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Review article

Seasonal Changes in Strength and Power in Elite Rugby League: A Systematic Review and Meta-Analysis

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Abstract

The ability of a rugby league player to express high levels of strength and power is crucial for success in competition. Although researchers have shown relationships between physical attributes and performance, there is a lack of information related to changes in strength and power across various phases of the season. The purpose of this review was to identify the magnitude of change in muscular strength and power during different phases of an elite rugby league season. Percentage change and effect size were calculated to evaluate the magnitude of changes in strength and power. Meta-analyses were conducted to provide pooled estimates and 95% confidence intervals. Twelve studies were included; six reported changes following pre-season training, two during the competition phase and four examined changes over multiple seasons. Pooled estimates indicated large increases in upper and lower body strength 0.81 [0.43 - 1.19] and 1.35 [0.79 - 1.91], respectively, following pre-season training. Studies incorporating predominantly heavier loads (≥ 80% 1 RM) in training reported greater increases in maximal strength than studies completing lighter loads. Four studies used a wave-like programming strategy to obtain large improvements in strength and power 0.91 [0.36 - 1.45] and 0.90 [0.22 - 1.57], over multiple seasons. The results of this review highlight the limited current evidence and provides a preliminary reference point for strength and conditioning coaches aiming to develop and maintain strength and power across various stages, and over multiple seasons. Importantly, the results also indicate that higher loads result in greater increases in strength than lower loads.

Key words: Resistance training, football, professional, pre-season, competition.

Introduction

Numerous sports require athletes to possess a variety of physical qualities to meet the demands of competition, such as; muscular strength and power, speed, agility, repeat sprint ability, aerobic power and high-intensity running ability (Cronin and Hansen, 2005; Johnston et al., 2014; Waldron et al., 2011). An athlete's capacity to express high levels of strength and power is particularly important for success in impact sports, such as rugby league, where competition is characterised by many intense physical collisions and high velocity movements (Cronin and Hansen, 2005). Specifically, during matches, rugby league players are involved in an average of 0.68 collisions per minutes, while generally travelling 90 - 100 m per minute, 300 - 500 m of this at high-speed and completing an average number of accelerations 1.1 ± 0.56 per minute (Gabbett et al., 2012a; Johnston et al., 2014; 2019a; 2019b). During peak periods, elite rugby league players can be involved in up to 1.5 collisions per minute, travel 154 - 172 m per minute and accelerate 1.22 - 1.28 $m.s^{-2}$ per minute (Delaney et al., 2015; Hulin et al., 2015; Weaving et al., 2019). Rugby league players are required to express high levels of force to effectively tackle, tolerate impacts during physical contact and generate large amounts of power to evade an opponent or quickly play-the-ball following a tackle (Baker, 2001a; Johnston et al., 2014; Kraemer and Newton, 2000; Mayhew et al., 1989).

Maximal strength and power have been identified as important physical qualities that are associated with a broad range of technical skills (Gabbett et al., 2011a; Johnston et al., 2014; Redman et al., 2021), a lower risk of injury, and have been reported to increase with playing standard in rugby league (Baker, 2001b; Baker and Newton, 2008c; Gabbett et al., 2011b; 2012b). While the current literature has shown relationships between physical attributes and performance, there is a lack of information on the development and maintenance of strength and power in elite rugby league following training. Given the importance of providing the optimal training dose to elicit positive adaptation, information on magnitude of change and the training load associated with such changes would be useful for strength and conditioning coaches.

In order to develop physical attributes (i.e. strength, power and aerobic power) with technical and tactical skills required to meet the demands of rugby league competition, concurrent resistance and aerobic training is implemented in training (Baker, 2001b; McMaster et al., 2013). The literature on strength and power and the associated changes following concurrent resistance and aerobic training in sport is extensive (Appleby et al., 2012; Baker, 2001b; McMaster et al., 2013) and shows that muscular strength and power can be developed despite the challenges of concurrent training (Docherty and Sporer, 2000). These findings are likely due to the aerobic conditioning completed as interval training which has been shown by numerous researchers to minimise the mixed signaling effect associated with concurrent training (Balabinis et al., 2003; Sale et al., 1990). Players previous concurrent training experience, along with the duration, frequency and mode of training, may also affect the muscles ability to adapt to the training stimulus (Baker, 2001b; Docherty and Sporer, 2000). As concurrent resistance and aerobic training can affect adaptation, a systematic approach is necessary to achieve maximum adaptation throughout various phases of competition

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(Baker, 1998; 2001b; Baker et al., 1994). Numerous periodisation strategies have been established to optimise the adaptation to training over short and long periods of time (Bompa and Buzzichelli, 2015). This strategy is implemented in an effort to ensure players are in peak physical condition at a particular point during competition (Baker et al., 1994). Typically, rugby league adopts a classic periodisation model that divides the year into three main macrocycles i.e. pre-season, competition and off-season phases (Kelly and Coutts, 2007).

The primary goal during pre-season resistance training in rugby league is often to stimulate muscle hypertrophy while increasing maximal muscular strength and power (Baker et al., 1994). Resistance training sessions are more frequent during pre-season, enabling the development of physical attributes (de Lacey et al., 2014a). A limited number of studies have shown an elite rugby league player's lower body strength and power can be developed with a number of resistance training protocols during pre-season training (Comfort et al., 2012; de Lacey et al., 2014a; 2014b; Harris et al., 2008). What is not yet known is the magnitude of change in strength and power qualities a strength and conditioning coach would expect to observe following pre-season training period without this information coaches are potentially unable to optimise training sessions (i.e. exercise selection, frequency, intensity).

In rugby league, the principal objective of resistance training during the competition phase is to maintain strength and power developed in the pre-season (Baker, 1998). The competitive season is 24 - 32 weeks, with competition on a weekly basis, and this competition necessitates a decrease in resistance training load to allow for increases in the volume of technical and tactical skill training. In addition, muscle damage and inflammation following a match, potentially causing decrements in muscle performance, which may be problematic for developing or maintaining muscular strength and power (Baker, 1998; Baker and Newton, 2006; Twist and Highton, 2013). Given the reduced resistance training load, a better understanding of the magnitude of change (or lack thereof) would enable coaches to enhance training programs to optimise adaptation.

Long-term resistance training, considered to be regular training across multiple seasons (at least four), in elite rugby league aims to develop and/or maintain (depending on the players training age) muscular strength and power (Baker and Newton, 2006). This may be challenging in an elite rugby league environment given injuries, training age, contractual arrangement etc. It is unclear if training protocols change across multiple seasons for players of varying experience and what the expected changes of strength and power are across a player's career (Baker, 2013). Therefore, identifying specific training protocols and adaptations of players with varying experience may assist strength and conditioning coaches programming for a diverse group of players.

To date, two reviews have combined the changes of strength and power across various football codes (Hrysomallis, 2010; McMaster et al., 2013). One review was limited as it reported upper body changes occurring during the competitive season for American football, rugby union and rugby league (Hrysomallis, 2010). Moreover, no further analysis was performed (i.e. pooling, effect magnitude) in the review to determine the magnitude of change (Hrysomallis, 2010). A meta-analysis would provide practical knowledge on the magnitude of the effect of the training interventions. The second review investigated rugby league players of all levels throughout all phases of the season and reported changes per session completed (McMaster et al., 2013). To date, no systematic review has combined the current literature on changes of strength and power in elite rugby league throughout various points of a season. Given the importance of strength and power to physical preparation and performance in rugby league, and other collision sports, a review may provide strength and conditioning coaches with a valuable reference point to allow better optimisation of training prescription across each phase of a season or a player's career (following multiple seasons). The primary purpose of this review was to identify the magnitude of change in muscular strength and power, following various resistance training programs, across various stages, and over multiple, seasons in elite rugby league. Further, a meta-analysis was completed to determine the size of the effect of the training intervention.

Methods

Eligibility criteria

Studies were included if they were original empirical research, the participant groups were elite level rugby league players contracted to play and train fulltime in the National Rugby League or Super League competition. Further, studies that reported direct measurements of strength or power pre and post a resistance training intervention during a phase of the season (i.e. pre-season, competition, off-season) were included. Studies were excluded if participant groups were not rugby league players, or were semi-elite, amateur or junior rugby league players, if the training intervention did not include a resistance training program, if the study did not specify the phase of the season it occurred over and if changes in strength or power were acute. Only articles that were available in the English language were consulted.

Search strategy

A systematic literature search was conducted using EBSCO Host MEDLINE, PubMed, Web of Science and SportDiscus with dates ranging from the earliest record to October 2018. The search terms contained 'rugby league' AND 'resistance training' OR 'strength training' OR 'weight training' AND 'power' OR 'strength'.

Selection of studies and data extraction

The search identified 668 potentially relevant studies that were extracted into a spreadsheet. Following the removal of duplicates, the total remaining was 442. Titles and abstracts were reviewed for inclusion against eligibility criteria by one of the authors. Any doubts on a study meeting the inclusion criteria resulted in two authors reviewing the full text. Disagreements were resolved by discussion between the authorship team. Of these articles, twelve met the selection criteria (Figure 1).

Data relating to the number of participants, participant characteristics, competition, assessment of strength or power, length of training, training intervention were extracted and categorised based on phase of season (Table 1). The methodological quality of each study was appraised using the Newcastle-Ottawa Scale adapted for cross-sectional studies (Table 2) (Stang, 2010). This scale has been used in systematic reviews of elite athletes and has established content and interrater reliability (Ashley et al., 2015; Gupta et al., 2017).

Data analysis

All data is presented as mean (± SD). To evaluate the magnitude of changes in muscular strength and power, percentage change ($[\text{Post-}X_{mean} - \text{Pre-}X_{mean}]/\text{Pre-}X_{mean} \times 100$) and effect size ($[\text{Post-}X_{mean} - \text{Pre-}X_{mean}]/\text{PreSD}$) were calculated for each dependent variable for each study. Percent change was used to estimate the magnitude of change in strength and power across all studies. The strength of the effect was classified based on Cohen (Cohen, 1988), which suggests effect sizes (ES) of ≤0.2, 0.21 - 0.5, 0.51 - 0.8 and >0.8 for trivial, small, moderate, and large magnitudes of effect, respectively. Further quantitative analysis was conducted in R Studio (version 3.6.3; RStudio, Inc.). Data were pooled and standardised mean difference (SMD) and 95% confidence intervals (CI) were calculated using random-effects models between post- and pre-training measurements. SMD allowed standardised values obtained using different methods into a consistent scale to complete the meta-analysis. The size of the effect of the intervention was considered small (SMD 0.20), moderate (SMD 0.5) or large (SMD 0.80). Statistical heterogeneity was investigated using I^2 statistics and was considered low (I^2 <25%), moderate (I^2 25 - 49%) or high (I^2 >50%) (Higgins et al., 2003).

Results

Methodological quality

The methodological quality of these studies was moderate, with scores ranging from six to seven, out of ten, across the three categorise that were assessed (Table 2). All studies, participant selection was representative of the sample with description of players anthropometric qualities. Given the nature of professional rugby league training environment sample sizes were limited (n = 6 - 22) and there were no control groups. Pre and post strength and/or power outcome variables were measured in eleven studies whilst the other study reported change in power variables.

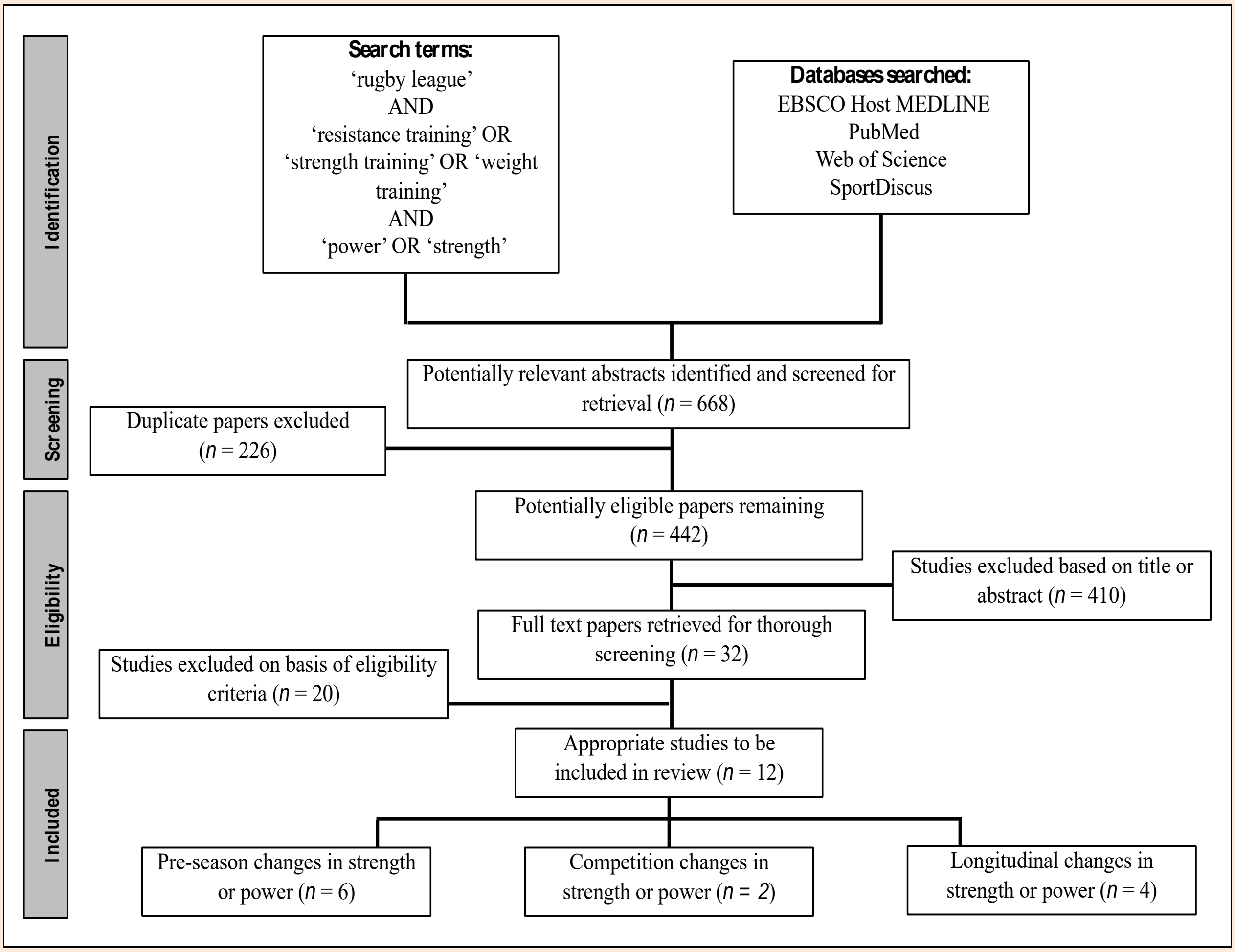

Figure 1. Flow diagram describing publication selection for this review.

Table 1. Summary of training intervention and changes in professional rugby league strength and power studies.

Study	Competition	Participant characteristics	Performance measures	Length of intervention	Training stimulus	Performance effect %	ES
Pre-Season							
O'Connor and Crowe, 200)	NRL	*n* = 8 24.9 ± 1.5 yrs, 94.7 ± 2.0 kg,	3 RM bench press 3 RM deadlift 3 RM DB shoulder press 3 RM prone row Chin ups 10 s leg power test	6 weeks	RT 3/wk (25-30 sets/session x 2-6 reps @ 80-95%) Speed/power 1/wk Con 4/week TP 4/wk	BP ↑ 3.5 ± 0.1 DL ↑ 10.9 ± 0.5 DB SP ↑ 7.6 ± 1.3 Row ↑ 0.8 ± 0.5 Chins ↑ 3.4 ± 1.7 W/kg ↑ 6.8 ± 1.0	0.71 1.55 1.25 0.20 0.30 0.86
Rogerson et al., 2007	NRL	*n* = 11 19.0 ± 1.3 yrs, 87.6 ± 9.0 kg, 1.81 ± 0.05 m	2 RM bench press 2 RM leg press 2 RM deadlift 2 RM seated row	5 weeks	RT 4/wk LB (4 sets x 2-8 reps) Vol load: 15,394 ± 2,085 kg UB (4 sets x 2-8 reps and 2 sets x 20 reps) Vol load: 6,715 ± 569 kg Whole-body RT (4 sets x 1-4 reps) Vol load: 8,120 ± 1,207 kg	BP ↑ 10.9 ± 3.6 LP ↑ 25.1 ± 5.6 DL ↑ 17.4 ± 3.2 SR ↑ 10.2 ± 5.8	0.78 1.15 0.84 0.69
Harris et al., 2008	NRL	*n* = 18 21.8 ± 4.0 yrs, 96.2 ± 9.9 kg, 1.81 ± 0.05 m	1 RM hack-squat machine Loaded hack-squat machine squat jumps @ 20, 30, 40, 50, 60, 70 and 80% of 1 RM	7 weeks	Machine squat jumps 5 sets x 5 reps @ 80% 2/wk (except week 4 1/wk) UB 2/wk Sprints*	1 RM ↑ 16.6 ± 3.2 1 RM/kg ↑ 16.5 ± 1.3 N ↓ 8.8 ± 9.9 N/kg ↓ 9.9 ± 8.8 W ↓ 17.1 ± 9.1 W/kg ↓ 17.1± 9.0	0.86 0.99 N/A N/A N/A N/A
				7 weeks	Machine squat jumps 6 sets x 10-12 reps @ individual PP output 2/wk (except week 4 1/wk) UB 2/wk Sprints*	1RM ↑ 9.2 ± 0.9 1RM/kg ↑ 8.3 ± 1.2 N ↓ 2.2 ± 10.1 N/kg ↓ 4.5 ± 10.1 W ↓ 6.0 ± 18.3 W/kg ↓ 6.5 ± 16.6	0.47 0.40 N/A N/A N/A N/A
Comfort et al., 2012	Super league	*n* = 19 96.2 ± 11.11 kg, 1.84 ± 0.06 m,	1 RM back squat	8 weeks	RT and TP 2/wk Ag and Plyo1/wk Weeks 1 – 4 strength (4 sets x 4-6 reps @ 85-90%) Week 5 – 8 power (4 sets x 3-6 reps @ 85%)	1 RM ↑ 17.7 ± 3.7 1 RM/kg ↑ 15.2 ± 5.8	1.04 0.84
de Lacey et al., 2014a	NRL	*n* = 9 24 ± 3.6 yrs, 99.0 ± 12.2 kg, 1.83 ± 0.06 m	Jump squats @ 25, 50, 75 and 100% body mass	3 weeks	7 wks, IRV 358.4/wk (6-15 reps at 65-83%) 6 wks, IRV ↓ to 156.87/wk (3-6 reps at 80-95%) 3 wks, IRV ↓ to 40.8/wk Field sessions 60 mins 3-4/wk	W/kg ↑ 28.2 ± 23.4 JH25% ↑ 20.6 ± 14.9 JH50% ↑ 32.9 ± 22.7 JH75% ↑ 43.2 ± 29.8 JH100% ↑ 42.9 ± 50.3	0.82 0.88 1.05 0.99 0.89

*denotes limited information presented in study, NRL; national rugby league, RM; maximal strength, RT; resistance training, Con; aerobic conditioning, TP; team practice, BP; bench press, DL; deadlift, DB SP; dumbbell shoulder press, PP; peak power, LB; lower body, UB; upper body, LP; leg press, SR; seated row, RM/kg; relative maximal strength, ↑; increase, ↓; decrease, W; peak power, W/kg; relative peak power, N; peak force, N/kg; relative peak force, Ag; agility training, Plyo; plyometric training, IRV; mean intensity relative volume, Pmax; maximal power, JH; jump height, BT; bench throw, SJ; jump squat, CMJ; counter movement jump, JH; jump high, IMTP; isometric mid-thigh pull, PF; peak force, P40; power output at 40 kg, P60; power output at 60 kg, P80; power output at 80 kg, P100; power output at 100 kg.

Table 1. **Continued..**

Study	Competition	Participant characteristics	Performance measures	Length of intervention	Training stimulus	Performance effect %	ES
Pre-Season							
Daniels et al., 2019	Super league	*n* = 22 23.3 ± 4.4 yrs, 91.6 ± 8.9 kg, 1.81 ± 0.07 m	3 RM back squat Prone pull ups 1 RM bench press Bench throw Jump squat	7 weeks	RT 4/wk Wrestle 2/wk TP 4/wk Con 1/wk	3 RM ↑ 9.9 ± 1.1 Pull ups ↑ 53.3 ± 2.5 1 RM ↑ 4.0 ± 0.3 BT PP ↑ 6.0 ± 0.6 SJ PP ↑ 3.0 ± 0.2	0.63 0.89 0.26 0.36 0.45
Competition							
Baker, 2001b	NRL	*n* = 14 24.5 ± 3.5 yrs, 93.7 ± 10.1 kg, 1.82 ± 0.07 m	1 RM bench press Bench throw @ 40, 50, 60, 70 and 80 kg Jump squats @ 40, 60, 80 and 100 kg	29 weeks	RT 2 whole-body/wk 1st session strength maintenance 2nd session power maintenance Con 2-3 x 20-30 min/wk TP 3-5 x 60 min/wk 1 match/wk	1 RM ↓ 1.2 ± 1.1 BT Pmax ↓ 0.3 ± 5.6 JS Pmax ↓ 1.2 ± 0.3	-0.11 -0.02 -0.07
Crewther et al., 2011	Super league	*n* = 12 23.4 ± 3.6 yrs, 95.4 ± 11.0 kg, 1.83 ± 0.55 m	Countermovement jump height Isometric mid-thigh pull	6 weeks	6 days/wk 12 sessions/wk RT, Con, TP, recovery x 45-90 min/session 1-2 matches/wk	CMJ JH ↑ 4.17 ± 1.59 IMTP PF ↓ 1.07 ± 0.93	0.3 -0.1
Longitudinal							
Baker and Newton, 2006	NRL	*n* = 12 21.3 ± 1.4 yrs, 95.5 ± 10.4 kg, 1.86 ± 0.05 m	1 RM bench press Bench throw @ 40, 50, 60, 70 and 80 kg	4 years	General preparation UB RT 2/wk LB RT 2/wk Con 5/wk Specific preparation UB RT 2/wk LB RT 2/wk Con 2-3/wk Competition RT 2 whole-body/wk 1st session strength maintenance 2nd session power maintenance Con 2-3 x 20-30 min/wk TP 3-5 x 60 min/wk	1 RM ↑ 6.0 ± 0.5 Pmax ↑ 5.0 ± 2.7	0.55 0.39
Baker and Newton, 2008a	NRL	*n* = 6 19.3 ± 1.0 yrs, 95.8 ± 9.8 kg, 1.85 ± 0.05 m	1 RM back squat Jump squats @ 40, 60, 80 and 100 kg	4 years		1RM ↑ 14.1 ± 0.3 Pmax ↑ 13.3 ± 6.2 P40 ↑ 15.3 ± 8.9 P60 ↑ 15.2 ± 8.9 P80 ↑ 12.1 ± 3.9 P100 ↑ 5.3 ± 11.6	0.65 0.64 0.73 0.78 0.54 0.25
Baker and Newton, 2008b	NRL	*n* = 11 20.3 ± 1.7 yrs, 97.8 ± 9.7 kg, 1.87 ± 0.05 m	1 RM bench press Bench throw @ 40, 50, 60, 70 and 80 kg	6 years		1 RM ↑ 11.1 ± 0.6 Pmax ↑ 14.9 ± 3.2	0.68 0.70
Baker, 2013	NRL	*n* = 6 19.3 ± 1.6 yrs, 95.8 ± 14.6 kg, 1.86 ± 0.07 m	1 RM bench press Bench throw @ 40, 50, 60, 70 and 80 kg	10 years		1 RM ↑ 22.3 ± 13.0 Pmax ↑ 23.1 ± 0.9	1.09 1.17

*denotes limited information presented in study, NRL; national rugby league, RM; maximal strength, RT; resistance training, Con; aerobic conditioning, TP; team practice, BP; bench press, DL; deadlift, DB SP; dumbbell shoulder press, PP; peak power, LB; lower body, UB; upper body, LP; leg press, SR; seated row, RM/kg; relative maximal strength, ↑; increase, ↓; decrease, W; peak power, W/kg; relative peak power, N; peak force, N/kg; relative peak force, Ag; agility training, Plyo; plyometric training, IRV; mean intensity relative volume, Pmax; maximal power, JH; jump height, BT; bench throw, SJ; jump squat, CMJ; counter movement jump, JH; jump high, IMTP; isometric mid-thigh pull, PF; peak force, P40; power output at 40 kg, P60; power output at 60 kg, P80; power output at 80 kg, P100; power output at 100 kg.

Table 2. Methodological quality appraisal of the included studies using the Newcastle-Ottawa Scale.

Study	Selection[a]					Comparability[a]			Outcome[b]			Statistics			
	Representation of the sample	Sample size	Non-respondents	Description of players	Subtotal	Control for most important factor (training experience)	Control for other factors (starting strength or power)	Subtotal	Assessment of outcome	Statistical test	Subtotal	Total (out of 10)	High (>7)	Mod-high (5-7)	Low (<5)
Comfort et al., 2012	1	1	0	1	3	0	0	0	2	2	4	7	0	1	0
Harris et al., 2008	1	0	0	1	2	0	1	1	1	2	3	6	0	1	0
O'Connor and Crowe, 2007	1	0	0	1	2	0	0	0	2	2	4	6	0	1	0
Rogerson et al., 2007	1	0	0	1	2	0	1	1	2	2	5	7	0	1	0
de Lacey et al., 2014a	1	0	0	1	2	0	0	0	2	2	4	6	0	1	0
Daniels et al., 2019	1	1	0	1	3	0	0	0	2	2	4	7	0	1	0
Baker, 2001b	1	1	0	1	3	0	0	0	2	2	4	7	0	1	0
Crewther et al., 2011	1	1	0	1	3	0	0	0	2	2	4	7	0	1	0
Baker and Newton, 2008a	1	0	0	1	2	0	0	0	2	2	4	6	0	1	0
Baker and Newton, 2006	1	1	0	1	3	0	0	0	2	2	4	7	0	1	0
Baker and Newton, 2008b	1	0	0	1	2	0	0	0	2	2	4	6	0	1	0
Baker, 2013	1	0	0	1	2	0	0	0	2	2	4	6	0	1	0

[a] subscale items rated 0-1; [b] subscale items rated 0-2.

Pre-season

Six studies examined changes in strength and power during an elite rugby league pre-season. A wide variety of training volumes and intensities were prescribed, during five to eight weeks, eliciting strength gains (Table 1) (Comfort et al., 2012; Daniels et al., 2019; Harris et al., 2008; O'Connor and Crowe, 2007; Rogerson et al., 2007). Four studies reported large increases in lower body strength, all of which prescribed heavy loads (≥80% 1 RM) (Comfort et al., 2012; Harris et al., 2008; O'Connor and Crowe, 2007; Rogerson et al., 2007). While, studies that prescribed lighter loads showed small to moderate improvements (Daniels et al., 2019; Harris et al., 2008). The meta-analysis showed an overall large increase of lower body strength (Figure 2; **A**) with significant and high heterogeneity of studies ($I^2 = 63\%$; $p = 0.01$).

Three studies showed small to large increases in upper body pushing and pulling strength following pre-season training (Daniels et al., 2019; O'Connor and Crowe, 2007; Rogerson et al., 2007). Pooling these studies showed large increases in upper body strength (Figure 2; **B**) with non-significant and moderate heterogeneity of studies ($I^2 = 35\%$; $p = 0.15$).

Four studies reported changes of muscular power during the pre-season (Daniels et al., 2019; de Lacey et al., 2014a; Harris et al., 2008; O'Connor and Crowe, 2007). One study reported decreased kinematic outputs during a loaded jump squat for both training groups (Harris et al., 2008). Conversely, two studies reported a large increase in relative peak power (de Lacey et al., 2014a; O'Connor and Crowe, 2007) (Table 1). One study reported small increases in bench throw peak power (Daniels et al., 2019). The meta-analysis of three lower body power studies (Figure 2; **C**) showed an overall moderate increase and low non-significant heterogeneity of studies ($I^2 = 0\%$; $p = 0.64$).

Competition

Two studies examined changes in rugby league players strength and power during the competition phase (Table 1) (Baker, 2001b; Crewther et al., 2016). One study reported trivial decreases of upper body strength and upper and lower body power throughout a 29-week elite rugby league season (Baker, 2001b). Similarly, during 6-weeks of competition, players demonstrated trivial decreases in isometric mid-thigh pull peak force (Crewther et al., 2016). Although, this study showed small increases in lower body power, measured via countermovement jump height (Crewther et al., 2016).

Longitudinal

Four longitudinal studies have shown upper (Baker and Newton, 2008b; Baker, 2013; Baker and Newton, 2006) and lower (Baker and Newton, 2008a) body muscular strength and power improvements across 4 - 10 years of competition (Table 1). Two studies reported over a four-year period, highly trained rugby league players (minimum two years resistance training at the commencement of the study) reported moderate increases in maximal strength and small to moderate increases in power (Baker and Newton, 2008a; Baker and Newton, 2006). Over a 6-year period moderate increases in upper body strength and power were shown (Baker and Newton, 2008b). Further, upper body strength and power across a 10-year period showed larger increases (Baker, 2013).

Pooling three studies reporting upper body strength and power changes of elite rugby league players over multiple seasons (Figures 2; **D** and **E**), showed large increases and non-significant low heterogeneity of studies ($I^2 = 0\%$; $p = 0.48$ and $I^2 = 32\%$; $p = 0.23$), respectively.

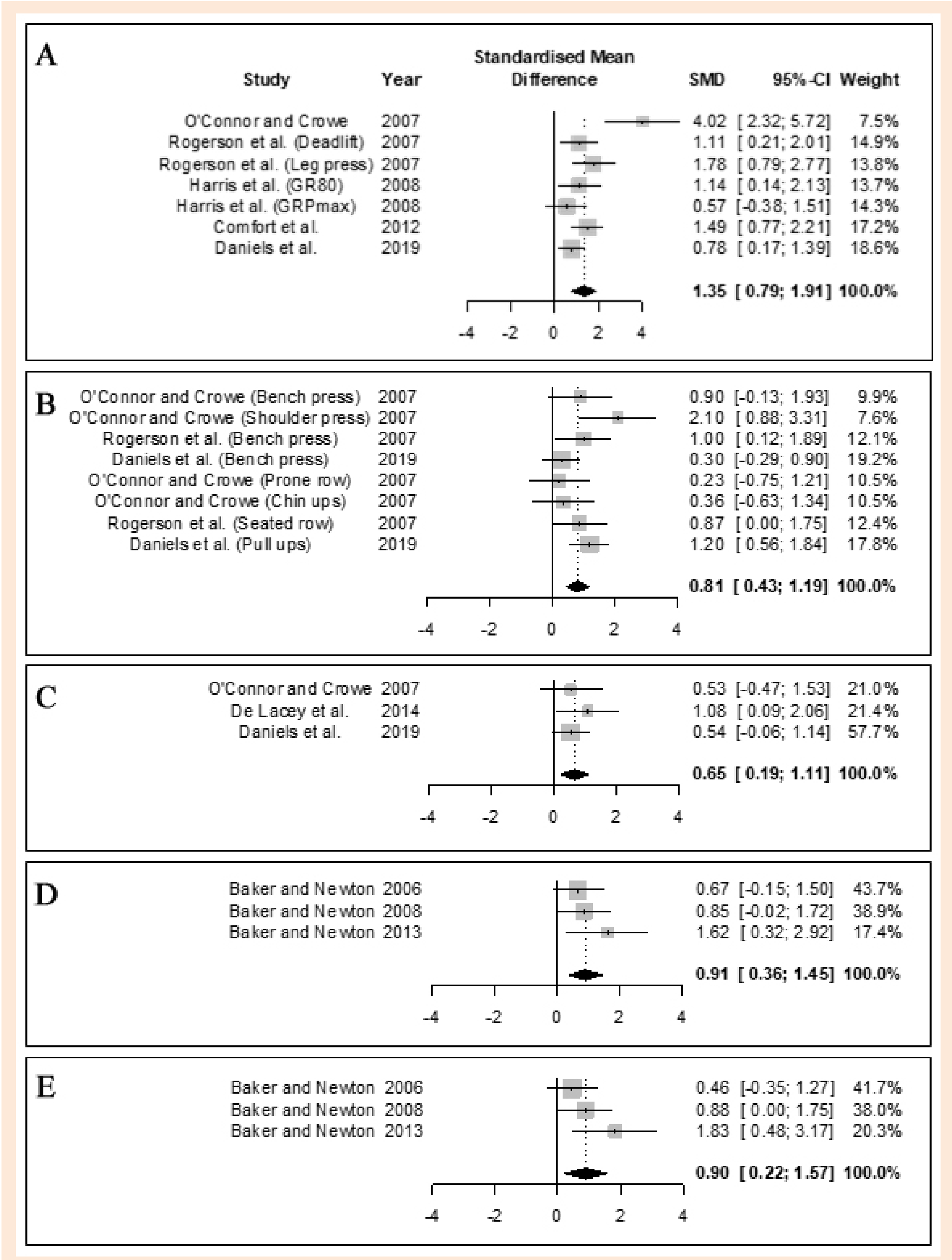

Figure 2. A. Meta-analysis of lower body strength changes following pre-season training. B. Meta-analysis of upper body strength changes following pre-season training. C. Meta-analysis of lower body power changes following pre-season training. D. Meta-analysis of longitudinal changes in upper body strength changes following pre-season training. E. Meta-analysis of longitudinal changes in upper body power changes following pre-season training. Forest plots (SMD and 95% CI) used to present the results of the meta-analysis and combined pooled estimates (random effects model).

Discussion

The purpose of this review was to identify the magnitude of change in strength and power, following various resistance training programs, during various phases of the season in elite rugby league. Following a systematic search, twelve studies satisfied the eligibility criteria; six studies reported changes of strength and power following pre-season training, two during the competition phase and four examined strength and power changes over multiple seasons (Table 1). The key observations of the analysis were consistent with the general goals of a strength and conditioning coach; pre-season resistance training reported large improvements in strength and moderate increases in lower body muscular power, players maintained strength and exhibited a small increase in power during and following competition, over multiple seasons players reported large increases in upper body strength and power (Figure 2).

Based on the collective findings following the pre-season, a greater increase in lower body strength was observed when players lifted predominantly heavier loads (≥ 80% 1 RM) during resistance training sessions (Figure 2; **A**) over five - eight weeks, completing two - four sessions per week (Comfort et al., 2012; de Lacey et al., 2014a; Harris et al., 2008; O'Connor and Crowe, 2007; Rogerson et al., 2007). During the pre-season concurrent training load is at its peak and this along with the concomitant lighter lower body resistance training loads, appears to result in smaller improvements in lower body strength (Table 1) (Daniels et al., 2019; Harris et al., 2008). Moreover, superior increases in upper body pushing strength may be attributed to prescription of lower repetitions and higher loads (Table 1) (O'Connor and Crowe, 2007; Rogerson et al., 2007). Although, it appears these studies observed contrasting results for upper body pulling strength; two studies (O'Connor and Crowe, 2007; Rogerson et al., 2007) reported trivial - moderate improvements while one observed large increases (53.3 ± 2.5 %) (Daniels et al., 2019). Given these findings and the lack of detail on upper body push and pull prescription, it is reasonable to suggest one study (Daniels et al., 2019) focused on improving pulling strength while the others concentrated more on pushing (O'Connor and Crowe, 2007; Rogerson et al., 2007). The evidence highlights heavier loads will more likely improve strength during the pre-season although more research is required to provide conclusive data of expected changes across a pre-season (~16 weeks) as the current literature lacks evidence.

Four studies examining changes in lower body power during pre-season showed differing results (Daniels et al., 2019; de Lacey et al., 2014a; Harris et al., 2008; O'Connor and Crowe, 2007). One study reported decreased kinematic outputs during a loaded jump squat for both groups following eight weeks of training (Harris et al., 2008). These findings may be due to a variety of reasons; fatigue from concurrent training stimulus, lack of new strength stimulus or adaptation occurred early in the training intervention. Whereas, three studies reported large maximal power increases which may have been a result of benefits gained from the previous hypertrophy training phase (Figure 2; **C**) (Daniels et al., 2019; de Lacey et al., 2014a; O'Connor and Crowe, 2007). Two studies were completed leading into the in-season and results may indicate a super-compensation effect of recovery following a prolonged pre-season training period leading into the competition phase (de Lacey et al., 2014a; O'Connor and Crowe, 2007). It appears that when training volume is reduced, and intensity maintained, an increase in power during pre-season training would be expected. However, if training volume and intensity are maintained for an extended period of time, decrements in lower body power may be anticipated due to lack of new training stimulus or fatigue (Stone et al., 2007). It is also worth considering the modality in which the lower body training was performed, 'i.e. hack squat or barbell'. Previously, researchers have shown that free weights are superior to machines (e.g. hack squat) in transferring strength gains to athletic performance (e.g. jumping, sprinting). Therefore, training with a barbell may have contributed to a disparity in maximal power output as it likely increased stabilisation and coordination of the trunk, resulting in an improved performance during testing (Haff, 2000).

An undulating pattern of strength (higher-load (e.g. squat and bench press 3 x 8 - 3 x 5 @ 70 - 90% 1 RM)) and power (lower-load (e.g. power clean and hang clean 3 x 5 - 4 x 2 @ 75 - 93% 1 RM)) training sessions appears to maintain upper body strength and power throughout a competitive season (Baker, 1998; Baker, 2001b). It is important to note that this study did not report any confounding factors such as; players time out of training potentially due to injury or representative commitments (Baker, 2001b). One study demonstrated small improvements in power and a trivial decrease in strength assessments during the competition (Table 1) (Crewther et al., 2016). This study provided little detail on the training players completed throughout the six weeks of the study and no information regarding the phase of competition (i.e. start, middle, end) (Crewther et al., 2016). The muscle damage and inflammation following a match, may potentially cause decrements in muscle performance, however it appears to not have been problematic for maintaining muscular strength and power during competition (Baker, 1998; Baker and Newton, 2006; Twist and Highton, 2013). More studies are required to make conclusive statements concerning changes of strength and power in elite rugby league over a season. New studies are necessary as there have been various rule changes, occurring since this study, that have altered the demands of the game and subsequently player preparation and likely player physical attributes (Eaves and Evers, 2007; Gabbett et al., 2008).

To date, there is no literature examining the effect of the off-season on strength and/or power, consequently what it is not yet clear is the impact this time away from structured training has on strength and power in elite rugby league. This is an important area to consider given strength and conditioning coaches are required to implement training programs within days of players returning from the off-season.

Based on the collective findings from three of the longitudinal studies, a large increase in upper body strength and power following multiple seasons of wave-like resistance training in elite rugby league would be expected (Figure 2; **D** and **E**) (Baker and Newton, 2006; 2008a; 2008b; Baker, 2013). Further, this approach appears effective in developing lower body strength and power (Baker and Newton, 2006; 2008a). Although, as only one study investigated changes in lower body strength and power across multiple seasons, more studies are required to make conclusive statements regarding the expected changes. Indeed, myogenic adaptations (e.g. muscle fibre hypertrophy, increased myofibrillar cross-sectional area, preferential hypertrophy of type II muscle fibres, alterations to muscle architecture, increased musculotendinous stiffness and tendon thickness) likely contributed to the development of rugby league players muscular strength and power across multiple seasons (Bompa and Buzzichelli, 2015). It is important to note that at the commencement of the 10-year study, rugby league players were participating in the second division (semi-elite) and training to become elite rugby league players, following three years all players were competing in the elite rugby league competition (Baker, 2013). Furthermore, it is highly probable that the findings of the longitudinal studies are from the same playing group, potentially limiting the results to that particular group of players.

Conclusion

This review provides a reference point for strength and conditioning coaches to examine when prescribing training to assist with designing programs to elicit positive adaptations at various stages, and over multiple, seasons. Although, more research is required to develop an evidence base for magnitude of change in strength and power in elite rugby league following various resistance training programs, across different points, and following numerous, seasons that will provide coaches with information to optimise training. What is not yet clear in the available literature is the external workloads associated with the subsequent changes over the course of an entire season. Given the complex nature of an elite rugby league training environment, a variety of factors contribute to strength and power changes; training and match scheduling, running volume and intensities, training experience, playing position and fitness characteristics (Baker, 2001b). These studies have not investigated the confounding variables (external training loads from other aspects of training e.g. field sessions) that relate to changes in strength and power. Therefore, additional research is necessary to understand the influence of the limitations on outcomes while accounting for all other variables. Further understanding of the workloads required to maximise strength and power development or maintenance during difference phases of an elite rugby league season, additionally for players with various resistance training experience, would serve as a valuable reference point for strength and conditioning specialists of highly trained athletes given the time constraints in an elite environment.

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Key points

- This review presents an evidence base for commonly expected changes of strength and power in elite rugby league at various phases of a season and over multiple seasons.
- Based on the collective findings following the pre-season, a greater increase in lower body strength was observed when players lifted predominantly heavier loads (≥ 80% 1 RM) during resistance training sessions.
- The undulating pattern of strength (higher-load) and power (lower-load) training sessions appears to maintain upper body strength and power throughout a competitive season.
- Based on the findings from three of the longitudinal studies, a large increase in upper body strength and power following multiple (four - ten) seasons of wave-like resistance training programming in elite rugby league would be expected.
- There is no literature to date examining the effect of the off-season, consequently what it is not yet clear is the impact this time away from structured training has on strength and power in elite rugby league.

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