2006

46. Elmer S, Hahn S, McAllister P, Leong C, Martin J. Improvements in multi-joint leg function following chronic eccentric exercise. Scand J Med Sci Sports, 22(5): 653-661, 2012. doi: 10.1111/j.1600-0838.2011.01291.x

47. English K, Loehr J, Lee SM, Smith SM. Early-phase musculoskeletal adaptations to different levels of eccentric resistance after 8 weeks of lower body training. Eur J Appl Physiol, 114(11): 2263-2280, 2014. doi: 10.1007/s00421-014-2951-5

48. Fang Y, Siemionow V, Sahgal V, Xiong F, Yue GE. Distinct brain activation patterns for human maximal voluntary eccentric and concentric muscle actions. Brain Res, 1023(2): 200-212, 2004. doi: 10.1016/j.brainres.2004.07.035

49. Fang Y, Siemionow V, Sahgal V, Xiong F, Yue GH. Greater movement-related cortical potential during human eccentric versus concentric muscle contractions. J Neurophysiol, 86(4): 1764-1772, 2001. doi: 10.1152/jn.2001.86.4.1764

50. Farthing JP, Chilibeck PD. The effects of eccentric and concentric training at different velocities on muscle hypertrophy. Eur J Appl Physiol, 89: 578-586, 2003. doi: 10.1007/s00424-003-0842-2

51. Farup J, Rahbek SK, Vendelbo MH, Matzon A, Hindhede J, Bejder A, Ringgard S, Vissing K. Whey protein hydrolysate augments tendon and muscle hypertrophy independent of resistance exercise contraction mode. Scand J Med Sci Sports, 24: 788-798, 2014. doi: 10.1111/sms.12083

52. Franchi MV, Atherton PJ, Reeves ND, Fluck M, Williams J, Mitchell WK, Selby A, Beltran Valls RM, Narici MV, Valls Architectural, functional, and molecular responses to concentric and eccentric loading in human skeletal muscle. Acta Physiol, 210: 642-654, 2014. doi: 10.1111/apha.12225

53. Friedrich-Bette B, Bauer T, Kinscherf R, Vorwald S, Klute, K, Bischoff D, Muller H, Weber MA, Metz J, Kauczor HU, Bartsch P, Billeter R. Effects of strength training with eccentric overload on muscle adaptation in male athletes. Eur J Appl Physiol, 108(4): 821-836, 2010. doi: 10.1007/s00424-009-1292-2

54. Fry AC, Allemeier CA, Staron RS. Correlation between percentage fibre type area and myosin heavy chain content in human skeletal muscle. Eur J Appl Physiol, 68(3): 246-251, 1994.

55. Fry AC, Schilling BK, Staron RS, Hagerman FC, Hikida RS, Thrush JT. Muscle fibre characteristics and performance correlates of male Olympic-style weightlifters. J Strength Cond Res, 17(4): 746-754, 2003.

56. Fry AC, Webber JM, Weiss LW, Harber MP, Vaczi M, Pattison NA. Muscle fiber characteristics of competitive power lifters. J Strength Cond Res, 17(2): 402-410, 2003. doi: 10.1519/00124278-200305000-00031

57. Gabbett TJ. Influence of ball-in-play time on the activity profiles of rugby league match-play. J Strength Cond Res, 29(3): 716-721, 2015. doi: 10.1519/JSC.000000000000446

58. Gabbett TJ, Jenkins DG, Abernethy B. Correlates of tackling ability in high-performance rugby league players. J Strength Cond Res, 25: 72-79, 2011a. doi: 10.1519/JSC.0b013e3181ff506f

59. Gabbett TJ, Jenkins DG, Abernethy B. Physical collisions and injury in professional rugby league match-play. J Sci Med Sport, 14(3): 210-215, 2011b. doi: 10.1016/j.jsms.2011.01.002

60. Gabbett TJ, Wheeler AJ. Predictors of repeated high-intensity effort ability in rugby league players. Int J Sports Physiol Perform, 10: 718-724, 2015. doi: 10.1123/ijssp.2014-0127

61. Godfrey RJ, Whyte GP, Buckley J, Quinlinv R. The role of lactate in the exercise-induced human growth hormone response: Evidence from McArdle disease. Br J Sports Med, 43(7): 521-525, 2009. doi: 10.1136/ bjsm.2007.041970

62. Golas A, Maszczyk A, Zajac A, Mikolajek K, Stasnty P. Optimizing post activation potentiation for explosive activities in competitive sports. J Hum Kin, 52: 95, 2016. doi: 10.1515/hukin-2015-0197

63. Goldspink G, Harridge S. Cellular and molecular aspects of adaptation in skeletal muscle. In: Strength and Power in Sport. P.V. Komi, ed. Blackwell Science, 2003. pp. 231-251.

64. Handford MJ, Bright TE, Mundy P, Lake J, Theis N, Hughes JD. The need for eccentric speed: A narrative review of the effects of accelerated eccentric actions during resistance-based training. Sports Med, 10: 1-23, 2022. doi: 10.1007/s40279-022-01868-z

65. Harden M, Wolf A, Haff GG, Hicks KM, Howatson G. Repeatability and specificity of eccentric force output and the implications for eccentric training load prescription. J Strength Cond Res, 33(3): 676-683, 2019. doi: 10.1519/JSC.0000000000002965

66. Harden M, Wolf A, Russell M, Hicks KM, French D, Howatson G. An evaluation of supramaximally loaded eccentric leg press exercise. J Strength Cond Res, 32(10): 2708-2714, 2018. doi: 10.1519/JSC.0000000000002497

67. Haun CT, Vann CG, Osburn SC, Mumford PW, Roberson PA, Romero MA, Fox CS, Johnson CA, Parry HA, Kavazis AN, Moon JR, Badisa VLD Mwashote BM, Ibeanusi V, Young KC, Roberts MD. Muscle fiber hypertrophy in response to 6 weeks of high-volume resistance training in trained young men is largely attributed to sarcoplasmic hypertrophy. PLoS One, 14(6): e0215267, 2019a. doi: 10.1371/
80. Holmberg, P., M., Jenkins, D. G., & Kelly, V. G. (2020). International Journal of Strength and Conditioning. 2022

81. Kraemer RR, Castracane VD. Endocrine alterations during the competition phase in team sports. Strength Cond J, 29: 32-37, 2007. doi: 10.1519/1533-4295(2007)29[32:PAMTLD]2.0.CO;2

82. Krzysztofik M, Wilk M, Lockie RG, Golas A, Zajac A, Bogdanis GC. Postactivation performance enhancement of concentric bench press throw after eccentric-only conditioning exercise. J Strength Cond Res, 36(8): 2077-2081, 2020. 10.1519/JSC.000000000003802

83. Krzysztofik M, Wilk M, Wojdala G, Golas A. Maximizing muscle hypertrophy: A systematic review of advanced resistance training techniques and methods. Int J Environ Res, 16(24): 4897, 2019. doi: 10.3390/ijerph16244897

84. Kubo K, Ishigaki T, Ikebukuro T. Effects of plyometric and isometric training on muscle and tendon stiffness in vivo. Physiol Rep, 5(15): e13374, 2017. doi: 10.14814/phy2.13374

85. Kyrolainen H, Komiv P, Kim DH. Effects of power training on neuromuscular performance and mechanical efficiency. Scand J Med Sci Sports, 35: 559-565, 2014. doi: 10.1055/s-0033-1358471

86. Liang H, Ward WF. PGC-1α: A key regulator of energy metabolism. Adv Physiol Educ, 2006.

87. Lieber R, Friden J. Selective damage of fast glycolytic muscle fibres with eccentric contraction of the rabbit tibialis anterior. Acta Psychiatr Scand, 133(4): 587-588, 1988.

88. Linnamo V, Bottas R, Komiv P. Force and EMG power spectrum during and after eccentric and concentric fatigue. J Electromyogr Kin, 10(5): 293-300, 2000. doi: 10.1016/S1050-6411(00)00021-3

89. Liu C, Chen CS, Ho WH, Fule RJ, Chung PH, Shiang TY. The effects of passive leg press training on jumping performance, speed, and muscle power. J Strength Cond Res, 27(6): 1479-1486, 2013. doi: 10.1519/JSC.0b013e31826bde9f

90. Malisoux L, Francaux M, Nielsens H, Theisen D. Stretch-shortening cycle exercises: An effective training paradigm to enhance power output of human single muscle fibers. J Appl Physiol, 100(3): 771-779, 2006. doi: 10.1152/japplphysiol.00021.2005

91. Malliaras P, Kamal B, Nowell A, Farley T, Dhamu H, Siompson V, Morrissey D, Langberg H, Maffulli N, Reeves ND. Patellar tendon adaptation in association with quadriceps muscle structure and maximum cycling power. Int J Sports Med, 35: 559-565, 2014. doi: 10.1055/s-0033-1358471
eccentric conditioning stimuli on subsequent countermovement jump performance. J Strength Cond Res, 30(3): 747–754, 2016.

107. Paddon-Jones D, Leveritt M, Lonergan A, Abernathy P. Adaptation to chronic eccentric exercise in humans: The influence of contraction velocity. Eur J Appl Physiol, 85: 466-471, 2001. doi: 10.1007/s004210100467

108. Papadopoulos C, Theodosiou K, Bogdanis GC, Gkantiraga E, Gissis I, Sambanis M, Sougias A, Sotiropoulos A. Multiaxial isokinetic high-load eccentric training induces large increases in eccentric and concentric strength and jumping performance. J Strength Cond Res, 28(9): 2680-2686, 2014. doi: 10.1519/JSC.0000000000000456

109. Pensini M, Martin A, Maffioletti NA. Central versus peripheral adaptations following eccentric resistance training. Int J Sports Med, 23: 567-574, 2002. doi: 10.1055/s-2002-35558

110. Pereira PEA, Motoyama YL, Esteves GJ, Quinelato WC, Botter L, Tanaka KH, Azevedo P. Resistance training with slow speed of movement is better for hypertrophy and muscle strength gains than fast speed of movement. Int J Appl Exerc Physiol, 5: 37-43, 2016.

111. Potier TG, Alexander CM, Seynnes OR. Effects of eccentric strength training on biceps femoris muscle architecture and knee joint range of movement. Eur J Appl Physiol, 105: 939-944, 2009. doi: 10.1007/s00421-008-0980-7

112. Potteiger JA, Lockwood RH, Haub MD, Dolezal BA, Almuzaini KS, Schroeder JM, Zebas CJ. Muscle power and fiber characteristics following 8 weeks of plyometric training. J Strength Cond Res, 13: 275-279, 1999. doi: 10.1519/00124278-199908000-00016

113. Proske U, Morgan DL. Muscle damage from eccentric exercise: Mechanism, mechanical signs, adaptation and clinical adaptations. J Physiol, 537: 333-345, 2001. doi: 10.1111/j.1469-7793.2001.00333.x

114. Pryor RR, Sforzo GA, King DL. Optimizing power output by varying repetition tempo. J Strength Cond Res, 25: 3029-3034, 2011. doi: 10.1519/JSC.0b013e31820f50cb

115. Raue U, Terpstra B, Williamson DL, Gallagher PM, Trappe SW. Effects of short-term concentric vs. eccentric resistance training on single muscle fiber MHC distribution in humans. Int J Sports Med, 26: 339-343, 2005. doi: 10.1055/s-2004-821041

116. Redman KJ, Wade L, Kelly VG, Connick MJ, Beckman EM. Predicting rugby league tackle outcomes using strength and power principal components. Int J Sports Physiol Perform, 1-8, 2021. doi: 10.1123/ijssp.2021-0075

117. Redman KJ, Wade L, Whitley R, Connick MJ, Kelly VG, Beckman, EM. The relationship between match tackle outcomes and muscular strength and power in Professional rugby league. J Strength Cond Res, 2021. doi: 10.1519/JSC.0000000000003940

118. Roberts MD, Haun CT, Vann CG, Osburn SC,
Young KC. Sarcoplasmic hypertrophy in skeletal muscle: A scientific "unicorn" or resistance training adaptation? Front Physiol, 11: 816, 2020. doi: 10.3389/fphys.2020.00816

119. Roig M, O’Brien K, Kirk G, Murray R, McKinnon P, Shagdan B, Reid WD. The effects of eccentric versus concentric resistance training on muscle strength and mass in healthy adults: A systematic review with meta-analysis. Br J Sports Med, 43(8): 556-568, 2009. doi: 10.1136/bjsm.2008.051417

120. Schiaffino S, Gorza L, Ausoni S, Bottinelli R, Reggiani C, Larson E, Edstrom L, Gundersen K, Lomo T. Muscle fiber types expressing different myosin heavy chain isoforms. Their functional properties and adaptive capacity. In: The Dynamic State of Muscle Fibers, de Gruyter, 2019. pp. 329-342. doi: 10.1515/9783110884784-028

121. Schoenfeld BJ. The mechanisms of muscle hypertrophy and their application to resistance training. J Strength Cond Res, 24(10): 2857-2872, 2010. doi: 10.1519/JSC.0b013e3181e84013

122. Schoenfeld B, Fisher J, Grigic J, Haun C, Helms E, Phillips S, Steele J, Vigotsky A. Resistance training recommendations to maximize muscle hypertrophy in an athletic population: Position stand of the IUSCA. Int J Strength Cond, 16: 1(1), 2021. doi: 10.47206/ijsc.v1i1.81

123. Seger JY, Thorstensson A. Electrically evoked eccentric and concentric torque-velocity relationships in human knee extensor muscles. Acta Psychiatr Scand., 169(1): 63-69, 2000.

124. Seitz LB, Reyes A, Tran TT, de Villarreal ESS, Haff GG. Increases in lower-body strength transfer positively to sprint performance: A systematic review with meta-analysis. Sports, 7: 15, 2019. doi: 10.1016/j.saps.2019.01-1107-8

125. Seynnes OR, de Boer M, Narici MV. Early skeletal muscle hypertrophy and architectural changes in response to high-intensity resistance training. J Appl Physiol, 102: 368-373, 2007. doi: 10.1152/japplphysiol.00789.2006

126. Sharifnejhad A, Marzilger R, Arampatzis A. Effects of load magnitude, muscle length and velocity during eccentric chronic loading on the longitudinal growth of the vastus lateralis muscle. J Exp Biol, 217(15): 2726-2733, 2014. doi: 10.1242/jeb.100370

127. Shepstone TN, Tang JE, Dallaire S, Schuenke MD, Staron RS, Phillips SM. Short-term high- vs. low-velocity isokinetic lengthening training results in greater hypertrophy of the elbow flexors in young men. J Appl Physiol, (98): 1768-1776, 2005. doi: 10.1152/japplphysiol.01027.2004

128. Staron RS, Karapondo DL, Kraemer WJ, Fry AC, Gordon SE, Finkel JE, Hagerman FC, Hikida RS. Skeletal muscle adaptations during early phase of heavy-resistance training in men and women. J Appl Physiol, 76(3): 1247-1255, 1994.

129. Stasiak AN, Zaras N, Methenitis S, Bogdanis G, Terzis G. Rate of force development and muscle architecture after fast and slow velocity eccentric training. Sports, 7(2): 41, 2019. doi: 10.3390/sports7020041

130. Stauber WT. Eccentric action of muscles: Physiology, injury, and adaptation. Exerc Sport Sci Rev, 17: 157-185, 1988.

131. Stone MH, Moir G, Glaister M, Sanders R. How much strength is necessary? Phys Ther Sport, 3(2): 88-96, 2002. doi: 10.1054/ptsp.2001.0102

132. Stone MH, Stone M, Sands WA. The concept of periodization. In: Principles and Practice of Resistance Training. Champaign: Human Kinetics, 2007. pp. 259-286.

133. Suchomel TJ, Nimphius S, Bellon CR, Stone MH. The importance of muscular strength: Training considerations. Sports Med, 48: 765-785, 2018. doi: 10.1007/s40279-018-0862-z

134. Suchomel TJ, Wagle JP, Douglas J, Taber, CB, Harden M, Haff GG, Stone MH. Implementing eccentric resistance training – part 1: A brief review of existing methods. J Funct Morphol Kinesiol, 4(2): 38, 2019a. doi: 10.3390/jfmk4020038

135. Suchomel TJ, Wagle JP, Douglas J, Taber, CB, Harden M, Haff GG, Stone MH. Implementing eccentric resistance training – part 2: Practical recommendations. J Funct Morphol Kinesiol, 4(3): 55, 2019b. doi: 10.3390/jfmk4030055

136. Taber CB, Vigotsky A, Nuckols G, Haun CT. Exercise-induced myofibrillar hypertrophy is a contributory cause of gains in muscle strength. Sports Med, 49(7): 993-997, 2019. doi: 10.1007/s40279-019-01107-8

137. Tallent J, Goodall S, Gibbon KC, Hortobagyi T, Howatson G. Enhanced corticospinal excitability and volitional drive in response to shortening and lengthening strength training and changes following detraining. Front Physiol, 8: 57, 2017. doi: 10.3389/fphys.2017.00057

138. Tesch PA, Karlsson J. Muscle fibre types and size in trained and untrained muscles of elite athletes. J Appl Physiol, 59(6): 1716-1720, 1985.

139. Terzis G, Sengpos K, Mascher H, Georgiaidis G, Manita P, Blomstrand E. The degree of p70S6K and S6 phosphorylation in human skeletal muscle in response to resistance exercise depends on the training volume. Eur J Appl Physiol, 110(4): 835-843, 2010. doi: 10.1007/s00421-010-1527-2

140. Toumi H, Thiery C, Maitre S, Martin A, Vanneuville G, Pourmarat G. Training effects of amortization phase with eccentric/concentric variations – the vertical jump. Int J Sports Med, 22: 605-610, 2001. doi: 10.1055/s-2001-18525

141. Van den Tillaar R. Effect of descent velocity upon muscle activation and performance in two-legged free weight back squats. Sports, 7: 15, 2019. doi: 10.3390/sports7010015

142. Vangsgaard S, Taylor JL, Hansen EA, Madeleine P. Changes in H reflex and neuromechanical properties of the trapezius muscle after 5 weeks of eccentric training: A randomized controlled trial. J Appl Physiol, 116(12): 1623-1631, 2014. doi: 10.1152/
Varley MC, Gabbett T, Aughey RJ. Activity profiles of professional soccer, rugby league and Australian football match play. J Sports Sci, 32(20): 1858-1866, 2013. doi: 10.1080/02640414.2013.823227

Vikne H, Refsnes PE, Ekmark M, Medbo JI, Gundersen V, Gundersen K. Muscular performance after concentric and eccentric exercise in trained men. Med Sci Sports Exerc, 38(10): 1770-1781, 2006. doi: 10.1249/01.mss.0000229568.17284.ab

Vogt M, Hoppeler HH. Eccentric exercise: Mechanisms and effects when used as training regime or training adjunct. J App Physiol, 2014.

Westing SH, Cresswell AG, Thorstensson A. Muscle activation during maximal voluntary eccentric and concentric knee extension. Eur J App Physiol, 62(2): 104-108, 1991.

Wickiewicz TL, Roy RR, Powell PL, Perrine JJ, Edgerton VR. Muscle architecture and force-velocity relationships in humans. J Appl Physiol, 57(2): 435-443, 1984.

Wilk M, Golas A, Krzysztofik M, Nawrocka M, Zajac A. The effects of eccentric cadence on power and velocity of the bar during the concentric phase of the bench press movement. J Sports Sci Med, 18: 191-197, 2019.

Zamparo P, Minetti A, di Prampero P. Interplay among the changes of muscle strength, cross-sectional area, and maximal explosive power: Theory and facts. Eur J Appl Physiol, 88: 193-202, 2002. doi: 10.1007/s00421-002-0691-4