THE RELATIONSHIP BETWEEN TWO MEASURES OF PHYSICAL CAPACITY AND MATCH PERFORMANCE IN SEMI-PROFESSIONAL AUSTRALIAN RULES FOOTBALL

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Available at: https://works.bepress.com/chris-joyce/18/
Editorial

Welcome to the JASC supplement edition which documents all the outstanding presentations and posters that were presented at this year’s National ASCA Conference, held at the sometimes sunny Gold Coast. The ASCA would like to thank all the international and domestic speakers for putting so much time and effort into their presentations, posters and lecture notes and I hope you all find some time over the Christmas holidays to read through the excellent information contained in this supplementary issue of JASC.

Congratulations to my old friend and work colleague, Rudi Meir, from Southern Cross University, the winner of the Senior Investigator Poster award for his study, with the excellent title “Water, water everywhere, nor any drop to drink: Fluid loss in Australian recreational surfers.” Congratulations also to Brendan Scott from the University of Newcastle, the winner of the Best Student Investigator Poster Award for the second year running, with his study entitled “Systemic hypoxia acute responses to moderate load resistance exercise.” Well done and keep up the good work.

The ASCA would also like to thank all our conference sponsors and exhibitors who are listed in this issue of JASC. The continued support from these companies provides important funding so that our organization can provide a first class international conference. Additionally the cutting edge technology, products, education, software and services produced by these companies provides important stimulus for the further development of the strength and conditioning field. Going around and seeing all the latest products and technology on offer to our profession is always one of the highlights of the conference for me and it was no exception this year.

Often at conferences the quest is to find the newest and latest cutting edge research with the most extravagant and complicated training designs and using the most sophisticated and high cost technology. However, at this year’s conference one of the stand out presentations was Brendyn Appleby’s “Program design principles: Simple is the new black.” It would seem that the more things change, the more they stay the same! Another highlight for me was the presentation delivered by Dr Craig Duncan entitled: “How to use monitoring information to make well informed decisions.” In this presentation Craig openly and honestly covered many topics including the fact that many professional sporting clubs were now using their highly prized and very expensive high altitude training rooms as storage spaces. The fad of high altitude training having reached its peak and now fallen out of favour in many clubs. Such occurrences should make us all in the strength and conditioning field more circumspect about new developments and ensure that we carefully review all of our performance enhancement and injury reduction practices over time, and do not rely on wishful thinking and what everyone else is currently doing. A fact Craig elegantly made during his presentation.

I hope you enjoy the contents of this special conference supplementary issue of JASC and find the information to be of great use in its application to your athletes and tactical operators. We look forward to welcoming you again next year when we return to Melbourne, the home of Australian sport, to celebrate the 2016 National ASCA Conference.

Gregory Wilson PhD
JASC Editor In Chief
Contents

2015 ASCA International Conference on Applied Strength and Conditioning
Presenters and Presenter Notes  Page 5
Sponsors & Exhibitors  Page 10
Poster Presentations  Page 11

Systemic hypoxia enhances acute responses to moderate-load resistance exercise.
Brendan R. Scott, Katie M. Slattery & Ben J. Dascombe  Page 12

Water, water, everywhere, nor any drop to drink: Fluid loss in Australian recreational surfers.
Rudi Meir, Blake Duncan, Zachary Crowley-McHattan, Christian Gorrie & Jeremy Sheppard  Page 16

The effects of varying inter-set rest durations during resistance exercise in normoxia and hypoxia.
Cathrina Lockhart, Brendan R. Scott, Bradley Thosheby, Jake F. Sutherland, & Ben J. Dascombe  Page 21

Three weeks cessation from strength training in adolescent athletes increases lower-body isometric strength.
Josh L. Secomb, Sophia Niphius, Oliver R. L. Farley, Lina Lundgren, Tai T. Tran, Joanna Parsonage & Jeremy M. Sheppard  Page 26

The effect of a structured 3 weeks conditioning program to minimise detraining during the transition phase.
Cheah Boon Chongscs, Loo Lean Hiong, Tey Woan Jin & Chris Teen Chow Li  Page 30

The application of isokinetic testing to understand factors predicting performance in the 100m, 400m, long jump and high jump.
Ian T Heazlewood & Daniel Gahreman  Page 34

Junior college football: Physical and physiological profiling and differences between linemen, offensive backfield, and defensive backfield players.
Robert G. Lockie, Randal C. Stone, Farzad Jallivand, Matthew E. Hank & Nicholas W. Mosich  Page 38

Progesterone and estradiol levels are predictors of planned agility, 10m and 20m sprint performance in young male Australian football athletes.
Alanna C Martin, Ian T Heazlewood, Isabelle Lys, Cecilia M Klic & Liam Johnson  Page 42

Isometric strength influence on a change of direction task with pre, mid and post-adolescent performers.
Barry Shillabeer, Patrick Mills & Jon Goodwin  Page 46

The relationship between measures of aerobic and anaerobic performance with physical performance across a team sport match play simulation.
Bradley Thosheby, Cathrina Lockhart, Jake F. Sutherland, Christopher J. Stevens, Job Fransen & Ben J. Dascombe  Page 50

Blood flow restriction training as a novel approach to improve jumping performance.
Christopher M. Gaviglio, Will Brown & Jared Coleman-Stark  Page 54

Assessment of sleep patterns in elite female basketball athletes throughout a competitive season.
Craig A. Staunton, Brett A. Gordon, Edhem Custovic & Michael IC. Kingsley  Page 59

Maximal isometric lower body strength and vertical jump performance in starting and bench semi-elite male basketball players.
Frans H. van der Merwe & Michael E. Mann  Page 63

Powerlifting: success and failure at the 2012 Oceania and 2013 classic world championships.
Hayden J. Pitchard & R Hugh Morton  Page 67

The effects of concentric/ eccentric training versus concentric only training on peak power and functional muscle performance.
Hayden J. Pitchard, Philip W Firk & Stephen R Stannard  Page 71

Match demands of semi-professional rugby league referees: A Comparative study.
Jake F. Sutherland, Nathan Elsworth, Matt Jeffress, Cameron Black, Bradley Thosheby, Cathrina Lockhart & Ben J. Dascombe  Page 76

The meaningful use of sprint paddling data to determine surfer’s strengths and weaknesses: A gender comparison.
Joanna Parsonage, Josh L. Secomb, Sophia Niphius, Oliver R. L. Farley, Lina Lundgren, Tai T. Tran & Jeremy M. Sheppard  Page 79

The training-specific adaptations resulting from a short block of combined strength, plyometric and gymnastics training.
Josh L. Secomb, Sophia Niphius, Lina Lundgren, Joanna Parsonage, Oliver R. L. Farley, Tai T. Tran & Jeremy M. Sheppard  Page 83

Acute changes in sprint running performance following ballistic exercise with added lower body loading.
Kim Simperringham, John Cronin, Simon Pearson & Angus Ross  Page 86

A comparison of smith Machine & barbell half squats to elicit potentiation in countermovement Jump performance.
Mathew W. O’Grady, Warren B. Young & Scott Talpey.  Page 90

Tracking 6 weeks of training/surfing sessions of adolescent competitive surfers: Just what are these young surfers up to?
Oliver R. L. Farley, Josh L. Secomb, Joanna Parsonage, Lina Lundgren, Chris Abbiss & Jeremy M. Sheppard  Page 95

Incidence of injury in junior rugby league players.
Paul Inglis, Kenji Doma & Glen Deakin  Page 98

The effect of chronotype upon physical performance during Australian rules football matches scheduled in the morning, afternoon and evening.

Asymmetry of lower limb functional performance in amateur male kickboxers.
Robert Stanton, Associate Professor Peter Reaburn & Luke Delvecchio  Page 105

Correlations between attacking agility, defensive agility, change of direction speed and reactive strength in Australian footballers.
Russell J. Rayner & Warren B. Young  Page 108

Deconstructing a conventional deadlift with inertial sensors: Observational analysis of spine movement during weighted and unweighted lifts.
Sam Gleadhill, James Lee & Daniel James  Page 112

The relationship between two measures of physical capacity and match performance in semi-professional Australian Rules Football.
Toby Edwards, Ben Piggott, Chris Joyce & Paola Chivers  Page 117
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AUSTRALIA
Below is the 2015 Presenter Profiles and Session Notes. Please note the following presenter profiles were current at the time of the 2015 Conference and some presenters may have changed positions of employment or education status.

The ASCA would like to take this opportunity to thank all of the presenters for volunteering their valuable time to enhance the education and training of the ASCA conference delegates.

The ASCA prides itself on being the Peak National Body for strength and conditioning in Australia and is honoured to be associate with the below list of quality presenters.

**Keynote Presentations**

**Loren Landow**

‘Implementation of agility for performance enhancement in multi-directional sports with injury prevention tactics for the lower quadrant’

**Inigo Mujika PhD**

‘Strength training for endurance performance’

**Bo Sandoval - NSCA**

‘Relevancy of weightlifting for sport performance’

**Alex Wolf - UKSCA**

‘Performance problem solving - A model for sustained medal success’
Practical Presentations

Brendyn Appleby

'Program design principles: Simple is the new black'

Peter Culhane

'Lower body movement limitations - Quick and intuitive assessment on the gym floor'

Matt Jordan

'ACL injury prevention in elite alpine ski racers: Neuromuscular assessment and training philosophy'

Lina Lundgren

'Landing training to enhance performance and reduce injury risk'

Ross Smith

'Developing the links between capacity development and sport specific training'

Lecture Presentations

Natalie Deegan

'Heat and simulated altitude training protocols'

Greg Haff PhD

'Theoretical and practical aspects of strength power potentiation complexes'
Nathan Heaney
'Aerobic conditioning for team sport and endurance athletes'

Hiroshi Hasegawa
'Analysis of early acceleration and sprinting in field sport athletes and its application to training'

Carl Woods
'Talent identification and development in junior Australian football - The importance of athletic movement competency'

Matt Jay
'A Guide to the experiences and challenges of being a young strength & conditioning coach'

Darren Roberts
'Action sports athletes - Managing the unmanageable'

Mike McGurn
'Improving cognitive ability of an athlete/team through a strength and conditioning perspective'

Mark McKean PhD
‘Basic human movements in children – Using 7 exercises as a screening tool'
<table>
<thead>
<tr>
<th>Presenter</th>
<th>Title</th>
<th>Read Full Bio</th>
<th>Presenter Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travis McMaster</td>
<td>'Strength and ballistic profiling to guide programming'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>David Watts</td>
<td>'A guide to the experiences and challenges of being a young strength &amp; conditioning coach'</td>
<td></td>
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<tr>
<td>Alex Sakadjian</td>
<td>'Factors considered important by managers to gaining employment in high performance sport – a qualitative study of high performance sports programs'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emily Nolan</td>
<td>'ASCA BIF female study group tour'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bessie Hayes</td>
<td>'What can we learn from big budget colleges and high performance facilities in the U.S?'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Krystal Tate</td>
<td>'Train your brain, perform better'</td>
<td></td>
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</tr>
<tr>
<td>Carla Petty</td>
<td>'Long term athlete development and the pathway to success'</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TSACA Presentations

Tim Doyle PhD

‘Neuromuscular screening for injury risk of Australian Army Special Forces Soldiers’

Rodney Pope PhD

‘Managing risks arising from mismatches between physical conditioning and tactical task requirements’

Katie Sell PhD

‘The role of physical training and recommendations for future study’

Anthony Walker

‘Hot workers are not safe workers’
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dan Baker Strength
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Research Papers

Each year the ASCA invites submission of research papers for presentation at the Conference. This provides opportunities for presentation of new research knowledge for Conference delegates as well as the opportunity for researchers and students to present their work and receive feedback from some of the most highly respected Strength & Conditioning Specialists in Australia and overseas.

Papers include information on research studies, analysis of practical “from the field” studies or descriptions/evaluations of innovative programs that will be of interest to Strength and Conditioning Professionals.

Awards and Prizes granted in 2015

Best Student Paper -  
Winner!

Brendan Scott (for the second year running!)

'Systemic hypoxia acute responses to moderate load resistance exercise'

Brendan received:
- 12 month ASCA membership
- full set of 2015 Conference session recordings
- registration to the 2016 ASCA Conference
- iPad mini.

Best Senior Investigator -  
Winner!

Rudi Meir

'Water, water everywhere, nor any drop to drink: Fluid loss in Australian recreational surfers.'

Rudi received:
- 12 month ASCA membership
- full set of 2015 Conference session recordings.

Highly Commended -  
There were many excellent submissions received this year, with two ‘Highly Commended’ awards granted, both who received 10 of the Conference session recordings, going to:

Catriona Lockhart - ‘The effects of varying inter set rest durations during resistance exercise in normoxia and hypoxia’

Josh Secomb - ‘Three weeks cessation from strength training in adolescent athletes increases lower body isometric strength’

The judges, Stuart Cormack PhD, Justin Keogh PhD and Glen Deakin PhD, whom we thank sincerely for volunteering their time, were highly impressed with the level of work presented.

Congratulations to all those who were successful in having their poster displayed this year and we look forward to seeing what the poster section will bring in 2016.
INTRODUCTION
Performing resistance training under acute hypoxic conditions has been shown to enhance muscular strength and/or hypertrophy using both low (7) and moderate (6.9) loads. While intermittent hypoxic resistance training (IHRT) may be a promising new method to enhance muscular development, little is known regarding the physiological mechanisms that may underpin these adaptations. In theory, a fundamental response to IHRT is a more hypoxic intramuscular environment. This would increase reliance on anaerobic metabolism during exercise, resulting in heightened metabolic stress. To this end, studies using untrained participants have demonstrated increased blood lactate (BLa) concentrations during resistance exercise when combined with systemic hypoxia (4.5).

Heightened metabolic stress during resistance training is proposed to moderate increased recruitment of muscle fibres (10). Simply stated, if more of the muscle is recruited during exercise, then a greater number of muscle fibres will be stimulated to adapt to training. Previous research has observed greater muscle activation during submaximal isometric contractions when breathing hypoxic compared to normoxic air (3). However, it is not yet known whether resistance exercise under systemic hypoxia can augment motor unit recruitment. An important consideration however, is whether increased muscle activation may result in greater absolute muscle damage and subsequent soreness. This could also have detrimental effects on perceived wellbeing, and consequently impact on the following training sessions. Therefore, this study aimed to determine whether systemic hypoxia could enhance the accumulation of metabolites and muscle activation in well-trained individuals, and the impact of such responses on muscle soreness and overall wellbeing.

METHODS
Eight young men (age: 25.3 ± 2.7 yr.; height: 179.4 ± 7.5 cm; body mass: 80.6 ± 6.5 kg) with at least 3 years of resistance training experience (mean training age: 5.1 ± 1.2 yr.) were recruited for this study. All participants were informed of the aims of the research, and provided informed consent. Prior to experimental trials, participants were tested for 1-repetition maximum (1RM) in both the back squat and deadlift exercises.

Experimental Trials
Using a randomised, single-blind crossover design, participants performed two moderate-load resistance exercise sessions in normoxia (NORM; fraction of inspired oxygen \([\text{FiO}_2] = 21\%\)) and hypoxia (HYP; \([\text{FiO}_2] = 16\%\)), separated by one week. Hypoxic air was inspired via a portable hypoxic unit (ATS-BASE KIT, Altitude Training Systems, Australia). The exercise protocol comprised two warm-up sets of 10 repetitions using 40% and 50% 1RM for the back squat, before 3 sets of 10 at 60% of 1RM, with 60 s rest between all sets. Participants rested for 8 minutes following the final set of squats, before completing the same scheme for the deadlift exercise.

Prior to exercise and immediately following the final set of back squats and deadlifts, a capillary blood sample (0.2 μL) was obtained from a hyperaemic earlobe and immediately analysed for BLa concentration (Lactate Scout, SensLab GmbH, Leipzig, Germany). This analyser has been shown to exhibit acceptable reliability, with a mean coefficient of variation of 3.5% across a range of lactate concentrations (1). Muscle activation of the left gluteus maximus (GM), biceps femoris (BF), vastus lateralis (VL) and vastus medialis (VM) muscles was monitored during each set via surface electromyography (EMG; Trigno™ Wireless, Delys Inc., Boston, USA). EMG data were sampled at 2000 Hz, and band pass filtered (fourth order Butterworth filter) at 16-500 Hz. The mean integrated EMG (iEMG) during the concentric phase of each repetition was calculated. The summed iEMG for groups of two repetitions was determined and normalised to the first two repetitions of a warm-up set at 50% 1RM. Subjects also rated their muscle soreness prior to and at 24 and 48 hours following trials by marking a 100 mm line at a point between 0 (no soreness) and 100 (maximum soreness). At these time points, overall wellbeing was also assessed via psychological questionnaire (8).

Statistical Analyses
All data approximated a normal distribution and are represented as mean ± SD. Data were analysed using a 2-way ANOVA with repeated measures. Where a significant main effect was observed, paired sample t-tests were employed to assess where differences existed. These analyses were completed using SPSS (version 22.0; IBM Corp., Somers, NY, USA). The level of statistical significance was set at \(p \leq 0.05\).
RESULTS

Table 1 illustrates BLa concentrations prior to exercise and after the final set of squats and deadlifts. A significant main effect was observed between conditions ($F_{1,7} = 5.689$, $p = 0.049$, $\eta^2 = 0.448$). Paired sample t-tests confirmed higher BLa levels after deadlifts ($p = 0.001$, ES = 0.77).

Table 1 - Blood lactate (BLa) concentration (mmol·L$^{-1}$) prior to exercise and immediately following the final set of back squats and deadlifts.

<table>
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<th>Pre-exercise</th>
<th>Back squat</th>
<th>Deadlift</th>
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<tr>
<td>NORM</td>
<td>1.5 ± 0.3</td>
<td>5.6 ± 2.1</td>
<td>8.5 ± 2.0</td>
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<tr>
<td>HYP</td>
<td>1.4 ± 0.3</td>
<td>6.4 ± 1.8</td>
<td>10.8 ± 2.8 *</td>
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*Significantly different between conditions.

Figure 1 shows the concentric iEMG for each muscle assessed during the back squat, with iEMG values summed in groups of 2 repetitions, and made relative to the first 2 repetitions of a warm-up at 50% 1RM. For the GM and BF there were no significant main effects between conditions. For the VL, a significant main effect was observed during set 2 ($F_{1,7} = 6.901$, $p = 0.034$, $\eta^2 = 0.496$), though t-tests did not identify differences between conditions at any point. A significant main effect was also observed between conditions during set 3 ($F_{1,6} = 12.566$, $p = 0.012$, $\eta^2 = 0.677$), with t-tests confirming differences between conditions for repetitions 1–2 ($p = 0.046$, ES = 0.52) and 7–8 ($p = 0.041$, ES = 0.55). For the VM, a significant main effect was observed between conditions during set 3 ($F_{1,6} = 9.402$, $p = 0.022$, $\eta^2 = 0.610$), with differences between conditions for repetitions 1–2 ($p = 0.018$, ES = 1.01) and 9–10 ($p = 0.001$, ES = 0.86).

Due to the close proximity of the bar to the thigh during the deadlift exercise, the VM electrode was removed and excluded from the analysis. At the remaining electrode sites for this exercise, there appeared to be a trend for increased iEMG in HYP (Figure 2). However, differences between conditions were not statistically significant.

Muscle soreness was increased from pre-exercise values at 24 and 48 hours following exercise ($p \leq 0.03$), though there were no differences between conditions (Figure 3). While overall wellbeing appeared to decrease from pre-exercise at 24 and 48 hours, there were no significant main effects for condition or time.
Figure 2 - Mean iEMG values during the back squat for the gluteus maximus (GM), biceps femoris (BF) and vastus lateralis (VL). Each data point represents the summed iEMG for 2 successive repetitions, normalised to the first 2 repetitions of a warm-up set at 50% 1RM.

Figure 3 - Perceived levels of muscle soreness and overall wellbeing prior to and at 24 and 48 hours following exercise trials. *Significantly different to pre-exercise values.

DISCUSSION

The current study is the first to report that moderate-load IHRT can increase a marker of metabolic stress in well-trained participants. These findings corroborate previous data showing elevated BL_{a} concentrations following low-load (5) and moderate-load (4) hypoxic resistance exercise for untrained subjects. However, while the current study observed higher BL_{a} values in HYP following both exercises, this was only significant following the deadlift. It is possible that for large hypoxia-mediated increases in metabolic stress, repetition volume must be sufficient to facilitate substantial metabolic responses, and that this was not reached after the back squats. Furthermore, research using longer rest periods with low-load (2) or high-load (11) resistance exercise (90 s and 180 s, respectively) has not observed hypoxia to increase BL_{a} concentration. A likely explanation for this is that the longer inter-set recovery periods allow for additional metabolites to be removed from the muscle and oxidised, limiting any hypoxia-mediated accumulation. Although further research is needed, it is likely that the duration of inter-set rest periods and the repetition volume during IHRT must be appropriately manipulated to maximize the effects of a hypoxic stimulus. If this is achieved, enhanced metabolic stress may play a key role in moderating several downstream processes involved in hypertrophy such as increased muscle fibre recruitment (10).

The current data provide evidence for increased muscle recruitment during IHRT, with significantly greater iEMG values calculated in the VL and VM towards the end of the back squat protocol. Researchers have suggested that increased metabolic stress can cause premature muscular fatigue, and result in increased recruitment of additional motor units to maintain force production (10). Nevertheless, as significant between-condition differences in BL_{a} concentrations were not observed following back squats, these findings are difficult to explain. It is possible that there is a disconnect between intramuscular metabolic stress and systemic BL_{a} concentration. In addition, while iEMG appeared to increase in HYP during the deadlift, particularly for the VL (Figure 2), these values were not significantly greater than in NORM. This is
despite a significantly higher \text{BLA}\(^{+}\) concentration following the deadlift. Another possible explanation for these findings is the inherent variability in test-retest results for EMG variables during multi-joint resistance exercise. Previous research has reported that the inter-test coefficient of variation for iEMG during squats at 70\% 1RM varies greatly across different repetition schemes from 21.2-52.8\% (12). This may be due to small changes in segmental orientation of the limbs and torso during dynamic exercises such as squats and deadlifts, which would influence the degree of muscle activation measured via surface EMG. Further research is required to determine the influence of hypoxia-mediated metabolic stress on muscle activation during IHRT.

Interestingly, while muscle soreness was increased at 24 and 48 hours following trials, there were no differences between conditions. Similarly, overall wellbeing did not differ between conditions. While greater muscle recruitment may have been expected to increase the absolute magnitude of muscle damage and subsequent soreness, this was not the case. These data highlight that despite increased physiological demands during IHRT, participants do not perceive exercise to cause greater levels of muscle soreness or to negatively impact on practical markers of psychological wellbeing.

**PRACTICAL APPLICATIONS**

This study suggests that moderate-load IHRT can enhance acute responses relevant for hypertrophy in well-trained individuals. This has applications for athletes who must concurrently develop numerous physiological qualities, as muscular development may be possible at lower training volumes which would require less time and effort. Importantly, when considering the current findings in conjunction with existing IHRT research, it is evident that resistance exercise should be structured to elicit increased metabolite accumulation whilst not allowing complete removal between sets (i.e. ≥ 10 repetitions per set with brief rest periods) to provide benefit over the equivalent normoxic exercise. Therefore, this research provides guidelines for coaches seeking to implement IHRT strategies, as well as for researchers investigating the efficacy of this novel training method.

**REFERENCES**


Winner – Senior Investigator 2015

WATER, WATER, EVERYWHERE, NOR ANY DROP TO DRINK:
FLUID LOSS IN AUSTRALIAN RECREATIONAL SURFERS

Rudi Meir¹, Blake Duncan¹, Zachary Crowley-McHattan¹, Christian Gorrie¹ and Jeremy Sheppard²,³

¹ School of Health and Human Sciences, Southern Cross University, Lismore, New South Wales, Australia
² Surfing Australia, Hurley High Performance Centre, Casuarina, New South Wales, Australia
³ Centre of Exercise and Sport Science Research, Edith Cowan University, Joondalup, Australia

INTRODUCTION

Despite its popularity, research into the physiological demands of the surfing is limited (18). Previous research has shown that even at the recreational level surfing can involve participants spending on average 2 hours in the water, with some participants spending considerably longer when the environmental conditions allow (16). Recreational surfers have been shown to spend a significant proportion of their time when in the water paddling (~50%) or stationary (~40%), and the least amount of time actually catching and riding waves (~4-8%) (1,15,18). Previous research has reported that the average heart rate while surfing varies between 135-146 (±6-16.8) b.min⁻¹ for recreational surfers (1, 15), and 139-146 (±11-20.0) b.min⁻¹ for competitive surfers (7, 19).

A range of physical characteristics are called upon when surfing and these include high levels of aerobic endurance, anaerobic fitness, flexibility, balance and coordination (7,11,15). The proportion of those fitness qualities utilised while in the water is heavily influenced by factors such as the prevailing surf conditions (e.g. swell size, presence of currents/rips) and location of the break (e.g. beach break, point break). Level of competence of the surfer, and their ability to catch waves, will also play a part.

Paddling out to the take-off area, and then being able to maintain an optimal position in the take-off area, clearly places significant demands on the cardiovascular system. Energy demands are also increased while making numerous short, high intensity paddling efforts (explosive anaerobic efforts) needed to not only catch waves, but to also negotiate breaking waves while paddling out to the take-off area.

In land based sporting activities, one would expect that the physiological demands of sport participation could result in significant increases in body temperature and fluid loss from sweating (22), particularly in warm humid environments. Increases in body temperature during sport participation results in disruption to the body’s fluid and electrolyte balance (5,10). This means athletes in the heat can experience significant increases in sweat rate (≥ 1-1.5 L.h⁻¹) and fluid loss (4,10,12,20). Yet, the response seems to be highly variable between individuals (10) and can occur despite water being freely available for consumption throughout physical activity (5). However, surfing is undertaken in a fluid environment and so visual indicators of sweating (i.e. sweat beading on the surface of the skin) are not evident. Having no visual indication of fluid loss can give surfers the impression that they are not experiencing any significant fluid loss as a result of their physical effort while in the water.

THE RESEARCH PROBLEM

There has been no reported research into the fluid loss resulting from surfing. The research evidence shows that a loss of 2% of body mass is the threshold at which aerobic performance becomes impaired (6,13,23). Because water is the medium of cardiovascular function any reduction in body water will result in increased cardiovascular and thermoregulatory stress during exercise (8,13). Hence, fluid loss should be carefully monitored during exercise and physical activity, and this includes surfing.

In unpublished research by Meir et al. (17) it was reported that approximately a quarter of all surfers indicated that they “never” drank additional fluids before surfing. Given the length of time typically spent in the water surfing, and the physical effort produced, the need for adequate levels of hydration prior to entering the water cannot be over stated. As a result, this study aimed to establish the extent of fluid loss resulting from a recreational surf session (mean duration of ~75 minutes) conducted during the warmer months of late summer to early autumn on the Far North Coast of Northern New South Wales. Such information could be used to help inform surfers of the consequences of surfing on their fluid status and the importance of being adequately hydrated prior to entering the water. Research in team sport (football) has established that recording pre- and post-body mass changes provides useful information related to fluid loss from exercise (9). Notwithstanding this, urine colour and urine osmolality may also provide useful additional information (13). The advantage of these three indices is that they are non-invasive and thus lend themselves to use with surfers.
METHODS

Participants
Seven self-identified male recreational surfers (mean age 21.6 ±2.5 years; age range 20-27 years) volunteered to participate in this study. All participants provided written informed consent prior to their participation and the Southern Cross University Human Research Ethics Committee approved the project (ECN-12-305). Participants were provided with an information sheet, which described the details of the study, the nature of their involvement and any potential risks associated with their participation. Participants were advised that they were free to withdraw their consent at any time during data collection.

Procedure
All surfing sessions were conducted at beach breaks located on the Northern NSW with a variety of conditions experienced across different days. Because these sessions were conducted in late summer to early autumn participants wore only board shorts. Measures of body mass, urine colour and urine osmolality (mOsmol/kgH2O) and tympanic temperature were collected prior to entering the water and immediately after the session had finished. Any fluid consumption and urine excretion between data collection (pre- and post-surf measures) was recorded and used to adjust recorded values accordingly. Environmental measurements including ambient temperature, relative humidity, and water temperature, as well as wind speed and direction. Participants were given no instruction other than to surf as they normally would, given the prevailing conditions. Each session was also recorded for time-motion analysis purposes.

Body mass
Body mass (BM) was recorded pre- and post-surf using Charder MS3200 portable medical scales (Charder Electronic Co, Ltd. Taichung City, Taiwan), which measures body mass to the nearest 0.1kg. Participants were weighed in underwear only for both measurements and were towel-dried prior to being weighed post-surf. Participants were asked to empty their bladder prior to being weighed pre-surf. Post-surf BM was recorded prior to collection of the post-surf urine sample.

Urine Colour:
Urine colour (UC) was determined by comparing the collected mid-stream urine sample directly against the NCAA’s Assess Your Hydration Status urine colour chart (Armstrong et al., 1994). The chart uses an 8-point scale with a score between 1 (very light yellow/clear colour) and 8 representing (dark yellow/brown colour) the participant’s hydration status. This process was repeated after the surfing session was completed.

Urine Osmolality:
Urine osmolality (mOsmol/kgH2O) was determined from the same sample used in the urine colour assessment. An Osmocheck digital refractometer (Vitech Scientific Ltd., UK) was calibrated using bottled water to give a neutral reading prior to the transfer from the collection container to the refractometer using a pipette calibrated to 200μL. The same sample of bottled water was used for each trial. The refractive index of the urine sample is measured by the refractometer, which calculates and displays urine osmolality in mOsmol/kg of H2O. The American College of Sports Medicine (ACSM) position stand (3) suggests that a urine osmolality ≤700 mOsmol/kgH2O is indicative of euhydration (i.e. normal state of body water content – absence of absolute or relative hydration of dehydration).

Tympanic Temperature:
Tympanic temperature (TtempTym) was measured following the collection of the previous data. A ThermoScan IRT 3020 ear thermometer (Braun, Germany) was turned on and had a disposable probe cover placed on it prior to inserting it in the external auditory canal of the participant’s right ear. This was measured before entering the water and immediately following the conclusion of the surf session. The ear was dried prior to collecting the post-surf measurement.

Environmental Conditions:
Surf conditions (size, wind speed and direction) and water temperature were recorded for each session using the daily surf report accessed from CoastalWatch.com. Ambient temperature and relative humidity values were also measured using a Testo 608-H1 hygrometer (Testo Limited, UK) pre- and post-surf. The hygrometer was left on the beach for the duration of the session to ensure the measurement was as accurate as possible.

Time-Motion Analysis
Each surf session was recorded using a Panasonic NV-GS150 handheld video camera. The recording was transferred to a digital format and analysed in order to determine how long each participant spent performing each of the five activities considered for the study (paddling, stationary, paddling for a wave, riding a wave and miscellaneous). This was determined by pausing the video playback and recording the start/finish time each time the participant changed from one activity to another.

Statistical Analysis
Pre- and post-surf data values for body mass, urine colour, urine osmolality and tympanic temperature were recorded for each trial. The data was assessed using IBM SPSS Statistics software (v22.0) to gather mean, standard deviation
and value ranges. Paired t-tests were implemented for each variable to analyse significant differences between pre- and post-surf values. Significance level was set at p<0.05.

RESULTS

Descriptive Statistics
The mean (±SD) water temperature across all 7 sessions was 24.3 °C (±0.8), with a range of 24-26 °C. Mean (±SD) ambient temperature and relative humidity (RH%) at the start and finish of each session was 21.0 °C (±3.9) RH 75.4%, and 25.0 °C (±4.9) RH 64.8% respectively. A summary of the activity patterns recorded by time-motion analysis are presented in Table 1. A summary of all pre- and post-surf measures are presented in Table 2. There were significant reductions in body mass (p=0.005) and tympanic temperature (p<0.005), but no significant change in urine colour or urine osmolality (p>0.05). The individual changes in these measures is presented in Table 3.

Table 1 - Group mean percentage time spent for specified activities during a recreational surf session (N = 7).

Table 2 - Mean (±SD) pre- and post-surf measures of hydration after a recreational surf session (N = 7).

Table 3 - Absolute (Δ kg) and relative (% KG) change in body mass, absolute change in tympanic temperature (Δ TempTymp) and osmolality (Δ mOsmol/kgH2O) post-surf (N = 7).

DISCUSSION

The aim of the present study was to determine the fluid loss experienced by surfers during a recreational surf session. Degree of fluid loss from sweating was determined using a range of indices that are suited to field collection (i.e. non-laboratory based methods of assessment) (2). The results showed significant changes in pre- and post-surf body mass and tympanic temperature after surfing for approximately 76 minutes.
Body mass changes varied greatly with one participant experiencing a reduction equivalent to 4.6% of their pre-surf body mass. This individual also reported the largest change in urine osmolality and the largest change in urine colour pre- to post-surf. However, their pre-surf osmolality (470 Osmol) was well within the generally considered “acceptable” range (200-600 Osmol) reported in some team sports (14). This may be the result of the total time spent paddling with this participant recording the highest for the group at almost 55% of their total time in the water. This participant also recorded the longest period in the water (see Table 3).

Overall relative body mass changes were typically below the 2% threshold considered detrimental to cardiovascular performance (6,13,23). Notwithstanding this, some literature suggests body mass changes equivalent to 1% fluid loss are sufficient to start impacting on performance (23). Given this, 3 participants (range = -1.0 to -4.6%) in the current study were likely to have been experiencing the effects of dehydration. However, all of the recorded relative changes in body mass need considering in the context of a 2 hour plus surf session, which is more indicative of the time spent by recreational surfers in the water (16).

Tympanic temperature in all participants fell from to pre- to post-surf values. This is not surprising since tympanic temperature is known to be influenced by factors such as the ambient conditions. Given that participants would have had their head immersed in the water (mean water temperature = 24.3 °C ±0.8) at various points in their respective sessions, and that this would have resulted in water entering the ear canal, it is likely that this would account for the recorded post-surf scores, in combination with the ambient temperature. Given this, future research should use ingestible wireless telemetric temperature pills (e.g. CorTEmp®) to record body temperature in real time (24).

Of most concern was the pre-surf osmolality scores of 4 of the participants with these being higher than the 700 mOsmol/kgH2O recommended by the ACSM. These scores ranged from 740-980 Osmol. This appears to confirm the evidence by Meir et al. (17) that some surfers are not hydrating adequately prior to entering the water. Given that all participants in this study spent only an average of ~76 minutes in the water, it could be reasonably expected that the reported indices of hydration would be more markedly changed the longer they surfed.

**PRACTICAL APPLICATIONS**

Surfing is a sport that places significant demands on the physical qualities of its participants. As a result surfers can expect to experience fluid loss attributed to sweating, with the likely consequence of this being that physical performance may be compromised. The evidence from this study shows that even within a relatively short surf session some surfers will experience significant changes in pre- to post-surf body mass. Since body mass is a simple, non-invasive measure that can be used to calculate fluid loss when urine excretion and fluid intake are accounted for (21,9), post-surf body mass changes are an effective and reliable measure of fluid status following surfing. On this basis it is recommended that surfers use body mass changes as a simple yet effective way of better managing their hydration and fluid status before and after surfing.
REFERENCES


The effects of varying inter-set rest durations during resistance exercise in normoxia and hypoxia.  
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Highly Commended 2015

THE EFFECTS OF VARYING INTER-SET REST DURATIONS DURING RESISTANCE EXERCISE IN NORMOXIA AND HYPOXIA

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INTRODUCTION

It has been demonstrated that the hypertrophic and strength adaptation of skeletal muscle following resistance training can be influenced by manipulating a number of factors, including training volume (number of sets and repetitions), the load lifted, the duration of inter-set rest periods, movement velocity, exercise selection and order, and training frequency (2). Recent evidence suggests that altering the intra-muscular environment with additional hypoxia may also impact hypertrophic and strength responses (11). One proposed method is to systemically reduce muscular oxygenation by inhaling hypoxic air, known as intermittent hypoxic resistance training (IHRT). Theoretically, this technique creates a hypoxic intramuscular environment that potentially increases the metabolic stress within the muscle as a result of an increased reliance on anaerobic pathways (15). An elevation of metabolic stress could theoretically mediate the downstream mechanisms relevant for hypertrophy, such as muscle activation and cellular swelling (12).

Whilst IHRT has been shown to facilitate greater muscular hypertrophy and strength than the equivalent training in normoxia (6, 9-11), how best to employ the hypoxic stimulus during resistance exercise remains to be explored. Research that has employed long rest periods has shown no additional benefit of IHRT (3), whilst investigations using short rest periods have shown promising results (4). These differences suggest a role of methodological constraints such as the duration of inter-set rest periods employed (14). Furthermore, it remains unclear if the additional hypoxic stimulus influences the perceptual responses of muscle pain and exertion following resistance exercise. Therefore, the aim of this investigation was to determine the effects of short and long inter-set rest periods on physiological and perceptual responses to resistance exercise in normoxic and hypoxic conditions.

METHODS

Eleven healthy moderately trained males (age: 25.7 ± 5.7 yr.; height: 178.0 ± 6.1 cm; mass: 82.4 ± 14.3 kg) were recruited to participate in this study. The study followed a single-blind randomised cross-over design in order to determine the effects of inter-set rest periods and hypoxia on the acute physiological responses to resistance exercise. All subjects were randomly assigned their experimental conditions using an automated random number generator that corresponded to each condition. Subjects were required to attend the laboratory on five separate occasions (one trial per week) to complete a resistance exercise protocol in moderate hypoxia and normoxia using inter-set rest periods of either 60 or 180 s. All exercise trials were completed on a Force USA bilateral plate loaded leg extension machine (LifeCore Fitness, Carlsbad, CA, USA) and the hypoxic stimulus was provided through the use of two portable hypoxic units (ATS-BASE KIT, Altitude Training Systems, Australia).

One Repetition Maximum Testing

During the first visit to the laboratory each participant underwent a test for 1-repetition maximum (1RM) of bilateral leg extension (1). Subjects were required to lift the weight from 90° knee flexion to 180° knee extension that was determined via an elastic string line set for each individual’s range of motion. Subjects performed single repetitions until they were unable to successfully perform a lift. Three minutes of passive rest was provided between attempts, and 1RM was defined as the heaviest successful repetition.

Experimental Trials

Prior to the resistance exercise protocol, subjects were fitted with a face mask that was connected to the hypoxicator units and sat passively for ten minutes to acclimate to the experimental condition. Immediately following this time, participants completed two warm up sets of ten repetitions of bilateral leg extension at 30% and 50% 1RM respectively. Following this, each subject then completed five working sets (ten repetitions at 70% 1RM) with varying rest periods. The experimental conditions were randomly assigned, and included:

1. Normoxia with short rest (FIO₂ = 21%) with 60 s inter-set rest (NORM60);
2. Hypoxia with short rest (FIO₂ = 15%) with 60 s inter-set rest (HYP60);
3. Normoxia with long rest (FIO₂ = 21%) with 180 s inter-set rest (NORM180);
4. Hypoxia with long rest (FIO₂ = 15%) with 180 s inter-set rest (HYP180).
Physiological Measures
Blood lactate concentration ([BLa \(^{-}\)]) and thigh girth were assessed prior to and immediately following completion of the exercise protocol to quantify metabolic stress and muscle swelling. Capillary blood samples were drawn from a hyperaemic earlobe and analysed using a Lactate Scout Plus (EFK Diagnostics, Japan). Thigh girth was obtained from the mid-point between the greater trochanter and the tibial tuberosity using a steel anthropometer tape. A reliability analysis was conducted from the repeated measures of thigh girth taken both before and after the experimental trials (CV: 0.3%). The cardiovascular (CV) responses were assessed immediately following each set by measuring both heart rate (HR; Polar Electro, OY, Finland) and arterial oxygen saturation (SpO\(_2\); Rossmax Innotek Corp. Taipei, Taiwan).

Perceptual Measures
A Borg CR-10 scale was used to assess rating of perceived exertion (RPE) immediately after each set of leg extension. Separately, a 100mm visual analogue scale (VAS) was used to quantify quadriceps muscle soreness prior to, immediately after as well as 24 and 48 hours following the exercise protocol. To assess muscle soreness, subjects were instructed to perform three body weight squats prior to providing their perceived rating of muscle soreness. Further to this, a session RPE (sRPE) was obtained from each subject 15 minutes after the exercise protocol and multiplied by the duration of the session (minutes) to provide a measure of internal training load for each condition (sRPE load).

Statistical Analyses
Data were assessed for normality using Mauchly’s Test of Sphericity and demonstrated a normal distribution. A 2 x 4 ANOVA with repeated measures was used to analyse thigh girth and blood lactate data. Where a significant main effect was observed, paired sample t-tests were employed to determine between which variables these differences were located. A 4 x 4 ANOVA with repeated measures was used to analyse HR, RPE, SpO\(_2\), and VAS data. A one-way ANOVA with repeated measures was used to analyse sRPE data. Statistical significance was set at \( \rho < 0.05 \), and data are expressed as mean ± SD. All statistical analyses were performed using Statistical Package for the Social Sciences Statistics (version 22; IBM corp., Somers, NY, USA).

RESULTS
Figure 1 illustrates the \([BLa \^{-}]\) responses to experimental trials. No significant effect of condition was observed for changes in \([BLa \^{-}]\) (\( \rho = 0.69 \)). However, a significant main effect was observed between pre- and post \([BLa \^{-}]\) measures across all conditions (\( F_{1,40} = 341.23; \rho < 0.001; \eta^2 = 0.90 \)). A significant main effect of time was observed for the change in thigh girth between conditions (\( F_{3,40} = 4555.35; \rho < 0.001; \eta^2 = 0.99 \)), with post-hoc tests observing a difference between the NORM\(_{60}\) and HYP\(_{60}\) conditions (\( \rho = 0.04 \)). A significant effect for time was determined for all conditions in thigh girth measurements (\( F_{1,40} = 48.62; \rho < 0.001; \eta^2 = 0.55 \)), with thigh girth significantly increasing in all conditions (\( \rho \leq 0.008 \)) (see Figure 2).

![Figure 1 - Changes in blood lactate concentration (mean ± SD) across conditions.](image-url)
Figure 2 - Change in thigh girth (mean ± SD) across conditions (* significantly different to NORM60).

All CV and perceptual data are presented in Table 1. There was no significant effects for between-condition differences in HR ($\rho = 0.60$). There was a significant main effect for time in HR across conditions ($F_{s,160} = 14.19; \rho < 0.001; \eta^2 = 0.26$), with post-hoc analysis revealing the majority of differences across time were between sets 1-2 and 4-5 ($\rho = 0.001-0.04$). SpO2 demonstrated a significant main effect for condition ($F_{s,160} = 11.68; \rho < 0.001; \eta^2 = 0.23$) with differences observed between the hypoxic and normoxic conditions. There was a significant main effect for time in SpO2 for all conditions ($F_{3,40} = 46.59; \rho < 0.001; \eta^2 = 0.78$), with the exception of HYP180 ($\rho = 0.08$). Likewise, the significant differences over time were predominately between the SpO2 values between sets 1-2 and 4-5 ($\rho = 0.001-0.04$). Further, there was no significant effect of condition for RPE ($\rho = 0.12$). However, RPE significantly increased with time across all conditions ($F_{4,160} = 161.70; \rho < 0.001; \eta^2 = 0.80$), with sets 4-5 rated harder than sets 1-2 ($\rho = 0.016-0.001$). There was no significant difference between conditions for perceived muscle soreness ($\rho = 0.94$), despite a main effect observed for muscle soreness across all conditions ($F_{3,120} = 59.25; \rho < 0.001; \eta^2 = 0.60$) (see Figure 3). Lastly, sRPE load did not significantly vary across conditions ($\rho = 0.11$), despite small differences observed between the different rest conditions (NORM60: 239 ± 62; HYP60: 227 ± 80; NORM180: 205 ± 56; HYP180: 200 ± 62 AU).

Table 1 - Cardiovascular and perceptual responses (mean ± SD) during five working sets of bilateral leg extension.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Condition</th>
<th>Working Sets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Heart Rate (b min⁻¹)</td>
<td>NORM60</td>
<td>119 ± 16</td>
</tr>
<tr>
<td></td>
<td>HYP60</td>
<td>121 ± 18</td>
</tr>
<tr>
<td></td>
<td>NORM180</td>
<td>115 ± 14</td>
</tr>
<tr>
<td></td>
<td>HYP180</td>
<td>118 ± 18</td>
</tr>
<tr>
<td>SpO2 (%)</td>
<td>NORM60</td>
<td>98 ± 1</td>
</tr>
<tr>
<td></td>
<td>HYP60</td>
<td>88 ± 4</td>
</tr>
<tr>
<td></td>
<td>NORM180</td>
<td>98 ± 1</td>
</tr>
<tr>
<td></td>
<td>HYP180</td>
<td>87 ± 5</td>
</tr>
<tr>
<td>RPE (AU)</td>
<td>NORM60</td>
<td>4 ± 1</td>
</tr>
<tr>
<td></td>
<td>HYP60</td>
<td>5 ± 1</td>
</tr>
<tr>
<td></td>
<td>NORM180</td>
<td>4 ± 1</td>
</tr>
<tr>
<td></td>
<td>HYP180</td>
<td>4 ± 1</td>
</tr>
</tbody>
</table>

<sup>a</sup> significantly different to set 1; <sup>b</sup> significantly different to set 2; <sup>c</sup> significantly different to set 3; <sup>d</sup> significantly different to set 4.
DISCUSSION

The findings of this investigation demonstrate no differences in the metabolic stress imposed between conditions during moderate load resistance exercise. However, it is possible that there is a disassociation between systemic [BLa] and intramuscular metabolic stress (5). Blood lactate concentration was assessed immediately after the final set of leg extension, which may not have allowed sufficient time for intramuscular metabolites to be removed from the working muscles and taken up into circulation. Future investigation is required in this area.

Separately, it has been proposed that cellular swelling could potentially augment muscular hypertrophy by triggering the responsible intra-muscular anabolic signalling cascade (7,8,13). It has been theorised that increases in metabolite accumulation may be linked to cellular swelling (8). The acute increases in thigh girth observed across all conditions, in conjunction with elevated [BLa] across all conditions could further support this theory. Additionally, it was shown that thigh girth significantly increased after a short rest period in hypoxia, suggesting that a 60 s rest period in moderate hypoxia could augment muscle swelling, more so than a 180 s rest period or normoxic conditions. This further supports the proposed disassociation between systemic lactate concentrations and intramuscular metabolic stress, given that no significant increase in [BLa] was observed between conditions, whilst significant increases in thigh girth were reported with a shorter rest period.

Further results demonstrate expected CV responses to resistance training as HR increased with the number of sets during trials with a 60 s rest period. However, CV responses were not augmented by the hypoxic stimulus in these trials, indicating that moderate IHRT with a short inter-set rest period did not induce additional CV demands compared to the equivalent training in normoxia. As expected, SpO2 was affected by both inter-set rest duration and moderate hypoxia, as was observed by the decrease in SpO2 across sets in all conditions (although not significant in HYP180). Further, RPE was not affected by inter-set rest duration or hypoxic stimulus, indicating that subjects did not perceive exercise to be any more difficult with either shorter inter-set rest periods or the addition of hypoxia to experimental trials. The fact that moderate load IHRT could be performed without any increase in internal training load (sRPE load) means that it could be employed without adding additional training stress, despite the potentially greater training adaptations. Lastly, the results demonstrate that perceived muscle soreness increased immediately after exercise compared to pre exercise values, irrespective of condition. Furthermore, muscle soreness had returned to resting values in all conditions after 48 hours.

PRACTICAL APPLICATIONS

This study suggests that moderate-load IHRT coupled with a 60 s rest period can enhance acute thigh girth, and potentially muscle swelling in moderately trained individuals, without eliciting higher levels of perceived exertion or muscle soreness. However, the [BLa] data from this investigation are inconclusive, making it difficult to provide exact recommendations regarding the implementation of rest periods in IHRT. Further research investigating the effects of rest periods during IHRT should aim to quantify metabolic responses via intra-muscular [BLa], rather than systemic [BLa], in order to obtain an accurate representation of metabolic stress.
REFERENCES


Three weeks cessation from strength training in adolescent athletes increases lower-body isometric strength.

Three weeks cessation from strength training in adolescent athletes increases lower-body isometric strength. J. Aust. Strength Cond. 23(6) 26-29. 2015 © ASCA.

THREE WEEKS CESSATION FROM STRENGTH TRAINING IN ADOLESCENT ATHLETES INCREASES LOWER-BODY ISOMETRIC STRENGTH

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INTRODUCTION

It has previously been reported that there can be a delay in the onset of lower-body strength increases following resistance training, in adults (2, 7). Kubo et al. (7) identified that whilst the adaptations in neural activation of the lower-body were near identical at two months, and three months following the commencement of resistance training, strength gains were significantly larger at three months compared to two months. Furthermore, Ogawara et al. (9) recently compared the effects of a continuous 24 week periodised training program, to a periodic training program, whereby the participants performed six weeks of training, followed by three weeks cessation from training for a total of 24 weeks, in adult males. Following the end of the 24 weeks there was no significant difference in pre- to post-testing muscle cross-sectional area (CSA) or strength change, between the groups. In fact, the periodic training group experienced periods of accelerated muscle CSA and strength increases following the three week block of training cessation (9). However, to our knowledge no research has investigated whether adolescents also experience a delayed onset of lower-body strength following resistance training.

Research has demonstrated that training-specific adaptations in lower-body strength are typically associated with concomitant changes in lower-body muscle structure. Specifically, it has been reported that training-specific increases in lower-body force producing capabilities are associated with increases in vastus lateralis (VL) thickness, pennation angle, and fascicle length (FL) (1, 3, 8). However, it could be hypothesized that the aforementioned delayed onset of strength after cessation of training also occurs in association with delayed concomitant changes in muscle structure. Therefore, the purpose of this study was to determine whether there was a delay of onset in lower-body muscle structure, strength or jumping performance following three weeks cessation from strength training, in adolescents.

METHODS

Experimental Approach

The current study required all participants to complete two sessions a week for seven weeks (14 sessions) of an appropriately block periodised strength training intervention. In addition, participants completed pre- and post-testing assessments of lower-body muscle structure, and strength and jumping performance. These assessments were performed in the week prior to, and following the training intervention, respectively. Furthermore, following three weeks of cessation from the training intervention the participants performed the testing battery again (three weeks post-testing). Lower-body muscle structure, and strength and jumping performance were assessed with a testing battery including: ultrasonography, countermovement jump (CMJ), squat jump (SJ) and isometric mid-thigh pull (IMTP).

Participants

Eight competitive adolescent surfers (15.1 ± 1.4 y; 163.8 ± 6.0 cm; 56.2 ± 12.3 kg) volunteered to participate in this study. For inclusion in the study, subjects were required to be: (i) a member of a local high school surfing excellence program (ii) aged 13-18 years, and (iii) currently free of any injury or medical condition, as per a health screening questionnaire. The study and its procedures were approved by Edith Cowan University Human Ethics Committee (approval number: 10228), and participants and their guardians were provided with information detailing the study prior to providing informed consent and screened for medical contraindications.

Procedures

Strength Training Program

All strength training session were performed under the supervision of an accredited strength and conditioning coach. Each session commenced with a warm-up consisting of dynamic movements, squats and lunges (11). The strength training sessions consisted of both upper- and lower-body compound movements, that were appropriately block periodised (16).

Ultrasonography

Assessments of VL and lateral gastrocnemius (LG) muscle structure were performed with a real-time B mode ultrasonography (SSD-1000; Aloka Co., Tokyo, Japan), utilising a 7.5MHz linear probe (8, 11). VL and LG muscle thickness and pennation angle measures were taken at 50% of the distance between the greater trochanter and lateral epicondyle of the femur, and at two-thirds of the distance between the lateral epicondyle of the femur and lateral
Additionally, VL measures were taken with the participants in a supine position, and with the participants in a prone position for the LG measures (4, 10). The FL of the VL and LG were calculated with the equation of; 
\[(FL = \text{muscle thickness} \times (\sin \text{pennation angle})^{-1})\] (6). Two images were recorded of the VL and LG from both legs, with analysis performed as previously described in Secomb et al. (11). The results of the left and right leg were combined and averaged for analysis. The reliability for all muscle structure variables have previously been reported as high in a similar adolescent cohort (Intraclass Correlation Coefficient (ICC): 0.93-1.00 and Coefficient of Variation (CV%): 0.6-4.7%) (11).

Lower-Body Strength and Jumping Performance

Following a warm up identical to that performed prior to each training session, participants performed the testing in the following order; CMJ, SJ and IMTP (10). The CMJ and SJ were performed on a portable force plate (400 Series Performance Force Plate; Fitness Technology, Adelaide, Australia), with participants holding a wooden dowel across their backs, to eliminate any potential arm-swing contribution (10). In addition, for the SJ trials, a linear position transducer was attached to the wooden dowel (PT9510; Fitness Technology, Adelaide, Australia), which interfaced with the force plate (10). The force plate was connected to a portable laptop an associated software package (Ballistic Measurement System; Fitness Technology, Adelaide, Australia), with data sampling at 600 Hz. Starting position for the SJ trials required the top of the thighs were parallel with the ground. Participants held this position for three seconds, before being instructed to jump as high as possible (12). Participants performed three trials of the CMJ and SJ, separated by one minute between trials, with the instructions to jump as high and quickly as possible (10, 13). Furthermore, three minutes of rest was provided between the CMJ and SJ trials (11). Trials for the SJ were discarded in the event of a small amplitude countermovement of greater than 2 cm, as determined from the displacement-time trace on the analysis software (12). Each participant’s best trial for the CMJ and SJ, as determined by greatest jump height, was used for analysis. All jumps were analysed for the variables of; peak force (PF), PF relative to body weight (rPF) (N·BW -1), peak velocity (PV), eccentric peak velocity (V_{ecc}), and jump height (H). Furthermore, eccentric leg stiffness was calculated from the CMJ, with the equation of \[k_{\text{leg}} = \frac{\text{CMJ PF}}{\text{CMJ } H_{\text{ecc}}},\] (CMJ PF = peak ground reaction force; CMJ H_{ecc} = eccentric centre of mass (COM) displacement) (10, 11).

The IMTP was performed on the portable force plate, with the methods previously described in Sheppard et al. (13). Participant performed two trials of the IMTP, with two minutes of rest between each trial (11). A third trial was performed in the event of a difference in the PF between the two trials of greater than 250 N, performed a third trial (11). Each participant’s best trial, as determined by the highest PF, was used to determine the PF and rPF (10). Additionally, the dynamic strength deficit (DSD) ratio was calculated using the formula; \[\text{DSD} = \frac{\text{CMJ PF}}{\text{IMTP PF}}\] (15). All variables of the CMJ, SJ and IMTP have been reported as high with a similar cohort (ICC: 0.88-0.99; CV%: 2.1-6.8%) (10).

Statistical Analysis

All data was assessed for normality with Mauchly’s Test of Sphericity. In the event of the assumption of normality being violated, the data were log-transformed before analysis. To determine whether a significant effect for time was present between pre-testing, post-testing, and three weeks post-testing, a repeated measures (1x3) ANOVA was performed on all muscle structure, and strength and jumping performance variables. Following a significant effect for time, a least significant differences post-hoc was utilized to determine where the effect occurred. All tests were performed using a statistical analysis package (SPSS, Version 23.0; IBM, Chicago, USA) with statistical significance set at \(p \leq 0.05\).

RESULTS

The mean (±SD) pre-testing, post-testing, and three week post-testing for all lower-body muscle structure, and strength and jumping performance variables are presented in Table 1.
Table 1 - The mean (±SD) for pre-testing, post-testing, and three week post-testing for all variables of vastus lateralis (VL) and lateral gastrocnemius (LG) muscle structure, and the countermovement jump (CMJ), squat jump (SJ), and isometric mid-thigh pull (IMTP).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre-Testing (mean ± SD)</th>
<th>Post-Testing (mean ± SD)</th>
<th>Three Weeks Post-Testing (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LG Thickness (cm)</td>
<td>1.44 ± 0.20</td>
<td>1.41 ± 0.32</td>
<td>1.47 ± 0.24</td>
</tr>
<tr>
<td>LG Angle (°)</td>
<td>14.2 ± 2.8</td>
<td>14.7 ± 3.1</td>
<td>13.9 ± 2.5</td>
</tr>
<tr>
<td>LG FL (cm)</td>
<td>6.08 ± 1.16</td>
<td>5.80 ± 1.73</td>
<td>6.20 ± 0.76</td>
</tr>
<tr>
<td>VL Thickness (cm)</td>
<td>2.06 ± 0.42</td>
<td>2.16 ± 0.41</td>
<td>2.06 ± 0.36</td>
</tr>
<tr>
<td>VL Angle (°)</td>
<td>17.1 ± 2.1</td>
<td>17.3 ± 2.7</td>
<td>18.5 ± 2.5</td>
</tr>
<tr>
<td>VL FL (cm)</td>
<td>7.11 ± 1.34</td>
<td>7.35 ± 1.58</td>
<td>6.60 ± 1.21</td>
</tr>
<tr>
<td>CMJ rPF (N•BW⁻¹)</td>
<td>2.10 ± 0.23</td>
<td>2.09 ± 0.22</td>
<td>2.03 ± 0.20</td>
</tr>
<tr>
<td>CMJ PV (m•s⁻¹)</td>
<td>2.42 ± 0.21</td>
<td>2.47 ± 0.21</td>
<td>2.45 ± 0.25</td>
</tr>
<tr>
<td>CMJ H (m)</td>
<td>0.41 ± 0.07</td>
<td>0.40 ± 0.05</td>
<td>0.40 ± 0.07</td>
</tr>
<tr>
<td>CMJ Hₑₑₑ (m)</td>
<td>0.43 ± 0.09</td>
<td>0.43 ± 0.09</td>
<td>0.43 ± 0.08</td>
</tr>
<tr>
<td>Eccentric Leg Stiffness (N•m⁻¹)</td>
<td>2740 ± 757</td>
<td>2728 ± 615</td>
<td>2745 ± 925</td>
</tr>
<tr>
<td>SJ rPF (N•BW⁻¹)</td>
<td>1.90 ± 0.15</td>
<td>1.94 ± 0.08</td>
<td>1.90 ± 0.14</td>
</tr>
<tr>
<td>SJ PV (m•s⁻¹)</td>
<td>2.43 ± 0.24</td>
<td>2.55 ± 0.37</td>
<td>2.27 ± 0.33</td>
</tr>
<tr>
<td>SJ Height (m)</td>
<td>0.34 ± 0.06</td>
<td>0.36 ± 0.06</td>
<td>0.35 ± 0.06</td>
</tr>
<tr>
<td>IMTP PF (N)</td>
<td>1561 ± 455</td>
<td>1686 ± 437</td>
<td>1847± 390</td>
</tr>
<tr>
<td>IMTP rPF (N•BW⁻¹)</td>
<td>2.81 ± 0.47</td>
<td>3.02 ± 0.38</td>
<td>3.34 ± 0.62</td>
</tr>
<tr>
<td>DSD Ratio</td>
<td>0.76 ± 0.10</td>
<td>0.70 ± 0.10</td>
<td>0.62 ± 0.10</td>
</tr>
</tbody>
</table>

a = significantly different to pre-testing p≤0.05, b = significantly different to post-testing p≤0.05

DISCUSSION

The purpose of this study was to determine whether there was a delay of onset in lower-body muscle structure, strength or jumping performance following three weeks cessation from strength training in adolescents. The results of this study suggest that following the cessation of strength training, the adolescent athletes experienced significant increases in IMTP rPF and VL pennation angle, with significant decreases observed in VL thickness and FL. These results suggest that in the present adolescent athletes, there was a delay in the onset of strength increases and changes in lower-body muscle structure, following the cessation of strength training.

Interestingly, the present adolescent athletes experienced significant increases in IMTP rPF, following the three weeks cessation from the strength training. This results are in agreement with Ogasawara et al. (9), which reported that...
following three weeks cessation from strength training, adults experienced a period of accelerated strength and hypertrophy increases in a subsequent training block. To our knowledge the present data indicating that there is a delay of onset in strength adaptations following the cessation of strength training in adolescents is novel. Previously, Tran et al. (14) reported that four weeks of training cessation was enough to result in significant detraining of IMTP performance, in adolescents. Together, these results suggest that adolescent athletes may require greater time to achieve strength adaptations from training, or during a complete de-loading period (of no longer than three weeks) may learn to utilise the adaptations gained during the training period. These results may have significant implications for the testing and program design for adolescent athletes, particularly where intensive skills training, travel or tournament play creates an impractical scenario where formalized resistance training cannot continue.

The results that significant changes occurred in lower-body muscle structure supports the contention that increases in lower-body strength are associated with concomitant changes in lower-body muscle structure (1, 3, 8). The initial strength increases, achieved from pre- to post-testing, in this study were associated with increased VL thickness. This was likely due to a preferential increases in the number of sarcomeres in series, as noted by the tendency for increased VL FL (5). However, following the three weeks of cessation from strength training, where the increase in IMTP rPF was of a greater magnitude, this was associated with a significant increase in VL pennation angle, and a significant decrease in VL FL, with VL thickness returning to pre-testing values. This suggests that different muscle structure changes may result in similar strength adaptations. As such, it appears that in this study the delayed onset of lower-body strength increase was associated with significant lower-body muscle structure changes.

**PRACTICAL APPLICATIONS**

The results of this study indicate that the adolescent athletes experienced significant increases in IMTP rPF following three weeks cessation from strength training. This suggests that strength and conditioning coaches and sport scientists working with adolescent athletes may not always be able to evaluate the true magnitude of change from the training, if testing only occurs in the common 48–72 hours post a “training period”. Specifically, delayed onset adaptations occur and may be true indication of the benefit of training. Furthermore, it may be that prior to commencing a subsequent training block, a de-loading period following strength training, or even a training cessation period of no longer than three weeks, can still allow for maximisation of their training-specific adaptations. This may be a beneficial finding particularly when planning for extended travel or tournaments in various adolescent athletes. Additionally, the results that lower-body muscle structure adaptations also experienced a delayed onset is novel, and may provide new information regarding the mechanisms for increased lower-body strength in adolescent athletes.

**REFERENCES**


THE EFFECT OF A STRUCTURED 3 WEEKS CONDITIONING PROGRAM TO MINIMISE DETERTRAINING DURING THE TRANSITION PHASE

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1Penang Satellite Centre, National Sports Institute of Malaysia
2Physiology Centre, National Sports Institute of Malaysia

ABSTRACT

During the transition period, that follows important competitions, national-level elite athletes may experience a reduction in performance and positive adaptations that were gained during the competition phase. The purpose of this study is to examine the effect of a 2d/wk. x 3-wks maintenance conditioning program on lower body Rate of Force Development (RFD), Peak Force (PF), and Peak Power (PPW) during the transition phase in karate athletes. Six subjects (3 male and 3 female) from the national karate team was chosen for this study. BCA was done using skinfold method. RFD, PF, PPW data was collected using SJ on force platform. Pre-test data was done 4 days prior to the start of the transition phase and post-test data was collected 4 – 7 days after the start of the preparation phase. The conditioning program was performed twice a week over 3 weeks and consisted of 3 sets x 8 RM for strength exercises (10 exercises) and 12 RM for individualized pre-habilitation exercises. There was an increase in body fat % but the Effect Size was deemed trivial (ES=0.1). Mean post data showed trivial increase in RFD (ES=0.1), but moderate and small improvement in PF (ES=1.0) and PPW (ES=0.2) respectively. The results of this study showed that with a structured twice weekly conditioning program during transition period is able to overcome detraining and maintain the positive performance gain from the competition phase.

INTRODUCTION

Kata is an event within competitive karate with predetermined steps of attacking, defending and counter attack (a series of rhythmic isometric, concentric and eccentric movement) (15). World champions of Kata and Kumite have approximately the same maximal aerobic and anaerobic power in relation to body weight (1). In a simulated competition, the Kata event’s metabolic power is lower than VO2max and the aerobic and anaerobic (a-lactic and lactic) sources are almost equally divided (3). The only difference of physical and physiological characteristics between Kata and Kumite athletes is the whole body acceleration (1). This conclusion seems plausible on the ground that Kata is about performing a series of predetermine movement and not as dynamic as a Kumite match that is more versatile.

In most high performance sports, the ability to exert force and exhibit a rate of force development is thought to be crucial to success during competition. Thus, the measures of rate of force development (RFD), peak force (PF) and peak power (PPW) is of great importance and interest to the coaches and conditioning specialists. Plausibly, any large reductions in force generating qualities may indicate a loss of movement speed or quality, which could hinder the performance of a karate athlete.

During the transition period following important competitions, national-level elite athletes may experience a reduction in the performance and positive adaptations that were gained during the competition phase. With the introduction of a league championship by the World Karate Federation, it is considered by coaches that are important that the athletes return to training with minimal detraining or able to maintain the performance gains of the previous training and competition blocks. A significant reduction in force generation qualities would mean that the athlete will have to spend a considerable part of training phase to return to their previous individual optimal performance levels.

With regards to the detraining effect, strength-trained athletes showed slight but insignificant reductions in bench press, isometric and isokinetic concentric knee extension force, and vertical jump after 2 weeks without training but significant 8 to 13% decline in electromyogram (EMG) activity of the vastuslateralis muscle and isokinetic eccentric knee extension (9, 5). Trained swimmers are also able to maintain muscular strength during 4 weeks of inactivity; however the athlete’s ability to apply force in water was significantly reduced by 13.6% in swim power (10).

The purpose of this study is to examine the effect of a 2d/wk x 3-wks maintenance conditioning program on RFD, PF, and PPW in national Karate exponents during the transition phase.

METHODS

Subjects were tested for body composition and lower body measures of force generation before and after a structured 3-wks conditioning program during the transition phase. Testing was performed on 2 separate days with Body Composition Assessment (BCA) on the 1st day and force generation tests during a Squat Jump (SJ) on the 2nd day.
Transition phase commenced 1 week after the World Championship for 3 weeks. Pre-test data collection was done 4 days prior to the start of the transition phase. Post-test was done 1 week after the start of the general preparation phase.

Subjects
Six subjects (3 male and 3 female) with mean age of = 23.00±3.16yrs, and height of= 167.80 ± 3.67cm participated in this study. All are seasoned fulltime national-level elite Karate (Kata) exponents with a mean competitive training age of 8.17±2.48 years. All are ranked highly in Asia with the least being 3rd for the female and the males are ranked 3rd in the world.

Evaluation of Body Composition
Body weight and height was measured using a height and weight scale (Seca 769, Germany) and skinfold thickness was measured using a Harpenden skinfold calliper (Baty International RH15 9LR, England). Average of 2 trials for the skinfold of seven sites (triceps, subscapular, biceps, illiac crest, supraspinale, abdominal, front thigh and medial calf) was measured in accordance to the standards of the International Standards for Anthropometric Assessment (ISAK) (7). Body fat %was estimated using a standardized formula for male athlete and female athlete (13, 14).

Evaluation of Rate of Force Development, Peak Force and Peak Power
A squat Jump (SJ) was used to assess dynamic measures of force generation such as RFD, PF and PPW. SJ was used as it is identical to a movement in Kata performance where the exponent will move to a particular stance with at least 3s of isometric contraction before commencing to the next movement. Subjects were asked to start from a stationary half squat position. Subjects were then instructed to execute a maximal vertical jump without any downward movement on the force plate (400 Series Performance Force Plate, Fitness Technology, Adelaide, Australia). The force curve was inspected through computer software (Ballistic Measurement Software, Fitness Technology, Adelaide, Australia) to verify there is no downward movement before the jump. Power was calculated as the product of the vertical velocity (displacement and time data) and force data (vertical ground reaction force measured directly by the force plate). The concentric phase of the jump (positive displacement portion of the squat jump) was assessed. PPW and PF were determined as the maximal values achieved during the concentric phase of the jump. RFD was assessed from the initiation of the concentric phase to the point at which the peak force appear (2).

Training Approach
The training program lasted 3 weeks, with a frequency of training of twice a week. The training prescription was 3 sets of 8 RM for strength exercises (10 exercises) and 12 RM for individualized pre-habilitation exercises. A 1 – 1.5 minutes of rest was maintained between sets. There was limited to no karate specific skill training during the 3-wks transition phase.

Statistical Analysis
Means, standard deviations and z-score were used to describe the data. Independence T-test was used to analyse significant differences between genders. Significant of difference was set at P<0.05. Smallest worthwhile changes (SWC) were used to describe the changes of each subject. Smallest worthwhile change was set at 0.2 of the between subject standard variation. Effect Size (ES) was used to describe changes between pre and post data. Changes in mean was categorized as Trivial: 0.0 – 0.1; Small: 0.2 – 0.5; Moderate: 0.6 – 1.1; Large: 1.2 – 1.9; Very Large: 2.0 – 3.9; Perfect: > 4.0 (5). Independent T-test, mean and standard variation was analysed using SPSS version 21 and smallest worthwhile change was analysed using excel (Microsoft Office 360).

RESULTS
There is no significant differences between genders for BF % (P=0.20), RFD (P=0.61), PF (P=0.61), and PPW (P=0.26). Accordingly, the data can be presented as the pooled data for all six subjects

Table 1 - Pre-test and post-test body composition and squat jump performance (mean ± SD).

<table>
<thead>
<tr>
<th>Test</th>
<th>Pre-test</th>
<th>Post-test</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Fat (%)</td>
<td>14.75 ± 6.63</td>
<td>15.35 ± 6.48</td>
<td>0.1</td>
</tr>
<tr>
<td>SJ RFD (Nms⁻¹)</td>
<td>46834.83 ± 15536.17</td>
<td>47831.83 ± 20279.23</td>
<td>0.1</td>
</tr>
<tr>
<td>SJ PF (N)</td>
<td>1387.62 ± 151.50</td>
<td>1536.17 ± 138.09</td>
<td>1.0</td>
</tr>
<tr>
<td>SJ PPW (W)</td>
<td>3246.58 ± 611.89</td>
<td>3373.23 ± 691.11</td>
<td>0.2</td>
</tr>
</tbody>
</table>

SJ=Squat Jump; RFD=Rate of Force Development; PF=Peak Force; PPW=Peak Power

Body Composition
There was trivial increment in group mean BF% (ES=0.1). Individual smallest worthwhile changes for BF% were any changes of 1.33%. All subjects showed no real SWC except for subject D with an increase of 1.4%.
BF %=Body Fat percentage; RFD=Rate of Force Development; PF=Peak Force; PPW=Peak Power.

**Figure 1** - Changes in pre and post scores of BF%, RFD, PF, PPW presented in Z score.

**Rate of Force Development, Peak Force, and Peak Power**

RFD showed trivial improvement (ES=0.1). However, PPW showed small improvement in scores (ES=0.2) and PF showed moderate improvement as compared to pre mean data (ES=1.0). Individual data of each subjects for RFD showed real changes for subject D and subject E (SWC ≥ 3107.23 Nms⁻¹). All subjects excluding subject D showed real changes in pre post data in their PF scores (SWC ≥ 30.30 N). For PPW, all subjects except for subject B and subject C showed real changes (SWC ≥ 122.38 W).

**Table 2** - Smallest worthwhile changes for each parameter.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Gender</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>BF%</td>
</tr>
<tr>
<td>A</td>
<td>F</td>
<td>0.5</td>
</tr>
<tr>
<td>B</td>
<td>F</td>
<td>1.0</td>
</tr>
<tr>
<td>C</td>
<td>F</td>
<td>-0.3</td>
</tr>
<tr>
<td>D</td>
<td>M</td>
<td>1.4</td>
</tr>
<tr>
<td>E</td>
<td>M</td>
<td>1.1</td>
</tr>
<tr>
<td>F</td>
<td>M</td>
<td>-0.1</td>
</tr>
</tbody>
</table>

SWC 1.33 3107.23 30.30 122.38

BF %=Body Fat percentage; RFD=Rate of Force Development; PF=Peak Force; PPW=Peak Power

**DISCUSSION**

The results of this study showed that with a structured twice weekly conditioning program during transition period is able to maintain positive performance gain from the competition phase. The increase in body fat % though trivial may be due to the reduction in frequency of high volume sports specific karate training that the athletes are used to during the preparation and competition phases. Our findings are similar with other study which showed a lower increase in body fat percentage for subjects who followed an organized training program as compared to those who was in a control group (12).

Strength performance can be retained up to 4 weeks of inactivity but eccentric force and sports specific power may suffer significant declines (9). With a twice weekly organized conditioning program, our results showed that it is possible to retain and increase, though trivial to small values PPW and RFD. A decline in RFD and peak power requires the athlete to spend a considerable span of time during the preparation phase to rebuild what was lost if a maintenance conditioning program is not being implemented. In this study, PF showed moderate improvement as the program intervention paid attention to strength development. As suggested in a previous study (8), a higher level of muscle strength would be preferable to reduce the risk of injuries in the maintenance and rebuilding phase of the training period.
These authors further stated that a 6 – 7 week break from training practice leads to a significant loss of beneficial adaptations (8).

In conclusion, a twice weekly structured conditioning program is able to improve PPW, RFD and PF by trivial to moderate amounts. Thus, the athletes do not experience any force generation detraining effects and are able to commence the next training block in better physical condition and not waste training time attempting to regain lost physical capabilities.

PRACTICAL APPLICATION

While the results of this maintenance program are as expected, the individually of changes experienced by these elite athletes should also be considered. In high performance sports, more individualisation of training may be required as the difference between a gold medallist and a silver medallist can be small. As the only negative change exhibited during this training program was a trivial increase in body fat %, a combination of conditioning and diet program may be a better choice to increase the effects of the maintenance program during this period, as frequency of training will be markedly reduced. A power maintenance program (combination of absolute power and plyometric) can also be considered during the transition period to increase or maintain RFD.

ACKNOWLEDGEMENT

The authors would like to thank Erik Tan, Louis Yiau and Thung Jin Seng (sequence arranged alphabetically) for giving their input and support. The authors would also give a heartfelt gratitude to the coaches of the Malaysian Karate (Kata) team, Ku Jin Keat and Lim Lee Lee for giving us the full support in gathering the data and implementation of their input and support. The authors would also give a heartfelt gratitude to the coaches of the Malaysian Karate (Kata) team, Ku Jin Keat and Lim Lee Lee for giving us the full support in gathering the data and implementation of the conditioning program. Not forgetting the national exponent for giving the full effort in making this program successful.

REFERENCES

The application of isokinetic testing to understand factors predicting performance in the 100m, 400m, long jump and high jump.

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THE APPLICATION OF ISOKINETIC TESTING TO UNDERSTAND FACTORS PREDICTING PERFORMANCE IN THE 100M, 400M, LONG JUMP AND HIGH JUMP

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INTRODUCTION

Strength or force and power in athletics have been identified as important factors linked to, and in some situations determining performance (1,2,3,4,5). Power is defined as the mechanical work done in a specified period of time (1,3,6) or the product of force by velocity (3,6) and as the ability of the human neuromuscular system to produce the greatest possible impulse in a given period of time (2). Strength is defined as neuromuscular force exerted against movable and immovable objects or as peak force or torque generated by voluntary muscular contractions. Strength and force are often used interchangeably in sport (6). Research (1) examined the power in sprinting and concluded that high power production was characteristic of high performance male and female sprinters based on research of indoor and outdoor competitions, especially the role of hip and knee flexors and extensors. Research by Schmidtbleicher (2) indicated that movements with a duration of less than 0.25 seconds the maximal rate of force development and the initial rate of force development are the main factors that influence performance. The maximal rate of force development is analogous to power or force time velocity construct.

Sprint running, high jump and long jump events require the use of fast stretch shortening cycle actions (ground contact phases) that last from 0.10 to 0.25 seconds, which would indicate that factors as power development and torque acceleration energy (TAE) should be important and predictive factors of performance in sprint and jump events. Torque acceleration energy is defined as the amount of energy expended (work performance) in the first 0.125 seconds of torque production in a dynamic contraction. TAE is indicative of muscular “explosiveness” and the greater the energy generated in this short timeframe the greater the TAE (7). According to Schmidtbleicher (2), Wilson (3) and Ackland et al., (6) the quality of power production in the stretch-shortening cycle is essentially dependent on the structure of the innervation patterns and the training state of the tendomusclular system in terms contractile and elastic (energy storing) abilities. It must be emphasised the gains in strength training will not necessarily be reflected in in enhanced power production and transfer or be the best predictors of sprint and jump performances or where movements are very fast and with limited time to produce force.

Isokinetic testing has displayed some variable relationships with different sports, such as the importance of high peak torque production for jumpers (4) whereas other research has indicated minimal relationship of isokinetic leg extension/flexion performance at 60°s⁻¹ and 300°s⁻¹ with 5m, 10m and 30m sprint acceleration performance in a sample of semi and professional adult male Rugby League players (5).

A number of research problems have been identified based on previous research using isokinetic testing to assess the correlation of force, work and power with sprint and jump performances. These include limited sample sizes of youth, high performance and non-athletic populations and not evaluated a range of ability levels to assess if athletes require high levels of force, power and TAE as they may relate to different athletic events, such as the 100m, 400m, long jump and high jump events. Statistical techniques utilised in previous research were based mainly on methods of association, such as correlation and not predictive statistical modelling, such as multiple linear regression that can assess the prediction of competition performance based on laboratory derived measures as peak torque, work, power, torque/weight, power/weight and TAE that can be derived validly, reliably, accurately and objectively. The research aims were to more completely understand the relationship between isokinetic measures for leg extension/flexion across three isokinetic speeds (60°s⁻¹, 180°s⁻¹ and 300°s⁻¹) and track and field performance in the 100m, 400m, long jump and high jump in young adult male and female athletes. Quantifying the multivariate contributions of peak torque, work, power, torque/weight, power/weight and TAE to each event. The findings will enable a more systematic approach for athletes, coaches and sport scientists to design and monitor training programs and athlete adaptations to training and assess if isokinetic testing will enable a new dimension to identify potential talent in talent identification programs?

METHODS

The research design represented applied research (8, 9) where researchers identify a real world problem that can have direct relevance to practice. In this context direct applications to understanding performance factors and developing training programs based on such factors to enhance performance. The design was a non-experimental cross-sectional correlation predictive design. The real world problem in this research is can isokinetic derived measures of torque, work, power, torque/weight, power/weight and TAE predict performance in the 100m 400m, long jump and high jump, as well as identify key factors that are associated with competition performances?
Ethical approval was granted to conduct the research. Participants were 25 males and 31 females with an age range of 18-26 years (mean 19.23 years, S.D.=1.67 years) who were involved in a three month athletics/track and field program. The ability levels of the athletes were average to reasonably high ability athletes. Isokinetic dynamometry was evaluated in a university exercise and sport science laboratory to assess torque work, power and TAE and secondary derived measures of torque/weight and power/weight. The CYBEX-HUMAC NORM extremity testing and rehabilitation system was used to measure the identified variables (7, 10). Calibration of the instrument was according the manufactures guidelines. Isokinetic dynamometry testing has been proven to be a reliable and valid instrument with reliability coefficients of 0.97 test-retest statistics (7, 10) and the correlation of isokinetic testing with isotonic testing has displayed validity coefficients of 0.89 (11). All athletes in the study competed in all four events.

All participants performed extension/flexion movements of the preferred leg and instructed to perform maximally following a warm-up sequence with each isokinetic speed. The settings for each participant complied with manufacturer guidelines for testing leg extension/flexion. The sequence is as follows for leg extension/flexion. Gravity correction was selected during the testing.

Warm up x 4 reps at 60°s⁻¹ : test x 4 reps at 60°s⁻¹
Warm up x 4 reps at 180°s⁻¹: test x 4 reps at 180°s⁻¹
Warm up x 4 reps at 300°s⁻¹: test x 30 reps at 300°s⁻¹

All data generated from the testing was recorded and saved to a hard drive. The following data were used in the analysis across the different isokinetic speeds for leg extension/flexion: peak torque, total work, average power, relative average power and TAE. This permitted the constructs of strength power, power/weight and TAE to be evaluated. The laboratory data were gathered in the last week of the three month athletics (track and field) program. The competition performances were measured at the completion of the three month athletics program at a surveyed and certified athletic track compliant with IAAF/Athletic NSW guidelines and competition was conducted according to Athletic NSW guidelines and rules.

Statistical analysis consisted of assessing data that complied with the assumption of normal distribution, such as homogeneity of variance, Pearson product moment correlation to assess variable association at the bivariate level, and concepts of linearity. Stepwise multiple linear regression was applied to assess linear additive effects of the predictor variables on predicting 100m and 400m times in seconds and long jump and high jump distances in metres. The goals of multiple linear regression are; 1. To develop an equation that summarises the relationship between dependent variables (100m, 400m, long jump and high jump) and the set of independent variables (torque, power, torque/weight, power/weight and TAE). 2. To identify the subset of independent variables that are most useful for predicting the dependent variable. 3. To predict the values for a dependent variable from the values of the independent variables. The quality of fit or model using multiple regression was be based on the multiple R value (multiple correlation concept), R-square value (a measure of the amount of explained variance in the dependent variable in terms of the predictor (independent) variable set), the level of significance or the p-value and the residuals (which represent the difference between the actual score and the predicted scores based on the regression equations) (12). Regression effect sizes were calculated based on Cohen's $f^2$ where 0.02 – 0.15 is small, 0.15-0.34 is medium and 0.35 and above is large.

RESULTS

The predictive trends for both genders were very similar; therefore all participants were pooled in the analysis. The focus is on the correlation analysis and the different regression solutions so the results will focus on these outcomes. The results indicated a very significant relationships in terms of bivariate correlations between ($p<.001$) isokinetic measures and the 100m, 400m, long jump and high jump. The correlation matrix is displayed in table 1.

The multiple linear regression solutions were based on both the stepwise and block methods. The stepwise method to be reported derives equation based on those predictor variables that contribute statistically significant explained variance, which will then be included in the equation. Non-statistically significant variable are omitted from the equations. The dependent variable in each equation is the athletic event.

Specifically, 100m and 400m were predicted power/weight ratio at 300°s⁻¹ for leg extension, high jump was predicted by work output for leg extension at 300°s⁻¹ and long jump was predicted by power/weight ratio at 300°s⁻¹ leg extension, TAE 60°s⁻¹ leg flexion and TAE 300°s⁻¹ leg extension. All multiple regression solutions were significant at <0.001, displayed high R-square values (50%-76% explained variance) and large effect sizes for all events, specifically $f^2$ values 100m=1.33, 400m=1.0, long jump=3.12 and high jump=1.94. The residuals for all events were small and this indicates good explanatory and predictive models. A best subset of the predictor variables was selected based on stepwise regression statistical criteria (12), which enables a more refined set of predictive models for the 100m, 400m, long jump and high jump. It is important to note that the sprints, long jump and high jump were represented by different predictive equations.
The following regression equations reflect the specific relationships.

\[
100m \text{ Time (s)} = -0.122 \text{ (Power/Weight Leg Ext 300s}^{-1}) + 17.500 \quad \text{Multiple R} = 0.75: R^2 = 0.57: f^2=1.33
\]

\[
400m \text{ Time (s)} = -0.072 \text{ (Power/Weight Leg Ext 300s}^{-1}) + 90.17 \quad \text{Multiple R} = 0.71: R^2 = 0.50: f^2=1.0
\]

\[
\text{Long Jump (m)} = -0.009(\text{Power/Weight Leg Ext 300s}^{-1}) + .072(\text{TAE Leg Flex at 60s}^{-1}) - .023(\text{TAE Leg Ext at 300s}^{-1}) + 2.177 \quad \text{Multiple R} = 0.87: R^2 = 0.76: f^2=3.12
\]

\[
\text{High Jump (m)} = -0.009 \text{ (Work 300s}^{-1} \text{ Leg Ext}) + .743 \quad \text{Multiple R} = 0.82: R^2 = 0.66: f^2=1.94
\]

DISCUSSION

The results indicated laboratory measures using isokinetic dynamometry for leg extension/flexion were highly predictive of speed (100m and 400m sprints) and power (high jump and long jump) events, especially at high isokinetic speeds of 300s\(^{-1}\) for leg extension. Events such as 100m, 400m, long jump and high jump are dependent upon rapid generation of force with limited contact time (0.10 to 0.25 seconds). These types of sport activities are dependent on what Schmidtbleicher (2) defined as the short period stretch-shortening cycle. It is important to note that whatever the ability of the athletes in the different events in this study, all athletes were highly dependent on power production at high isokinetic speed to solve the competition motor tasks as the data for all participants closely fitted the predictive models.

The different events reveal some interesting underpinning factors associated with higher performance and these factors direct the athlete and coach towards training programs that can link training effects directly to competition. In the 100m only power/weight leg extension at 300s\(^{-1}\) was identified as significant as many of the other predictor variables shared common variance with power/weight leg extension at 300s\(^{-1}\) and became redundant predictors in the model. The relationship indicates high increases in power/weight leg extension at 300s\(^{-1}\) results in significant improvements in sprint times. It is important to note that as training progresses this construct can be evaluated directly with isokinetic testing to assess if the training has direct transfer to enhance the power/weight leg extension at 300s\(^{-1}\). It is important to note that lower velocity isokinetic speeds for leg extension and flexion as well as TAE for both were not contributing significantly to the explained variance once power/weight leg extension at 300s\(^{-1}\) was included, and although important at the bivariate level not as important at the multivariate level. The 400m is predicted in a similar way to the 100m where increased power/weight leg extension at 300s\(^{-1}\) will result in reduced sprint times. The influence of the other predictor variables is similar to the 100m situation where they do not contribute to the predictive model.

The long jump model included some additional predictor variables to power/weight leg extension at 300s\(^{-1}\) although this variable was still the most predictive and entered at step one. The additional variables were TAE leg flexion at 60s\(^{-1}\) and TAE leg extension at 300s\(^{-1}\), which both increased jump length the higher the values for these TAE scores. This make theoretical and practical sense when you consider TAE is indicative of muscular “explosiveness” and the greater

---

**Table 1 - The correlation matrix indicating the relationship between the 100m, 400m, long jump, and high jump with isokinetic measures of TAE, power/weight and work.**

<table>
<thead>
<tr>
<th></th>
<th>100m</th>
<th>400m</th>
<th>HJ</th>
<th>5</th>
<th>15</th>
<th>19</th>
<th>22</th>
<th>23</th>
<th>25</th>
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</thead>
<tbody>
<tr>
<td>100m</td>
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<td>400m</td>
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</tr>
</tbody>
</table>

\(p<0.001\) in all cases and \(n\) of cases = 50
the energy generated in this short timeframe and it is important to emphasise the long jump take-off is considered an “explosive” stretch-shortening cycle. As a consequence of this relationship training methods to enhance TAE can be monitored via isokinetic testing to plot training adaptations.

The high jump appears somewhat paradoxical when considering the interactions mapped by the stepwise regression solutions for 100m, 400m and long jump, as work output at 300\(^{\circ}\)s\(^{-1}\) leg extension was identified as the only significant predictor of performance for the high jump. That is more of this work factor the athlete possesses results in higher heights jumped. Once again, we have 300\(^{\circ}\)s\(^{-1}\) leg extension or the higher velocity isokinetic speed being the most important, but why work and not power/weight at 300\(^{\circ}\)s\(^{-1}\)? The high jump requires the athlete to raise his/her body vertically and this change in position is a change in potential energy/positive work. Potential energy is mass times gravitational field times change in height or \(PE = mgh\) which equals force times distance and which is the formula for work. The change in work represents the change in the potential energy, so high jumpers require a high capacity to develop vertical work. Once again, the isokinetic testing can monitor changes in work output and the specific and predictive work output required, that is isokinetic leg extension work at 300\(^{\circ}\)s\(^{-1}\).

**PRACTICAL APPLICATIONS**

1. These findings direct the athlete and coach to measurable and underpinning biomechanical and motor fitness factors based on laboratory based isokinetic performances that predict significantly performance in 100m, 400m, long jump and high jump athletic events.

2. The different events were predicted by different isokinetic variables, such as 100m and 400m by power/weight at 300\(^{\circ}\)s\(^{-1}\) leg extension; long jump by power/weight at 300\(^{\circ}\)s\(^{-1}\) leg extension, TAE leg flexion at 60\(^{\circ}\)s\(^{-1}\) and TAE leg extension at 300\(^{\circ}\)s\(^{-1}\); and high jump by work output at 300\(^{\circ}\)s\(^{-1}\)leg extension. These findings provide a focus for training in terms of a hierarchy of importance as to what factors to train.

3. The factors can be systematically measured and monitored continuously over a training season to evaluate if the training is inducing the appropriate adaptation.

4. The findings provide another dimension to the training process beyond just monitoring times and distances achieved in training and enable accurate, objective measures of change and these evaluations are time efficient when assessing athletes.

**REFERENCES**

JUNIOR COLLEGE FOOTBALL: PHYSICAL AND PHYSIOLOGICAL PROFILING AND DIFFERENCES BETWEEN LINEMEN, OFFENSIVE BACKFIELD, AND DEFENSIVE BACKFIELD PLAYERS

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²Athletics Department, Santa Monica College, Santa Monica, USA

INTRODUCTION

College athletics in the USA, which is administered by the National Collegiate Athletic Association (NCAA), is a multi-billion dollar industry, with American football being the most dominant sport (12). Division I is the highest level of competition, and there is great competition between schools with the recruitment of athletes to their respective programs. Indeed, it is incumbent on athletic programs, most notably football, to recruit the best athletes possible. High-quality recruits to a football program can have a major impact for a university not only on the field (10), but financially as well (2). Although most collegiate football players will be recruited straight from high school, acquiring junior college transfers is another method by which players can be brought into a program.

Junior college athletes will generally spend two years within a program at this level, before transferring to a four-year institution where they will have academic credit and the opportunity to participate in athletics. As high school football players will often need time to physically mature before they are competitive with experienced collegiate players (6), the same could be expected of junior college players. However, there has been little research of this specific athletic population, and the research that does exist is over 20 years old (4, 5). Furthermore, there has been no direct documentation of the physical or physiological characteristics of junior college football players. dos Remedios and Holland (5) did conduct a survey of 35 junior college football programs, so as to compare the data to the Division I football players profiled by Berg et al. (1). The data indicated that junior college players were generally smaller in stature, weaker in maximum bench press and squat strength tests, and slower in the 36.6-metre (m), or 40-yard, sprint. Nevertheless, it would be of great benefit to collegiate football and strength and conditioning coaches to know the traits of junior college players before they enter higher-level college football competition.

Therefore, this study documented the physical and physiological characteristics of football players from a junior college in Los Angeles that has regularly had players transfer to Division I programs. The players were assessed in tests commonly used for football: 36.6-m sprint; pro-agility shuttle; three-cone drill; vertical jump (VJ) and standing broad jump (SBJ); and the bench press and front squat (6, 7, 11, 13, 14). Additionally, the subjects were split into offensive backfield (OBF; quarterbacks, running backs, wide receivers, and tight ends), defensive backfield (DBF; defensive backs and linebackers), and linemen (LM; offensive and defensive linemen) to compare the physical and physiological traits across the different position groups (11, 14). It was hypothesised that comparisons between the OBF, DBF, and LM groups would be reflective of previous research (6, 11), whereby the OBF and DBF groups would perform better in the performance tests, but the LM would be physically taller and heavier. It was further hypothesised that when compared to data from Division I players, the junior college players would generally be smaller in stature, and perform worse in the performance tests. Establishing a baseline of performance assessments for junior college football players from the USA will provide useful information for college football and strength and conditioning coaches, in that they will be more aware of the characteristics of players who may enter their program from this level of competition.

METHODS

Sixty-two junior college football players (age = 20.11 ± 1.60 years; height = 1.83 ± 0.07 m; mass = 93.66 ± 14.16 kilograms [kg]) from the one school were recruited for this study. By position, there were: two quarterbacks (QB); seven running backs (RB); 13 wide receivers (WR); one tight end (TE); 18 defensive backs (DB); eight linebackers (LB); and 13 linemen (offensive and defensive – LM). Due to the relatively small number of offensive LM tested compared to other positions, as well as the fact that at the junior college level LM will often play offense and defence, all LM were grouped together. Nonetheless, the sample included all members from the squad that were currently participating in full training. As stated, subjects were further split into OBF, DBF, and LM groups for further analysis.

The assessments utilised in this study were those often used for American football players (6, 7, 11, 13, 14), and were conducted as part of their usual pre-season assessment conducted by the team’s coaching staff. Physical stature was measured by height, body mass, and body mass index (BMI; \(\text{height}^{-\frac{1}{3}} \times \text{body mass}^{-\frac{1}{4}}\)). The performance tests included: VJ height and power index, calculated via the Lewis formula: \(\text{Power} = \sqrt{4.9 \times \text{Body Mass} \times \text{vertical jump height}}\); SBJ distance and relative SBJ (11); 36.6-m sprint, which incorporated the 0-4.57 m (0-5 yards), 0-9.14 m (0-10 yards), and 0-36.6 m (0-40 yards) intervals; pro-agility shuttle; three-cone drill; and bench press and front squat strength tests. For the bench press, the WR and DB lifted a load of 84 kg (185 pounds) for as many repetitions as possible. All other positions lifted a load of 102 kg (225 pounds) for as many repetitions as possible. The junior college’s strength and
Means and standard deviations were calculated by positions (QB, RB, WR, TE, LB, DB, and LM), so that the data can be presented as an initial normative profile and compared to existing data from Division I, II, and III collegiate football players. As previously acknowledged, to further investigate positional characteristics, subjects were grouped together as OBF (QB, RB, WR, and TE), DBF (DB and LB), and LM (11, 14). A one-way analysis of variance, with Bonferroni post hoc for multiple comparisons, was used to calculate any differences between the OBF, DBF, and LM groups. Statistical significance was set at $p < 0.05$. All statistical analyses were processed using the Statistics Package for Social Sciences (Version 22.0; IBM Corporation, New York, USA).

RESULTS

Table 1 displays the data for age and stature for the individual positions, and the position groups. The LM were significantly taller than the DBF group ($p = 0.01$), and were heavier and had a greater BMI when compared to both the OBF and DBF groups ($p < 0.01$). Table 2 displays the data for 36.6-m sprint intervals, and the pro-agility shuttle and three-cone drill. When compared to the LM, the OBF and DBF groups were significantly faster in the 0-9.14 m ($p = 0.02$) and 0-36.6 m ($p < 0.01$) intervals, as well as the pro-agility shuttle ($p < 0.01$) and three-cone drill ($p < 0.01$). The jump data is shown in Table 3. Both the OBF and DBF groups had a significantly greater VJ height when compared to the LM ($p < 0.01$). However, the LM generated significantly greater VJ power when compared to the DBF group ($p = 0.02$). The OBF ($p < 0.01$) and DBF ($p = 0.04$) groups had a significantly greater SBJ distance when compared to the LM, and both groups were also superior in the relative SBJ ($p < 0.01$). The strength data is shown in Table 4, and there were no significant differences in strength measured by the bench press or front squat between any of the groups.

### Table 1 - Characteristics (mean ± SD) by position and position groupings (LM, OBF, and DBF) in age, height, mass, and body mass index (BMI).

<table>
<thead>
<tr>
<th></th>
<th>Age (years)</th>
<th>Height (m)</th>
<th>Mass (kg)</th>
<th>BMI (m·[kg]$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QB</td>
<td>19.00 ± 0.00</td>
<td>1.84 ± 0.06</td>
<td>85.05 ± 1.61</td>
<td>25.14 ± 1.07</td>
</tr>
<tr>
<td>RB</td>
<td>20.00 ± 1.41</td>
<td>1.74 ± 0.08</td>
<td>92.15 ± 14.65</td>
<td>30.31 ± 3.82</td>
</tr>
<tr>
<td>WR</td>
<td>20.23 ± 1.17</td>
<td>1.85 ± 0.07</td>
<td>85.80 ± 5.79</td>
<td>24.96 ± 1.37</td>
</tr>
<tr>
<td>TE</td>
<td>19.00 ± 0.00</td>
<td>1.93 ± 0.00</td>
<td>107.96 ± 0.00</td>
<td>28.98 ± 0.00</td>
</tr>
<tr>
<td>DB</td>
<td>20.22 ± 2.18</td>
<td>1.79 ± 0.05</td>
<td>82.81 ± 6.78</td>
<td>25.88 ± 1.62</td>
</tr>
<tr>
<td>LB</td>
<td>20.38 ± 1.3</td>
<td>1.84 ± 0.04</td>
<td>102.68 ± 4.69</td>
<td>30.43 ± 1.51</td>
</tr>
<tr>
<td>LM</td>
<td>20.00 ± 1.58</td>
<td>1.88 ± 0.05</td>
<td>112.04 ± 10.26</td>
<td>31.84 ± 3.06</td>
</tr>
<tr>
<td>OBF</td>
<td>20.00 ± 1.21</td>
<td>1.82 ± 0.09</td>
<td>88.63 ± 10.18</td>
<td>26.78 ± 3.38</td>
</tr>
<tr>
<td>DBF</td>
<td>20.27 ± 1.93</td>
<td>1.80 ± 0.05 *</td>
<td>88.92 ± 11.18</td>
<td>27.28 ± 2.64 *</td>
</tr>
</tbody>
</table>

* Significantly ($p < 0.05$) different from the LM group.

### Table 2 - Characteristics (mean ± SD) by position and position groupings (LM, OBF, and DBF) in 0-4.57 m, 0-9.14 m, 0-36.6 m, pro-agility shuttle, and three-cone drill times.

<table>
<thead>
<tr>
<th></th>
<th>0-4.57 m (s)</th>
<th>0-9.14 m (s)</th>
<th>0-36.6 m (s)</th>
<th>Pro-Agility Shuttle (s)</th>
<th>Three-cone Drill (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QB</td>
<td>1.110 ± 0.056</td>
<td>1.800 ± 0.057</td>
<td>5.105 ± 0.078</td>
<td>-</td>
<td>8.040 ± 0.000</td>
</tr>
<tr>
<td>RB</td>
<td>1.070 ± 0.067</td>
<td>1.734 ± 0.104</td>
<td>4.988 ± 0.412</td>
<td>4.745 ± 0.357</td>
<td>7.566 ± 0.239</td>
</tr>
<tr>
<td>WR</td>
<td>1.012 ± 0.073</td>
<td>1.659 ± 0.081</td>
<td>4.811 ± 0.207</td>
<td>4.469 ± 0.222</td>
<td>7.444 ± 0.351</td>
</tr>
<tr>
<td>TE</td>
<td>1.040 ± 0.000</td>
<td>1.680 ± 0.000</td>
<td>4.840 ± 0.000</td>
<td>4.300 ± 0.000</td>
<td>-</td>
</tr>
<tr>
<td>DB</td>
<td>1.039 ± 0.088</td>
<td>1.703 ± 0.098</td>
<td>4.958 ± 0.160</td>
<td>4.625 ± 0.147</td>
<td>7.658 ± 0.235</td>
</tr>
<tr>
<td>LB</td>
<td>1.000 ± 0.018</td>
<td>1.670 ± 0.058</td>
<td>4.983 ± 0.235</td>
<td>4.492 ± 0.076</td>
<td>7.598 ± 0.196</td>
</tr>
<tr>
<td>LM</td>
<td>1.080 ± 0.064</td>
<td>1.804 ± 0.084</td>
<td>5.402 ± 0.266</td>
<td>4.970 ± 0.272</td>
<td>8.252 ± 0.339</td>
</tr>
<tr>
<td>OBF</td>
<td>1.041 ± 0.073</td>
<td>1.697 ± 0.093 *</td>
<td>4.894 ± 0.274 *</td>
<td>4.531 ± 0.281 *</td>
<td>7.537 ± 0.327 *</td>
</tr>
<tr>
<td>DBF</td>
<td>1.029 ± 0.078</td>
<td>1.694 ± 0.089 *</td>
<td>4.964 ± 0.173 *</td>
<td>4.586 ± 0.142 *</td>
<td>7.639 ± 0.218 *</td>
</tr>
</tbody>
</table>

* Significantly ($p < 0.05$) different from the LM group.
Table 3 - Characteristics (mean ± SD) by position and position groupings (LM, OBF, and DBF) in vertical jump (VJ) height and power, and standing broad jump (SBJ) distance and relative SBJ.

<table>
<thead>
<tr>
<th></th>
<th>VJ height (m)</th>
<th>VJ Power (kg m s⁻¹)</th>
<th>SBJ (m)</th>
<th>Relative SBJ (m·BM⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QB (n = 2)</td>
<td>-</td>
<td>-</td>
<td>2.55 ± 0.06</td>
<td>0.030 ± 0.001</td>
</tr>
<tr>
<td>RB (n = 7)</td>
<td>0.62 ± 0.20</td>
<td>156.20 ± 15.05</td>
<td>2.50 ± 0.41</td>
<td>0.029 ± 0.008</td>
</tr>
<tr>
<td>WR (n = 13)</td>
<td>0.78 ± 0.11</td>
<td>170.32 ± 18.38</td>
<td>2.87 ± 0.20</td>
<td>0.033 ± 0.002</td>
</tr>
<tr>
<td>TE (n = 1)</td>
<td>0.69 ± 0.00</td>
<td>198.19 ± 0.00</td>
<td>2.87 ± 0.00</td>
<td>0.027 ± 0.000</td>
</tr>
<tr>
<td>DB (n = 18)</td>
<td>0.71 ± 0.04</td>
<td>154.16 ± 12.54</td>
<td>2.58 ± 0.15</td>
<td>0.031 ± 0.002</td>
</tr>
<tr>
<td>LB (n = 8)</td>
<td>0.71 ± 0.06</td>
<td>192.13 ± 9.55</td>
<td>2.57 ± 0.20</td>
<td>0.025 ± 0.002</td>
</tr>
<tr>
<td>LM (n = 13)</td>
<td>0.58 ± 0.07</td>
<td>187.17 ± 10.73</td>
<td>2.35 ± 0.28</td>
<td>0.021 ± 0.004</td>
</tr>
<tr>
<td>OBF (n = 23)</td>
<td>0.74 ± 0.15*</td>
<td>168.53 ± 19.29</td>
<td>2.75 ± 0.29*</td>
<td>0.032 ± 0.005*</td>
</tr>
<tr>
<td>DBF (n = 26)</td>
<td>0.71 ± 0.05*</td>
<td>165.55 ± 21.22*</td>
<td>2.57 ± 0.16*</td>
<td>0.029 ± 0.004*</td>
</tr>
</tbody>
</table>

* Significantly (p < 0.05) different from the LM group.

Table 4 - Characteristics (mean ± SD) by position and position groupings (LM, OBF, and DBF) in bench press (BP) and front squat (FS) tonnage, and relative BP and FS.

<table>
<thead>
<tr>
<th></th>
<th>BP Tonnage (kg)</th>
<th>Relative BP (kg·BM⁻¹)</th>
<th>FS Tonnage (kg)</th>
<th>Relative FS (kg·BM⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QB (n = 2)</td>
<td>204.00 ± 0.00</td>
<td>2.37 ± 0.00</td>
<td>408.00 ± 0.00</td>
<td>4.73 ± 0.00</td>
</tr>
<tr>
<td>RB (n = 7)</td>
<td>1085.00 ± 417.65</td>
<td>11.96 ± 5.43</td>
<td>1141.00 ± 609.36</td>
<td>12.90 ± 7.46</td>
</tr>
<tr>
<td>WR (n = 13)</td>
<td>840.00 ± 274.34</td>
<td>9.69 ± 2.70</td>
<td>1221.82 ± 558.92</td>
<td>14.30 ± 6.14</td>
</tr>
<tr>
<td>TE (n = 1)</td>
<td>1224.00 ± 0.00</td>
<td>11.34 ± 0.00</td>
<td>1938.00 ± 0.00</td>
<td>17.95 ± 0.00</td>
</tr>
<tr>
<td>DB (n = 18)</td>
<td>981.75 ± 520.27</td>
<td>11.66 ± 5.68</td>
<td>1209.60 ± 759.83</td>
<td>13.81 ± 7.72</td>
</tr>
<tr>
<td>LB (n = 8)</td>
<td>1351.50 ± 718.67</td>
<td>13.06 ± 6.64</td>
<td>1938.00 ± 792.72</td>
<td>18.57 ± 7.32</td>
</tr>
<tr>
<td>LM (n = 13)</td>
<td>1028.50 ± 582.64</td>
<td>8.99 ± 4.86</td>
<td>994.50 ± 395.98</td>
<td>8.73 ± 3.19</td>
</tr>
<tr>
<td>OBF (n = 23)</td>
<td>898.00 ± 361.72</td>
<td>10.07 ± 3.99</td>
<td>1191.16 ± 58581</td>
<td>13.55 ± 6.50</td>
</tr>
<tr>
<td>DBF (n = 26)</td>
<td>1105.00 ± 604.51</td>
<td>12.12 ± 5.91</td>
<td>1482.75 ± 829.77</td>
<td>15.59 ± 7.70</td>
</tr>
</tbody>
</table>

DISCUSSION

This is the first study to provide a detailed profile of junior college American football players. Previous research has detailed the characteristics of Division I (1, 7, 13), II (7), and III (14) football players, such that the results from this study can be contextualised. Regarding the performance tests used in this study, it was hypothesised that OBF and DBF players would perform better when compared to LM. Generally, this hypothesis was confirmed. It was also hypothesised that higher-level players from Division I school would be physically bigger, and perform better in the football-specific tests. As will be discussed, to an extent this was confirmed as well.

As was expected, the LM were heavier than both the OBF and DF groups, and taller than the DBF group (Table 1). This also led to a greater BMI for the LM. The nature of the position for LM dictates the need for greater body size. Interestingly, across the different positions, the junior college football players from this study tended to be larger in stature than Division III players that were investigated by Stuempfle et al. (14). Most positions were also comparable in height to Division I players, and the WR, TE, DB, and LB were similar in body mass compared to this population (7, 13). However, there were differences in body mass for certain positions. The two QB from this study were almost 10 kg lighter than the QB from Secora et al. (13), while the RB were approximately 5 kg lighter than those from Garstecki et al. (7). The LM from this study were between 10-20 kg lighter than Division I LM (7, 13). Junior college football players from these positions should be aware of the need to increase body mass when progressing to the next level of play.

Both the OBF and DBF groups were faster than the LM in the 0-9.14 m and 0-36.6 m sprint times, as well as the pro-agility shuttle and three-cone drill (Table 2). Interestingly, there were no significant differences in the 0-4.57 m sprint interval, which could relate to the high-intensity, acceleration demands placed upon all American football positions due to the structure of the sport. When compared to Division III football players, the junior college players from this study were faster over the 36.6-m sprint and pro-agility shuttle (14). However, across all positions, the junior college players were slower in the 36.6-m sprint time when compared to Division I and II players (7). To progress to the next level of collegiate play, junior college football players must focus on improving maximal running speed.

The OBF and DBF groups performed better than the LM in the VJ, SBJ, and relative SBJ (Table 3). However, the LM, possibly due to their greater body mass, generated higher VJ power. The football players from this study were comparable in the VJ when compared to Division II players (7), and superior when compared to Division III players (14). However, as for the speed tests, Division I football players (7) were superior across all positions in the VJ when compared to the junior college players from this research. Thus, junior college football players should also target lower-body power development when attempting to progress to Division I competition.
Strength is measured via different methods in American football players, sometimes with one repetition-maximum (1RM) tests (7, 13), or maximal repetition assessments (3), such as that from the current study. As a result, it is difficult to contextualise the strength data from this study with previous research. Nevertheless, when using methods to normalise the strength assessment across different positions using tonnage and relative strength, no significant differences were established between the position groups (Table 4). To provide more detailed information, future research should assess the 1RM of junior college football players in strength tests common to football (e.g. bench press, front and back squat, power clean), to further profile the traits of these athletes.

PRACTICAL APPLICATIONS

The data from this study can be used for normative profiling, for coaches at the high school, junior college, and NCAA levels. Furthermore, the results indicated that junior college football players demonstrate relatively similar traits that have been shown by high school-aged (6, 11) and collegiate (7, 13, 14) players when comparing between position groups (i.e. OB and DBF players tend to be faster and physically smaller when compared to LM). More importantly, the study data highlighted areas for improvement in junior college football players who wish to progress to Division I competition. Certain positions (e.g. QB, RB, and LM) should target increased body mass. All players should improve maximal running speed, in addition to lower-body power. Finally, future research should measure 1RM strength in junior college football players so that more specific recommendations can be provided with regards to maximal strength.

REFERENCES

PROGESTERONE AND ESTRADIOL LEVELS ARE PREDICTORS OF PLANNED AGILITY, 10M AND 20M SPRINT PERFORMANCE IN YOUNG MALE AUSTRALIAN FOOTBALL ATHLETES

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INTRODUCTION

Steroid hormones are important regulators of physiological processes (20). They are classified according to their physiological functionality, such as androgens, glucocorticoids, estrogens and progestins (20). Testosterone is an androgenic steroid hormone secreted in humans (23). It stimulates the development of male secondary sex characteristics (e.g. deepening of the voice, hair growth and genital growth during puberty) (20), and the production of skeletal muscle (14) and red blood cells (1). Cortisol is a glucocorticoid primarily involved in gluconeogenesis, reducing glucose utilization and raising blood glucose concentrations (16). It is also actively involved in the formation of adrenaline (29), protein degradation (23) and immune function (13). Estradiol is a naturally secreted estrogen primarily responsible for the stimulation of the primary and secondary female sex characteristics (e.g. breast development, hair growth and menstrual cycle regulation) (20). It is also involved in the maintenance of bone health (10) and can increase mitochondrial efficiency and reduce oxidative stress in cerebral blood vessels (27). Progestins are essential for reproduction (20), and progesterone, the primary progestin, is a precursor for the production of other steroid hormones, including testosterone, cortisol and estradiol (20). Progesterone also stimulates neuroprotection, axonal regeneration, and myelin formation and repair (25) and has known antiestrogenic actions (15). Whilst the steroid hormones are primarily responsible for different physiological processes they also interact permissively (24), synergistically (22) and antagonistically (17).

Steroid hormones are not secreted continuously, but in pulses subject to biological rhythms (19), such as diurnal (twice daily) and circadian (approximately every 24h) rhythms (18). In addition to biological rhythms, steroid hormone levels can be acutely influenced by stress (9), sleep (19), diet (4), medications (8), and exercise (11). Given the importance of steroid hormones to physiological processes (20), variations in steroid hormone levels have the potential to affect the components of physical performance, such as agility, speed, power and endurance. In males, an increase in the testosterone/cortisol ratio is positively associated with greater performance in power and strength (7) tests. Higher testosterone levels have been associated with improved speed, power and strength and higher cortisol levels have been associated with reduced speed and power though current evidence is inconsistent (6, 7). This research was univariate in nature evaluating the pairwise relationships of hormone effects on motor fitness and not evaluating the multiple and interacting effects. The next logical development is to evaluate these influences via multiple linear regression analysis.

The aim of this study is to evaluate the capacity of testosterone, cortisol, progesterone and estradiol levels to predict countermovement jump (CMJ), agility, 5m, 10m and 20m sprint and multi stage fitness test (MSFT) performance in young male Australian Football (AF) athletes. The aim is to improve understanding of the influence that steroid hormones have on physical performance in male AF athletes, both at the level of individual hormones and in combination with each other. Due to the complex relationship between steroid hormones, it is hypothesised that a combination of testosterone, cortisol, estradiol and progesterone will be a stronger predictor of physical performance than any of the hormones predicting physical performance in isolation.

METHODS

Fifty eight (n=58) young male AF athletes were recruited to participate in this study (mean ± standard deviation; age 17.1 ± 0.7 years, height 184.8 ± 6.1 cm, body mass 77.4 ± 6.0 kg, sum of 7 skinfolds 46.5 ± 9.7 mm). All participants were members of the Australian Football League (AFL) Tasmania State Academy and were free from illness or injury at the time of testing. Institutional ethics approval was provided by the Charles Darwin University Human Research Ethics Committee (Approval Number: H12155) and the participants or parents/guardians when the participants were under 18 years of age, provided written informed consent.
RESULTS

Results of the linear regression analysis between the hormonal and physical performance parameters is detailed in table 1. Linear regression models demonstrated that progesterone levels (multiple R = 0.32, multiple $R^2=0.10$, $p = 0.01$) and estradiol levels (multiple $R = 0.41$, multiple $R^2 = 0.15$, $p = 0.001$) were positive and negative predictors of planned agility performance respectively. Cubic regression models demonstrated that estradiol levels accounted for 19.4% of the variance in planned agility performance (multiple $R=0.44$, $p = 0.006$). Stepwise regression models demonstrated that together estradiol and progesterone levels determined a significant 30.9% (multiple $R = 0.56$, $p = 0.00002$, $f^2=0.45$) of the variance in planned agility performance.

Linear regression models demonstrated that progesterone levels was a positive predictors of both 10m (multiple $R = 0.37$, multiple $R^2=0.14$, $p = 0.003$) and 20m sprint speed (multiple $R =0.41$, multiple $R^2 = 0.17$, $p = 0.001$). The application of non-linear regression/curve estimation to assess relationship was non-linear in nature indicated a cubic regression solution where progesterone levels accounted for a significant 18.4% and 23.2% of the variance in 10m (multiple $R=0.43$, $p = 0.01$) and 20m sprint speed (multiple $R=0.48$, $p = 0.001$) respectively. Stepwise regression models demonstrated that together progesterone and estradiol levels determined 19.1% (multiple $R = 0.44$, $p = 0.002$, $f^2=0.24$) and 20.2% (multiple $R = 0.45$, $p = 0.001$, $f^2=0.25$) of the variance in 20m sprint performance respectively.

Best fit solutions for motor fitness test with cortisol and testosterone indicated a cubic regression model where cortisol levels accounted for a moderate 15.9% of the variance in CMJ performance (multiple $R = 0.40$, $P = 0.02$). A Logarithmic regression model indicated testosterone levels accounted for a low 6.3% of the variance in VJL performance (multiple $R = 0.25$, $p = 0.05$).

The following significant regression equations were derived reflecting the relationship between specific motor fitness variables and progesterone and estradiol concentrations:

- 10m Sprint ($s$) = $2.042 - 0.127 \times (\log_{10}\text{progesterone}) + 0.161 \times (\log_{10}\text{estradiol})$
- 20m Sprint ($s$) = $3.414 - 0.181 \times (\log_{10}\text{progesterone}) + 0.198 \times (\log_{10}\text{estradiol})$
- Planned Agility ($s$) = $8.846 + 0.741 \times (\log_{10}\text{estradiol}) - 0.392 \times (\log_{10}\text{progesterone})$

No significant predictors were evident for performance in the VJR, 5m sprint, and MSFT performance tests.
This study is novel in its investigation of possible hormonal predictors of physical performance using both univariate and multivariate approaches in male AF athletes. The research hypothesis was supported, as individual hormones were slightly less predictive of physical performance than hormones in combination as evident by slightly higher R values for multiple linear regression. Findings that progesterone and estradiol are stronger predictors of performance in tests of agility and speed than testosterone and cortisol in male AF athletes is novel, as estradiol and progesterone are largely thought of as ‘female hormones’ and as such are rarely considered in research involving male athletes. This cross-sectional study provides the basis for further research into how estradiol and progesterone levels affect the physical performance of male athletes.

The regression models indicate that higher salivary progesterone levels and lower salivary estradiol levels in the athletes, resulted in faster 10m and 20m sprint and planned agility times. This finding suggests that higher levels of progesterone along with lower levels of estradiol may be beneficial to speed and agility. It is unclear as to why the effects of progesterone and estradiol on speed and agility are stronger when combined than in isolation. It is possible that it may be due to the antagonistic effects of progesterone on estradiol at a receptor level, as liganded progesterone receptors can suppress estradiol-stimulated estrogen receptor activity (15). The mechanisms in which progesterone and estradiol may affect speed and agility are also not clear. A possible model is that progesterone promotes the formation and reparation of myelin (25) a coating which surrounds the axons of neurons that increases nerve impulse propagation and is positively associated with movement speed (2). We speculate then that progesterone’s effects on myelin may promote increased movement speed, resulting in faster 10m and 20m sprint and planned agility times. The significant positive predictive ability of progesterone on some motor fitness constructs above that of testosterone, which was minimal, is paradoxical and suggests recommendations for further research. This research should focus on increasing sample sizes and replicating the study with other sport populations to evaluate the generalisation of these findings.

Some possible research limitations should be considered. The cross-sectional design restricts the results of this study to the population of athletes tested and results may not be indicative of the general population or athletes from other sports. The hormonal data was collected immediately prior to the warm-up, and may not reflect hormone levels during test performance, though our methodology is similar to previous studies of this nature (21). Hormone levels are not the only factors to consider when attempting to predict agility and speed performance. Previous research on soccer players using regression analysis has identified that maximal strength measures can predict 68-74% of 10m sprint performance (28), 41.6% of 20m sprint performance and 51% of 505 agility performance (28). Whilst these percentages are greater than the 19.1%, 20.2% and 30.9% of 10m sprint, 20m sprint and agility performance respectively predicted in the current study it does not lessen the importance of considering athlete hormone levels when attempting to maximise athlete speed and agility performance.

**PRACTICAL APPLICATIONS**

Based on the results of this study the progesterone and estradiol levels of young AF athletes may assist in predicting 10m and 20m sprint and planned agility performance. In concert with strength training and conditioning work, coaches and their young male athletes may consider including appropriate strategies that optimise progesterone levels by non-prohibited/accepted methods when speed and agility performance are important to their sport.
REFERENCES


Isometric strength influence on a change of direction task with pre, mid and post-adolescent performers.

ISOMETRIC STRENGTH INFLUENCE ON A CHANGE OF DIRECTION TASK WITH PRE, MID AND POST-ADOLESCENT PERFORMERS

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INTRODUCTION

The ability to change direction rapidly is crucial to successful performance in multiple sports. This ability to change direction, in a pre-planned course, can be grossly separated into the change of direction (COD) phase and the travelling phase where the athlete will cover ground to achieve their desired position (7). The speed of the player between COD movements may be assisted by the COD itself but it has been shown that COD performance alone is not strongly linked to straight line sprint velocity therefore the two variables are considered separate qualities (10). Therefore with this study being a COD assessment, it is deemed important to separate the turn from travelling phase.

There is reasonable evidence as to what physical qualities relate to COD performance in adult populations. Dynamic jumping performance, isokinetic and isometric leg extensor strength values and reactive strength parameters have all been shown to relate to COD performance (7, 8, 9). However, these relationships have not been extensively reviewed within youth populations and it is known that as young performers mature they experience significant changes with their physical traits creating difficulties in both sensory motor control and application of force (2, 3, 5). Given the anthropometric and physiological changes within this population it is of interest to understand how these physical changes can affect the relationship between COD performance and isometric squat strength.

METHODS

Experimental Approach to the Problem

This research aimed to investigate how strength assists in a completion of a 180 degree COD task. Performance data across the separate maturational groups were analysed to understand how the COD task variables interact with bilateral and isometric strength both within and between maturational groups. Further to this, the increasing distance of the COD task will be investigated to see how strength and maturational status effects the overall COD performance and whether course length has any bearing on the relationships found.

Subjects

Twenty sports academy participants from squash, table tennis and multi-sport volunteered for this study (table 1). All participants are currently involved in COD based activities and their sport training reflects multiple and varied COD actions. The participants all had training exposure of between 5-8 sessions a week undertaken by professional sports coaches. The participants were separated into maturational groups as per the method shown by Mirwald, Baxter-Jones, Bailey and Beunen (2002) and assigned to groups based on their peak height velocity (PHV). Subjects were grouped as follows; at least 1 year before PHV (pre-adolescent), those between 1 year pre-adolescence and 1 year post-adolescence (mid-adolescent) and those in excess of 1 year post PHV (post-adolescent). All participants were required to be injury free before and during testing. This study conformed to the recommendations of the Declaration of Helsinki and was approved by the local and external review boards.

Table 1 - Physiological characteristics of subjects.

<table>
<thead>
<tr>
<th>Maturational Group</th>
<th>Group count</th>
<th>Age ± Years</th>
<th>Height M</th>
<th>Mass Kg</th>
<th>PHV Years ±</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-adolescent</td>
<td>9</td>
<td>12.5 ± 0.5</td>
<td>1.49 ± 0.08</td>
<td>41.2 ± 4.5</td>
<td>-1.59 ± 0.51</td>
</tr>
<tr>
<td>Mid-adolescent</td>
<td>6</td>
<td>14.1 ± 0.9</td>
<td>1.62 ± 3.2</td>
<td>54.8 ± 9.2</td>
<td>-0.1 ± 0.39</td>
</tr>
<tr>
<td>Post-adolescent</td>
<td>5</td>
<td>17.5 ± 2.1</td>
<td>1.76 ± 6.9</td>
<td>70.7 ± 7.7</td>
<td>4.47 ± 3.37</td>
</tr>
</tbody>
</table>

Procedures

Bilateral and Unilateral Isometric Strength Assessment

Maximal force production was ascertained using bilateral and unilateral isometric squat testing on a force plate (400 series performance plate; Fitness Technology, Adelaide, Australia) sampling at 500 Hz. This test has been shown to be reliable for multiple assessments with an ICC of 0.97 and TEM 68.7 N (1). A standard warm-up was completed followed by 2 isometric squat warm-up trials at 50% and 80% self-rated efforts. In bilateral testing subjects were required to take a shoulder width stance with feet flat and a knee angle of 140°. In the following unilateral test, the free leg was flexed at 90° and kept off the force plate. Subject were asked to exert a maximal downward force for a period of 4 seconds with
2 minutes rest between each leg for three trials each side. The highest peak force value expressed relative to bodyweight (N.kg⁻¹) from the isometric squat assessment was recorded.

**Change of Direction Task**

![Figure 1 – Layout of the COD course and force plate positioning.](image)

The course was laid out as per figure 1. The start line for each trial was set 30 cm back from the timing gates to control for false starts and momentum issues on the start. Dual-beam false-signal processing timing gates (Smartspeed, Fusion Sports, Grabba Systems, Australia) were set up on the 2.0, 5.0 and 10.0 m lines. Participants were asked to complete three 180° COD efforts changing direction off both legs with a 1 minute rest between trials. The total time for course completion and the time from 2 m prior to, and 2 m post the turn (4 meter turn-around time), were considered the key metrics of a successful COD effort within analysis. The point of direction change was directly on top of a floor level recessed triaxial force plate, dimension of 600 x 900 mm sampling at 500 Hz (Kistler type 9281CA, Winterthur, Switzerland). All kinetic data collection was managed through Bioware software (version 5.2.1.3) and custom designed spreadsheets (Microsoft Excel, 2013). The best trial from each distance was analysed.

**Statistical Analysis**

A factorial analysis of variance (ANOVA) and Pearson product-moment correlation analysis was used to establish relationships and effects on the dependant variable within the study design. All ANOVA tests had a level of significance set at p = 0.05 with greater significances shown where appropriate and positive or negative correlations were described as per Hopkins and Batterham (2009). Standard error of measurement (SEM), intra-class correlation coefficient (ICC) (Weir, 2005) and coefficient of variation (CV) was used to determine the reliability of the isometric task. All data was managed by IBM SPSS statistic package (version 20.0; IBM Corporation, New York, USA).

**RESULTS**

A Shapiro-Wilk test (P > .05) (6) showed that the isometric strength data did not violate the assumptions of normal distribution. The test-retest reliability was performed on the double leg (DL) and single leg (SL) isometric squat assessment with good outcomes (ICC = 0.99 (DL), and 0.98 (SL)), SEM = 67.7 N (DL), and 74.5 N (SL), CV = 4.7% (DL) and 4.9% (SL). The correlation between bilateral and unilateral isometric squat assessment was very strong and significant (r = -0.956, p > 0.001).

When comparing the isometric squat test results across all groups there was a significant difference in double and single leg absolute strength levels (F(3, 25) = 21.96, p = 0.002). Analysis of all data showed the bilateral relative measure was different between pre and post-adolescent groups (F(2, 17) = 3.61, p = 0.049) but not between pre and mid adolescent groups. Single leg relative strength scores were also significantly different across all maturational groups (F(2, 17) = 10.51, p = 0.001). See table 2 for values.

When analysing the COD task for differences across all maturational groups it was found that there was no significant difference between the shortest 4 m COD task. The 10 m change of direction assessment (5m start line) was significantly different between groups on the right leg turn (F(2, 17) = 4.44, p = 0.028) but not the left leg turn. The 20m COD (10m start line) was significantly different between the groups on both left and right leg turns (F(2, 17) = 9.06, p = 0.02). Post-hoc analysis showed the following significant differences; mid and post-adolescent group on the right leg 10 m course (p = 0.033), pre and post group on the left leg 20 m course (p = 0.021), pre and post group on the right leg 20 m (p = 0.02), mid and post group on the right leg 20 m course (p = 0.008).
Table 2 - Mean (± SD) values from all isometric and COD assessments for the maturational groups.

<table>
<thead>
<tr>
<th></th>
<th>Pre-adolescent</th>
<th>Mid-adolescent</th>
<th>Post-adolescent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bilateral Isometric relative force N/Kg</td>
<td>3.95 (0.33)**</td>
<td>4.06 (0.35)</td>
<td>4.8 (0.89)</td>
</tr>
<tr>
<td>Left Leg Isometric relative force N/Kg</td>
<td>2.67 (0.57)**</td>
<td>3.06 (0.61)**</td>
<td>3.83 (0.45)**</td>
</tr>
<tr>
<td>Right Leg Isometric relative force N/Kg</td>
<td>2.75 (0.54)*</td>
<td>2.97 (0.49)*</td>
<td>4.16 (0.55)</td>
</tr>
</tbody>
</table>

Figure presented as mean value (± SD)
** - significant to the p = <0.01 level
* - significant to the p = <0.05 level

Bilateral isometric squat relative scores were significantly correlated to COD time in all distances off both leg turns (p = 0.026) with the exception of 4 m left leg turn. Unilateral isometric squat relative scores were only related to performance in the 20 m COD task off both legs. The following relationships in the 20 m COD task were found; left leg turn and left leg strength measure over 20 m course (r = -0.468, p = 0.037), right leg turn and right leg strength measure over 20 m course (r = -0.556, p = 0.011). Further analysis of the bilateral isometric strength measures also showed significant relationship with 4mTAT in the left and right turn on the 10 m course (r = -0.52, p = 0.019; r = -0.531, p = 0.016 respectively) and for right leg on the 20m course. Analysis within each maturational group did not show relationships between strength and COD performance over any distance and therefore the within group, strength mediated, performance change was not seen.

Complete data set analysis revealed significant correlation coefficients when analysing total time to complete the COD course compared to the 4mTAT sector within each distance. This analysis gives bearing as to how important the actual COD segment of the task was to the overall performance. There were significant results found in the left leg 4mTAT within distances of 10 m (r = 0.829, p = 0.001), 10 m right side turn (r = 0.572, p = 0.008), 20 m left side turn (r = 0.582, p = 0.007) and 20 m right side turn (r = 0.661, p = 0.002). When analysis was conducted within the maturational group further significant relationships were found between the 4mTAT with the post-adolescent group on the 20 m distance (p = 0.02). This relationship was not replicated with the mid and pre-adolescent groups. In all distances, the 4mTAT was faster with the post-adolescent participants although significance was only reached in the 20 m performances. Finally, PHV was increasingly correlated with performance in the COD task over greater distances. Shorter distances resulted in weaker correlations as shown in figure 2 below.

Figure 2 - Correlational results for isometric squat and PHV variables against total course performance.

No significant relationship was found between any of the force plate variables and either the change of direction or isometric squat performance. The mean values (± SD) relative to body mass found for the vertical braking and drive phases within the COD action are as follows: 10 m COD course vertical braking force 2.15 ± 0.39, drive phase 1.84 ± 0.48. Horizontal braking and drive phase results on the 10 m course were; horizontal braking force 1.82 ± 0.48, and horizontal drive forces 1.25 ± 0.36. Additionally there were no relationships found between contact time on the turn foot and strength or COD performance.
DISCUSSION

The aim of the study was to ascertain if there were any relationships or differences between maturational groups completing an isometric strength and COD assessment. The main results of the study were that bilateral and unilateral isometric relative squat strength did relate to total course and 4mTAT performance on the 10 m and 20 m distances. The results show that shorter range COD tests did not prove useful in allowing expression of strength within this study and it would seem that assessing the acute COD performance is better done within a longer course and not singled out in isolation. This is likely to be for technical reasons and a short time duration of the test.

Analysis revealed that the strength of correlation between COD performance and the strength measure (both unilateral and bilateral) increased as the distance of the course increased. It is reasonable to assume that the correlation between strength and COD performance would hold equally strong regardless of age but there was a progressive correlation as age increased. Potentially older performers may have developed multiple skills and attributes that allow for better performance in the longer COD course. Having the time to express COD skills regardless of strength levels can feasibly lead to improved performance since technique is important within a COD task (11).

It may still be appropriate to assess ground contact data from the plant foot on the COD action however in this study the data could not be used to find relationships to either isometric squat performance or COD performance. Of interest is work completed by Graham-Smith, Atkinson, Barlow & Jones, (2009) which showed that importance of the penultimate step into a 180° COD which suggests that a successful COD starts before the turn contact. Potentially the differences in the actual plant foot kinetics are not discriminatory between stronger and weaker individuals and maybe the understanding of a COD should be extended back to include the steps prior to final foot placement.

PRACTICAL APPLICATIONS

This study shows the positive relationship between a strength quality and COD performance which is aligned with other research conducted in the area. Training 12-19 year old performers to exert high force would appear to be a useful pathway and one that allows for improved COD performance in addition to the other benefits of increased relative strength within their sporting actions. It is recommended that coaches train younger participants to exert high levels of lower body force, with appropriate tuition and guidance, if the aim is improve COD based performance. The subject population of youth performers have provided useful reference data in isometric squat assessment and COD test from various approach distances.

REFERENCES

The relationship between measures of aerobic and anaerobic performance with physical performance across a team sport match play simulation.

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THE RELATIONSHIP BETWEEN MEASURES OF AEROBIC AND ANAEROBIC PERFORMANCE WITH PHYSICAL PERFORMANCE ACROSS A TEAM SPORT MATCH PLAY SIMULATION

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INTRODUCTION

The use of laboratory-based team sport match simulations have become commonplace in the field of research to investigate various aspects of performance or ergogenic interventions (1, 5). This is due to their ability to replicate the physical demands of match play, in addition to being able to accurately manipulate various external variables such as environmental conditions. Past research has demonstrated that such simulated treadmill protocols demonstrate strong reliability (CV: <4.6%) and reflect physical and physiological changes typical of match play (CV: <5%) (1). Thus, such protocols allow for a high level of reproducibility and for the magnitude of specific interventions to be investigated.

However, a limitation of match simulation protocols is that they determine work intensities for set locomotor categories from an individual’s peak sprint speed (PSS). However, this is in opposition to existing literature that typically reports locomotor categories through absolute running speeds (low intensity activity [LIA]; <14.4 km h⁻¹; high-intensity activity [HIA]; >14.4 km h⁻¹; very high-intensity activity [VHIA]; >20 km h⁻¹). Furthermore, researchers have demonstrated that the total distance covered during soccer match play shares a stronger relationship to an individual’s maximal aerobic capacity (VO₂max) [r=0.77-0.87, (3)] than their peak sprint speed [r=-0.69, (7)]. To date, no significant correlations have been reported between an individual’s PSS and VO₂max (2). Hence, we suggest that a methodological limitation of laboratory-based match simulations is that they are prescribed based on an individual’s maximal anaerobic power, despite it being well established that team-sport match play is largely reliant on aerobic metabolism (6). Potentially, this may result in a team-sport athlete who is anaerobically superior, but aerobically poor being prescribed a match protocol that is in excess of their typical match constraints. Hence, the aim of this study was to identify the relationship between VO₂max and PSS on changes in physical performance across a laboratory-based team sport match simulation.

METHODS

Ten male soccer players (age: 23.3 ± 3.1 yr; height 180.5 ± 5.9 cm; body mass 74.9 ± 7.7 kg) were recruited from local soccer teams to participate in this study. Participants were required to have played in the highest level amateur soccer competition in their respective region as an outfield player for the past 3 years. Participants were required to attend the laboratory on two separate occasions that were separated by one week. Each participant was to abstain from vigorous exercise for 48 hours prior to testing, as well as avoiding caffeine and alcohol for 24 hours prior to testing. Each participant was instructed to follow their usual match day food and drink intake the day of testing prior to each session.

Familiarisation Testing

Initially, participants were required to attend a familiarisation session in order to obtain relative data that consisted of body composition, PSS and VO₂max. Upon arrival at the laboratory, each participant underwent a full anthropometric assessment that consisted of height, weight and sum of 7 skinfolds. Participants then completed a five minute warm up on a Curve 3™ Non-Motorised Treadmill (NMT) (Woodway, Waukesha, WI, USA) that was followed by five minutes of dynamic stretching. Participants then completed a PSS assessment that consisted of 3 x 3 and 3 x 6 second sprints interspersed with periods of walking and jogging (3 min recovery between sprints). Treadmill data was collected using Pacer Performance software (XPV7, Fitness Technologies, Adelaide, Australia) with PSS defined as the highest velocity achieved for a duration of one second.

Upon the conclusion of the PSS assessment, participants were provided a 10-minute recovery period during which water was given ad libitum. Participants were then required to complete a VO₂max test on the NMT, with all expired gases analysed using Parvo Medics TrueOne® 2400 metabolic measurement system (Parvo Medics, UT, USA). The test protocol was a ramp test that consisted of 1-minute stages beginning at 7 km h⁻¹, which increased by 1 km h⁻¹ until either VO₂max was observed or the participant reached volitional exhaustion. Each participant’s velocity at VO₂max (vVO₂max) was recorded as the velocity at which VO₂max was observed. The final component of the familiarisation session involved 30 minutes of the laboratory team sport protocol that was used in the primary testing session (see Figure 1 below).
Primary Testing
Participants attended the laboratory and undertook a 15-minute standardised warm-up on the NMT, which was followed by a 5-minute period of passive sitting in order to simulate match-day preparations. During this 20-minute period, participants were provided with 7.5 g·kg⁻¹ tepid sports drink to ingest in order to standardise fluid and carbohydrate levels. Following this, each participant underwent a 90-minute laboratory-based team sport match simulation, as per a previously reported protocol (1). The protocol was separated into 2 x 45 min halves with a 15 min half time interval. Each 45-min half comprised of three repeated 15-min periods as shown below in Figure 2.

The locomotor categories were defined as a percentage of the maximal speed attained during the PSS assessment. Locomotor categories were made relative to each individual’s PSS and the relative frequency of each category matching that reported throughout actual match-play. The simulation consisted of standing (0% PSS; 16 % time), walking (20% PSS; 34% time), jogging (35% PSS; 23% time), running (45% PSS; 12% time), fast running (65% PSS; 4% time) and sprinting (100% PSS; 4% time). Between the 14th and 15th minute of each 15-minute block, a non-prescribed period of 1-minute was provided where each participant was instructed to run as fast and uniformly as possible for the entire 1 – minute period. The average running speed across each minute was taken as a performance measure of maximal aerobic speed (MAS).

![Figure 1 - The 45-minute Team Sport Protocol for a subject with a maximal sprinting speed of 30 km·h⁻¹](image)

Data Analysis
All treadmill running data was recorded using Pacer Performance software (XPV7, Fitness Technologies, Adelaide, Australia). From this, the total distance (TD) covered across each half as well as the entire simulation was determined as was the distance covered in low-intensity running (LIR; <14.4km·h⁻¹) and high-intensity running (HIR; >14.4km·h⁻¹). Given that each locomotor category was prescribed from each individual PSS, the total distance covered was made relative to the prescribed distance (PD) as a measure of performance. Furthermore, heart rate was averaged across each 15 minute block and expired gases were averaged across each MAS period.

Statistical Analysis
The statistical significance of any differences in the total, LIR and HIR distances covered between the first and second halves were determined using paired sample t-tests. Differences in the MAS distance and physiological measures for each 15-min block were determined using a one-way Repeated Measures ANOVA. If main effects were identified, LSD post-hoc analysis was undertaken in order to determine where the significant differences occurred, with the significance value set at p<0.05. Correlations between VO₂max, PSS and MAS and all treadmill data were determined using Pearson’s Correlation Coefficient. The strength of each correlation was defined as per Hopkins (4). Significance was set at p<0.05 and all statistical analyses were performed using SPSS (Version 21; IBM, Armonk, NY, USA).

RESULTS
The team sport athlete cohort presented with descriptive statistics of VO₂max: 55.3 ± 3.7 ml·kg⁻¹·min⁻¹; PSS: 28 ± 1.5 km·h⁻¹ and vVO₂max: 15.0 ± 0.8 km·h⁻¹. Significant differences were observed between each 15-minute block during the team sport simulation for the relative PD covered (p=0.01), TD covered (p=0.01) and HIR distance covered (p=0.020) (Table 1). Contrary to these findings, no significant differences were observed in either the MAS distance (p=0.216) or LIR distance covered (p=0.579) across the 15-min blocks. In addition to this, there was no significant difference in the measures of match fatigue (last 15 min block – first 15 min block) for any measures between the two halves (Table 2). Large correlations existed between VO₂max and changes in both TD and PD across both halves (r= -0.506- -0.725) and simulation (r= -0.544- -0.690). Similarly, vVO₂max showed large to very large correlations with HIR distance (r= 0.642 - 0.799), TD (r= 0.587 - 0.827) and PD (r= 0.566 - 0.711) covered across each 15-minute period, with large to very large correlations being found in blocks 1, 2, 5 and 6 for the MAS distances covered (r=0.545-0.803). Further to this, moderate to large correlations were observed between PSS and PD in the first half (r= 0.609) and total match (r= 0.498). Similar moderate to large correlations were observed for HIR distance covered in both the first half (r= 0.424), second half (r= 0.495) and total match (r= 0.607), with large to very large correlations being observed across each 15-minute block (r=...
0.626 - 0.824). Additionally, PSS showed large negative correlations with LIR distance covered across the total simulation \( (r = -0.567) \) as well as across blocks 1-5 \( (r = -0.508\text{--}0.641) \), with further moderate to very large correlations for TD covered in the first half \( (r = 0.587) \), across the entire simulation \( (r = 0.530) \) and for blocks 1, 2, 4, 5 and 6 \( (r = 0.482 \text{--} 0.765) \).

Table 1 - Summary of distances covered during each 15-minute block of the team sport simulation.

<table>
<thead>
<tr>
<th>Locomotor Category</th>
<th>Time Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-15</td>
</tr>
<tr>
<td>Low Intensity Running (m)</td>
<td>1463 ± 137</td>
</tr>
<tr>
<td>High Intensity Running (m)</td>
<td>736 ± 235</td>
</tr>
<tr>
<td>MAS Distance (m)</td>
<td>258 ± 27</td>
</tr>
<tr>
<td>Total Distance (m)</td>
<td>2199 ± 150</td>
</tr>
<tr>
<td>Prescribed Distance (%)</td>
<td>102.1 ± 9.9</td>
</tr>
</tbody>
</table>

\(^a\)significantly different to 0-15 min; \(^b\)significantly different to 15-30 min; \(^c\)significantly different to 30-45 min; \(^d\)significantly different to 45-60 min; \(^e\)significantly different to 60-75 min

Table 2 - Match fatigue indexes for distances covered during team sport simulation (%).

<table>
<thead>
<tr>
<th>Locomotor Category</th>
<th>Time Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st Half</td>
</tr>
<tr>
<td>Low Intensity Activity (m)</td>
<td>-2.48 ± 4.15</td>
</tr>
<tr>
<td>High Intensity Activity (m)</td>
<td>-8.59 ± 17.87</td>
</tr>
<tr>
<td>MAS Distance (m)</td>
<td>-2.03 ± 9.47</td>
</tr>
<tr>
<td>Total Distance (m)</td>
<td>-5.49 ± 4.71</td>
</tr>
<tr>
<td>Prescribed Distance (%)</td>
<td>-5.87 ± 4.70</td>
</tr>
</tbody>
</table>

**DISCUSSION**

This study is the first to assess the relationship between measures of aerobic and anaerobic performance on changes in physical performance across a 90-minute laboratory based team sport protocol. There is currently limited research on the most effective way in order to prescribe training protocols for team sports. Interestingly it was observed that the most commonly used method of exercise prescription for team sport simulations (i.e. based off an individual’s PSS) did not correlate strongest with measures of physical performance across a laboratory match-simulation.

The large negative correlations observed between VO\(_{2}\)max with PD and TD covered suggest that the higher an individual’s VO\(_{2}\)max, the less fatigued that they become throughout the simulation, which allowed them to cover increased distances during exercise. Further, correlations between PSS and both HIR and LIR distances covered indicated that the greater an individual’s PSS, the greater the amount of HIR distance covered and the lower the LIR distances covered during the simulation, as would be expected due to the nature of the prescribed exercise. The large to very large correlations observed between an individual’s VO\(_{2}\)max and HIR, TD, PD and MAS distances covered suggests that the previously used model of exercise prescription from PSS during team sport simulations may be inadequate for athletes who are anaerobically superior.

Individuals covered the greatest amount of distance in relation to PD during the first 15-minute block followed by steady declines across the half. There were similar findings across the second half, before a slight increase in distance covered in the last 15-minute block, which would suggest the use of pacing strategies across the duration of the simulation. Similar observations were also made in reference in the HIR distance covered. This increase in both TD and HIR distance covered in the final 15-minute block would be indicative of an “end spurt”, which allows individuals to work at an elevated intensity when knowing that exercise cessation was nearing.

In conclusion, it is apparent that across the duration of the team sport protocol, individuals displayed physical performance characteristics of a pacing strategy in order to allow for the completion of testing, with the highest levels of fatigue occurring across the first half of the simulation. Further, it is apparent that previous methods of exercise prescription have been largely flawed, as exercise prescription based on an individual’s PSS does not account for individuals who are anaerobically superior but aerobically poor.
**PRACTICAL APPLICATIONS**

The findings from this study highlighted the current flaw in methods of exercise prescription for laboratory based team sport protocols being performed on a NMT. Current methodologies state that work rates should be prescribed based on an individual’s PSS, however, this method does not account for individuals who are anaerobically superior but aerobically poor. Therefore, we suggest that the exercise prescription of such laboratory based team sport protocols should be based on an individual’s MAS rather than PSS, or perhaps even a combined algorithm of the aerobic and anaerobic velocities.

**REFERENCES**

BLOOD FLOW RESTRICTION TRAINING AS A NOVEL APPROACH TO IMPROVE JUMPING PERFORMANCE

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BLUF

The intermittent application of an occlusive stimulus set at 50% of estimated arterial occlusion to the lower-limbs during low intensity exercise (30% 1RM) enhances training power gains from 3-week structured training blocks when compared to non-occluded training in strength trained males.

ABSTRACT

The purpose of this study was to examine the effects of low load exercise with and without blood flow restriction on vertical jump power and height. Four male strength trained subjects were randomised to a lower-body blood flow restricted intervention (occlusion cuff inflated to 50% of estimated arterial occlusion worn intermittently on the proximal thighs) or a control intervention that trained without occlusion in a crossover design. Eight, twice a day experimental training sessions were performed. The first session consisted of two gymnasium-based exercises; back squats (four sets of fifteen repetitions at 30% of their estimated 1RM) and single leg Bulgarian squats (two sets of 10 repetitions each leg at body weight). The second session consisted of single leg Bulgarian squats (four sets of 10 repetitions each leg at body weight). The response to the blood flow restriction intervention resulted in moderate-large increases in jump height at bodyweight (4.1% vs. −0.7%; ES: 0.94) and under a loaded (+30kg) jumps condition (1.9% vs. −2.5%; ES: 0.64). The difference in peak power for the unloaded condition was small (1.4% vs. −1.0%; ES: 0.54). A very large and significant (p<0.05) difference was observed in peak power for the loaded condition as a result of the BFR response when compared to non-occluded training (4.1% vs. −4.6%; ES: 3.1). The use of blood flow restriction in conjunction with lower loadings can potentially be a suitable intervention to enhance training power gains. This could be of benefit during an intensive training block, within a competitive phase or with power and strength based athletes who are returning from injury.

Key Words - Blood flow restriction, strength training, power.

INTRODUCTION

Resistance exercise is a major part of an athlete’s training regime. Depending on the type of resistance exercise, benefits include improvements in power, strength, muscular endurance and hypertrophy (5). The load lifted by the athlete should be at least 60% of their one repetition maximum (1RM) in order to stimulate increases in strength and that optimal strength gains result from loads in excess of 80% of 1RM (20). Furthermore, training below this level of intensity rarely produces increases in muscle size or strength (10). More recently, the use of blood flow restriction (BFR) combined with low-load resistance training (20-40% 1RM) has demonstrated both morphological and strength responses (16). This novel intervention is a method of strength training “with the addition of pressure” through the application of an inflatable cuff or tourniquet around a limb which limits blood delivery to and from contracting muscles.

Concurrent BFR and low-load resistance training has demonstrated rapid increases in muscle size and strength in athletic populations (2,21). This type of training methodology has also showed enhanced performance across markers of physical performance including maximal strength (6,21), countermovement jump power (6), maximal and repeated sprint performance (2,6) in well-trained athletes. Low intensity exercise such as walking or cycling in conjunction with BFR has also demonstrated significant improvements in lower body strength and muscle cross-sectional area (CSA) (1,3). The underlying mechanisms responsible for these effects are not well defined although both metabolic stress and mechanical tension has been suggested as factors responsible for the enhanced hypertrophy and strength gains resulting from BFR training. These factors are theorized to signal a number of mechanisms for the stimulation of muscle growth, including fast-twitch fibre recruitment (22), systemic and localized hormone production (6,15), cell swelling (12) and increased production of reactive oxygen species (9).

The advantage of using low loads in conjunction with BFR in athletic populations may be useful for those athletes who need to decrease their training loads, whilst providing a physiological stimulus for muscular adaptation. Equally, the decrease in mechanical stress when substituting high-load resistance exercise for low-load training with BFR may assist athletes looking to increase their longevity in sport (16).

Therefore, the purpose of this investigation was to compare the functional training effects following intermittent BFR training with non-occluded training across a six-week training period for trained athletes. It was hypothesized that,
compared to non-occluded training, BFR training would elicit greater power gains due to the provision of an additional stressor.

METHODS

Subjects
Four male athletes (Table 1) volunteered to participate in the study and provided written informed consent. Each subject had a minimum of four years of resistance training experience.

Design
Participants performed short-term (2x3 weeks) low-intensity resistance training of the lower body under restricted (BFR) or unrestricted (control) blood flow conditions. To examine possible training-induced changes, anthropometric (girths) and lower body physical (power) tests were performed before and after each training period.

During the time of the study all participants were encouraged to keep their diets and external physical activity consistent across the training blocks.

Testing Protocol
In the 48-hour period prior to performing the tests, the subjects did not perform any high-intensity activities that were considered to be fatiguing in respect to the maximal power testing. Blood pressure and anthropometric measurements were taken in a rested state prior to the commencement of the warm-up. This warm-up consisted of 5 minutes of stationary cycling (self-selected resistance at 80 RPM) followed by 5 minutes of mixed calisthenics. Three to five sub-maximal unloaded countermovement jumps (CMJ) were performed prior to the commencement of power testing.

Power Profile
Subjects performed two maximal effort CMJ at body mass (unloaded) and body mass + 30kg (loaded). Two minutes of passive recovery was specified between jump attempts. Jumps were performed on a force plate (400 Series Performance Plate; Fitness Technology, Adelaide, Australia) interfaced with a position transducer (PT5A; Fitness Technology) connected to a wooden stick (unloaded) or weightlifting bar and lifting plates (loaded) held across the top of the shoulders. Jump height and peak power were measured using computer software (Ballistic Measurement System; Fitness Technology). Sampling frequency of the force plate was set at 600Hz and displacement, velocity and acceleration was filtered at 0, 16 and 10Hz respectively.

Anthropometric variables
The subjects were assessed for height, weight and lower body circumferences; calf (maximal), thigh (measured at 33%, 50% and 75% of the distance from the inguinal crease to the top of the patella) and gluteal (maximal).

Training Blocks
The two groups were randomly assigned to one of the two training interventions in a crossover fashion. Each training block was approximately three weeks long, which included eight twice-a-day experimental resistance-training sessions. The first session was performed at 12:00pm and the second session a minimum of four hours later.

Standard Training
Subjects commenced their first training session of the day by performing 5 minutes of aerobic exercise on an elliptical cross-trainer (Johnson E7000 Elliptical Trainer, Johnson Health Tech. Co., LTD. Taiwan, R.O.C.) at 70 rpm using a self-selected resistance. They then completed two gymnasium-based exercises; back squats (four sets of fifteen repetitions at 30% of their estimated 1RM) and single leg Bulgarian squats (two sets of 10 repetitions each leg at body weight). The second session consisted of single leg Bulgarian squats (four sets of 10 repetitions each leg at body weight). Sixty seconds rest was given between sets.

Blood Flow Restriction (BFR) Training
The BFR training was identical to the standard training above, except that lower-limb blood flow was restricted with an occlusion cuff (width 8cm). The cuff pressure was inflated to a percentage of estimated lower body arterial occlusion; 25% for the aerobic exercise and 50% for the gymnasium based exercises (Table 1). BFR was applied intermittently whilst the subject was performing the exercise. Immediately after completing each exercise set, the pressure was released. The cuff was then reinfated to the predetermined pressure immediately prior to the conclusion of the 60-second rest period.

Arterial occlusion was determined via a predictive equation (11) (occlusion = 5.893 \times \text{thigh circumference} + 0.734 \times \text{lower body diastolic blood pressure} + 0.912 \times \text{lower body systolic blood pressure} – 220.046). Thigh circumference of the right thigh was measured at 33% of the distance from the inguinal crease to the top of the patella. Blood pressure was measured using an automatic blood pressure monitor (Sanitas Blood Pressure Monitor, FitZone Solutions P/L, NSW, Australia) and the cuff was placed at the ankle in order to detect the pulse of the posterior tibial artery (11). Blood pressure was taken in duplicate and values were averaged for use in the equation.
Subjects performed a 4-week familiarization trial prior to the experimental protocol to accustom themselves to the training protocol and BFR training. Exercise and repetition scheme was kept identical except that squat loadings were performed at 20% 1RM and the BFR pressure was lower than those used in the study (120-150mmHg). Due to the novelty of this training intervention, the loadings and pressure were specifically lowered from both a safety and compliance perspective. A one-week wash out period of no lower body resistance exercise was enforced before the commencement of the study.

Table 1 - Physical Characteristics of the Athletes.

<table>
<thead>
<tr>
<th></th>
<th>Subject 1</th>
<th>Subject 2</th>
<th>Subject 3</th>
<th>Subject 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>37</td>
<td>23</td>
<td>24</td>
<td>29</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>185</td>
<td>185</td>
<td>180</td>
<td>184</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>106.5</td>
<td>90.0</td>
<td>73.0</td>
<td>92.6</td>
</tr>
<tr>
<td>Thigh circumference @ 33% (cm)</td>
<td>68.8</td>
<td>63.9</td>
<td>58.5</td>
<td>61.2</td>
</tr>
<tr>
<td>Cuff Pressure: 50% AO (mmHg)</td>
<td>190</td>
<td>165</td>
<td>150</td>
<td>165</td>
</tr>
<tr>
<td>Cuff Pressure: 25% AO (mmHg)</td>
<td>95.0</td>
<td>82.5</td>
<td>75.0</td>
<td>82.5</td>
</tr>
<tr>
<td>Squat load: 30% 1RM (kg)</td>
<td>60.0</td>
<td>30.0</td>
<td>30.0</td>
<td>50.0</td>
</tr>
</tbody>
</table>

AO – arterial occlusion; Thigh circumference @ 33% of the distance from the inguinal crease to the top of the patella.

Statistical Analyses
Relative (%) changes in the group mean of each measure were used to assess magnitudes of effects by dividing these changes by the appropriate between-athlete standard deviations using Microsoft Excel (8). Magnitude of standardised effects (r ± 90% confidence intervals) was interpreted using thresholds of 0.2, 0.6, 1.2 and 2.0 for small, moderate, large and very large respectively (7). To make inferences about the large-sample value of an effect, the uncertainty in the effect was expressed as 90% confidence limits (CL). The relative anthropometric changes were compared across each treatment using paired t-tests. The significance level was set at p≤0.05.

RESULTS

When the two training interventions were compared (Figure 1), the response to BFR resulted in moderate-large increases in jump height for both the unloaded (4.1±2.5% vs. −0.7±5.1%; ES: 0.94, 81%) and loaded conditions (1.9 ± 2.6% vs. −2.5 ± 6.8%; ES: 0.64, 67%) when compared to non-occluded training. The difference in peak power for the unloaded condition was small (1.4 ± 2.6% vs. −1.0 ± 4.4%; ES: 0.54, 67%). There was a very large and significant (p<0.05) difference observed in peak power for the loaded condition as a result of the BFR response when compared to non-occluded training (4.1 ± 5.4% vs. −4.6 ± 2.8%; ES: 3.1, 95%).

There were no observed differences (p>0.05) in anthropometric measures (data not presented).

Figure 1 - Adaptive responses within a 3-week resistance-training block with or without blood flow restriction (BFR). Black column: BFR applied to the lower-limbs during exercise. Grey column: no occlusion stimulus applied during training (Control). Error bands represent standard deviations. * p<0.05
DISCUSSION

Our data demonstrated that the intermittent application of an occlusive stimulus set at 50% of estimated arterial occlusion to the lower-limbs during low intensity exercise (30% 1RM) enhances training power gains from 3-week structured training blocks when compared to non-occluded training in strength trained males. Cook et al. (6) observed improvements in countermovement jump power using an BFR intervention at 180mmHg (squat: five sets of five repetitions at 70% of 1RM) whereas another study highlighted that jumping performance was not improved using a BFR intervention at 240mmHg (squat: three sets of 15 repetitions at 20% of 1RM) (2).

BFR training studies using low intensities (20-50% 1RM) have typically only reported improvements in strength or muscle CSA (18,19). There is a strong relationship between strength, jumping ability and power in athletic populations (5). Furthermore literature agrees that the load lifted by the athletes should be at least 60% of their 1RM in order to stimulate increases in strength and that training below this level of intensity rarely produces increase in muscle size or strength (10). Therefore the observed difference in jump performance may have been due to relative strength improvements with the addition of the BFR intervention or rather an attenuation of the effects of training at a lower training intensity. Other mechanisms that may be responsible for the observed results include a greater accumulation of metabolites and related increases in anabolic hormone concentrations, intramuscular signalling, and intracellular swelling (12,16).

The lack of change in muscle CSA may be due to the intermittent pressure implemented during the BFR protocol and the previous training age of the subjects recruited. Most of the studies which highlighted significant increases in muscle CSA recruited participants with little or unspecified resistance training experience (17). Studies of resistance-trained athletic populations (2,21) that reported increases in muscle CSA with BFR (240mmHg; unspecified pressure; 5cm cuff width) and low-intensity exercise (20% 1RM) utilised a continuous pressure protocol. Continuous BFR at low intensity (20% 1RM) has reported a similar metabolic stimulus to that of multiple sets of high-load resistance exercise (14). Conversely, intermittent BFR training does not reach the same level of metabolic stress following continuous BFR or high-load resistance exercise (14). With the degree of metabolic stress purported to be a powerful moderator of hypertrophic responses to resistance training (4), this data may highlight the need to consider protocol specificity according to the desired response (i.e. power = intermittent pressure, hypertrophy = continuous pressure). It must also be noted that other factors may contribute to the response of BFR training (e.g. cuff width, type of cuff, restrictive pressure, exercise selection) and BFR studies vary in these factors (13,16).

PRACTICAL APPLICATION

Our data demonstrated that the inclusion of a BFR stimulus to low-intensity resistance training was beneficial in terms of increasing countermovement jump height and power in trained males subjects. These results are suggestive of an advantage of combining occlusion with low resistance loads (30% 1RM) during an intense training block or even within a competitive phase. This type of training intervention may also be useful for strength-power athletes returning from injury.
REFERENCES


Assessment of sleep patterns in elite female basketball athletes throughout a competitive season. J. Aust. Strength Cond. 23(6):59-62. 2015 © ASCA.

ASSESSMENT OF SLEEP PATTERNS IN ELITE FEMALE BASKETBALL ATHLETES THROUGHOUT A COMPETITIVE SEASON

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INTRODUCTION

Frequent travel is common for modern athletes. Professional basketball athletes competing in the highest level of competition in Australia play approximately one half of their matches away from home. In addition, when travelling interstate these basketball teams are often required to play two games over consecutive days.

This frequent travel, which may include movement across multiple time zones, as well as busy match schedules has the potential to disrupt circadian rhythms and affect sleep quality and quantity (1, 2). This is particularly true for regionally based teams, who often have additional travel requirements in comparison to their metropolitan based counter-parts. Sleep is a basic requirement for human health and is recognised as an important component of athlete recovery due to its physiological and psychological restorative effects. Although only based on anecdotal evidence, sleep has been reported to be the single most efficacious recovery strategy (3).

Reduced sleep and poor sleep quality have been associated with negative effects on athletic performance (4), as well as psychological well-being/mood state and decision making ability (5). Although the relationship between exercise and sleep remains equivocal, loss of sleep has been associated with overtraining syndrome/overreaching (6) with research studies demonstrating a negative relationship between sleep quality and training load (6, 7).

Increased sleep (~2 hours per night over 5-7 weeks) has been shown to improve shooting accuracy (free throw and 3-pt increase 9%), reaction time and psychological well-being (improved POMS score) (8) in basketball athletes. Therefore, total sleep and sleep quality appears to be an important variable to consider when assessing the recovery and training status of an individual. Assessing the sleep patterns of athletes may help coaches and sport scientists to better understand the physiological and psychological state of their athletes, helping to maximize performance and potentially reduce the rate of injury.

Wristwatch Actigraphy is a non-intrusive, cost-effective tool used to estimate sleep quantity and quality which has been compared to polysomnography, showing an accuracy of up to 80% in sleep disordered patients for total sleep time and sleep efficiency (9, 10) and as such is widely used in the sleep literature (1, 2, 8, 11-13). Wristwatch Actigraphy is ideally suited to the monitoring of elite athletes and other sports people due to the practicality and ease of data collection and analysis.

Few studies have monitored the sleep patterns of athletes (1, 2, 8, 13). The sleep patterns of female athletes during a competitive season, which includes tough travel and match schedules, has not previously been investigated despite the potential to influence physiological recovery (3), player well-being (5) and match performance (8).

Therefore, the aims of this study were to utilise Wristwatch Actigraphy to monitor sleep patterns of elite basketballers playing in the highest level of competition in Australia (WNBL). In particular, this study aimed to assess the sleep quality and quantity of professional female basketballers from a regionally based team and assess the effect of travel and match schedules on sleep patterns.

METHODS

Twelve elite female basketball players from one WNBL basketball club (Bendigo Spirit) were monitored over the course of 17 weeks of their in-season competition: Start of competition (October 2014); End of competition (March 2015).

Sleep patterns were assessed using previously validated commercially available accelerometers (Actigraph GT3-x). Devices were worn throughout all training sessions, daily activities and sleep and only removed when exposed to water (i.e., washing and swimming) or when downloading data (~1 hour per week). Tri-axial data were analyzed using the manufacturer’s software (Actilife v6.11). Sleep was determined using the Cole-Kripke automatic sleep/wake identification algorithm, where sleep is classified based upon activity levels and a sleep/wake calculation. This algorithm has been previously validated to classify sleep in adults (14).

Baseline measurements were assessed from at least two consecutive nights neither immediately preceding nor following a match. Previous data has demonstrated no difference between the averages of sleep parameters taken.
across this time period (2). Pre-match measures were taken as the sleep period prior to the day of the match. Match day measures were taken as the sleep period following matches and Post Match measures were taken as the sleep period the day following the match.

In cases where there were two matches on consecutive days, a Double-Header measure was taken as the average of the Match measure across the two consecutive days. Regular match schedules were considered as any other schedule. Home matches were considered as matches played at the clubs home court (Bendigo Stadium). Away matches were considered as any other match not played at Home.

In total there were 9 Home matches and 9 Away matches analysed during this study, of which 15 matches were considered as Regular and 3 as a Double-Header.

Data were presented as sleep efficiency (percentage time in bed that was spent sleeping) and total sleep time in hours, and are expressed as mean ± standard deviation (SD). Any sleep period was capped at 720 minutes. Differences between outcome measures were assessed using a repeated measures 2-way ANOVA (within factors: timing, condition) using IBM SPSS Statistics software (version 22).

Data were assessed for sphericity using Mauchly’s test. If data was non-spherical, Greenhouse-Geisser correction was used to identify difference between outcome measures. The interaction effect was consulted first to determine pattern differences in timing and condition before assessing the main effects of timing or condition. Significant interaction effects were explored using repeated one-way ANOVAs and subsequent pairwise comparisons with Bonferroni correction. Significant main effects of timing were followed up using pairwise comparisons with Bonferroni correction. Significance was set at P≤0.05.

RESULTS

During Baseline measurements, participants slept for 7.2 ± 1.1 hours with a sleep efficiency of 93.3 ± 1.6%.

The Double-Header condition changed the pattern of normal sleep compared with Regular conditions as evidenced by a significant timing * condition interaction (P=0.004, Effect Size=0.33; Fig 1). Total sleep time Pre-Match during Double-Header was significantly greater than all other timings (P<0.05).

For Home versus Away conditions there was a main effect for timing (P=0.018, Effect Size=0.258). Total sleep time Pre-match was on average 10.7% greater compared with Baseline (Fig. 2; P=0.032).

For sleep efficiency there was a main effect for condition (P=0.014, Effect Size = 0.434) such that sleep quality was on average 1.0% greater for Away compared with Home conditions (Fig 3). There were no differences in sleep efficiency between Regular and Double-Header conditions.

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For Home versus Away conditions there was a main effect for timing (P=0.018, Effect Size=0.258). Total sleep time Pre-match was on average 10.7% greater compared with Baseline (Fig. 2; P=0.032).

For sleep efficiency there was a main effect for condition (P=0.014, Effect Size = 0.434) such that sleep quality was on average 1.0% greater for Away compared with Home conditions (Fig 3). There were no differences in sleep efficiency between Regular and Double-Header conditions.

**Figure 1** - Total sleep time in Regular versus Double-Header conditions at different timings. NB: Significant timing * condition interaction (P=0.004).
Figure 2 - Total sleep time in Home versus Away conditions at different timings. *P<0.05 main effect for timing.

Figure 3 - Sleep Efficiency in Home versus Away conditions at different timings. *P<0.05 main effect for condition.

DISCUSSION

This study demonstrates that a busy match schedule, including double-headers (two matches in two days), influences the normal sleep patterns of elite female basketball athletes competing in the highest level competition in Australia (WNBL). In addition, it is apparent that this group of athletes understand the importance of sleep on performance. This is demonstrated by the increase in total sleep time at Pre-match. However, despite this, only at Pre-match is the total sleep time close to or above the 8 hours of sleep necessary to prevent the neurobehavioural deficits associated with sleep loss (15, 16).

The average sleep efficiency of 93.5 ± 2.2% in athletes who participated in this study was within the range of those reported previously in young healthy individuals (17) as well as in male Australian footballers (1). Interestingly, the athletes in this study had a greater sleep efficiency in the Away condition compared with Home. This is in contrast to results previously found in elite male Australian footballers (2), where there was no difference in any Actigraphy-based measure of sleep between home and away conditions (1). This might be due to less distractions, such as accessibility to electronic devices when staying in hotels away from home. Blue light from electronic sources is known to affect melatonin levels and influence sleep quality (18). Other possible reasons may be due to reductions in other stressors associated with factors outside of basketball, such as work and social related stressors.
Notably, although total sleep time was reduced, there was no difference in sleep efficiency in the Double-Header compared with Regular conditions. This suggests that sleep quality remains high when faced with a tough match schedule.

A notable limitation of this study was that sleep periods were capped at a maximum of 720 minutes total sleep time. On a small number of occasions total sleep time values were above this threshold. The accelerometry signal could have been visually inspected as a method to confirm actual total sleep time. However, due to the large amount of data this was not possible within current time restrictions.

**PRACTICAL APPLICATIONS**

- Travel has little effect on sleep patterns in elite female basketballers competing in the WNBL.
- Total sleep levels were greater the night prior to a match; however, the total sleep levels were generally below the minimum recommend 8 hours.
- Match schedules can have a large impact on the normal sleep patterns of elite female basketball athletes competing in the WNBL.
- Sleep efficiency is not affected by travel or match schedules and in fact were higher in the Away condition.
- Reducing distractions may help to improve sleep efficiency at home.

**REFERENCES**


MAXIMAL ISOMETRIC LOWER BODY STRENGTH AND VERTICAL JUMP PERFORMANCE IN STARTING AND BENCH SEMI-ELITE MALE BASKETBALL PLAYERS

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¹Universal College of Learning, Palmerston North, New Zealand

INTRODUCTION

Basketball is a court-based sport consisting of high intensity, powerful activities such as jumping, change of direction (COD), sprinting as well as sport specific movements (10). Research has found that different basketball playing positions showcase different strength, power, speed and agility characteristics relative to their demands (2) and that individuals who are stronger, jump higher, are faster or more agile in general played more minutes than other individuals in their position (4). The optimal development of a basketballer’s strength, power, speed and COD would thus appear to be beneficial to performance. The interaction between strength, power and COD is gaining more attention of late from both researchers and strength and conditioning practitioners who are all looking to give their athletes the edge (1, 6). A number of these studies have investigated the relationship between isometric strength and power to vertical jump performance (7, 11). However, to the authors’ knowledge, the differences in maximal isometric lower body strength and vertical jump performance in starting and bench basketball players has not been examined before. Therefore, the comparison of isometric lower body strength and power is required to identify whether specific physical qualities differentiate between these athletes. This will allow coaches to identify weaknesses within muscular performance and implement specific training protocols to develop these qualities to an appropriate standard.

METHODS

Participants

Ten (n=10) male basketball athletes; five starting (age: 24.8 ± 3.7 yrs; height: 196.2 ± 9.6 cm; body mass: 96.96 ± 16.82 kg), and five bench players (age: 20.6 ± 1.5 yrs; height: 196.2 ± 6.2 cm; body mass: 90.36 ± 14.33 kg) were recruited for this study. Athletes were placed in the starting group (SG) if they started in 60% or more of the total games in the season with anyone starting less than this placed in the bench group (BG). All athletes had a minimum of one year experience playing at the semi-elite level with strength training, COD and jumping movements forming part of the regular training regime. Athletes were free from injury at the time of testing and informed consent and ethical approval was obtained prior to testing.

Lower Body Power Assessment

Athletes performed a series of squat jumps (SJ) and countermovement jumps (CMJ), on a portable forceplate sampling at 600 Hz (400 Series Performance Plate, Fitness Technology, Adelaide, Australia). Both tests required the athletes to position their hands on their hips, with their feet positioned shoulder width apart, and to jump maximally during each attempt. The SJ condition required the athletes to start in a self-selected depth squat position held for three seconds, before performing the explosive concentric only action. For the CMJ the athletes were required to start in a standing position, descend into a self-selected depth squat and jump as high as possible. Variables of interest including jump height (m), peak force (N), peak velocity (m.s⁻¹), peak power (W) were measured and calculated using the Ballistic Measurement system software (Fitness Technology, Adelaide, Australia), with the average of three trials of SJ and CMJ each retained for analysis.

Lower Body Isometric Strength Assessment

The isometric mid-thigh pull (IMTP) was performed on a portable forceplate sampling at 600 Hz (400 Series Performance Plate, Fitness Technology, Adelaide, Australia) located in a power rack to ensure the desired testing position where relative knee angle was held at approximately 130°, the bar positioned below the hip crease and the trunk in an upright position. Athletes were instructed to place their hands on the bar and upon the instructor’s verbal instructions pull against the bar with maximal effort as quickly as possible for three seconds. Variables of interest including isometric peak force (N), maximal rate of force development (N.s⁻¹), impulse 100 (N.s), impulse 200 (N.s), impulse 300 (N.s) and total impulse (N.s) was collected and calculated using the Ballistic Measurement system software (Fitness Technology, Adelaide, Australia), with the average of three trials retained for analysis.

Statistical Analysis

Reliability of performance measures was assessed by intraclass correlation coefficient (ICC), coefficient of variation (%CV), typical error (TE) and calculation of the relative percentage change in mean (5). Data was analysed, using descriptive statistics, and absolute and relative (measurement / body mass) results summarised as mean ± standard deviation (SD). Athletes were grouped into starter (n = 5) and bench (n = 5) groups based on their normal playing roles. Two-tailed independent t tests were used to assess the differences between the means of the starter and bench groups. Effect sizes were also calculated according to Cohen’s d formula. Effect sizes were interpreted as trivial (< 0.19), small
(0.20 – 0.59), moderate (0.60 – 1.19), large (1.20 – 1.99), and very large (2.0 – 4.0)(3). Additionally, 95% confidence intervals were used to ascertain the certainty with which effects occurred.

RESULTS

The ICC’s, %CV, TE and percentage (%) change in the mean for each IMTP, CMJ and SJ variable are shown in Table 1.

Table 1 - Reliability data for IMTP, CMJ, and SJ variables.

<table>
<thead>
<tr>
<th>Reliability Variable</th>
<th>ICC  (90% CI)</th>
<th>%CV (90%CI)</th>
<th>TE</th>
<th>Change in mean (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isometric mid-thigh pull</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPF (N)</td>
<td>0.99 (0.96-1.00)</td>
<td>2.0 (1.5-3.4)</td>
<td>57.29</td>
<td>0.8</td>
</tr>
<tr>
<td>mRFD (N.s⁻¹)</td>
<td>0.99 (0.96-1.00)</td>
<td>7.3 (5.3-12.3)</td>
<td>623.91</td>
<td>1.0</td>
</tr>
<tr>
<td>I100 (N.s)</td>
<td>0.91 (0.79-0.97)</td>
<td>6.3 (4.8-10.0)</td>
<td>6.58</td>
<td>1.4</td>
</tr>
<tr>
<td>I200 (N.s)</td>
<td>0.97 (0.91-0.99)</td>
<td>5.5 (4.3-8.8)</td>
<td>13.29</td>
<td>1.5</td>
</tr>
<tr>
<td>I300 (N.s)</td>
<td>0.98 (0.96-0.99)</td>
<td>3.3 (2.4-5.5)</td>
<td>18.04</td>
<td>3.2</td>
</tr>
<tr>
<td>Total Impulse</td>
<td>0.97 (0.93-0.99)</td>
<td>2.0 (1.5-3.3)</td>
<td>214.06</td>
<td>0.1</td>
</tr>
<tr>
<td>Countermovement jump</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PV (m.s⁻¹)</td>
<td>0.75 (0.49-0.87)</td>
<td>5.0 (3.8-7.6)</td>
<td>0.12</td>
<td>2.8</td>
</tr>
<tr>
<td>PF (N)</td>
<td>0.98 (0.94-0.99)</td>
<td>2.5 (1.9-3.8)</td>
<td>47.92</td>
<td>1.7</td>
</tr>
<tr>
<td>PP (W)</td>
<td>0.97 (0.93-0.99)</td>
<td>2.2 (1.7-3.3)</td>
<td>97.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Jump Height (m)</td>
<td>0.97 (0.93-0.99)</td>
<td>2.9 (2.2-4.4)</td>
<td>0.01</td>
<td>1.6</td>
</tr>
<tr>
<td>Squat jump</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PV (m.s⁻¹)</td>
<td>0.94 (0.83-0.98)</td>
<td>2.0 (1.6-3.2)</td>
<td>0.05</td>
<td>0.2</td>
</tr>
<tr>
<td>PF (N)</td>
<td>0.74 (0.50-0.85)</td>
<td>7.7 (5.9-12.2)</td>
<td>164.37</td>
<td>-1.9</td>
</tr>
<tr>
<td>PP (W)</td>
<td>0.91 (0.88-0.94)</td>
<td>5.1 (3.9-8.0)</td>
<td>58.3</td>
<td>-2.2</td>
</tr>
<tr>
<td>Jump Height (m)</td>
<td>0.91 (0.69-0.97)</td>
<td>8.2 (5.7-15.2)</td>
<td>314.15</td>
<td>8.8</td>
</tr>
</tbody>
</table>

IPF = isometric peak force; mRFD = maximum rate of force development.
CI = confidence intervals; PV = peak velocity; PF = peak force; PP = peak power

The means and SDs for strength and power performance variables of the isometric IMTP, CMJ and SJ in absolute and relative terms are shown in Table 2.
**Table 2** - Absolute and relative performance variables for strength and power measurements in the isometric mid-thigh pull, countermovement jump, and squat jump for a semi-professional basketball population (n = 10).

<table>
<thead>
<tr>
<th></th>
<th>Absolute</th>
<th>Relative</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Isometric mid-thigh pull</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPF (N)</td>
<td>2809.83 ± 388.52</td>
<td>N.kg⁻¹</td>
</tr>
<tr>
<td>mRFD (N.s⁻¹)</td>
<td>12712.57 ± 4365.94</td>
<td>N.kg.s⁻¹</td>
</tr>
<tr>
<td>I100 (N.s)</td>
<td>106.88 ± 18.08</td>
<td>N.kg.s</td>
</tr>
<tr>
<td>I200 (N.s)</td>
<td>229.13 ± 51.45</td>
<td>N.kg.s</td>
</tr>
<tr>
<td>I300 (N.s)</td>
<td>366.79 ± 101.85</td>
<td>N.kg.s</td>
</tr>
<tr>
<td>Total Impulse (N.s)</td>
<td>7996.65 ± 1004.69</td>
<td>N.kg.s</td>
</tr>
<tr>
<td><strong>Countermovement Jump</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PV (m.s⁻¹)</td>
<td>2.69 ± 0.15</td>
<td></td>
</tr>
<tr>
<td>PF (N)</td>
<td>2154.23 ± 263.09</td>
<td>N.kg⁻¹</td>
</tr>
<tr>
<td>PP (W)</td>
<td>4607.22 ± 492.03</td>
<td>W.kg⁻¹</td>
</tr>
<tr>
<td>Jump Height (m)</td>
<td>0.35 ± 0.04</td>
<td></td>
</tr>
<tr>
<td><strong>Squat Jump</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PV (m.s⁻¹)</td>
<td>2.74 ± 0.24</td>
<td></td>
</tr>
<tr>
<td>PF (N)</td>
<td>2399.14 ± 247.88</td>
<td>N.kg⁻¹</td>
</tr>
<tr>
<td>PP (W)</td>
<td>5105.02 ± 938.76</td>
<td>W.kg⁻¹</td>
</tr>
<tr>
<td>Jump Height (m)</td>
<td>0.34 ± 0.06</td>
<td></td>
</tr>
</tbody>
</table>

Values are expressed as mean ± SD.

mRFD = maximum rate of force development; PV = peak velocity; PF = peak force; PP = peak power; IPF = isometric peak force.

Differences between starting and bench player relative means are presented in Table 3. A statistically significant difference (p ≤ 0.05) was found between SJ relative peak velocities for the two groups. Large effect sizes were found for age, relative I100, relative I200 and relative I300.

**Table 3** - Comparison between starting and bench semi-professional basketball players in relative isometric mid-thigh pull, countermovement jump, and squat jump force-time-velocity-time variables.

<table>
<thead>
<tr>
<th></th>
<th>Starters (n = 5)</th>
<th>Bench (n = 5)</th>
<th>p value</th>
<th>Cohen Effect Size [95% CI]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Body Mass (kg)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>24.80 ± 3.71</td>
<td>20.60 ± 1.50</td>
<td>0.09</td>
<td>1.48** [0.07, 8.33]</td>
</tr>
<tr>
<td><strong>Isometric mid-thigh pull</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPF (N.kg⁻¹)</td>
<td>29.77 ± 2.68</td>
<td>30.84 ± 4.85</td>
<td>0.71</td>
<td>-0.27 [-6.78, 4.64]</td>
</tr>
<tr>
<td>mRFD (N.kg⁻¹.s⁻¹)</td>
<td>152.06 ± 69.00</td>
<td>125.54 ± 31.87</td>
<td>0.51</td>
<td>0.49 [-104.56, 109.51]</td>
</tr>
<tr>
<td>I100 (N.kg.s)</td>
<td>1.23 ± 0.13</td>
<td>1.07 ± 0.11</td>
<td>0.09</td>
<td>1.33** [-0.02, 0.34]</td>
</tr>
<tr>
<td>I200 (N.kg.s)</td>
<td>2.79 ± 0.57</td>
<td>2.16 ± 0.26</td>
<td>0.09</td>
<td>1.42** [-0.12, 0.28]</td>
</tr>
<tr>
<td>I300 (N.kg.s)</td>
<td>4.63 ± 1.21</td>
<td>3.33 ± 0.54</td>
<td>0.10</td>
<td>1.39** [-0.07, 2.67]</td>
</tr>
<tr>
<td>Total Impulse (N.kg.s)</td>
<td>85.33 ± 7.18</td>
<td>86.53 ± 4.55</td>
<td>0.79</td>
<td>-0.20 [-9.97, 7.57]</td>
</tr>
<tr>
<td><strong>Countermovement Jump</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PV (m.s⁻¹)</td>
<td>2.74 ± 0.12</td>
<td>2.63 ± 0.17</td>
<td>0.34</td>
<td>0.75 [-0.10, 0.32]</td>
</tr>
<tr>
<td>PF (N.kg⁻¹)</td>
<td>22.74 ± 1.70</td>
<td>23.61 ± 2.5</td>
<td>0.58</td>
<td>-0.41 [-3.99, 2.25]</td>
</tr>
<tr>
<td>PP (W.kg⁻¹)</td>
<td>50.08 ± 4.51</td>
<td>49.47 ± 6.24</td>
<td>0.88</td>
<td>0.11 [-7.33, 8.55]</td>
</tr>
<tr>
<td>Jump Height (m)</td>
<td>0.35 ± 0.02</td>
<td>0.36 ± 0.05</td>
<td>0.79</td>
<td>-0.26 [-0.07, 0.05]</td>
</tr>
<tr>
<td><strong>Squat Jump</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PV (m.s⁻¹)</td>
<td>2.89 ± 0.2</td>
<td>2.58 ± 0.16</td>
<td>0.04*</td>
<td>1.71** [0.05, 0.57]</td>
</tr>
<tr>
<td>PF (N.kg⁻¹)</td>
<td>27.22 ± 5.07</td>
<td>25.03 ± 3.58</td>
<td>0.50</td>
<td>0.50 [-4.21, 8.59]</td>
</tr>
<tr>
<td>PP (W.kg⁻¹)</td>
<td>56.87 ± 6.22</td>
<td>52.84 ± 8.08</td>
<td>0.45</td>
<td>0.56 [-6.49, 14.55]</td>
</tr>
<tr>
<td>Jump Height (m)</td>
<td>0.36 ± 0.03</td>
<td>0.31 ± 0.07</td>
<td>0.26</td>
<td>0.93 [-0.03, 0.13]</td>
</tr>
</tbody>
</table>

Values are expressed as mean ± SD.

IPF = isometric peak force; mRFD = maximum rate of force development; I100 = impulse 100 ms; I200 = impulse 200 ms; I300 = Impulse 300 ms; PV = peak velocity; PF = peak force; PP = peak power

* Significant difference at p ≤ 0.05.
** Large magnitude of effect size

**DISCUSSION**

The aim of the current study was to assess the differences in IMTP and vertical jump performance exhibited by starting and bench semi-elite male basketball players. Findings from the study indicate that starting players demonstrate significantly greater relative SJ PV (p ≤ 0.05). The magnitude of effect size show large effect sizes for age, relative I100, relative I200, relative I300 and SJ PV and moderate effect sizes for CMJ PV and SJ jump height. There was no significant difference in force production for the two groups during the study for any of the tests. The greater relative impulses and
mRFD exhibited by the starting group shows that starters generate force faster than bench players which may lead to faster execution of skills on court. The findings of this study are similar to previous research indicating that elite athletes exhibited greater RFD and impulses than less experienced athletes [9]. A limitation in this study may be the small subject pool and age range of the subjects who participated in this research. Future research should focus on investigating the determining factors that can improve performance on these variables.

**PRACTICAL APPLICATIONS**

According to the results of this study strength and conditioning coaches should aim to maximise impulse and RFD by designing programs which incorporate explosive weighted and un-weighted exercises e.g. plyometric and Olympic lifts [7, 8]. In addition, the testing of RFD and impulses as part of an informed physiological testing battery is also advised when working with higher level athletes.

**REFERENCES**

Powerlifting: success and failure at the 2012 Oceania and 2013 classic world championships.
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POWELIFTING: SUCCESS AND FAILURE AT THE 2012 OCEANIA AND 2013 CLASSIC WORLD CHAMPIONSHIPS

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²Massey University, Palmerston North, New Zealand

INTRODUCTION

Powerlifting is a barbell based strength sport consisting of three disciplines: the squat, the bench press and the deadlift. World records are ratified by the International Powerlifting Federation (IPF) which governs the sport internationally. A competition sanctioned by the IPF involves lifters of various weight classes completing three attempts at each discipline, with the winner of each weight class being the lifter who has the largest combined total of their best successful lifts. An overall winner for a meet is awarded using a bodyweight adjusted calculation called the Wilks formula (7). There are two ways to compete in an IPF event, either classic (raw or unequipped) or equipped. Classic powerlifting allows the use of non-supportive equipment, such as a soft suit, weight lifting belt, wrist wraps and neoprene knee sleeves. Equipped powerlifting allows the use of supportive equipment, such as squat and deadlift suits, bench shirts, wrist wraps and knee wraps.

Published research on powerlifting appears to cover only such aspects as biomechanics (1, 5, 12, 14), injuries (3, 6, 11), training benefits (3, 4, 13), hormonal or doping/steroidal aspects (9, 15), anthropometry (8, 16) or allometric scaling (2, 10). However these aspects are not directly relevant to a study of the results of competition, and we can find no published research on aspects of powerlifting success and failure; either on an attempt by attempt basis, or on performance in elite competitions. Commercially available advice based on this type of analysis is however available online.

The purpose of this study was therefore to examine the published results from two recent elite classic powerlifting championship events in order to examine whether strategy, gender or location factors affect the relative frequencies of success or failure at such events; and whether, when considering each sequence of three attempts at a given lifting discipline, any sequences are more commonly occurring and/or may be considered to be “good strategies” in the sense of identifying more with placing in the top three rather than with non-placing competitors. More specifically we would like to determine the influence of attempt selection in dictating success or failure, in that attempting too big a jump between lifts may be more likely to result in failure and that correct attempt selection may be more likely to lead to success and winning.

METHODS

We sourced the detailed results for both men and women from the Oceania Powerlifting and Bench Press Championships held in Sydney, Australia, 7-9 December, 2012 (open access, located online at http://www.powerliftingaustralia.com/Results/2012/2012results40.htm); and from the 1st Classic World Championships held in Suzdal, Russia, 11-16 June, 2013 (open access located online at http://www.powerlifting-ipf.com/369.html#c662). These were selected because data were accessed for the first time on 4 March 2013. Our institutional ethics board does not require ethical approval to access and analyse public domain data available on the web.

These detailed results include each attempt by each competitor in each weight class at each lifting discipline. There were 111 male and 34 female lifters competing in Sydney and 94 and 60 respectively in Suzdal, amounting to 813 first attempts in total. Performance standards, as measured by the Wilks scores, do differ significantly between the two championships and between males and females, but as we shall see later this has no impact on the overall results.

Outcomes were annotated as follows: the appropriate numeral for the attempt, together (where appropriate) with a + or = sign indicating whether the weight had incremented above or was equal to the previous attempt, followed by a S, F or X indicating success, failure or a “pass”. (A pass occurs when a lifter declines to attempt any lift, but in so doing forfeits any remaining lifts in that set of three.) This annotation results in thirteen different “states”, and following the starting state each lifter transitions through a sequence of three states, each being one of these thirteen.

From tabulation of these details we extracted firstly the relative frequencies of success at each attempt for each lifting discipline, for males vs. females, and for the Oceania vs. World Championships. Secondly we recorded the relative frequencies of each observed sequence of three states in similar fashion.
We used Chi-squared ($\chi^2$) contingency table analyses for all cross-tabulated frequencies. The significance level was set for $p < 0.05$ throughout. Although a number of such tests are involved, we elected to treat each test individually, rather than use a Bonferroni (or similar) adjustment when interpreting results and aggregating data.

RESULTS

The relative frequency of successful lifts on any attempt declines significantly from the first, to second, and to third attempts. This pattern is consistent, with very minor and insignificant differences, when making all the following comparisons: for the squat vs. bench press vs. dead lift; for males vs. females; and for the Oceania vs. Classic World Championships ($p$-values for all $\chi^2$ tests by attempt number are $< 0.001$, whereas $p$-values for all other comparative tests are $> 0.7$). Given this consistency and the insignificant differences, we have aggregated all data for each numbered attempt; yielding overall relative frequencies of $92.1 \pm 0.9\%$, $75.3 \pm 1.5\%$ and $43.3 \pm 1.7\%$ respectively, from the 813 recorded attempts at each stage throughout both competitions. The relative frequency of a successful first lift is however slightly higher ($94.0\%$) amongst those who placed in the first three of their weight class and discipline than those who were unplaced ($91.3\%$), but this small difference is not significant ($p = 0.176$).

Using the coding system described above, we can identify 27 possible transition sequences, many of which do not occur. Table 1 tracks the collated pathways of all 813 first attempts. Table 1 is in the form of a transition matrix, with rows designating the ‘transition from’ state, and columns designating the ‘transition to’ state. Thus for example, of the 62 failures at their first attempt (i.e. transitioned from ‘Start’ to ‘1F’, 9 were successful at an increased weight at their second attempt ($2+S$), 5 failed at an increased weight ($2+F$), 33 were successful at an equal weight ($2=S$), 14 failed at an equal weight ($2=F$) and 1 passed ($X$). Greyed out cells in the matrix indicate transitions which are not possible.

Table 1 - Transition frequency matrix.

<table>
<thead>
<tr>
<th></th>
<th>1S</th>
<th>1F</th>
<th>1X</th>
<th>2+S</th>
<th>2+F</th>
<th>2=S</th>
<th>2=F</th>
<th>2X</th>
<th>3+S</th>
<th>3+F</th>
<th>3=S</th>
<th>3=F</th>
<th>3X</th>
</tr>
</thead>
<tbody>
<tr>
<td>From</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Start</td>
<td>749</td>
<td>62</td>
<td>2</td>
<td>570</td>
<td>175</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1S</td>
<td>570</td>
<td>175</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1F</td>
<td>9</td>
<td>5</td>
<td>33</td>
<td>14</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1X</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2+S</td>
<td>281</td>
<td>291</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2+F</td>
<td>7</td>
<td>20</td>
<td>45</td>
<td>97</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2=S</td>
<td>13</td>
<td>20</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2=F</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>8</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2X</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>8</td>
<td>0</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Enumeration from Table 1 reveals that there are a maximum of 27 different pathways or sequences through the system. However, careful scrutiny of the detailed results from the two competitions reveals that the frequencies of occurrence are dominated by two sequences, with a few others less common, and several not occurring at all.

Analogous $\chi^2$ analyses to those above indicate that the frequencies of the dominant sequences are no different between the lifting disciplines, nor between males and females, nor between the Oceania and World Championships ($p$-values for all comparative $\chi^2$ tests are again $> 0.7$). On the other hand, there are significant differences in the frequencies of the dominant sequences between those placing in the top three in any weight division and/or lift discipline, and other non-placing competitors ($p = 0.005$, Table 2). More specifically the sequence Success: Success: Success ($1S 2+S 3+S$) is significantly more frequent amongst top finishers ($43.7\%$ vs. $31.0\%$) and a group of “other” sequences significantly less frequent ($4.8\%$ vs. $10.7\%$).

Table 2 - Sequence frequencies: Placed vs. unplaced.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Placed</th>
<th>Unplaced</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1S 2+S 3+S</td>
<td>110</td>
<td>174</td>
<td>284</td>
</tr>
<tr>
<td>1S 2+F 3+S</td>
<td>84</td>
<td>196</td>
<td>280</td>
</tr>
<tr>
<td>1S 2+F 3+F</td>
<td>4</td>
<td>15</td>
<td>19</td>
</tr>
<tr>
<td>1S 2+F 3=S</td>
<td>13</td>
<td>32</td>
<td>45</td>
</tr>
<tr>
<td>1S 2+F 3=F</td>
<td>24</td>
<td>69</td>
<td>93</td>
</tr>
<tr>
<td>1F 2=S 3+F</td>
<td>5</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>All other sequences</td>
<td>12</td>
<td>60</td>
<td>72</td>
</tr>
<tr>
<td>TOTALS</td>
<td>252</td>
<td>561</td>
<td>813</td>
</tr>
</tbody>
</table>
Turning from analysing sequences and aggregating over the three disciplines in each weight division, those who achieve 8 or 9 successes in the Oceania competition are no more likely to be amongst the top three placings (i.e. medal winners) than those who succeed less often (p > 0.9). At the Worlds however this is only so for females (p = 0.111). On the other hand, male competitors at the Worlds who manage to succeed in 8 or 9 of their attempts do appear to be more likely medal winners than those who score fewer successes (57.7% vs. 13.2%, p < 0.001). Table 3 below provides the count data.

**Table 3 - Success frequencies: Placed vs. unplaced.**

<table>
<thead>
<tr>
<th>Competition</th>
<th># Successes</th>
<th>Placed</th>
<th></th>
<th>Unplaced</th>
<th></th>
<th>TOTALS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Total</td>
<td>Male</td>
<td>Female</td>
<td>Total</td>
</tr>
<tr>
<td>Oceania</td>
<td>8 or 9</td>
<td>6</td>
<td>4</td>
<td>10</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>7 or less</td>
<td>18</td>
<td>10</td>
<td>28</td>
<td>31</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>24</td>
<td>14</td>
<td>38</td>
<td>41</td>
<td>24</td>
</tr>
<tr>
<td>Worlds</td>
<td>8 or 9</td>
<td>15</td>
<td>9</td>
<td>24</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>7 or less</td>
<td>9</td>
<td>12</td>
<td>21</td>
<td>59</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>24</td>
<td>21</td>
<td>45</td>
<td>70</td>
<td>39</td>
</tr>
</tbody>
</table>

**DISCUSSION**

This is the first study that we are aware of that investigates a number of aspects of success and failure at powerlifting using data from elite-level championships. As such this study can be viewed as a lead-in to the topic. We hope to have initiated the interest of others sufficiently to investigate this type of count data more broadly.

It is not surprising that the percentage success declines from the first to second to third attempts. Undoubtedly this is because if a lifter is successful on an attempt the weight must be increased for the next attempt, whilst if unsuccessful the next attempted weight cannot be reduced. It is of course also possible that the onset of fatigue with repeated attempts may have a similar effect. Notwithstanding, the actual figures (92.1%, 75.3% and 43.3% respectively) may come as a surprise to some; particularly at attempt 3 if only perhaps because a lifter successful at the third attempt knows that they would be unlikely to have done better, whereas a failure introduces a significant element of doubt.

It is reassuring that these percentages were found to be no different between the lifting disciplines, between males and females, and between the Oceania and Classic World competitions, as this confirms a notion of uniformity across the sport. On the other hand, since we know lifters are encouraged to open with a lighter (i.e. almost certainly successful) first attempt, this interestingly does not predispose towards placing in the top three of their weight class and lifting discipline. Nevertheless, it will be confirmed below that it appears imperative that a lifter should make their opening lift on both their first and second attempts.

The tables and/or figures above can be utilised to extract data to examine a number of other questions regarding success or failure with progressive attempts. For example: of those who fail at their first attempt, 77.0% attempt an equal weight at their second; whilst of those who fail at their second attempt, a higher 85.2% attempt an equal weight at their third. Whilst this increased conservatism might be expected to occur, the increase is not statistically significant (p = 0.135).

Considering the success/failure sequences, it is similarly reassuring that the distribution of frequencies does not differ significantly between the lifting disciplines, nor between males and females, nor between the Oceania and the Classic World competitions. Examining Table 1, the dominant two sequences out of twenty seven, 1S 2+S 3+S and 1S 2+S 3+F, represent 69.4% of all occurrences. As with the decline in success percentage, this may not be unexpected. The next two most commonly occurring, 1S 2+F 3=F and 1S 2+F 3=S at 11.4% and 5.5% respectively, may also not be unexpected due perhaps to raised ambitions after a successful first attempt, and having failed at the second then not being able to reduce the weight for the third. Nevertheless, we would like to think that from the competitors’ point of view their relative frequencies perhaps ought to have been the other way around.

Given that winning is the objective of all competitors, and that the optimal strategy towards this end is not necessarily obvious, we examined sequence frequency differences between all those athletes who placed in the first three in any lifting discipline in any weight class, and all others, Table 2. We observe that the two dominant sequences make up 77% of those who placed as opposed to 66% of those unplaced, and that this difference is significant (p = 0.002). It therefore seems sensible tactically that competitors should be ensuring that they take attempts they are confident at making on both their first and second attempts. In more detail, the sequence 1S 2+S 3+S is significantly more frequent amongst top finishers (43.7% vs. 31.0%) and a group of “other” sequences significantly less frequent (4.8% vs. 10.7%) than amongst those unplaced. Aggregating over the three disciplines for each weight class, the notion that those succeeding in eight or 9 of their attempts are more likely to be medal winners appears only so for males in the Worlds.
Nevertheless, overall these results suggest that adopting weight selection with these sequence objectives in mind may predispose toward an improved probability of being placed in the first three. That is to say competitors should be choosing attempts that are within reach of their current ability in order to build a good total and therefore success, rather than jumping significantly beyond their current ability and seriously risk failure and loss of many kilograms on their total. Sequences of three successes do appear to lead to increased likelihood of winning, and it naturally follows therefore that those who are successful are more likely to evidence such a sequence.

PRACTICAL APPLICATIONS

In conclusion, this study has three practical implications for powerlifters and their coaches. (a) Athletes and their coaches will likely find informative and useful content within these Tables and/or Figures to assist with planning competitive and/or successful strategies when competing. (b) The sequence 1S 2+S 3+S, being significantly more evident amongst placed than non-placed competitors, is suggested as a possible means of improving the probability of being placed in the first three. (c) In order to improve the probability of achieving this sequence, it seems prudent to resist the temptation towards overly ambitious attempts, because although lifters are getting closer to their limits, decreasing weight after a failed attempt is not allowed.

REFERENCES

THE EFFECTS OF CONCENTRIC/ECCENTRIC TRAINING VERSUS CONCENTRIC ONLY TRAINING ON PEAK POWER AND FUNCTIONAL MUSCLE PERFORMANCE

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INTRODUCTION

Training to enhance power is of utmost importance to performance in many sporting disciplines. Numerous studies have shown that targeted resistance training can increase the maximal power of a specific movement pattern (5-7). For example, Decluse et al. (7) showed that performing resistance training (combined with running) significantly improved participant’s initial acceleration, and 100m sprint times when compared to passive (no running) and running controls, indicating that resistance training was better than simply performing the specific task alone. Increasing strength through resistance training increases both speed and acceleration through an increase in maximal muscular power.

Free weights, requiring an eccentric then concentric movement (stretch-shortening), are commonly used by athletes as their mode of resistance training. For many athletes the combined concentric and eccentric movement closely mimics muscle action in their sports. Others perform little eccentric work in their chosen sport, such as cycling and a number of water sports. Yet, prescribed resistance training for these sports is often based on free weights and involves an eccentric component. Despite this common practice, the utility of stretch-shortening (free weight) resistance exercise for improving concentric-only power is not well studied. Some published research using isokinetics shows individually-trained eccentric or concentric muscle to be effective at increasing action specific strength. Notably though, eccentric contractions tend to produce greater hypertrophy (8, 9), which in some concentric only sports (i.e. cycling) may not be desirable.

Interestingly, there have been no studies comparing the effects of multi-joint concentric only resistance training as a method of increasing concentric only power and strength even though for several sports this is the primary muscle action involved. Therefore, this study was designed to investigate whether concentric-only resistance training would bring about greater changes in functional muscle performance than regular eccentric/concentric (stretch-shortening) training can. We hypothesised that concentric-only training would confer greater benefits to measures of concentric strength and power only, and would not result in improvements in stretch-shortening exercises, i.e. the adaptations would be specific to the trained muscular action.

METHODS

Experimental Approach to the Problem

A counterbalanced design was used, in which participants performed concentric and stretch shortening training with different legs. Specifically, participants acted as their own controls as each leg was assigned, in a balanced fashion, to either the CON group or the SSC group. All training was at 60% of the single leg 1RM, with the 1RM being retested after three weeks of training to adjust the training load as leg strength increased. Legs were assigned to groups based on initial leg strength, with the strongest leg being dominant. From this, the dominant and non-dominant legs were assigned in a counterbalanced fashion to either the CON or SSC training groups to minimise experimental bias. Measures of single leg strength, power and functional power were taken before and after six weeks of training. A familiarisation session involving use of the leg press and the tests involved was undertaken by subjects prior to the initial testing session.

Subjects

Ten healthy active males volunteered to participate in this study (age 20.7±2.0 years, height 182.3±5.2 cm and weight 77.75±7.85 kg), this was the maximum number of participants able to be recruited. Participants were physically active for at least three days a week but had not performed regular strength training of the lower body within the past 12 months prior to the study. All procedures were approved by the institutional Human Ethics Committee.

Training Equipment

An inclined leg press, at an angle of 45 degrees, (Pivot, China) was adapted to work in such a manner that both regular concentric and eccentric movements could be performed and if desired solely the concentric phase could be performed. Compressed air was forced into a pneumatic ram after the concentric contraction and this was released in a controlled manner allowing the sled to be slowly lowered to the original stationary starting position. The time taken for the sled to drop was approximately two seconds. The height at which the air was signalled to enter the system was at the point where the leg was straight but the knee joint not locked out. This was adjusted for leg length and a marker placed for each participant so that the positioning was kept constant.
Participants performed a five minute warm-up on Monark cycle ergometer working at 100 watts (Monark Exercise AB, Varberg, Sweden) prior to all testing and training sessions. This was followed by stretches the participants wished to perform; all stretches performed by participants were kept consistent from pre to post testing.

**Testing**

Testing was performed at two time points. The first testing session (PRE) took place a minimum of 48 hrs, and maximum of 96 hrs, before the first training session. The second testing session (POST) took place a minimum of 48 hrs, and a maximum of 96 hrs, following the final training session. Testing sessions consisted of the following for each individual leg: leg press 1RM; peak power during knee extension of the leg press (from here ‘peak power’ refers to this measure) testing at 40% of 1RM (eccentric/concentric and concentric only); peak power testing at 60% of 1RM (eccentric/concentric & concentric only); single leg vertical jump; and a three hop test.

The 1RM-testing procedure was then performed on the leg press. Participants performed progressively increasing warm up sets of five repetitions until they reached a weight they estimated they could perform between 2-10 repetitions. Repetitions were only counted if the knee joint reached at least a 90° angle (the lead researcher judged this angle). Participants had at least three minutes between attempts on either leg. Leg used for each attempt was alternated to ensure sufficient recovery. Only two maximal attempts were allowed to ensure best performance was completed by minimising fatigue for the subsequent performance tests. After each successful attempt, a formula devised by Sale & MacDougall (11) was used to determine the 1RM for the leg being tested. An estimated 1RM testing procedure was used for safety reasons because participants were unfamiliar with the exercise. The formula used was: $1RM = \frac{Weight}{(1.0278 - (\text{Reps Performed} \times 0.0278))}$ (1). Following determination of 1RM the order of leg used for the remaining testing procedures were randomised for dominance.

Power testing then occurred and consisted of repetitions performed as described in the training section of the methods for CON and SSC training. For concentric testing, the weight was not assisted by the hydraulic system to prevent incorrect velocities that could occur due to the influx of air near the top of the movement. During these repetitions an accelerometer (WiTilt V3, SparkFun Electronics Inc., Colorado, USA) was recording. Each leg was tested alternately, this allowed for 60-90 seconds rest between each trial. Three maximal effort trials were performed of both eccentric/concentric and concentric only movements at 40% and 60% of 1RM for the both legs, with the peak power output of the three trials being calculated and reported. The order of trials always followed the same pattern, which was 40% 1RM eccentric/concentric then concentric only, followed by 60% 1RM eccentric/concentric then concentric only. Trial order remained the same during pre- and post-testing.

Accelerometer data was integrated using a Runge-Kutta procedure in MATLAB (The MathWorks, Inc., USA) to determine velocity. Once velocity had been determined, in the direction of sled movement, the powers were calculated through knowledge of the weight of the sled and added mass, hence determining power output at any point in time. As $Power = \text{Force} \times \text{Velocity}$ (2); where $\text{Force} = \text{Mass} \times \text{Acceleration} + \text{Mass} \times \text{Gravity} \times \cos 45^\circ$ (3).

Jump height was then estimated using a contact timing mat (Swift Performance Equipment, NSW, Australia). This system uses foot contact to determine flight time, the validity and reliability has previously been reported as similar to a force plate (4). The vertical jump testing took place a minimum of three minutes and no longer than five minutes after power testing. Participants had four attempts (separated by two minutes for each individual leg, the opposite leg performed the jump one minute after the preceding leg) and the best of the four attempts was recorded. Countermovement and arm movements were allowed. These were allowed because a one-leg jump may be an unfamiliar motion and so these allowed for a more natural performance of the movement.

The final test performed was a three-hop test. The test was simple and involved the participant performing three consecutive hops off the same leg with the aim being to travel as far as possible in the horizontal direction. Participants completed four measured attempts of the test with rest periods being the same as for the single leg vertical jump. The attempt in which the participant got the furthest was recorded as their score.

**Training**

The training programme undertaken consisted of two training sessions per week, separated by a minimum of 48 hours, for a total of six weeks. Each training session began with a warm up of five minutes easy cycling (~100W) on a Monark cycle ergometer (Monark, Sweden) followed by any static stretches the participants wished to perform. Static stretches performed were kept consistent throughout the training duration. The resistance training was performed on the customised leg press.

During each training session, the leg assigned to the CON condition performed eight sets of six repetitions at 60% of that individual leg’s 1RM whereas the leg assigned to the SSC condition performed only four sets of six repetitions at 60% of the individual legs 1RM. This was done to equalize the absolute value of external work between the two conditions. A single repetition for CON consisted of pushing the sled of the leg press from a stationary position at an approximate knee angle of 90° to full extension, intending to move as fast as possible. A single repetition for SSC consisted of the weight being lowered to a point where the knee joint angle was approximately 90° (the lead researcher supervised all trainings) and then immediately moved the sled upwards with the intent of moving as fast as possible.
Training compliance was 99.1%. After three weeks of training (six training sessions) all participants also completed a 1RM re-evaluation and training load was reset accordingly.

**Statistical Analyses**
To compare the effects of the two different training interventions, group (CON vs SSC) × training interactions were examined by employing a two-way repeated measures analysis of variance (ANOVA) for all dependant variables. This ANOVA was also used to determine if training itself had any effect on the dependant variables. Strength and functional performance measures had n = 9, however the power measures only had n = 6 as three participants accelerometer data was lost. An alpha level of P < 0.05 was set as the required level for statistical significance.

**RESULTS**
Note that in all results: *Denotes significant change from pre to post testing **Denotes significant change between training interventions

![Figure 1 - Concentric only peak power at 40% 1RM.](image1)

![Figure 2 - Eccentric/concentric peak powers at 40%.](image2)

There was a main effect of training such that both SSC and CON training significantly increased concentric only peak power at 40% of 1RM (P=0.042) from pre to post-tests; this also neared significance for eccentric/concentric peak power at 40% of 1RM (P=0.055) from pre-training to post-training. There was, however, no significant group differences for SSC or CON in either testing condition (P=0.499 and P=0.503, respectively). In both testing conditions CON increased the peak power output by a larger, but not significant, percentage (37% vs. 34% in the concentric only condition and 29% vs. 21% in the eccentric/concentric condition).
Both SSC and CON significantly increased concentric only peak power at 60% of 1RM (P=0.021) from pre to post-tests; but this was not significant for eccentric/concentric peak power at 60% of 1RM (P=0.083) from pre-training to post-training. There was however no significant group difference for SSC or CON training in either testing condition (P=0.499 and P=0.503, respectively).

**Table 1 - Changes in strength and functional performance measures.**

<table>
<thead>
<tr>
<th>Changes in Strength and Functional Performance Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training Type</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>1RM (kg)*</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Three Hop Test (m)*</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Vertical Jump (cm)*</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

No significant differences were found between training groups from pre to post values for any of the measures within the table, but all showed significant increases following training. Strength measures from pre to post increased significantly (P<0.001), as did the three hop test performance (P = 0.015) and single leg vertical jump performance (P = 0.041). Functional power tests had larger increases in performance with CON training while strength increased more in the SSC group, but none of these differences between training groups were significant.
DISCUSSION

The purpose of this study was to test the hypothesis that concentric-only training would confer greater benefits to measures of concentric strength and power only, and would not result in improvements in stretch-shortening exercises. It was seen however that all measures of functional muscular performance increased from pre to post-tests following training, and that the increase was not significantly different between the two training types. There appeared to be a trend in power measures of both contraction types, both functional and on the leg press, to produce slightly larger gains following CON training even though many of these actions required a stretch-shortening type movement. However, statistical analyses indicate that this change was not significant. One potential reason for this trend could be the additional sets (although controlled for external work) may have required more muscular effort to be completed, thus inducing greater adaptations.

Interestingly our training protocol at only a moderate resistance of 60% of 1RM was able to bring about significant increases in the specific strength and power (leg press) as well as functional performance increases. Although no specific training type caused a greater increase, this shows that when moderate loads are moved as quickly as possible it cause increases in strength, power and functional performance of recreationally active males. This result agrees with earlier research (1) which also showed light loads (45-50% 1RM) are able to increase the maximal dynamic strength in untrained participants. Perhaps this is a result of learning the exercise and developing more skilled coordination and motor patterns (10).

The one-legged study design employed was such that only peripheral changes could be responsible for changes. Central changes have a tendency to have a cross over effect during studies on one limb (2, 3). Since the study was performed with each participant training both legs in a different manner the individuals would have ruled out central effects as central adaptations would occur for both training mechanisms in each participant. This means that only peripheral changes could be the cause of changes within the study we carried out. Although the present research does control for central changes, this limits the findings as central changes may cause different changes to the peripheral adaptations due to the neural contribution involved in the interventions and the potential for cross-over.

The length of the training regime was limited to six weeks, which could be a factor that influenced the results. A period of training lasting only six weeks is generally considered to consist of mainly neural adaptations (12) and although these are primarily what would cause the difference here, a longer training period would ensure that greater gains are seen by the participants which in turn allows for clearer differences to be seen. The volume could also be increased through having participants train three times a week which would increase the frequency of the training stimulus and perhaps influence the magnitude of improvement that could be attained. On top of these recommendations, future research should also increase participant numbers in a similar style study, and avoid any crossover effects by employing a wash out period or assigning each training type to different participants.

CONCLUSION

All measures of functional muscular performance and strength increased from pre to post measures following both types of training, but there was no significant difference for training type for any variable measured. There did however appear to be a trend in power measures, both functional and on the leg press, to produce slightly larger gains following concentric only training even though many of these actions require a stretch-shortening type movement. Although statistical analyses indicate that this change was not significant.

REFERENCES

MATCH DEMANDS OF SEMI PROFESSIONAL RUGBY LEAGUE REFEREES: A COMPARATIVE STUDY

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INTRODUCTION

Rugby league referees are responsible for adjudicating on player actions during play to ensure a fair and safe competition during match play for competitors. In doing so, referees must endure extensive physical demands in order to keep pace with play and position themselves with an unobstructed view of play. Despite the importance of their role to match outcomes, limited research exists on the match demands of rugby league referees (1,2). Moreover, the recent introduction of the two-referee model (previously one referee) in the National Rugby League (NRL) and lower level National Youth competition (NYC) may have changed the physical demands of rugby league referees however this is yet to be verified. The two-referee model includes both a main referee (responsible for controlling the 10 meter defensive line) and assistant referee (responsible for controlling the ruck area). Given the differentiation of these refereeing duties, it is plausible to suggest that the physical running demands might be different between these referees, as well as the aforementioned one referee model.

To date, only one study has analysed the physical demands of the main and assistant referee roles of the two-referee model (1). The results were that the main referee performed less extensive movement demands than the assistant referee (second half total distance: 3902 ± 380 m vs. 4057 ± 412 m; VHSR distance: 89 ± 69 m vs. 106 ± 74 m, respectively). As such, this study highlighted the differences in refereeing roles under the two-referee model, however it did not examine the impact of the assistant referee on the match running demands typical of the one referee model. Therefore, the aim of this study was to investigate the match running demands of both the one and two referee models through the NYC. It was hypothesized that there will be substantial differences in the running demands between the NYC one-referee (NYC₁) as well as the NYC two-referee main (NYC₂M) as a result of the inclusion of the assistant referee (NYC₂A).

METHODS

A cohort of semi-professional rugby league referees (n=17, age: 30.5 ± 4.1 yr., body mass: 75.9 ± 8.1 kg, height: 176.8 ± 5.3 cm) were recruited from the NRL part time referee squad and New South Wales (NSW) grade squad to participate in this study. All participants were selected based on weekly appointments in the NYC using the one and two referee model. The NYC adopted the two-referee model (NYC₂) for all NYC matches that were nationally televised (two per week) whereas matches that were not televised (six per week) employed the one-referee model (NYC₁). The referees were classed as either the ‘main’ or ‘assistant’ referee in the two-referee model based on the selection by their coaching staff. A total of 37 data files taken from 26 NYC matches were included within the analysis (NYC₂M: n=11, NYC₂A: n=11, NYC₁: n=15).

During all matches, participants were fitted with a 5 Hz Minimaxx global positioning system (GPS) device (Catapult Innovations, Melbourne, Australia) and a Polar Team Pro heart rate monitor (Polar Electro, Kemple, Finland). The GPS device was fitted in an undergarment located between the scapulae that was worn underneath the referee’s normal on field communications vest and fitted ~30 min prior to match play. At the conclusion of each half, referees were required to rate their perceived exertion (RPE) using the CR-10 scale.

Following each match, data was downloaded to a computer using catapult sprint software (v5.1, Catapult Innovations, Melbourne, Australia), prior to being manually divided into halves with all non-playing data (half-time) being removed from analysis. Data was then transferred to a Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA) spreadsheet for data storage and analysis.

Match Analysis

Data were collected across a total of 26 matches during the 2015 NYC regular season. Measures of total distance (TD), relative distance (m·min⁻¹), as well as the time spent and distance covered at low speed running (LSR: <14.4 km·h⁻¹), high speed running (HSR: 14.4 km·h⁻¹ - 23 km·h⁻¹) and very high speed running (VHSR: >23 km·h⁻¹) were examined for each referee. Data were analysed across an entire match, and also divided into each half to determine within match variation. Heart rate data was recorded within the GPS units where it was downloaded concurrently for analysis, with mean and maximum heart rate determined for analysis.
STATISTICAL ANALYSIS

All data are presented as means ± standard deviations (SD). Data were assessed for normality and sphericity and was treated accordingly throughout subsequent analysis. Data were divided according to referee model (i.e. one or two referees) and referee role (i.e. main or assist) and identical analyses were performed on each discipline. Independent and paired samples t-tests were used for between (referee models) and within (match halves) comparisons, respectively. Cohen’s effect size statistics were calculated and interpreted as 0.5 (moderate), 0.8-0.99 (large) and >1 (very large). Analysis was performed using PASW (v22.0, SPSS Inc., Chicago, Illinois, USA) statistics package and Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA). Statistical significance was set at p < 0.05.

RESULTS

The data for distance covered and time spent in the various locomotor categories for each refereeing model is presented below in table 1. There were significant differences (p<0.05) between the NYC1 and NYC2M referee for distance covered through HSR across all time points, as well as the distance covered in LSR in the first half and total match. There was also a significant difference (p<0.05) between the NYC1 and NYC2M for the total distance covered across a match. There were no significant differences for time spent in locomotor categories across any referee level. Moderate to very large effect sizes were observed for distance covered and time spent in various locomotor categories between the NYC1 and NYC2M. Significant differences (p<0.05) were observed between halves for the average heart rate of the NYC1 referee between halves with a moderate effect observed for both NYC1 and NYC2M referees. Further, significant differences (p<0.05) were observed for RPE in the NYC1 and NYC2M referees between halves.

Table 1 - The distance covered and time spent in various locomotor categories for the National Youth Competition single referee (NYC1), two-referee main (NYC2M) and two-referee assistant (NYC2A) for the first and second halves of match play.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Distance (m)</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NYC1</td>
<td>NYC2M</td>
</tr>
<tr>
<td>1st Half</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSR</td>
<td>3206 ± 196</td>
<td>3331 ± 153</td>
</tr>
<tr>
<td>HSR</td>
<td>819 ± 163</td>
<td>1015 ± 301</td>
</tr>
<tr>
<td>VHSR</td>
<td>171 ± 94</td>
<td>152 ± 103</td>
</tr>
<tr>
<td>Total</td>
<td>4031 ± 238</td>
<td>4202 ± 218</td>
</tr>
<tr>
<td>Meterage (min⁻¹)</td>
<td>95 ± 5</td>
<td>98 ± 7</td>
</tr>
<tr>
<td>2nd Half</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSR</td>
<td>3298 ± 196</td>
<td>3534 ± 290</td>
</tr>
<tr>
<td>HSR</td>
<td>781 ± 229</td>
<td>1088 ± 363</td>
</tr>
<tr>
<td>VHSR</td>
<td>166 ± 99</td>
<td>196 ± 133</td>
</tr>
<tr>
<td>Total</td>
<td>4087 ± 475</td>
<td>4432 ± 382</td>
</tr>
<tr>
<td>Meterage (min⁻¹)</td>
<td>94 ± 10</td>
<td>98 ± 8</td>
</tr>
<tr>
<td>Match</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSR</td>
<td>6499 ± 586</td>
<td>6826 ± 279</td>
</tr>
<tr>
<td>HSR</td>
<td>1584 ± 236</td>
<td>2102 ± 621</td>
</tr>
<tr>
<td>VHSR</td>
<td>336 ± 162</td>
<td>348 ± 223</td>
</tr>
<tr>
<td>Total</td>
<td>8113 ± 609</td>
<td>8630 ± 543</td>
</tr>
<tr>
<td>Meterage (min⁻¹)</td>
<td>94 ± 6</td>
<td>97 ± 6</td>
</tr>
</tbody>
</table>

* significantly different to first half within respective group; # significantly different to NYC1; a moderate effect to NYC1, b large effect to NYC1, c very large effect to NYC1, d moderate effect to NYC2M.

DISCUSSION

This is the first study to report on the inclusion of an assistant referee (NYC2A) on the match running demands of the main referee (NYC2M) and it adds further data comparing the physical demands of the two-referee model to the historically-employed one referee model (NYC1) in rugby league. The current results are that the running demands of
the NYC\textsubscript{2M} referee were similar to that of the NYC\textsubscript{1} referee, suggesting that the inclusion of an assistant referee does not reduce the total running demands of the main referee. Of interest, some findings suggest that the running demands of the main referee in the two-referee model are increased when compared to the NYC\textsubscript{1}.

Interestingly, the distance covered at HSR across all time points were significantly greater in the NYC\textsubscript{2M} referee when compared to the NYC\textsubscript{1} referee. Moreover, the average heart rate of the NYC\textsubscript{1} referee was significantly reduced in the second half of the match, whilst the NYC\textsubscript{2m} referee showed no significant change. However, the NYC\textsubscript{2m} referee demonstrated a moderately lower average heart rate across all time points of the match, with both groups reporting significantly higher rating of perceived exertion scores in the second half. These findings suggest that the inclusion of an assistant referee does not reduce the running demands of the main referee and that the benefits of this model are possibly improved decision-making, but this is yet to be confirmed. Separately, similar match running demands were reported between the main and assistant referees in the two-referee model. Collectively, the data conflicts with the findings of Jeffriess et al (1) who reported that the running demands of the assistant referee were greater than the main referee in the professional National Rugby League competition (NRL). This may reflect the differences between the running demands of players and level of professionalism that exists within the NRL and NYC competitions.

CONCLUSION

In summary, from the present study we report the match running demands of various models of rugby league refereeing at the semi-professional level. The main findings are that the inclusion of an assistant referee does not reduce the match running demands of the main referee in the two-referee model. Of interest, the HSR running demands of the NYC\textsubscript{2M} referee was significantly greater than the NYC\textsubscript{1} referee across all time points of the match. It is likely that this reflects the need for the main referee to often switch positions on field with the assistant referee during play.

PRACTICAL IMPLICATIONS

The reported match running demands of semi-professional rugby league referees can be used in the development of specific training and testing protocols for this level of competition and for each specific referee roles.

ACKNOWLEDGEMENTS

The authors would like to thank the NRL part time referee squad, NSW grade squad and their respective coaching staff for their assistance in this project.

REFERENCES


THE MEANINGFUL USE OF SPRINT PADDLING DATA TO DETERMINE SURFER’S STRENGTHS AND WEAKNESSES: A GENDER COMPARISON

Joanna Parsonage¹,², Josh L. Secomb¹,², Sophia Nimphius¹,², Oliver R. L. Farley¹,², Lina Lundgren¹,², Tai T. Tran¹,² and Jeremy M. Sheppard¹,²

¹Surfing Australia High Performance Centre, Casuarina Beach, Australia  
²Centre for Exercise and Sport Science Research, Edith Cowan University, Joondalup, Australia

INTRODUCTION

Surfboard riding is one of Australia National sports participated by over 2.3 million people, with 3 in 10 surfers now being female (1). Despite this growth, females still have large windows of opportunity to reach their potential and progress within the world championship tour (WCT). At the competitive level, both competitive male surfers (CMS) and competitive female surfers (CFS) are judged on performance and complexity of manoeuvres (6). However, prior to wave riding, intense sprint paddle bouts are required allowing for a quicker pop-up and faster entry speed into the first manoeuvre (3). This requires surfers to possess upper body strength to facilitate surf specific performance characteristics such as sprint paddle ability (8). Previous research has noted females are significantly slower in sprint paddle velocity over 15 meters (7). However, the aforementioned research did not conduct a detailed analysis of time to complete each 5-metre split (e.g. 0-5 m, 5-10 m and 10-15 m). Much like a sprint start, the use of split times can provide a better representation of specific strengths and weaknesses (e.g. initial acceleration versus maximum velocity) of both genders in paddling ability over 15 metres. Therefore the purpose of this study was to report and compare CFS and CMS over a 15-metre sprint paddle, with the intention to identify both individual athlete difference and between gender differences during the initial acceleration phase (0-5 m) and maximum velocity phase (10-15 m).

METHODS

Experimental approach

A cross-sectional comparison between genders was performed to compare sprint times between male and female surfers. To identify individual surfer strengths and weaknesses, as well as gender comparisons, standardized (z-scores) 0-5 metres and 10-15 metres for CFS and CMS were used to determine if scores for each subject were meaningfully different from the group mean.

Subjects

Thirty-six competitive surfers completed the current study (age; 20 ± 4.5 years, mass; 65.5 ± 9.7 Kg, Height; 1.70 ± 0.7m, Sum of 7: 70.9 ± 26.9 mm). Male (n=18) and female (n=18) surfers were matched for both age and competitive level (table 1). Edith Cowan University Human Ethics Committee approved the study and its procedures, and participants were provided with an information letter detailing the study prior to obtaining their informed consent or assent and additional consent from the parents or guardians.

Table 1 - Descriptive characteristics for competitive male surfers (CMS) and competitive female surfers (CFS).

<table>
<thead>
<tr>
<th>Variables</th>
<th>CMS (n=18)</th>
<th>CFS (n=18)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>20.9±5.4</td>
<td>19.1±3.3</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>71.7±9.0</td>
<td>59.3±5.5</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.77±0.47</td>
<td>1.65±0.48</td>
</tr>
<tr>
<td>Sum of 7 (mm)</td>
<td>50.3±8.7</td>
<td>91.5±22.9</td>
</tr>
</tbody>
</table>

Procedures

Sprint paddle testing was conducted in an outdoor 25 m swimming pool. Subjects used their own surfboard for the testing (the one they use in competition) and wore their usual surfing attire (e.g. board shorts, swimsuits) in order to provide context validity. Before the paddling test, subjects performed a progressive paddling warm-up consisting of 200 m of low-intensity paddling, followed by a specific sprint paddling warm-up of 4 x 15 m sprint paddling efforts at 60, 70, 80, and 90% volitional effort on approximately two minute time intervals (8). After two minutes rest, the subjects then performed two maximal effort 15m sprint-paddling time-trials to determine maximum sprint paddling performance. The sprint paddle efforts were initiated from a stationary, prone lying position. Using a purpose-built horizontal position transducer (I-REX, Southport, Australia) attached to the back of each subject’s shorts, kinematic data was obtained and stored for analysis on a personal computer. The position transducer recorded a time-stamp for each 0.02 m of displacement, thereby allowing determination of sprint time (s) from the start to 5 m, 10m, and 15 m, and by differentiation to determine peak sprint paddle velocity, a procedure that has been validated previously with surfboard...
paddling in a pool (2). Our previous validation work has demonstrated a population-specific (TEM) of 0.11 s (%CV: 1.13) for the 15 m sprint paddle (9).

Statistical analysis
Means and standard deviations of 15 m sprint paddle times (0-5 m, 5-10 m and 10-15 m) were calculated for CFS and CMS. Independent t-tests were performed with a holm-bonferonni sequential correction for multiple comparisons (4). All statistical analysis was performed using SPSS (version 22.0; Chicago, IL) with statistical significance set at ps0.05. Further analysis determined whether 0-5 metre time and 10-15 metre times, provided a different assessment of sprint paddle ability over 15 metres. In order to do this both 0-5 metre and 10-15 metre split times were converted to z-scores using the following formula: z-score= (subjects test score - mean score from the sample)/ standard deviation. The SWC is equal to the between-subject SD multiplied by 0.2, which is the typical small effect (5). As all scores were standardized a z-score ≥ 0.2 exceeded the SWC and was deemed to have a meaningful difference. Negative z-scores over both 0-5 m and 10-15m, represented a faster than mean paddling performance, whilst a positive z-score represented a slower than mean paddling performance.

RESULTS
Descriptive data for the 15-metre sprint paddle test is presented in Table 2. All sprint paddle times were found to be significantly greater for CMS (P < 0.001) in comparison to CFS. Figure 1 and Figure 2 display the z-scores for both the acceleration phase (0-5 m) and maximum velocity phase (10-15 m) of the sprint paddle for each CMS and CFS participants. Not one CFS was faster than the group mean over the first five metres as indicated by all positive z-scores in Figure 2. However two CFS (participant 8 and 16) exceeded the SWC and had a faster than mean paddle performance over 10-15 metres. All except one CMS athlete produced a faster than SWC difference in 5 m) and maximum velocity phase (10-15 m) of the sprint paddle for

Table 2 - Sprint paddle performance M (±SD) of competitive male surfers (CMS) and competitive female surfers (CFS).

<table>
<thead>
<tr>
<th>Sprint Paddle</th>
<th>CMS</th>
<th>CFS</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5m (s)</td>
<td>3.69 ± 0.24</td>
<td>4.20 ± 0.17</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>5-10m (s)</td>
<td>2.91 ± 0.20</td>
<td>3.23 ± 0.24</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>10-15m (s)</td>
<td>2.94 ± 0.20</td>
<td>3.30 ± 0.16</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Figure 1 - Z-score for each CMS over 0-5 metres and 10-15 metres. The bars located within the dotted lines indicate a difference in Z-scores that is less than the ‘smallest worthwhile change’ (SWC) difference from the mean of the groups. Bars of a beyond either dotted line indicates paddling performance of either a faster or slower difference from the mean that is considered greater than a SWC. This allows individual to compare the magnitude of the performance in the initial acceleration (0-5) versus the maximal velocity (10-15) splits of paddling performance.
This in turn suggests that the group mean allowed for direct comparisons of the applied to the water has to occur at a faster rate. Despite this initial producing a faster than average 

disadvantage during the acceleration phase of sprint paddling, of which seems to influence their performance during the maximal velocity phase. Further, the use of z-scores over the two splits that represent the acceleration phase (0-5) and the maximal velocity phase (10-15) provide direct information on individual strengths and weakness of each athlete that varied both within and between genders.

**PRACTICAL APPLICATION**

Strength and conditioning practitioners need to focus on the relative maximal pull strength of their CFS, because it will aid their sprint paddle ability, specifically over during the first five metres of acceleration. An improvement in sprint

**DISCUSSION**

The purpose of this study was to report and compare the strength and weakness of CFS and CMS over a 15-metre sprint paddle test, specifically looking at the acceleration phase (0-5 m) and maximum velocity phase (10-15 m). First, there was a significant difference in sprint paddle time over 0-5, 5-10 and 10-15 metres between CFS and CMS (p<0.001). This is in support of previous work by Secomb and colleagues (7). Although, there is clearly a significant difference between the groups in means, it was of greater importance to present an example of individual performances, and strengths and weaknesses between individuals and in comparison between genders in initial acceleration paddling ability and maximal velocity paddling ability. This provides an understanding of which area of performance limits their overall 15-metre paddle velocity to the greatest degree.

The conversion of individual split times to z-scores, against the group mean allowed for direct comparisons of the strength and weaknesses of CFS and CMS over 0-5 and 10-15 metres. It is evident from the results that CFS are at a disadvantage during the first five metres (acceleration phase), with not one participant producing a faster than average paddling performance. Previous research has identified very strong correlations between relative upper body pulling strength and time to 5 metres (r=0.94) (8), implying that upper body pull-up strength accompanied by low fat mass are two factors important in optimizing sprint paddle performance when trying to accelerate. This in turn suggests that the lack of sprint paddling performance over the initial five metres may be attributed to a lack of upper body pull strength within the CFS population. Slower paddle performance by CFS over the initial five metres, may limit their ability to compete for the best waves against male surfers at local breaks, as surfing etiquette dictates that the surfer who is closest to the peak and can enter the wave earliest is the only person that can ride that wave.

Results showed that CMS also produced faster than average paddling performance during the maximum velocity phase (10-15 m), compared to 16 out of 18 CMS who produced a slower than average paddling performance. If CMS are able to produce a greater force over the first five metres, they will be entering the subsequent 5-10 metres and 10-15 metres with less inertia. Based on the force-velocity curve, as this velocity of movement increases, rate of paddle force application becomes critical; therefore the force applied to the water has to occur at a faster rate. Despite this initial deficit, there were 6 CFS surfers with greater deficits in acceleration (0-5) in comparison to maximum velocity (10-15) as demonstrated in Figure 2. In conclusion, CFS seem to be at a disadvantage during the acceleration phase of sprint paddling, of which seems to influence their performance during the maximal velocity phase. Further, the use of z-scores over the two splits that represent the acceleration phase (0-5) and the maximal velocity phase (10-15) provide direct information on individual strengths and weakness of each athlete that varied both within and between genders.

**Figure 2** - Z-score for each CMS over 0-5 metres and 10-15 metres. The bars located within the dotted lines indicate a difference in Z-scores that is less than the ‘smallest worthwhile change’ (SWC) difference from the mean of the groups. Bars of a beyond either dotted line indicates paddling performance of either a faster or slower difference from the mean that is considered greater than a SWC. This allows individual to compare the magnitude of the performance in the initial acceleration (0-5) versus the maximal velocity (10-15) splits of paddling performance.

The conversion of individual split times to z-scores, against the group mean allowed for direct comparisons of the strength and weaknesses of CFS and CMS over 15-metre sprint paddle test, specifically looking at the acceleration phase (0-5 m) and maximum velocity phase (10-15 m). First, there was a significant difference in sprint paddle time over 0-5, 5-10 and 10-15 metres between CFS and CMS (p<0.001). This is in support of previous work by Secomb and colleagues (7). Although, there is clearly a significant difference between the groups in means, it was of greater importance to present an example of individual performances, and strengths and weaknesses between individuals and in comparison between genders in initial acceleration paddling ability and maximal velocity paddling ability. This provides an understanding of which area of performance limits their overall 15-metre paddle velocity to the greatest degree.

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**PRACTICAL APPLICATION**

Strength and conditioning practitioners need to focus on the relative maximal pull strength of their CFS, because it will aid their sprint paddle ability, specifically over during the first five metres of acceleration. An improvement in sprint
Paddle performance will enable females to compete for a larger number of waves, increasing their wave riding time and number of manoeuvres executed. An increase in paddling velocity on wave entry will also allow for quicker pop-up and a longer wave ride. Additionally, use of z-scores allows practitioners to evaluate the strengths and weaknesses of their athletes both within and between the genders to assist in understanding the area for the greatest "window of adaptation".

REFERENCES

THE TRAINING-SPECIFIC ADAPTATIONS RESULTING FROM A SHORT BLOCK OF COMBINED STRENGTH, PLYOMETRIC AND GYMNASTICS TRAINING

Josh L. Secomb¹,², Sophia Nimphius¹,², Lina Lundgren¹,², Joanna Parsonage¹,², Oliver R. L. Farley¹,², Tai T. Tran¹,² and Jeremy M. Sheppard¹,²

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INTRODUCTION

It has been extensively reported that an athlete’s lower-body strength and jumping performance is important for competitive performance (1, 11). As such, it is important to understand how best to develop lower-body strength and jumping performance, or the training-specific adaptations that underpin these qualities using a variety of training modalities. Previous research has highlighted that vastus lateralis (VL) and lateral gastrocnemius (LG) muscle structures are significantly related to lower-body strength and jumping performance (4, 12), and are also highly adaptable to training (2, 9). Due to this, understanding the concomitant changes in muscle structure that result from a variety of training modalities provides highly useful information to strength and conditioning coaches and sport scientists.

Many sports, such as surfing, tennis and golf have limited time for training between major competitions, typically 2-6 weeks. As such, these sports often have no choice but to concurrently train strength, plyometric and other modalities within the same training block. Whilst, previous research has reported on the training-specific adaptations in lower-body muscle structure and physical qualities resulting from concurrent training (2, 9), to our knowledge no previous research has investigated the training-specific adaptations resulting from a combined strength, plyometric and gymnastics training block. Therefore, the purpose of this study was to determine whether likely training-specific adaptations in lower-body muscle structure, strength, and jumping performance result from a short six week block of combined strength, plyometric and gymnastics training.

METHODS

Experimental Approach

The current study required all participants to complete three sessions a week for six weeks (18 sessions) of a combined strength, gymnastics and plyometric training program. In addition, each participant completed a pre- and post-testing assessment of lower-body strength and power. Their strength and jumping performance were assessed by countermovement jump (CMJ), squat jump (SJ) and isometric mid-thigh pull (IMTP), and muscle structure of the VL and LG was assessed using ultrasonography. Participants were provided with an appropriately periodised, individual training program based on their pre-testing results.

Participants

Seven internationally competitive male surfers (22.8 ± 4.1 y; 176.3 ± 4.8 cm; 71.4 ± 7.6 kg) volunteered to participate in this study. For inclusion in the study, subjects were required to be: (i) actively competing at an international level, (ii) aged 18-35 years, and (iii) currently free of any injury or medical condition, as per a health screening questionnaire. The study and its procedures were approved by Edith Cowan University Human Ethics Committee (approval number: 10228), and participants were provided with information detailing the study prior to providing informed consent and screened for medical contraindications.

Procedures

Ultrasonography

Assessments of VL and LG muscle structure were performed with a real-time B mode ultrasonography (SSD-1000; Aloka Co., Tokyo, Japan), utilising a 7.5MHz linear probe (9, 13). VL muscle thickness and pennation angle measures were taken at 50% of the distance between the greater trochanter and lateral epicondyle of the femur, with the participants in a supine position (4, 12). LG measures were taken at two-thirds of the distance between the lateral epicondyle of the femur and lateral malleolus, with participants placed in a prone position (4, 12). The fascicle length (FL) of the VL and LG were calculated with the following equation; FL=muscle thickness x (sin pennation angle)⁻¹ (Fukunaga et al.(5)). Two images were recorded of the VL and LG from both legs, with analysis performed as previously described in Secomb et al. (12). For analysis, the results of the left and right leg were combined and averaged. The reliability for all muscle structure variables have previously been reported as high in a similar cohort (Intraclass Correlation Coefficient [ICC]: 0.87-1.00 and Coefficient of Variation [CV%]: 0.8-6.5%) (12).

Lower-Body Strength and Jumping Performance

Following a warm-up consisting of dynamic movements, squats and lunges, participants completed the strength and power testing in the order of; CMJ, SJ, and IMTP (12). Participants performed the CMJ and SJ on a portable force plate.

The training-specific adaptations resulting from a short block of combined strength, plyometric and gymnastics training.

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(400 Series Performance Force Plate; Fitness Technology, Adelaide, Australia) whilst holding a wooden dowel across their backs, to eliminate any potential arm-swing contribution (12). The force plate was connected to a portable laptop, which was interfaced with an analysis software package (Ballistic Measurement System; Fitness Technology, Adelaide, Australia), with data sampling at 600 Hz. The participants performed three trials of the CMJ and SJ, with the instructions to jump as high and quickly as possible (12, 15). One minute of rest was provided between each trial, with three minutes of rest between the CMJ and SJ trials (13).

The SJ trials were performed with a linear position transducer attached to the wooden dowel (PT9510; Fitness Technology, Adelaide, Australia), which was interfaced with the force plate (12). The starting position for the SJ trials were determined whereby the top of the thighs were parallel with the ground. Participants held this position for three seconds, before being instructed to jump as high as possible (14). Trials for the SJ were discarded in the event of a small amplitude countermovement of greater than 2 cm, as determined from the displacement-time trace on the analysis software (14). Each participant's best trial for the CMJ and SJ that was used for analysis, was determined by the greatest jump height. All jumps were analyzed for the following variables; peak force (PF), PF relative to body weight (rPF) (N-BW⁻¹), peak velocity (PV), eccentric peak velocity (Vₑₚ), and jump height (H). Furthermore, eccentric leg stiffness was calculated from the CMJ, with the equation of \( kₑ=CMJ\,PF/CMJ\,Hₑₚ \), whereby CMJ PF is the peak ground reaction force, and CMJ \( Hₑₚ \) is the eccentric centre of mass (COM) displacement (12, 13).

The IMTP was performed on the portable force plate, with the methods previously described in Sheppard et al. (15). Each participant completed two trials of the IMTP, with two minutes of rest between each trial (13). A third trial was performed if there was a difference in the PF between the two trials of greater than 250 N (7). Each participant’s best trial, as determined by the trial with the highest PF, was used to determine the PF and rPF (12). Furthermore, the dynamic strength deficit (DSD) ratio was calculated using the formula; \( DSD=CMJ\,PF/IMTP\,PF \) (16). Reliability of all variables during the CMJ, SJ and IMTP have been previously reported as high with a similar cohort (ICC: 0.82-0.99; CV%: 1.0-6.8%) (12).

**Statistical Analysis**

Hedge’s g effect sizes with 90% confidence intervals (90%CI) were used to determine the practically relevant magnitude of change from pre- to post-testing results of lower-body muscle structure, and strength and jumping performance variables. Hedge’s g was selected in preference of Cohen’s \( d \) in order to account for the small sample sizes. The magnitude of the change was determined with the criteria; <0.2 (trivial), 0.2-0.5 (small), 0.5-0.8 (moderate), and >0.8 (large) (3). Additionally, magnitude-based inferences were calculated for all variables, with the smallest worthwhile change determined as 0.2 \( \times \) between participants’ standard deviation (SD) (6). Using the CV%, the likelihood of true differences were calculated and interpreted with the following descriptors; <25%, trivial; 25-74%, possibly; 75-94%, likely; 95-99%, very likely; and 100%, certain (6).

**RESULTS**

The mean (±SD) pre-testing, post-testing, and measured change for all lower-body muscle structure, and strength and jumping performance variables are presented in Table 1. The magnitude of change (90%CI) and likelihood of true differences for all variables are shown in Figure 1.

**Table 1 - The mean (±SD) for pre-testing, post-testing, and change for all variables of vastus lateralis (VL) and lateral gastrocnemius (LG) muscle structure, and the countermovement jump (CMJ), squat jump (SJ), and isometric mid-thigh pull (IMTP).**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre-testing (mean ± SD)</th>
<th>Post-testing (mean ± SD)</th>
<th>Change (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LG Thickness (cm)</td>
<td>1.47 ± 0.26</td>
<td>1.54 ± 0.22</td>
<td>0.07 ± 0.16</td>
</tr>
<tr>
<td>LG Angle (°)</td>
<td>14.9 ± 1.5</td>
<td>15.5 ± 1.2</td>
<td>0.6 ± 1.4</td>
</tr>
<tr>
<td>LG FL (cm)</td>
<td>5.78 ± 1.04</td>
<td>5.82 ± 1.14</td>
<td>0.04 ± 0.66</td>
</tr>
<tr>
<td>VL Thickness (cm)</td>
<td>2.23 ± 0.22</td>
<td>2.46 ± 0.22</td>
<td>0.24 ± 0.13</td>
</tr>
<tr>
<td>VL Angle (°)</td>
<td>18.3 ± 2.0</td>
<td>19.0 ± 1.2</td>
<td>0.7 ± 2.3</td>
</tr>
<tr>
<td>VL FL (cm)</td>
<td>7.24 ± 0.80</td>
<td>7.65 ± 0.74</td>
<td>0.41 ± 1.00</td>
</tr>
<tr>
<td>CMJ rPF (N·BW⁻¹)</td>
<td>2.39 ± 0.21</td>
<td>2.54 ± 0.45</td>
<td>0.15 ± 0.37</td>
</tr>
<tr>
<td>CMJ PV (m·s⁻¹)</td>
<td>2.91 ± 0.12</td>
<td>3.00 ± 0.11</td>
<td>0.08 ± 0.05</td>
</tr>
<tr>
<td>CMJ PVₑₚ (m·s⁻¹)</td>
<td>2.85 ± 0.16</td>
<td>2.96 ± 0.09</td>
<td>0.11 ± 0.10</td>
</tr>
<tr>
<td>CMJ H (m)</td>
<td>0.53 ± 0.04</td>
<td>0.56 ± 0.04</td>
<td>0.03 ± 0.02</td>
</tr>
<tr>
<td>CMJ Hₑₚ (m)</td>
<td>0.46 ± 0.06</td>
<td>0.49 ± 0.05</td>
<td>0.03 ± 0.03</td>
</tr>
<tr>
<td>Eccentric Leg Stiffness (N·m⁻¹)</td>
<td>3635 ± 471</td>
<td>3622 ± 430</td>
<td>-13 ± 455</td>
</tr>
<tr>
<td>SJ rPF (N·BW⁻¹)</td>
<td>2.24 ± 0.54</td>
<td>2.07 ± 0.09</td>
<td>-0.16 ± 0.46</td>
</tr>
<tr>
<td>SJ PV (m·s⁻¹)</td>
<td>3.07 ± 0.25</td>
<td>3.02 ± 0.29</td>
<td>-0.05 ± 0.26</td>
</tr>
<tr>
<td>SJ Height (m)</td>
<td>0.49 ± 0.05</td>
<td>0.50 ± 0.05</td>
<td>0.01 ± 0.02</td>
</tr>
<tr>
<td>IMTP PF (N)</td>
<td>2466 ± 408</td>
<td>2947 ± 684</td>
<td>482 ± 372</td>
</tr>
<tr>
<td>IMTP rPF (N·BW⁻¹)</td>
<td>3.52 ± 0.45</td>
<td>4.15 ± 0.72</td>
<td>0.63 ± 0.49</td>
</tr>
<tr>
<td>DSD Ratio</td>
<td>0.68 ± 0.08</td>
<td>0.62 ± 0.09</td>
<td>-0.07 ± 0.10</td>
</tr>
</tbody>
</table>
DISCUSSION

The purpose of this study was to determine the magnitude of training-specific adaptations during a short block of combined strength, plyometric and gymnastics training. The results of this study identified that a small magnitude likely increase resulted in LG thickness, with a large magnitude certain increase observed in VL thickness. Additionally, a large magnitude very likely increase was calculated in IMTP PF and rPF. Furthermore, moderate magnitude very likely increases were identified in CMJ PV, \( V_{\text{ecc}} \) and \( H_{\text{ecc}} \), with a moderate magnitude likely, and possible increase in \( H_{\text{ecc}} \) and CMJ H, respectively. These results suggest that training-specific adaptations can be achieved from a short block of combined strength, plyometric and gymnastics training.

Significant relationships have previously been reported between VL and LG thickness, and IMTP PF (\( r=0.53-0.67; \ r=0.54, \) respectively) (12, 13). The relationship between these variables were strengthened from just correlations, as likely increases were observed in VL and LG thickness, with concomitant increases in IMTP PF and rPF. Secomb et al. (12) suggested that increased thickness may enhance the muscle force producing capabilities, due to a greater number of muscle subunits within a given area. As no likely changes were observed in either the pennation angle or FL of the VL or LG, it cannot be determined whether these increases in thickness were due to a preferential increase in the number of sarcomeres in parallel (pennation angle) or series (FL). Future research should perform an identical study, with greater subject numbers to determine what the underlying mechanism is for these increases in thickness.

The present athletes had likely increases in CMJ \( V_{\text{ecc}} \) and \( H_{\text{ecc}} \), suggesting that following the short training block they were better able to utilise the eccentric component of the CMJ. Secomb et al. (10) recently reported that a stronger group of athletes (based on IMTP rPF), had greater \( V_{\text{ecc}} \) (\( p<0.01, \ d=1.40 \)) and \( H_{\text{ecc}} \) (\( p<0.01, \ d=1.41 \)), when compared to a weaker group. As concomitant likely increases were observed in \( V_{\text{ecc}} \), \( H_{\text{ecc}} \) and IMTP PF in this study it appears that there is also cause and effect between increased lower-body isometric strength and the ability to utilise the eccentric component of the CMJ. Whilst it is unclear if this group improved their CMJ H as they only reported a possible increase, it may be that the short duration of the training block didn’t provide them with sufficient time to learn to use their increased lower-body isometric strength (8).

PRACTICAL APPLICATIONS

The results of this study indicate that likely training-specific adaptations can be achieved in lower-body muscle structure, and strength and jumping performance, following a short block of combined strength, plyometric and gymnastics training. As such, these results provide strength and conditioning coaches working with sports such as, surfing, golf and tennis, with data to determine how best to utilise the short training windows typically experienced between major competitions. Furthermore, these data suggest that cause and effect relationships exist between increases in VL and LG thickness, and increases in lower-body isometric strength and the ability to utilise the eccentric component of a CMJ.

REFERENCES

Acute changes in sprint running performance following ballistic exercise with added lower body loading.
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ACUTE CHANGES IN SPRINT RUNNING PERFORMANCE FOLLOWING BALLISTIC EXERCISE WITH ADDED LOWER BODY LOADING

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2School of Exercise, Biomedical and Health Sciences, Edith Cowan University, Perth, Australia
3High Performance Sport New Zealand, Auckland, New Zealand

INTRODUCTION

Acute enhancement or post-activation potentiation (PAP) of power performance is often studied following conditioning stimuli involving a heavy resistance exercise such as a back squat with a 1-5 repetition maximum (RM) load (e.g.11). However, pairing heavy resistance exercise and sprint-running has logistical limitations (e.g. maneuvering heavy and bulky equipment onto the track or training field), so recent research attention has also focused on ballistic exercises (e.g. jumps, modified Olympic lifts and dynamic warm-ups) as conditioning stimuli that may elicit acute enhancement of sprint performance (for review see: 9).

Potentiation and fatigue interact after a conditioning stimulus (14). The optimal recovery time after a conditioning stimulus to achieve PAP of sprint performance is dependent on the physical characteristics of the subject (e.g. strength level, muscle fibre type composition, training age and gender) and the intensity, volume and type of the conditioning stimulus selected (9, 14). Ballistic exercise (e.g. a jump or an explosive back squat with the load that maximises power output) results in reduced fatigue compared to heavy resistance exercise (e.g. a heavy back squat with a 1RM load) (5) and therefore the time course of the PAP response will change dependent on the intensity and type of conditioning stimulus used (5). Researchers reported an acute enhancement in sprint performance 4-8 minutes after 3 sets of single leg bounds and also 10-15 minutes after 2 sets of drop jumps (8, 16), but not 4-6 minutes after a single set of tuck jumps (15). Vest loading of 3-10% body mass (BM) added weight (AW) was used to increase the intensity of ballistic exercises by several authors and resulted in a 2-3% enhancement in sprint performance 4-8 min after loaded single leg bounds (16) and up to a 5% improvement in change of direction speed 0.25-6 min after a loaded badminton-specific dynamic warm-up (10). However, no change was reported when the time between a loaded dynamic warm-up and sprint performance was up to 17 minutes (4). Although PAP is often studied by pairing biomechanically similar exercises, no studies to date have investigated the PAP sprint response following ballistic exercise with lower body loading. The aim of this exploratory study was to determine the kinematic changes in sprint performance that occur after a range of ballistic exercise protocols with added lower body loading using a single subject research design (1).

METHODS

One male rugby union athlete (former international representative) (29.2 years, 180.8 cm, 87.2 kg) completed four days of testing (Figure 1) each involving a standardised 20-minute warm-up followed by three maximal effort 40 m sprints (pre-test). All elements of warm-up and sprint testing were completed on an indoor running track. On days 1-3 the standardised warm-up was completed with no additional load, while on day 4 an additional load of 3% BM (i.e. 1.3 kg per leg) was attached to the lower body for the duration of the warm-up period. The AW was attached using a Lila™ Exogen™ compression-based exoskeleton suit (Sportboleh Sdh Bhd, Malaysia), with the load evenly distributed between the anterior and posterior aspects of the upper and lower leg (2/3 and 1/3 of the total AW respectively) (Figure 2). After the three pre-test sprints on day 1-3, a short (<10 min) ballistic exercise (BE) protocol was completed prior to three post-test sprints. The BE protocols involved: Day 1 = 3 x 5 double leg drop jumps with 5% BM AW; Day 2 = 3 x 40 m loaded accelerations with 1-5% BM AW; Day 3 = 3 x 20 m flying sprints with 1% BM AW. The additional load was removed prior to all sprint testing. There was 5 minutes of passive rest before all sprints and 3.5 minutes of passive rest before all jumps (Figure 1).

Split times for sprint performance (10, 30, 40, 30-40 m) were recorded with photoelectic cells (Swift Speedlink, Swift Performance Equipment, Australia) (coefficient of variation ~1%; typical error ~ 0.02 s) (2, 3). Kinematic variables were recorded over the initial 15 m of each sprint with an Optojump system (Microgate, Italy; 1000 Hz) (Figure 3) (intraclass correlation coefficient = 0.96-0.99; mean bias = 0.4-2.7%) (6) and over the final 10 m of each sprint with high speed video (Sony RX 10, Sony, Japan; 300 Hz). The kinematic variables determined were flight time (FT), contact time (CT), step frequency (SF) and step length (SL). Additionally vertical stiffness (kVert) was determined from FT, CT and the BM of the subject (12). Each 40 m sprint was split into three phases: (I) the start (START; first 2 steps); (ii) the acceleration (ACCEL; steps 3-8); and, (III) maximum velocity (MAXV; four steps between the 30 and 40 m marks). Kinematic variables were averaged over the two to six steps in each phase. The mean and standard deviation (SD) for all three sprints during each set was calculated and analysed using a single subject AB research design (1). The mean and SD from the pre-test sets on days 1-3 provided a baseline for comparison. A substantial change was deemed to have
occurred if set means after the loaded conditioning stimuli (i.e. drop jumps, loaded accelerations, flying sprints or loaded warm up) fell outside a two SD band from the baseline mean value.

Figure 1 – Testing protocols for Days 1-4.

Figure 2 – Exogen exoskeleton lower body loading with 1.3 kg attached to each leg (i.e. 3% BM AW).

Figure 3 – Sprint test set-up including timing lights and Optojump equipment.

RESULTS

The changes in sprint split times (Table 1) and sprint kinematics (Table 2) were compared to baseline results.

Drop Jumps: SL was reduced by up to 5% during START and ACCEL. The 40 m split time was 1% slower after the drop jumps and this was associated with a 5% decrease in vertical stiffness during MAXV.

Loaded Accelerations: The 10 m split time was 3% faster after the loaded accelerations. CT was up to 3% longer during the START and ACCEL phases and SF was 2% lower during ACCEL. FT was 3% longer and SF was 3% lower during MAXV, however the 30-40 m split time was not substantially changed.
Flying Sprints: There was no substantial change in sprint performance at any distance after the flying sprints. CT was 3% longer during START, while during ACCEL CT was longer (4%) and FT/CT ratio (-4%), vertical stiffness (-9%) and SF (-2%) were all lower. The only substantial change during MAXV was a 2% reduction in SL.

Loaded Warm-Up: There was a substantial improvement in 10, 30 and 40 m split times of up to 4% after the loaded warm-up. CT was longer (4%) and the FT/CT ratio was lower (13%) during the START phase, while SF was slightly lower (1%) during ACCEL. The change in the 30-40 m time did not exceed the two SD threshold, but substantial changes in sprint kinematics were recorded during the MAXV phase: shorter CT (5%) and increased FT (2%), FT/CT ratio (7%), vertical stiffness (13%) and SF (1%).

Table 1 – Mean ± SD for sprint split times up to 40 m after a standardised warm-up (baseline) or after a ballistic intervention. Changes of more than two SD from baseline are deemed substantial and are highlighted in grey.

<table>
<thead>
<tr>
<th>Distance</th>
<th>BASELINE</th>
<th>START</th>
<th>ACCEL</th>
<th>MAXV</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 m (s)</td>
<td>1.87 ± 0.02</td>
<td>4.26 ± 0.03</td>
<td>5.38 ± 0.03</td>
<td>1.13 ± 0.02</td>
</tr>
<tr>
<td>30 m (s)</td>
<td>1.90 ± 0.09</td>
<td>4.31 ± 0.11</td>
<td>5.45 ± 0.12</td>
<td>1.14 ± 0.02</td>
</tr>
<tr>
<td>40 m (s)</td>
<td>1.81 ± 0.06</td>
<td>4.23 ± 0.07</td>
<td>5.38 ± 0.09</td>
<td>1.15 ± 0.03</td>
</tr>
<tr>
<td>30-40 m (s)</td>
<td>1.80 ± 0.08</td>
<td>4.18 ± 0.08</td>
<td>5.30 ± 0.08</td>
<td>1.12 ± 0.02</td>
</tr>
</tbody>
</table>

Table 2 – Mean ± SD for general sprint performance kinematic descriptors during the START (first two steps), ACCEL (steps 3-8) and MAXV (four steps after the 30 m mark) phases.

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>BASELINE</th>
<th>START</th>
<th>ACCEL</th>
<th>MAXV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight Time (s)</td>
<td>0.057 ± 0.003</td>
<td>0.085 ± 0.001</td>
<td>0.124 ± 0.0004</td>
<td></td>
</tr>
<tr>
<td>Drop Jumps</td>
<td>0.061 ± 0.001</td>
<td>0.084 ± 0.002</td>
<td>0.123 ± 0.003</td>
<td></td>
</tr>
<tr>
<td>Loaded Accel.</td>
<td>0.056 ± 0.003</td>
<td>0.086 ± 0.002</td>
<td>0.128 ± 0.008</td>
<td></td>
</tr>
<tr>
<td>Flying Sprints</td>
<td>0.057 ± 0.002</td>
<td>0.084 ± 0.001</td>
<td>0.124 ± 0.004</td>
<td></td>
</tr>
<tr>
<td>Loaded Warm-Up</td>
<td>0.051 ± 0.006</td>
<td>0.084 ± 0.003</td>
<td>0.126 ± 0.005</td>
<td></td>
</tr>
<tr>
<td>Contact Time (s)</td>
<td>0.175 ± 0.002</td>
<td>0.142 ± 0.001</td>
<td>0.107 ± 0.001</td>
<td></td>
</tr>
<tr>
<td>Drop Jumps</td>
<td>0.172 ± 0.005</td>
<td>0.142 ± 0.002</td>
<td>0.109 ± 0.003</td>
<td></td>
</tr>
<tr>
<td>Loaded Accel.</td>
<td>0.180 ± 0.007</td>
<td>0.145 ± 0.001</td>
<td>0.109 ± 0.001</td>
<td></td>
</tr>
<tr>
<td>Flying Sprints</td>
<td>0.181 ± 0.005</td>
<td>0.148 ± 0.001</td>
<td>0.108 ± 0.001</td>
<td></td>
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<tr>
<td>Loaded Warm-Up</td>
<td>0.182 ± 0.009</td>
<td>0.144 ± 0.001</td>
<td>0.102 ± 0.004</td>
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<tr>
<td>Flight Time / Contact Time</td>
<td>0.325 ± 0.020</td>
<td>0.599 ± 0.008</td>
<td>1.16 ± 0.02</td>
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<tr>
<td>Drop Jumps</td>
<td>0.357 ± 0.016</td>
<td>0.594 ± 0.010</td>
<td>1.12 ± 0.05</td>
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<tr>
<td>Loaded Accel.</td>
<td>0.309 ± 0.007</td>
<td>0.593 ± 0.014</td>
<td>1.18 ± 0.07</td>
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<tr>
<td>Flying Sprints</td>
<td>0.313 ± 0.016</td>
<td>0.567 ± 0.006</td>
<td>1.15 ± 0.04</td>
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<tr>
<td>Loaded Warm-Up</td>
<td>0.282 ± 0.044</td>
<td>0.585 ± 0.025</td>
<td>1.24 ± 0.09</td>
<td></td>
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<tr>
<td>Vertical Stiffness (kN/m/kg)</td>
<td>0.20 ± 0.01</td>
<td>0.33 ± 0.01</td>
<td>0.63 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>Drop Jumps</td>
<td>0.21 ± 0.01</td>
<td>0.33 ± 0.01</td>
<td>0.60 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>Loaded Accel.</td>
<td>0.19 ± 0.01</td>
<td>0.31 ± 0.01</td>
<td>0.62 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>Flying Sprints</td>
<td>0.19 ± 0.01</td>
<td>0.30 ± 0.01</td>
<td>0.62 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>Loaded Warm-Up</td>
<td>0.19 ± 0.02</td>
<td>0.32 ± 0.01</td>
<td>0.71 ± 0.06</td>
<td></td>
</tr>
<tr>
<td>Step Length (m)</td>
<td>1.11 ± 0.02</td>
<td>1.56 ± 0.01</td>
<td>2.05 ± 0.0003</td>
<td></td>
</tr>
<tr>
<td>Drop Jumps</td>
<td>1.06 ± 0.02</td>
<td>1.51 ± 0.02</td>
<td>2.04 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>Loaded Accel.</td>
<td>1.13 ± 0.02</td>
<td>1.56 ± 0.01</td>
<td>2.06 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>Flying Sprints</td>
<td>1.11 ± 0.02</td>
<td>1.56 ± 0.01</td>
<td>2.01 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>Loaded Warm-Up</td>
<td>1.14 ± 0.02</td>
<td>1.56 ± 0.01</td>
<td>2.04 ± 0.02</td>
<td></td>
</tr>
</tbody>
</table>

**Table 2 – Mean ± SD for general sprint performance kinematic descriptors during the START (first two steps), ACCEL (steps 3-8) and MAXV (four steps after the 30 m mark) phases.**
DISCUSSION

The two BE interventions that resulted in a substantial acute improvement in sprint performance were the loaded accelerations and the loaded warm-up protocol. Both protocols resulted in longer CT during START/ACCEL enabling more time for horizontal force application, lower SF during ACCEL and a performance improvement over the initial 10 m. However it was only following the loaded warm-up that VMAX sprint kinematics were altered in a way that is consistent with improved VMAX performance (increased FT, SF and vertical stiffness and decreased CT), and that the speed improvement was sustained through to the end of the 40 m sprint. Conversely, loaded drop jumps with 5% BM AW altered performance in a way that resulted in decreased START/ACCEL phase SL and a 5% decrease in MAXV phase vertical stiffness that was associated with an impairment in 40 m sprint performance.

Rather than the simple interaction of potentiation and fatigue explaining the acute changes in sprint performance observed in the current study, an alternate proposition is motor pattern interference caused by the lower limb loading of the prior activity. The added lower body loads lowered the subject’s centre of mass and likely kinesthetically reinforced the ideal leg “piston” sprint acceleration mechanics (providing strong negative feedback for letting the lower shank swing through) and perhaps encouraging a more horizontal ground reaction force application, which is important for acceleration performance (7, 13). Overloading the vertical force pattern with drop jumps and the more upright flying sprints likely had a reduced effect on the acceleration phase motor patterns and therefore did not result in a change in performance over this horizontal force dominant section.

Other authors have also reported acutely enhanced sprint performance after unilateral, cyclic BE with AW (10, 16). However the current study is the first to assess lower body loaded BE as a conditioning stimulus for the acute enhancement of sprint performance and to include extensive general kinematic descriptors of performance (e.g. CT, FT, SL, SF). Light lower body loading of sprint accelerations appears to potentially provide a non-verbal cue for improved sprint acceleration mechanics. Further research is required to test the acute and chronic efficacy of this training method with a larger group of athletes, including a more precise delineation of the performance effects at multiple time points after the conditioning stimulus. Quantifying the changes in sprint kinetics as well as early acceleration phase sprint mechanics and considering the impact of subject strength level and muscle fibre type composition will also enhance the understanding of this topic.

PRACTICAL APPLICATIONS

Added lower body loading equivalent to 3-5% BM worn during a dynamic speed warm-up or a series of 40 m sprint accelerations appears to be effective at acutely improving sprint acceleration performance. Rather than loaded bilateral, acyclic drop jumps, loading the sprint acceleration cycle directly is more effective at eliciting an acute enhancement in performance, perhaps due to the positive stimulus for lower limb acceleration mechanics provided by the lower body loading. Further research is required to determine if the performance changes include a PAP effect or are entirely motor pattern modification, and how this effect may differ with trained sprinters.

AFFILIATION DISCLOSURE

Kim Simperingham has received research funding from Sportboleh Sdh Bhd.

REFERENCES

INTRODUCTION

Post activation potentiation (PAP) is the phenomenon where the contractile history of a particular muscle group has a positive effect on future muscular contraction of that same group (18). To take advantage of this phenomenon, research has found that performance of a conditioning activity (CA) followed by an appropriate rest interval, will result in potentiation of a performance related outcome. Typically, this performance related outcome involves a jump (3), a throw (11) or a sprint (4). It has been suggested PAP occurs due to many reasons, with the first being the phosphorylation of the regulatory light chains on the myosin head (18). Other mechanisms of PAP include the higher order motor unit recruitment caused from the CA (9) as well as changes to the pennation angle of the muscle (13).

The type of CA used throughout the potentiation research has varied from maximal isometric contractions (17), plyometric activities (18) and heavy dynamic lifts such as squats or bench press (2, 7). A meta-analysis on the potentiation research performed by Wilson et al. (20) has suggested that the heavy dynamic lifts are the most effective in eliciting a potentiating effect. Young, Jenner & Griffiths (22) showed that a CA of four repetitions of half-squats at a five repetition maximum (5 RM) load had positive effects on jumping performance, with participants increasing their loaded jump squat height significantly by 2.8%.

Despite research showing the positive effects of potentiation (7, 9, 12), much of the research has failed to show increases in performance after performing a CA (6, 8). Reasons for this have included insufficient strength of the participants (7), inappropriate rest time after the completion of the CA (14), type or load of the CA (3) as well as individuality of participants (optimal loads or rest periods differ amongst participants) (16). With inconsistencies in the PAP literature, other potential contributing factors that could lead to these variable results need to be considered (squat depth, strength of participants). One contributing factor that has not been assessed in prior literature is whether performing a CA of half-squats in a Smith machine or as a free barbell (BB) has an effect on potentiating countermovement jump (CMJ) performance.

A Smith machine helps control the vertical movement of the bar whilst lifting, as it is on a fixed path (5), which should aid in participants squatting greater weight. Cotterman, Darby & Skelley (5) found that participants 1 RM parallel squat with the Smith machine squat was 3.8% greater than when they performed the 1 RM BB squat. Anderson & Behm (1) also found that electromyography (EMG) activation of vastus lateralis was significantly greater (p < 0.05) with Smith machine parallel squats compared to BB squats, whilst stabilizing trunk muscles were insignificantly greater (p > 0.05) during the BB squat than the Smith machine. Conversely, Schwanbeck, Chilibeck and Binstead (15) concluded that the EMG activity of the prime movers of the lower limb were 43% less when the half-squats (90° knee flexion) were performed in the Smith machine, as opposed to a BB half-squat. Despite this contradictory finding in the literature, it must be noted that only six participants were used within this investigation (15). With different force output and muscle activation between the two different squatting methods, it could have potential implication on how each CA potentiates jumping performance. Therefore, the purpose of the present study was to compare the effects of squat types (BB or Smith) on the capacity to potentiate CMJ performance.

METHODS

Participants

Nine recreationally strength trained males (age: 21.3 ± 1.8 years, height: 180.4 ± 5.1 cm, body mass: 78.4 ± 6.4) were recruited for this study. Participants were required to have at least 12 months resistance training experience, particularly with the half-squat exercise. All participants had to be injury free for the 12 months prior to the study. Participants were instructed to refrain from any resistance training or vigorous training of the lower body 48 prior to any testing session and not to consume any caffeine on the day of testing sessions.

Experimental Approach to the Problem

The investigation used a randomised repeated measures design to assess whether performing four half-squats in the Smith machine or as BB half-squats had any potentiating effect on CMJ performance. Countermovement jumps were performed on the Ballistic Measurement System (BMS; Innervations, Australia) which included a force platform (Fittech, Adelaide, Australia) that sampled at 600hz and a linear position transducer (LPT). The LPT was attached to a weight that participants held evenly across their trapezius muscle. All sessions were separated by at least two days to avoid the negative effect of fatigue, but fewer than five days to avoid training or detraining effects. Due to participant availability,
two participants exceeded the five days between testing sessions (6 & 8 days respectively) and this was considered as a limitation to the study.

Procedures
Participants took part in two familiarisation (to decrease any learning effects) and two testing sessions throughout this study. All sessions commenced with a warm-up that consisted of a 5-min jog, thorough dynamic stretching of the lower limbs and five maximal practice CMJ's. Prior to any heavy half-squats, three sub-max warm-up sets with eight (50% of 5RM), six (70% of 5RM) and four repetitions (90% of 5RM) were performed with two minutes rest between each set. On separate familiarisation sessions, each participant's half-squat height (half-squat was defined as a 90º angle at the knee joint) was determined by using a goniometer for both the Smith machine as well as the BB squat. Once the half-squat depth had been established, participants then performed a 5 RM half-squat test. On the Smith machine, participant's half-squat height was controlled by a marker on the vertical fixed track of the Smith machine. When participants lowered the weight to touch this marker, a research assistant gave a verbal signal to raise the weight up as the half-squat height had been reached. For the BB squats, half-squat depth was controlled for each participant by a research assistant holding an elastic tube that was fixed to the squat rack at an equivalent height of each participant's half-squat depth. Once the weight touched the tube, the research assistant instructed the participant to raise the weight. For the Smith machine testing session, at the completion of the warm-up, participants rested for four minutes before performing three CMJ’s on the BMS as their pre-test. Participants were instructed to perform the three CMJ’s for maximum height, taking a small amount of time between each jump to regather balance. Peak power, peak jump height, peak velocity and peak force were all measured as variables of CMJ performance using the BMS software. After the pre-test, participants rested for two minutes before performing their three warm-up sets of half-squats in the Smith machine (two minutes rest between each warm-up set). At the completion of the of the final warm-up set, participants rested for four minutes, before performing the CA of four half-squats with their 5 RM load in the Smith machine. At the completion of the CA, participants performed post CMJ’s at four and eight minutes. Two rest periods were used because literature suggests that the optimum rest period varies between individuals (20). The rest period that yielded the best CMJ performance was selected as that participants post-test CMJ data.

For the BB testing session, the same protocol was followed, except the warm-up sets and CA were performed as BB half-squats rather than in the Smith machine.

Data Analysis Procedures
For all dependent variables, the peak value achieved throughout all three of the CMJ’s was labelled “best,” whilst the mean peak of all three repetitions was also recorded for each variable.

Statistical Analysis
To determine if any changes in CMJ performance were different between the two squat types, a repeated measures ANOVA was used to assess the interaction between squat type and time. Paired sample t-tests were used to test for significant differences between pre and post results for all dependent variables; for both squat types. A paired t-test was also performed to test for significant differences between participants Smith machine half-squat 5 RM and BB half-squat 5 RM. These statistical analyses were completed using SPSS (Version 21, IBM Corp) and statistical significance was set at p < 0.05 for all analyses. Effect sizes (ES) were also calculated using the statistical spreadsheet by Hopkins (10) and were classified as follows: trivial (0.00-0.19), small (0.20-0.59), moderate (0.60-1.19), large (1.2- 1.99) and very large (>2.00).

RESULTS
Descriptive data (means, standard deviation and percentage differences), p-values and effect sizes are presented in Table 1 for the comparison of Smith machine and BB half-squats. Participants 5 RM half-squats in the Smith machine were significantly greater than the BB half-squats (p < 0.05).

Table 1 - Difference between participants 5 RM results for both the Smith machine half-squat and Barbell half-squat.

<table>
<thead>
<tr>
<th></th>
<th>BB Squat</th>
<th>Smith Squat</th>
<th>%Diff to BB Squat</th>
<th>E.S (description)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 RM (kg)</td>
<td>158.9 ± 21.5</td>
<td>177.2 ± 21.5</td>
<td>11.5</td>
<td>0.86 (moderate)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

The repeated measures ANOVA revealed a significant squat type by time interaction for the best peak power (p < 0.05), indicating that the increase in CMJ following the Smith machine squat was greater than for the BB squat. No other significant interaction occurred for any of the other dependent variables. Descriptive results for all pre and post CMJ dependent variables are presented in Table 2 along with p-values from the paired t-tests and effect sizes; as well as p-values for the interaction between squat type and time. A small significant increase from pre to post mean jump height (p < 0.05) occurred after the Smith machine CA. A small significant increase in peak force from pre to post occurred after the barbell CA. No other significant changes were identified for any other variable for either the Smith machine or Barbell CA.
Table 2 - Difference in pre and post jumping variables for both the Smith machine and barbell half-squats.

<table>
<thead>
<tr>
<th>Squat type by time interaction</th>
<th>Smith Machine</th>
<th>Barbell</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES (description)</td>
<td>p-value</td>
<td>ES (description)</td>
</tr>
<tr>
<td>Pre test</td>
<td>Post test</td>
<td>%Diff</td>
</tr>
<tr>
<td>Peak power best (W.kg⁻¹)</td>
<td>59.0 ± 4.4</td>
<td>60.3 ± 5.7</td>
</tr>
<tr>
<td>Peak power mean (W.kg⁻¹)</td>
<td>57.4 ± 4.5</td>
<td>58.0 ± 5.0</td>
</tr>
<tr>
<td>Jump height best (cm)</td>
<td>50.3 ± 5.3</td>
<td>51.3 ± 6.4</td>
</tr>
<tr>
<td>Jump height mean (cm)</td>
<td>48.3 ± 5.2</td>
<td>49.6 ± 6.2</td>
</tr>
<tr>
<td>Peak velocity best (m.s⁻¹)</td>
<td>2.74 ± 1.10</td>
<td>2.79 ± 0.14</td>
</tr>
<tr>
<td>Peak velocity mean (m.s⁻¹)</td>
<td>2.65 ± 0.11</td>
<td>2.71 ± 0.14</td>
</tr>
<tr>
<td>Peak force best (N)</td>
<td>1889 ± 209</td>
<td>1915 ± 221</td>
</tr>
</tbody>
</table>

*Bold p-value denotes a significant finding.

The pre to post percentage differences for both the Smith machine and BB across all the CMJ variables are displayed in figure 1. The percentage increase in peak force best was larger in the BB half-squat CA; however, for all other CMJ variables, performance increased by a larger percentage with the Smith machine CA.

![Figure 1](image-url)  
**Figure 1** - Percentage differences from pre to post for both CA’s across all CMJ variables.

**DISCUSSION**

The loads lifted in each CA were significantly different from one another, despite similarities in the movement mechanics. Participants 5 RM half-squats in the Smith machine were 11.5% greater than when the 5 RM was performed as BB half-squats. This result supports the findings by Cotterman, Darby & Skelley (5), where they found an increase of 3.8% in 1 RM parallel squats performed in the Smith machine. With the loads of each CA being significantly different, the activation of particular muscle groups could also be different, which was reported by Anderson & Behm (1). The increase in Smith machine 5 RM potentially occurred due to stable nature of the exercise. With less balancing required, the stabilizing muscles of the trunk would not limit a participant in achieving a higher 5 RM. The recreationally trained participants may have also felt more confident with the stable squatting environment provided by the Smith machine. If the two CA’s are different, they may be expected to have different effects on potentiating CMJ performance.

The descriptive statistics show that after performing the CA in the Smith machine, all the dependent variables of the CMJ improved from pre to post testing (figure 1). Despite all of the variables improving, the effect sizes of change were only small or trivial (ES range: 0.12-0.47). The repeated measures ANOVA revealed that generally the Smith machine was not significantly better than the BB condition, with the exception of the peak power best variable (p=0.03). The Smith machine CA attributed to a small non-significant 2.2% improvement in peak power best from pre to post CMJ’s. The BB CA in fact decreased participants’ best peak power by 1% when compared to the peak power displayed in the pre-test. After a CA, both potentiation and fatigue occur at the same time, with fatigue being greater than potentiation directly after a CA; however, fatigue dissipates quicker than potentiation allowing for an opportunity for performance to be enhanced (18). The decrease in peak power could be attributed to the amount of fatigue from the BB CA outweighing the potentiation effect and a longer rest interval may have allowed for a different result for this particular CA. Although the ANOVA revealed a significant interaction between squat type and time for the peak power best variable, there was no significant changes from pre to post, indicating a potentiation effect was unlikely.
Participants mean jump height displayed a significant improvement of 1.3 cm (2.7%, p=0.03; ES=0.24) when the CA was performed in the Smith machine, as opposed to a non-significant trivial improvement of 0.2 cm (0.4%; p>0.05, ES=0.03) with the BB CA. Despite the significant increase in mean jump height after the Smith machine CA, the repeated measure ANOVA showed no significant interaction between squat type and time for this particular dependent variable (p=0.16). Therefore, although the Smith machine CA significantly increased jump height mean from pre to post testing, the improvements from the Smith machine protocol were not significantly greater than the trivial CMJ improvements shown after the BB half-squat CA.

The BB half-squat CA significantly increased the peak force of the CMJ’s by 2.3% (p=0.03), whilst the Smith machine CA displayed a non-significant trivial 1.4% increase. The repeated measures ANOVA identified no significant interaction between CA type and time for peak force (p=0.51), suggesting that it could not be concluded that the BB CA was significantly better than the Smith machine CA in eliciting an improvement of peak force within CMJ’s. This small difference may have occurred due to the greater activation of the stabilising muscles in the BB CA contributing to the enhanced force production of the subsequent CMJ. This increase in force may not necessarily contribute to greater jump height, as jump height is determined by velocity at take-off (21). Research by Young, Cormack & Crichton (21) also showed that peak force in a CMJ does not correlate to the jump height achieved. Therefore, it is possible to have an increase in peak force that does not transfer to an increase in jump height.

Although the descriptive statistics display a trend that the Smith machine CA potentially elicits greater improvements in CMJ performance (six out of the seven dependent variables), this trend is not statistically significant and the effect sizes are either small or trivial across all variables. The small improvements may be due to the greater load that the participants lifted within the Smith machine. The greater load could have led to an increase in activation of the prime movers of the lower limbs that would be used for the CMJ, similar to that shown by Anderson & Behm (1). The BB CA may have had less activation of the prime mover muscles (due to the lighter load) and an increase in the activation of stabilising muscles, which would not be as important whilst performing the CMJ, possibly creating less of a potentiation effect. Further research is required into the optimal load and rest period after each different type of CA. With participants 5 RM loads being less in the BB half-squat, potentially a CA with less repetitions at a higher intensity (for example three repetitions at a 3 RM load) would be more beneficial to potentiate CMJ performance.

Further investigation into the comparison of Smith machine and BB half-squats as a CA is required. Although the following investigation displays some minor trends as to which is more effective, the low number of participants as well as the small effect makes it difficult to support these trends with statistical significance. Future research is needed to further investigate the area, placing a larger focus on EMG activation during each CA and biomechanical differences between the two half-squat techniques. In addition, future research could also compare the effect of squatting depth (parallel vs. half-squats) on CA’s performed in both Smith machine or as BB squats.

**PRACTICAL APPLICATIONS**

Strength and conditioning coaches firstly need to consider whether using the phenomenon of PAP can help their athletes improve their performance. This could be by performing a CA in a warm-up to potentiate competition performance, or using contrasting sets of heavy and lighter loads to enhance power production in a training environment. If a coach aims to improve jump height or relative peak power for recreationally trained athletes, the trend from the following investigation suggests performing the CA in the Smith machine will further potentiate these variables. Whilst if a coach wants an athlete to enhance the peak force produced during a CMJ, they should use a CA that uses the BB half-squat. Further investigation is required on whether the above suggestions apply to elite level athletes.
REFERENCES


INTRODUCTION

Limited research has investigated the duration adolescent competitive surfers spend free surfing, competing, being coached and spend physically training in terms of strength, balance and conditioning. It has been previously documented that surfers can spend between 3.7 – 5 hours a day practicing in good surf conditions, 3-5 days a week for recreational and international level surfers (1-3). Within juniors (>19 y), weekly surfing hours range between 7.5 (Recreational) and 18.1 (Competitive) hours surfing each week (4). Previous research within other sports has reported the weekly training hours to be approximately 4-6.7 hours for U14-U15 age groups, and 9-10 hours for U17 soccer players (5, 6). Furthermore, rugby union has reported approximately 15 hours of weekly training (7, 8), pre pubertal female gymnasts 14 hours (9), and triathlon approximately 16 hours (10). In terms of land-based training, surfers participate in minimal training sessions with an average of 0-2 sessions per week) (4, 11) with majority of a surfer’s training regime undertaken in the water (1). In comparison, field sports strength training in soccer for both U15 and 17 is approximately 0.90 mins per week (6), and 6 hours in rugby per week (12), and swimmers 2-3 times per week.

The assessment of weekly and even monthly surf practice/training hours is vital for understanding the loads that these up and coming surfers endure. Such information will help understand what kind of training these athletes are undertaking, how long they are surfing, what they consider training, and also areas that should be improved upon, in terms of specific training. Greater knowledge of what the juniors surfers are performing in terms of surfing hours, and any land-based training they are partaking in will aid coaches and strength and conditioning practitioners understanding workloads these athletes perform. This understanding can aid in the design and development of specific on-and off-water training programs to aid these athletes and potentially limiting likelihood of injuries from overuse/lacking strength.

Therefore, the purpose of this study was to establish surfers’ training hours in terms of strength, balance and conditioning hours, as well as surfing hours, coached hours and competition hours. The monitoring of the athletes will provide insights into the weekly surf hours compared to land-based training these athletes do.

METHODS

Experimental Approach

The current study was a descriptive analysis, whereby eight adolescent surfers were required to report their surfing hours and physical training hours over a six week period.

Subjects

Eight adolescent male (n=6, 153.7 ± 6.3 cm, 43.4 ± 5.8 kg, 13.5 ± 0.8 yrs.) and female (n=2, 156.2 ± 4.9 cm, 50.9 ± 10.8 kg, 14.5 ± 2.1 yrs.) surfers volunteered to participate in this study. For inclusion in this study the adolescents were required to be; (i) a member of a local high school surf coaching excellence program, (ii) free from any medical contraindication, and (iii) aged between 13 to 16 years. The study and its procedures were approved by ECU ethics committee, and all participants and the parent/guardian were provided with information regarding the study before provided written informed consent.

Procedures

After each training session over a six week period, the participants were asked to report their surfing and training hours for the week by filling in a questionnaire. Specifically, the participants were asked to provide the amount of hours spent free surfing, being coached, competing, strength training, conditioning and balance work. Athletes were questioned about what they did to make sure sections were filled in correctly in terms of the physical activity (i.e. running, skateboarding = conditioning, periodized strength training = strength, gymnastics = balance). The questionnaire was provided twice a week to ensure more accurate recording of hours spent surfing and training.

Statistical Analysis

Descriptive statistics were calculated for all variables and reported as mean ± SD. A one-way ANOVA was performed between the surfing variables; free surfing vs coach, coached vs competition, free surfing vs competition, and between the training variables; strength vs conditioning, conditioning vs balance, balance vs strength on the average weekly surf and training hours.
hours. Data was statistically analysed using statistical analysis package (SPSS, Version 22.0; Chicago, IL), with statistical significance defined as p≤0.05.

RESULTS

A significant difference was identified between weekly free Surfing hours and competition hours (p=0.037), no other significant differences were reported between the surfing variables (Free surfing vs Coached p=0.751; Coached vs Competition p=.523), or between the training variables (Strength vs Conditioning p=.553; Conditioning vs Balance p=.269; Balance vs Strength p=.722).

Table 1 - The average (±SD) hours spent surfing and training per week, over 6 weeks for 8 adolescent surfers.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Week 1 hours</th>
<th>Week 2 hours</th>
<th>Week 3 hours</th>
<th>Week 4 hours</th>
<th>Week 5 hours</th>
<th>Week 6 hours</th>
<th>Average hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surfing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free Surfing</td>
<td>16.63 ± 7.19</td>
<td>13.00 ± 6.02</td>
<td>15.38 ± 4.78</td>
<td>15.50 ± 3.07</td>
<td>12.75 ± 3.37</td>
<td>15.50 ± 4.11</td>
<td>14.79 ± 4.86</td>
</tr>
<tr>
<td>Coached</td>
<td>3.81 ± 3.35</td>
<td>2.75 ± 2.60</td>
<td>3.00 ± 2.39</td>
<td>3.44 ± 2.19</td>
<td>3.44 ± 2.19</td>
<td>3.50 ± 2.33</td>
<td>3.32 ± 2.51</td>
</tr>
<tr>
<td>Competition</td>
<td>0.13 ± 0.35</td>
<td>2.33 ± 3.28</td>
<td>0.25 ± 0.53</td>
<td>0.25 ± 0.71</td>
<td>0.18 ± 0.36</td>
<td>0.24 ± 0.37</td>
<td>0.56 ± 0.93</td>
</tr>
<tr>
<td>Training</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength</td>
<td>0.80 ± 1.14</td>
<td>1.30 ± 2.41</td>
<td>1.18 ± 2.07</td>
<td>1.05 ± 1.75</td>
<td>0.93 ± 1.43</td>
<td>1.30 ± 2.16</td>
<td>1.09 ± 1.83</td>
</tr>
<tr>
<td>Balance</td>
<td>1.05 ± 0.87</td>
<td>0.36 ± 0.44</td>
<td>0.61 ± 0.70</td>
<td>0.61 ± 0.70</td>
<td>0.74 ± 0.61</td>
<td>0.74 ± 0.66</td>
<td>0.69 ± 0.67</td>
</tr>
<tr>
<td>Conditioning</td>
<td>2.43 ± 4.04</td>
<td>3.03 ± 3.52</td>
<td>2.65 ± 2.80</td>
<td>2.28 ± 2.16</td>
<td>2.28 ± 2.16</td>
<td>2.44 ± 2.06</td>
<td>2.58 ± 2.84</td>
</tr>
<tr>
<td>Total training hours</td>
<td>4.28 ± 5.71</td>
<td>4.69 ± 6.37</td>
<td>4.44 ± 5.57</td>
<td>3.94 ± 4.60</td>
<td>3.94 ± 4.60</td>
<td>4.48 ± 4.88</td>
<td>4.35 ± 5.34</td>
</tr>
</tbody>
</table>

DISCUSSION

The assessment of weekly and even monthly surf practice/training is vital for understanding the amount of time spent practicing/training in and out of the water. Therefore, the purpose of this study was to gain an insight into the workloads a group of adolescent competitive surfers perform on a weekly basis in terms of strength, balance and conditioning work, as well as surfing, being coached and competing hours.

Data recorded from the eight athletes indicates that these surfers spend approximately 15 hours on average per week free surfing with an additional 3.3 hours being coached and approximately 30 mins competing. In contrast, on average land-based training hours are far less, with conditioning the greatest focus (2.5 hours), followed by strength training (1 hour), and balance work (>1 hour). These results are consistent with previously reported values for surfers (1-4), with a
high amount of practice hours in the water, and limited hours implementing land-based training exercises. Additionally, these results indicate that surfers are actually spending more time practicing than soccer (5, 6), but similar to rugby union (7, 8), gymnasts (9), and triathlon (10). However, the amount of time spent surfing is not necessary indicative of high intensity, structured work, which would likely be more with the aforementioned sports. This is due to the conditions of the surfing playing a major role in amount of time spent paddling, recovering and wave riding (13, 14).

The typical attitude for surfing athletes in terms of training is to simply surf, thus obtaining the most specific fitness responses, which is clearly demonstrated from the results. Some athletes questioned did not do any form of strength work, nor have a reason to why they should be implementing such an aspect into their weekly training routine. Often skateboarding was mentioned by the males as an activity they would partake in when surf was inadequate, or to have fun with friends. This would provide motor-skill acquisition, balance and conditioning work which would also develop the quadiceps endurance, considering some were doing it for an hour at a time. However, an outstanding result was the amount of time these athletes spent outside the surf doing land-based training. These results demonstrate that adolescent, competitive surfers partake in high amounts of surfing hours, and minimal training hours to aid in strength and balance. Previous research has reported that athletes with greater maximal strength demonstrate a greater transfer to performance, such as sprint paddling (15) and the pop-up phase of surfing (16). Therefore, it would be recommended that these athletes look to increase in fundamental strength training exercises, such as push-ups, pull-ups, squats, lunges etc. to aid in these aspects which are key performance requirements (1, 17).

Future research should monitor these athletes for a longer period, including monitoring higher-level professional adults to see if there are any differences in training routines, and amount of surf and land-based training hours.

**PRACTICAL APPLICATIONS**

A monitoring tool to track athletes’ workloads per week can be easily implemented by any surf coach to provide insights into the weekly surf hours compared to land-based training. Such monitoring would provide a better understand on the total surfing hours per day and week, which would aid the coaches in decision making to what training should be implemented on land, (i.e structured strength work, conditioning).

From the study it appears that adolescent surfers are implementing on average, 14 hours extra surfing than any form of land-based training, with approximately only 1 hour per week doing any form of strength work. Therefore, such athletes should be looking to increase training hours per week, especially strength work which would aid these athletes in terms of paddle ability though upper-body training (15, 16), turning manoeuvres and landings, through lower-body strength work (18). The added training may decrease chances of these athletes sustaining an injury through overuse from the amount of surfing performed each week, not to mention poor biomechanical landings/body movements, which if the athletes are not strong enough would likely increase the chances of sustaining an injury (19).

**REFERENCES**

18. Tran, T.T., Evaluation and training of sensorimotor abilities in competitive surfers, in School of Exercise & Health Sciences. 2015, Edith Cowan University.
INCIDENCE OF INJURY IN JUNIOR RUGBY LEAGUE PLAYERS

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James Cook University

INTRODUCTION

Rugby league is a collision sport that is intermittent in nature consisting of bursts of high intensity activity (e.g. sprinting and tackling) and low intensity activity (e.g. walking and standing) (1). Unfortunately, due to the high number of collisions and the physical nature of the game, muscular skeletal injuries are common (2).

A recent report from the Australian Institute of Health and Welfare (AIHW) revealed that there was a high rate of hospitalisations as a result of sports injuries sustained while playing football (i.e. Australian Rules, Soccer, Rugby League and Rugby Union) (3). This report also found that, within the football group, rugby league injuries represented one of the highest hospital admissions rates, especially rugby league players who are 15 to 17 year old and in regional and remote areas. Sports Medicine Australia responded to this report by highlighting the need to increase awareness of sports injury prevention and its management (4). Van Mechelen (5) proposed that the first step behind the injury prevention process is ongoing injury surveillance.

To date only six studies have been published on the incidence of injury in junior rugby league players with the majority of studies focusing on professional, semi-professional and amateur senior players. Of the six studies on junior rugby league injury rates, four have focused on post pubertal players aged between 16 to 19 years old (6-9) while two studies reported injuries to peri pubertal players aged between 6 to 15 years old (10, 11). The frequency of injury in junior rugby league players has typically been shown to increase with age with under 6 players recording an injury rate of 3.4 per 1000 playing hours (11) while under 19 players recorded an injury rate of 406 per 1000 playing hours (6). This increase in the rate of injury as the age group increases has been attributed to an increase in growth and development of the players and increase in body mass and speed which would result in greater impact forces between players (11).

Of the two studies that observed injury rates in junior rugby league players aged 6 to 15, a noticeable difference in injury rates between different age levels were found (10, 11). For example, Raftery et al (11) found the injury rate for players aged 6 to 11 ranged from 1.44 to 6.23/1000hr, while the injury rates for the players aged 12 to 15 was reported to increase significantly to 13.03 and 17.09/1000hr. Interestingly, they also found that the injury rates (13.53 to 15.58/1000hrs) for the players aged 16 to 17 were found to be slightly lower than the players aged 12 to 15 years old. The author was unable to identify any factors that contributed to the sharp increase in incidence of injury seen in the 12 to 15 year old players and subsequent decrease in 16 to 17 year olds. Similarly, the author of the other study on the incidence of injury to players aged 6 to 15 years old (10) found a significant increase in injury rates in players aged 14 years old and then a decrease injury rate in 15 year olds (10). Likewise, the author of this study could not identify any contributing factors to the significant increase in injury rates in the 14 year old players but postulated that the physical growth and maturation of that age group may have an impact on injury rates. However, the differences in injury rates of the peri pubertal players, who are not grouped by bodyweight but by chronological age, may be due to the difference between early- and late-maturing players resulting in an imbalance in impact forces in the tackle (12). In addition, the definition of injury may also be a contributing factor to the differences in injury rates with some studies only recording injuries that result in players missing a match and other recording all injuries regardless of time lost (2).

These findings and the paucity of research into injuries to junior rugby league players further highlights the need for further investigation in this field, particularly with the peri pubertal age group of 13 to 15 year olds. With this in mind the aim of this study was to investigate the incidence and characteristics of injuries to peri pubertal junior rugby league players over a competitive season.

METHODS

Participants

The participants were forty under 14 (U14) amateur junior rugby league players registered with the same junior rugby league club competing in the Cairns District Junior Rugby League competition. At the beginning of the season players were assigned into one of two teams being an under 14 A side and under 14 B side.

Study Design

The study, a prospective cohort observational study, was conducted over the course of the 2015 season, starting in April and finishing at the end of August comprising of 12 rounds of fixtures. Subjects received a clear explanation of the study, including the risks and benefits of participation and written consent was obtained before participating. Furthermore, all procedures were approved by the Institutional Human Research Ethics Committee.
Injury Definition and Collection

Injury data was collected by observation at all games by the principle investigator, as well as, consulting with each team’s designated sports trainer. Injury data was recorded using a standardised reporting form which identified the position of the injured player, when and how the injury occurred, location and type of injury as well as the severity of the injury. To allow for comparison with other rugby league injury studies an injury was defined as any pain or disability that occurred during participation in a rugby league match or training activity that was sustained by a player, irrespective of the need for match or training time loss or for first aid or medical attention (13). The injury incidence was calculated by using the standardized method as described previously and injuries were classified as either transient (no time lost), minor (1 week missed), moderate (2 to 4 weeks missed) or major (5 or more weeks missed) (13). Training attendance and training injuries were recorded at the twice weekly training sessions as well as what type of training was being performed (e.g. conditioning, skills, tactical).

Statistical Analysis

All injury data was expressed as a ratio of the number of injuries per 1000 playing hours and percentage with level of significance set at p<0.05. An ANOVA test was used to compare the different groups between the different variables. All Data was analysed using IBM SPSS Statistics 20 (IBM Corporation, Armonk, USA).

RESULTS

The incidence of injury was 62.9 per 1000 playing hours and 28 per 1000 playing hours for missed matches. The incidence of injury for training injuries over the course of the study for all teams combined was 2.56 per 1000 training hours.

Table 3.1 - Most Common Site and Type of Injury for the U14 Players.

<table>
<thead>
<tr>
<th>Site of Injury</th>
<th>Rate (%)</th>
<th>Rate (%)</th>
<th>Rate (%)</th>
<th>Rate (%)</th>
<th>Rate (%)</th>
<th>Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head/Neck</td>
<td>28 (22)</td>
<td>14 (11)</td>
<td>42 (33)</td>
<td>7 (6)</td>
<td>21 (17)</td>
<td>14 (11)</td>
</tr>
<tr>
<td>Shoulder</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbow/Wrist/Hand</td>
<td>35 (27.8)</td>
<td>28 (22.2)</td>
<td>35 (27.8)</td>
<td>7 (5.6)</td>
<td>7 (5.6)</td>
<td>14 (11)</td>
</tr>
<tr>
<td>Hip/Groin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Rate expressed per 1000 playing hours, (%) is total percent.

The elbow/wrist/hand was the most commonly recorded injury site with sprains and dislocations as the most common type of injury (Table 1). The majority of the injuries recorded in this study were found to be located on the left side of the body (61.1%) and the common cause of injury was the tackle contest (92.3%) with the person being tackled (66.7%) recording the most injuries. The majority of the injuries that were sustained during the course of the study were transient (55.6%) and did not result in any time loss. The majority of the U14A team’s injuries that occurred whilst tackling (75%) were to the upper body. While most of the U14B team’s injuries, whilst being tackled, were to the lower body (50%). The forwards (77.8%) recorded more injuries than the backs (22.2%) with the prop being the most common position injured followed by the second row (22.3%). Most of the injuries recorded were found to occur during the second half (72.2%) of the match. When looking at cause of injury and the side of body injured a high percentage of the injuries were found to be on the left side of the body while being tackled (82%) Moreover, it was found that all of the injuries recorded to the prop occurred during the second half of the match with 75% of these injuries being on the left side of the body and all of those injuries occurring while being tackled. Moreover, the majority of these injuries (55.6%) were to the lower limb and were mainly to the knee (33.3%) and ankle (33.3%).

DISCUSSION

The aim of this study was to investigate the incidence and characteristics of injuries to junior rugby league players in the peri pubertal age group over a competitive season.

The total incidence of injury was found to be 62.9 per 1000 playing hours, while the most common injury site was to the elbow/wrist/hand. Other studies on junior rugby league injury have found varying results for most common injury site with some reporting more injuries to the lower limb (8, 11) while others the upper limb (7, 10). The common type of injury recorded in this study were sprains and dislocations. Other studies in junior rugby league have found that the common types of injuries have been varied with some reporting sprains and strains (7, 8) while others have been fractures (11) and contusions (9, 10). Some have suggested that varying results of common injury site and type have been attributed to the teams different playing styles (2).

When looking at the site and type of injuries and cause of injury together, the U14 A team recorded more injuries to the upper body while tackling and recorded an equal amount of injuries to the head/neck, upper body and lower body while being tackled. This might suggest that the U14 A team may need to improve their tackling technique to reduce their risk of injury. Conversely, the U14 B team recorded more injuries to the lower limb while being tackled than any other type of injury which would suggest that they may need to alter their attacking style of running or falling technique to reduce their risk of injury. These findings highlight the differences in injury characteristics between teams of the same age.
groups and therefore show that comparison between studies of players of similar ages should be undertaken with caution.

Across both teams, the prop and second row were the most commonly injured playing positions which is in line with other studies (14) which have suggested that this is due to the high number of collisions that these players are involved in during a match. Furthermore, it was found that all of the prop’s injuries occurred during the second half of the match while being tackled. It has been proposed that injuries during the second half of the match are attributed to fatigue and accumulation of micro trauma (14). This might suggest that, to reduce the risk of injury of these players, regular substitutions should be made during the second half to allow them adequate time to recover.

However, the finding in this study that was distinct to other studies was that the majority of the prop’s injuries occurred to the left side of their body. Furthermore, it was found that the majority of these injuries to the prop on the left side of the body occurred whilst they were being tackled and were to the lower body, more specifically the knee area. To date no studies have identified what side of the body that players have been predominately injured. It was observed by the principle investigator that the majority of players, especially the forwards, carried the ball in their right arm and lead with their left side into tackles. This suggests that the first point of contact for the ball carrier with the defensive line was to their left side which therefore put them at a higher risk of being injured. This highlights the importance of designing skills training sessions that encourage players to run with the ball in not only the right hand side of their body but the left hand side as well.

These findings highlight that the differences exist in the type and extent of injuries between teams of the same age level and that comparison of studies amongst similar cohorts should be examined with caution. This study also shows the importance of keeping a record of injury risks that are specific to a particular team rather than solely relying on injury characteristics from other studies. Once the injury risks have been identified they can then be used as a guide to prescribe appropriate training conditioning and skills sessions to reduce the risk of injury.

REFERENCES

The effect of chronotype upon physical performance during Australian Rules Football matches scheduled in the morning, afternoon and evening. J. Aust. Strength Cond. 23(6)101-104. 2015 © ASCA.

THE EFFECT OF CHRONOTYPE UPON PHYSICAL PERFORMANCE DURING AUSTRALIAN RULES FOOTBALL MATCHES SCHEDULED IN THE MORNING, AFTERNOON AND EVENING

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INTRODUCTION

Individual differences in circadian rhythm or diurnal variations are referred to as chronotypes. A chronotype is a behavioural phenotype that has the ability to reflect ones innate circadian rhythm (1). Chronotypes are often measured on a continuous scale of “morningness-eveningness”. The current gold standard for evaluation of chronotype for general populations is the Horne-Östberg Morningness-Eveningness Questionnaire (2) which categorises individuals as “evening types”, “morning types” or “intermediate types”. Each end of this scale is viewed as dichotomous in nature with evening types often being referred to as owls and morning types as larks. These categories reflect the time of day in which individuals are most mentally and physically proficient. Individuals with a high score on morningness perform both mentally and physically better within the morning hours whilst their evening orientated counterparts have difficulties in getting up in the morning and perform best in the late afternoon or evening hours(3).

Although circadian rhythms have been examined since the early 1900s (4), the effects of individual chronotype has only been presented in the literature in the last few decades, with the influence of chronotype on sporting performance only recently examined. Circadian rhythms and chronotypes of sports people, both at an elite and recreational level, have been assessed for their effects on aerobic and anaerobic performance. For both aerobic and anaerobic activities there is evidence that suggests that diurnal variations in performance exist, with optimal performance being elicited in the evening hours (5-8). In contrast, a number of studies have also been unable to distinguish a diurnal variation pattern for these activities.(9-11) However, when assessed by individual chronotype evening types have been acknowledged to display superior aerobic performances in the evening(11-13), intermediate types in the early afternoon(1,13) and morning types in the morning(11-13).

Whilst the effects of time of day and individual chronotype on performance capacities have previously been established in terms of aerobic and anaerobic based activities, it is currently unknown whether or not these manifest in physical performance trends in sport specific matches. The influence of chronotype upon performance may be masked by the large degree of between match variation owing to contextual factors such as match status, team tactics and opposition (14-16). Despite this, a greater understanding of an individual’s chronotype may influence the interpretation of physical performance indicators in elite sports. Consequently, the aim of this study is to determine the effect of chronotype on physical performance during AFL competition played at different times of the day.

METHODS

Subjects
40 professional male AFL players (means±SD; age 21.7±2.3 years; height 189.2±7.6 cm; body mass 86.7±8.0 kg) with 3.2±2.0 years of experience of playing the game voluntarily participated in the study that took place over the 2014 competition season. 20 of the 22 round first grade AFL games and 17 of the 21 round reserve grade North East Australian Football League (NEAFL) games were examined. The study was approved by the institution’s ethical review board and all subjects provided informed consent.

General Procedures
Chronotype assessments took place between the months of March and August via the Horne-Östberg Morningness-Eveningness Questionnaire (2). All players completed the questionnaire over a two day period and were provided with verbal instructions. Player’s physical performance measures were recorded during competitive games using global positioning system (GPS) units sampling at 10 Hz (Optimeye S5, Catapult Interventions, Scoresby, Australia). Matches ranged in start time from 0930 hours to 1940 hours and were categorised as morning (0930 to 1200 hours; n=8), afternoon (1200 to 1600 hours; n=18) or evening games (1600 to 1940 hours, n=11).

Questionnaire Administration
The Horne-Östberg Morningness-Eveningness Questionnaire (2) consists of 19 questions. For many of the items, four choices are available, specifically corresponding to a definite morning type, moderate morning type, moderate evening type or definite evening type. The questionnaire was validated through the use of oral temperature measurements, since peak activity and preferred times of day are considered to be synchronous with elevated body temperature (17).
Physical Performance Monitoring
Individual physical performance metrics were recorded in each of the AFL and NEAFL competition games. Three AFL and four NEAFL games were excluded due to poor signal quality or instances where stadium roofs were closed. Physical performance measures recorded by GPS in each of the games included distance covered (m·min⁻¹), maximum speed (km·h⁻¹), number of sprint efforts (entries at or above 23 km·h⁻¹), high speed running distance (HSR (m·min⁻¹); > 17 km·h⁻¹). GPS data was downloaded post match using manufacture specific software for analysis. Match data was only recorded for the duration of on field play by each athlete. GPS samples were only accepted for analysis if the athlete played ≥ 70% of total match time, resulting in 532 eligible match observations.

Data Analysis
Linear mixed models were used to examine the effects of chronotype and match kick-off time (KO) upon our outcome measures. The Morningness-Eveningness questionnaire score and the match KO time were modelled as fixed effects, player was specified as a random intercept to account for within-player variation owing to repeated match observations, and positional role, dry-bulb ambient temperature, and competition standard (AFL vs NEAFL) were imputed as covariates. Bonferroni pairwise comparisons were administered where appropriate. Data are presented as the estimated marginal means ± 95% confidence intervals (CI).

RESULTS
11 players were identified as moderate morning types, 28 as intermediate types and 1 as a moderate evening type. Chronotype had no influence upon any of the physical performance measures examined (F: 0.001-0.138; P= 0.713-0.981). In contrast, match KO influenced both distance covered and HSR (F: 5.012-13.227; p = 0.001-0.007), which were both greater in evening versus morning and afternoon matches (p= 0.001-0.039; See Figure 1). No effects of match KO time were observed for maximum sprint speed efforts (F: 0.898; p = 0.408) or sprint efforts (F: 0.271; p = 0.763). Effect estimates revealed 0.82 (95% CI: 0.59-1.05) and 0.28 m/min (95% CI: 0.59-1.05) increases in distance covered and HSR, respectively, for each additional hour that a match commenced after 0930 hours. Ambient temperature and standard of competition were not significant co-variants in any of the models, whereas positional role was a significant covariate only for distance covered (F: 8.964; p = 0.003).

**Figure 1** - Comparisons of the effect of match KO in morning, afternoon and evenings on mean difference scores (with 95% CI) in a. distance covered b. maximum speed c. number of sprint efforts and d. HSR distance. *denotes a significant difference of evening match KO versus both morning and afternoon match KO (P < 0.05).

DISCUSSION
Using elite AFL athletes, this study examined the effects of chronotype and Match KO on physical performance measures including total distance covered, maximum speed, number of sprint efforts and relative HSR. The main findings were (a) chronotype had no significant effect on any physical performance measures, (b) total distance covered and relative HSR were significantly greater in evening than morning and afternoon matches and (c) no significant time of day effect existed for maximum speed and number of sprint efforts.
The results of this study are consistent with previous works that have determined a diurnal variation in physical performance, with evening peaks in both aerobic (5-7) and anaerobic (18-20) performance variables previously being established. Similarly, the absence of a chronotype effect on physical performance agrees with the works of Burgoon et al. (6), who were unable to distinguish a chronotype effect on endurance capacity. However, these findings contrast with recent studies where individual chronotype has been found to effect both aerobic (7,12-13) and anaerobic performance (8). These results may be due to the different modes of exercise assessed and variability of team performance indices in the present study, which have not previously been examined.

It is interesting to note that with the exception of one individual, all athletes in this study were categorised by chronotype as moderate morning or intermediate types, however superior performance in both distance covered and relative HSR took place in matches with evening KO. This is in agreement with Atkinson and colleagues (5) and Arnett (21) who found that despite warm-up intervention, cycling and swim performance increased in the evening hours, even amongst morning types. It has been suggested that this may be due to habitual scheduling of training, with evidence suggesting that a specific temporal specificity to strength training exists with enhanced adaptations observed at the time of day at which training was conducted (22). Similarly, temporal adaptations of performance from habitual training at a particular hour have also been suggested for aerobic based activity (1,7,11-12) but as of yet have not been assessed in regards to physical performance in stochastic team-sport activities such as AFL.

In the absence of a chronotype effect, physical performance may have been influenced by contextual factors such as match status and opposition. A recent AFL study determined that physical performance increased when teams were losing (23), agreeing with previous research in soccer that found players from less successful teams completed significantly greater HSR than their successful counterparts (24-25). In contrast, it has also been demonstrated that winning professional rugby league teams exhibited greater physical performance compared to losing teams (26). Standard of play was a covariant in the present study but had no effect on physical performance measures. In addition, despite body temperature being synchronous with physical performance (2,17), ambient temperature was also found to have no effect on physical performance measures.

**PRACTICAL APPLICATIONS**

Given our findings, the chronotype of an individual does not appear to impact upon physical performance during a match and would further suggest the administration of the Horne-Ostberg Morningness-Eveningness Questionnaire in this population is not warranted. However, the findings related to physical performance and time of day may be beneficial for considerations related to load monitoring. High performance managers and other performance analysts may need to consider the increase in load incurred during evening matches, particularly if they are in succession or occur during periods of heavy training. Finally, this may impact upon on periodised training programs developed for players returning from injury as well as return-to-play policies implemented by medical staff.

**CONCLUSION**

This was the first study of its kind to explore the effects of chronotype and match scheduling upon physical performance measures, over a season of AFL match play. It is possible that the questionnaire utilised for the purpose of chronotyping the athletes in this study is invalid for this purpose. Produced in 1976, the Horne-Ostberg Morningness-Eveningness Questionnaire (2) was validated in general populations, and predominately audits the respondents’ cognitive and behavioural behaviours. Further work may be necessary to develop chronotyping inventories based on more athletic criteria and training preferences.
REFERENCES


ASYMMETRY OF LOWER LIMB FUNCTIONAL PERFORMANCE IN AMATEUR MALE KICKBOXERS

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INTRODUCTION

Thai kickboxing is characterised by its powerful kicking techniques. International kickboxing rules state that contestants must deliver a minimum of eight kicks per round (14). Given the metabolic demands of the sport, competition success relies on the capacity to deliver effective strikes using the front kick and roundhouse kick techniques with either foot (8, 10). As such, kickboxing exponents should aim to minimise asymmetry in the functional performance characteristics required to deliver powerful and effective kicks. Studies from other martial arts including karate (9, 11) show the absence of bilateral isokinetic strength deficits in the knee extensor or flexor muscles. However, given the proximo-distal multi-joint sequencing of the front kick and roundhouse kicking techniques in kickboxing (12), isolated single joint studies may fail to capture the functional demands of the activity (5). Thus the application of these findings to practice must be interpreted with caution. To our knowledge, no previous studies have examined asymmetry in lower limb functional performance characteristics of kickboxers. Knowledge of possible lower limb functional asymmetry may have implications for the strength and conditioning of kickboxers. Therefore the purpose of the present study was to examine lower limb functional performance deficits between the preferred kicking leg and preferred stance leg in amateur male kickboxers.

METHODS

Eight well-trained amateur male kickboxers (30.7 ± 9.3 yr., 178.3 ± 6.4 cm, 83.0 ± 8.4 kg) volunteered for the study for which institutional ethical clearance was received. All participants provided written informed consent and were familiarised with all procedures prior to testing. Participants identified their preferred kicking leg and preferred stance leg for both the front kick and roundhouse kick techniques. Following a standardised and specific warm up (3), participants completed the following sequence of lower limb functional performance evaluations. In each test, the preferred kicking leg was tested first, followed by the preferred stance leg.

i) Maximal kicking performance
Maximal kicking impact power (W) and reaction time (ms) was assessed using a StrikeMate™ impact measurement device (Strike Research Limited, Norfolk, UK). Previous research has shown the StrikeMate™ to be a valid and reliable tool for the measurement of striking impact forces (4, 13). Using a standardised protocol (4) and commencing with the preferred kicking leg, participants delivered five maximal kicks to the strike zone of the device, with a five seconds rest interval between kicks. Participants firstly delivered kicks using a front kick technique, followed by the roundhouse kick technique. The highest value from the five trials was used for data analysis.

ii) Maximal single leg dynamic functional performance
Maximal power (W), jump height (cm), force (N) and velocity (m.s⁻¹) were assessed using a single leg vertical jump test. Participants wore a Myotest® (MYOTEST Inc. Durango, CO) accelerometer secured via a waist band over the superior aspect of the left iliac crest, in accordance with the manufacturer’s instructions and using standardised protocols (1). The Myotest® unit is a lightweight (52 g) commercial, tri-axial accelerometer which has been validated for the measurement of lower limb functional performance (1, 2) and previously used in the assessment of lower limb functional performance of adult male kickboxers (3). Three maximal vertical jump attempts were performed for each leg, each separated by two minutes of passive, standing rest. The highest value from the three trials was used for data analysis.

iii) Maximal single leg isometric strength
Maximal single leg isometric strength (kg) was assessed using an isometric dynamometer (Takei, Niigata-city, Japan). Using a single leg modification of a standardised protocol (7), participants stood in a single leg stance with the knee and hip flexed to approximately 135°. The handle of the dynamometer was securely grasped in the centre with both hands using an overhand grip. Participants were then instructed to apply a maximal vertical force by attempting to extend the knee and hip, while keeping their back straight. Details of the positioning for this test are shown in Figure 1. Three maximal attempts for each leg were performed, separated by two minutes of passive, standing rest. The highest value from the three trials was used for data analysis.
Figure 1 - Maximal single leg isometric strength.

Descriptive statistics (mean ± SD) were used to report demographic variables. Data were checked for normality using Shapiro-Wilks tests. Where data from both the preferred kick leg and preferred stance leg were normally distributed, independent samples t-test were used to examine the difference in functional performance between the preferred kicking leg and the preferred stance leg. Where data from either the preferred kick leg or preferred stance leg were non-normally distributed, the non-parametric Mann-Whitney U test for mean ranks was used. Effect sizes (Cohen’s $d$ and $r$) were calculated for normally, and non-normally distributed data respectively to examine the magnitude of the effect and interpreted according to Hopkins (6). Data analyses were conducted using SPSS Version 22.0. Statistical significance was accepted at the $p<0.05$ level (2 tailed).

RESULTS

Most (n=7, 87.5%) participants identified the right leg as the preferred kicking leg for both the front kick and roundhouse kick techniques. Table 1 shows the lower limb functional performance characteristics for the preferred kick leg and preferred stance leg.

Table 1 - Lower limb functional performance characteristics (mean ± SD) for the preferred kicking leg and preferred stance leg.

<table>
<thead>
<tr>
<th>Functional performance measure</th>
<th>Preferred kicking leg</th>
<th>Preferred stance leg</th>
<th>ES#</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical jump maximal power (watts)</td>
<td>2280.2±530.6</td>
<td>2515.6±649.3</td>
<td>0.19</td>
<td>0.32</td>
</tr>
<tr>
<td>Vertical jump height (cm)</td>
<td>21.8±3.4</td>
<td>21.6±4.4</td>
<td>-0.05</td>
<td>0.90</td>
</tr>
<tr>
<td>Vertical jump maximal force (N)</td>
<td>1642.1±202.7</td>
<td>1742.3±347.2</td>
<td>0.37</td>
<td>0.38</td>
</tr>
<tr>
<td>Vertical jump take-off velocity (m.s$^{-1}$)</td>
<td>1.71±0.28</td>
<td>1.80±0.28</td>
<td>0.31</td>
<td>0.45</td>
</tr>
<tr>
<td>Maximal isometric strength (kg)</td>
<td>146.3±16.4</td>
<td>152.8±11.3</td>
<td>0.48</td>
<td>0.25</td>
</tr>
<tr>
<td>Maximal front kick impact power (watts)$^*$</td>
<td>12058.9±4761.5</td>
<td>9485.9±2731.7</td>
<td>-0.41</td>
<td>0.04</td>
</tr>
<tr>
<td>Reaction time – front kick (ms)$^*$</td>
<td>794.6±149.6</td>
<td>806.2±134.1</td>
<td>-0.02</td>
<td>0.92</td>
</tr>
<tr>
<td>Maximal roundhouse kick impact power (watts)</td>
<td>32711.8±7697.2</td>
<td>24312.2±8113.6</td>
<td>-1.11</td>
<td>0.01$^*$</td>
</tr>
<tr>
<td>Reaction time – roundhouse kick (ms)</td>
<td>790.8±65.6</td>
<td>789.2±148.3</td>
<td>-0.14</td>
<td>0.93</td>
</tr>
</tbody>
</table>

$^*$ Denotes statistically significant difference between preferred kicking leg and preferred stance leg ($p<0.05$).

$^*$ Denotes non-parametric Mann-Whitney U test. Data shows mean ± SD.

$#$ Denotes Effect Size. Cohen’s $d$ is used for normally distributed data, $r$ is used for non-normally distributed data.

DISCUSSION

The present study demonstrates statistically significant asymmetry in maximal kicking impact power during the performance of the front kick and round house kicking techniques in well-trained amateur male kickboxers, although the magnitude of the effect size is only moderate. Importantly, this finding highlights that, although standard field measures of lower limb functional performance may not identify functional asymmetries, more sensitive, valid and specific measures such as the use of the StrikeMate™ impact measurement device are needed to comprehensively evaluate kicking performance in amateur male kickboxers. Previous studies using isokinetic dynamometry have demonstrated the absence of bilateral strength deficits in karate exponents (9, 11). However, the findings of such studies, and their application to decision-making in strength and conditioning must be interpreted with caution given complex multi-joint nature of the front kick and roundhouse kicks used in kickboxing (5, 12). Other previous studies examining the lower
limb functional parameters in martial artists suggest that kicking velocity is higher with the dominant, compared to the non-dominant lower limb (11). This conflicts with the findings of the present study which show that reaction time (time from stimulus to impact) did not differ between limbs in either the front kick or roundhouse kick. From the present study, a secondary analysis where mean kicking velocity, calculated by dividing the distance from the foot to the impact zone of the StrikeMate™, by the reaction time, was shown to be not significantly different between limbs for either the front kick or roundhouse kick. It must be noted, however, that this method of calculating velocity assumes a linear path which differs from the curvilinear path of the foot observed during the performance of the roundhouse kick. Asymmetries in strength of more than 10% have also been suggested to result in an increased injury risk in martial artists (11). Data from the present study shows a mean percentage difference between dominant and non-dominant lower limb of less than 10% for all measures with the exception of maximal impact power in the front kick and roundhouse kick. However, the effect of lower limb functional asymmetry on the magnitude and nature of injury risk in amateur make kickboxers remains to be fully evaluated. A strength of the present study is the use of field-based, low-cost measures of lower limb functional capacity which can be readily implemented by kickboxing coaches using valid and reliable measure of kicking performance. Although beyond the scope of field-based studies, future investigations of functional lower limb asymmetries in kickboxers may consider the use of isokinetic dynamometry or 3-d motion analysis in addition to functional performance tests to pinpoint the potential source of asymmetries in kicking impact power.

PRACTICAL APPLICATIONS

The findings of the present study build on existing data regarding asymmetry in lower limb functional performance in amateur kickboxers. Importantly, this study highlights that strength and conditioning coaches should include specific measures of kicking performance in addition to standard field measures of lower limb functional performance when evaluating lower limb functional asymmetries in amateur male kickboxers. A comprehensive analysis of such asymmetries may help guide the design and implementation of strength and conditioning programs. Specifically, such analyses will inform the choice of unilateral and bilateral lower limb exercises to maximise performance and minimise injury risk. Furthermore, kickboxing coaches may utilise data on asymmetries in kicking performance to develop training sessions which focus on the non-dominant limb. For example, skill sessions which emphasise kicking with the preferred stance leg, or simulated competition where the opponent deliberately targets use of the preferred stance leg for kicking may be implemented. Replication of the present study in female kickboxers and other martial arts is warranted.

REFERENCES

Correlations between attacking agility, defensive agility, change of direction speed and reactive strength in Australian footballers.

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CORRELATIONS BETWEEN ATTACKING AGILITY, DEFENSIVE AGILITY, CHANGE OF DIRECTION SPEED AND REACTIVE STRENGTH IN AUSTRALIAN FOOTBALLERS

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INTRODUCTION

Agility refers to “a rapid whole-body movement with a change of velocity or direction in response to a stimulus” (10). This is a separate physical quality to change of direction speed (CODS) which refers to rapid changes of direction which do not involve the cognitive response to a stimulus. There exists a large body of evidence investigating correlations between physical qualities and CODS (2,3,5,15). Despite this, due to the use of outdated definitions of agility in previous literature, research on agility remains limited.

To the authors’ knowledge, just one previous study has tested correlations between agility and reactive strength (15). The study tested 24 Australian Footballers using a video stimulus to assess defensive agility and found small correlation ($r = -0.10$) between defensive agility and reactive strength (15). Despite this, correlations between reactive strength and CODS were large ($r= -0.645$), suggesting that reactive strength is more important to CODS than agility. This is consistent with previous research which suggests reactive strength may be important in CODS performance (4,13,14).

Nevertheless, as the majority of agility tests used in literature are defensive, no correlational studies have been undertaken to investigate attacking agility and its correlations with defensive agility and CODS. Therefore, it is unknown if attacking and defensive agility are highly correlated or independent skills. In addition, past research has shown a low correlation between defensive agility and reactive strength, but it is unknown if this correlation will be similar for attacking agility (15). Previous research has noted the possibility of a higher correlation to attacking agility due to the speed of and intensity of the approach when approaching an agility scenario (15). As the attacking athlete has more time to make a movement decision, it is possible he or she may perform a more aggressive change of direction, therefore increasing the load on the leg muscles.

The purpose of this study is to understand the correlation between attacking and defensive agility and the relationship to reactive strength. This provides coaches with information on the importance of reactive strength to defensive and attacking agility.

METHODS

Subjects were comprised of 15 males (age: 22.7 ± 1.9 yr.; height: 182.1 ± 7.4 cm; mass: 81.9 ± 8.9 kg) who participated in community level Australian football competition within the last year. All participants were informed of the aims of the study and provided informed consent to participate. Subjects were injury free and pre-screened to ensure they exhibited safe change of direction technique prior to testing. In the week prior to experimental trials, all participants undertook the full battery of tests to familiarise themselves with the testing procedures.

Procedure

Following a standardised warm-up, participants undertook a battery of four tests in the same order; an attacking and defensive agility test, a CODS test (AFL planned agility), a vertical reactive strength test (drop jump), and a lateral reactive strength test (diagonal repeated bound).

Agility tests

A new field based agility test was used to assess the participant’s attacking and defensive agility. The test involved an attacking and defensive athlete positioned facing each other inside a 13 x 13 metre area outlined by cones as shown in figure 1. Both the attacking and defensive athletes began at one of 10 pre-determined locations within the testing area. While holding a football, the attacking player was instructed to attempt to evade the defensive player to reach the end line without being touched. Throughout the trial the attacking player was not allowed to leave the designated area or fend off his opponent. The defensive player’s aim was to get both arms around the attacking athlete with elbows bent in a position to tackle.

Live testers were used to simulate a match-like scenario and provide a stimulus to test cognitive and decision making skills along with the physical factors inherent in agility performance. All participants were tested against two opponents who remained constant throughout the entirety of the study. To minimise fatigue for these live testers, the first five trials were undertaken by one live tester with the second tester participating in the following five trials.
Contrary to the traditional approach of a time-based agility test where the participant’s score was based on the time taken to complete a set path, the aforementioned test was scored by the subject’s ability to successfully attack or defend. While attacking, the scoring protocol for each trial was; successfully evade defender – 3 points, touched by one hand - 2 points, touched by two hands - 1 point, run outside designated area / defender gets both arms around – 0 points. While defending, the scoring protocol was reversed; both arms around attacker/ attacker runs outside of designated area - 3 points, both hands touch attacker – 2 points, one hand touches attacker – 1 point, attacker successfully evades defender– 0 points.

The test consists of 10 attacking trials and 10 defensive trials with participants randomly allocated either defensive or attacking trials first. The score was then calculated from the sum of all attacking or defensive trials respectively, giving the athlete two scores out of 30. Scoring was initially recorded live and later reviewed using three video cameras to ensure the accuracy of the test. A previous study in our laboratory, currently awaiting publication, found the test to be reliable when analysing both test-retest reliability as well as inter-rater reliability.

**AFL planned agility test**
The AFL planned agility test, as used in the Australian Football League (AFL) draft combine, was used to test CODS (9). The test involved five changes of direction around stationary 1.4 metre poles positioned five metres apart. Starting with the chest in line with the starting beam, participants were timed using an electronic dual-beam, infrared timing gate system (Speedlight, Swift Performance Equipment). During trials, participants were not permitted to let any part of their body to pass above the poles or to knock any poles over. If this occurred, a retrial was permitted up to a maximum of 2 retrials. Participants were given three maximum effort trials with full rest in between efforts. The fastest time of the three trials was retained to represent the athlete’s CODS score.

**Drop jump**
The drop jump test was used to measure of vertical reactive strength, as is consistent with previous research (3,13–15). During testing, participants were required to step off a 30cm box and upon landing, jump for maximum height and minimum ground contact time. Participant’s reactive strength index (RSI) was then measured as height jumped (cm) / contact time (sec). Hands were placed on hips and participants were instructed to land with legs fully extended. Upon contact, participants were allowed to soften the landing by flexing at the hips, knees and ankles. A contact mat system (Swift Performance Equipment) was used to measure jump height and ground contact time (16). The participants were tested until no improvement was observed, and provided with full recovery between trials to achieve their best RSI.

**Diagonal repeated bound test**

Figure 1 – Reactive agility test setup.

Figure 2 – Diagonal repeated bound test.
A new diagonal repeated bound test was used to test for lateral reactive strength as shown in figure 2. As changing direction with side steps involves pushing off with one leg to achieve a new body direction, this test was developed as it was believed that a unilateral reactive strength test may better relate to CODS and agility performance than the drop jump. From a stationary start, participants were required to perform 11 diagonal bounds for maximum distance with the distance measured at the front of the foot at the 10th landing. The 11th bound was performed to prevent the athlete from performing an unnatural leap on the final bound to maximise the score. Bounds were performed over two parallel lines a distance of 55% of the participant’s leg length apart. This was an attempt to account for differences in leg length which was expected to influence total bound distance. A tape measure was laid along the length of the testing area and trials were measured live and later verified using video camera footage. Two trials starting on the left leg and two starting on the right leg were performed with full recovery provided between trials. The final score was calculated as the average of the best trial from either starting position.

**Statistical Analysis**

Statistical analysis was performed using SPSS software. Normality was assessed using the Anderson-Darling test and correlations were determined using the Pearson product-movement correlation coefficient (r). The qualitative strength of the correlation has been described using a scale adopted from Hopkins (6) as follows: 0.0-0.09 = trivial, 0.1-0.29 = small, 0.3-0.49 = moderate, 0.5-0.69 = large, 0.7-0.89 = very large, and 0.9-1.0 = nearly perfect.

**RESULTS**

**Table 1 – Correlation coefficients of performance variables.**

<table>
<thead>
<tr>
<th></th>
<th>Leg length</th>
<th>Diagonal Bound</th>
<th>RSI</th>
<th>CODS</th>
<th>Defensive Agility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attacking Agility</td>
<td>Correlation</td>
<td>-.044</td>
<td>.206</td>
<td>.782</td>
<td>-.522</td>
</tr>
<tr>
<td></td>
<td>P-Value</td>
<td>.877</td>
<td>.460</td>
<td>.001</td>
<td>.046</td>
</tr>
<tr>
<td>Defensive Agility</td>
<td>Correlation</td>
<td>-.364</td>
<td>.348</td>
<td>.504</td>
<td>-.377</td>
</tr>
<tr>
<td></td>
<td>P-Value</td>
<td>.182</td>
<td>.203</td>
<td>.055</td>
<td>.166</td>
</tr>
<tr>
<td>CODS</td>
<td>Correlation</td>
<td>.156</td>
<td>-.136</td>
<td>-.534</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P-Value</td>
<td>.578</td>
<td>.628</td>
<td>.040</td>
<td></td>
</tr>
<tr>
<td>RSI</td>
<td>Correlation</td>
<td>.200</td>
<td>.319</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>P-Value</td>
<td>.474</td>
<td>.246</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diagonal Bound</td>
<td>Correlation</td>
<td></td>
<td>.518**</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>P-Value</td>
<td></td>
<td>.048</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bold correlations are significant at the 0.05 level (2-tailed).

Relationships between performance variables are indicated in Table 1. Attacking agility was found to have large correlation with defensive agility (r = 0.666, p = 0.007, 95% CI [0.302, 0.881]) and this represented a common variance of 44%. Furthermore, attacking agility had a large correlation with CODS (r = -0.522, p = 0.046, 95% CI [-0.875, -0.088]) and a very large correlation with RSI (r = 0.782, p = 0.001, 95% CI [0.564, 0.899]). CODS and RSI exhibited a large correlation (r = -0.534, p = 0.040, 95% CI [-0.736, -0.301]) while a RSI showed a moderate correlation with the diagonal bound test (r = 0.476, p = 0.073, 95% CI [0.043, 0.829]). In addition, leg length was found to have a large correlation with the diagonal bound test (r = 0.518, p = 0.048, 95% CI [0.023, 0.780]).

**DISCUSSION**

No previous published literature has analysed relationships between attacking agility and other performance measures. In this study, while the correlation between attacking and defensive agility was large (r = 0.666, p = 0.007, 95% CI [0.302, 0.881]) the two measures share just 44% common variance, which suggests that attacking and defensive agility are different skills and that the two sub-tests assess different aspects of agility. Differences between attacking and defensive agility include differences in footwork patterns as well as differences in visual cues, such as the inclusion of the football in the visual field of the defender.

CODS displayed a large correlation (r = -0.552, p = 0.046, 95% CI [-0.875, -0.088]) with attacking agility but not defensive agility. This is likely due to similarities with the speed and intensity of the CODS and attacking agility movements and the ability for them to both utilize reactive strength.

Reactive strength showed a very large correlation with attacking agility (r = 0.782, p = 0.001, 95% CI [0.564, 0.899]) while displaying a smaller, non-significant correlation with defensive agility (r = 0.504, p = 0.055, 95% CI [-0.155, 0.837]). This suggests that reactive strength is more important for attacking agility than defensive agility, likely due to the differences in movements between attacking and defensive agility. While attacking, the athlete had time to gain momentum before performing the change of direction movement. This increases the loading on the leg allowing reactive strength to be exhibited to a greater extent. This is in contrast to defensive agility, where while waiting for the opposition to make a movement, smaller shuffling movements are common, which may reduce use of the stretch shortening cycle.
Reactive strength showed a large correlation with CODS ($r = -0.534$, $p = 0.040$, 95% CI [-0.736, -0.301]) indicating that reactive strength is important for the AFL planned agility test. This is likely because, due to the lack of a cognitive component, physical qualities make a larger contribution than during agility tests. Furthermore, as five changes of direction are performed in a small space, the stretch shortening cycle is utilised numerous times during each trial. This finding agrees with previous research which has also displayed significant correlations between CODS and reactive strength (4,13,15).

While the diagonal bound correlated moderately with the drop jump test ($r = 0.476$, $p = 0.073$, 95% CI [0.043, 0.829]) common variance was just 23%. Therefore, it can be assumed that the diagonal bound and the drop jump measure different qualities. The bound doesn’t correlate well with either the agility or CODS test which suggests that the standardisation of bounding width was not sufficient to account for differences in participant’s leg lengths. Furthermore, since the diagonal bound correlates largely with leg length ($r = 0.518$, $p = 0.048$, 95% CI [0.023, 0.780]), it appears this anthropometric measure detracts from the test’s capacity to reflect lateral reactive strength.

PRACTICAL APPLICATIONS

As the research shows clear differences between attacking and defensive agility, they should be trained and tested separately according to the role of the athlete. Also, while it is impossible to infer causation without a controlled training study, the study demonstrates the relationship between reactive strength and attacking agility. This strong correlation suggests that improving reactive strength, possibly with plyometric training, may be beneficial for increasing attacking agility in athletes, although further research is needed to verify this suggestion. Although, the lack of a significant correlation between reactive strength and defensive agility suggests that improving reactive strength may not be as beneficial for defensive athletes. Furthermore, as the AFL planned agility test is used during the AFL draft combine, improving the score in this test is beneficial to the athlete’s prospects of being drafted into the AFL. Therefore the test’s large correlation with reactive strength may indicate that plyometric training would be appropriate to improve its score. While this is impossible to verify without a controlled training study, research does suggest that plyometric training is effective in increasing CODS in athletes. Despite this, as the AFL planned agility test fails to incorporate a stimulus similar to a game situation, the test is not appropriate for determining the agility of an athlete (1,7,8,11,12).

REFERENCES

Deconstructing a conventional deadlift with inertial sensors: observational analysis of spine movement during weighted and unweighted lifts.

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DECONSTRUCTING A CONVENTIONAL DEADLIFT WITH INERTIAL SENSORS: OBSERVATIONAL ANALYSIS OF SPINE MOVEMENT DURING WEIGHTED AND UNWEIGHTED LIFTS

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INTRODUCTION

The conventional deadlift is the most recognised modified back lift method practiced for lifting an object off the ground. Although minute details in lifting styles and technique between individuals may vary, the gross lifting guidelines are the same for everyone (1). The conventional deadlift is a segmental exercise, with trunk, hip, and knee movements occurring primarily in the sagittal plane (2). The deadlift has recently been deconstructed into three distinct phases. These include the lift off (LO), the knee passing (KP) and lift completion (LC) phase (1, 3). These phases are defined from lifting kinematics and barbell location during the lift (1). Deconstructing the deadlift provides insight into technique and movement patterns, for better understanding of distinct characteristics separating the three phases of the lift. One variable that has known influences on deadlift technique is the weight lifted.

During heavy and maximal deadlifts, the kinematics appear to change, as it becomes more difficult to maintain a neutral spine position or a slight lumbar lordosis. This is due to the inability of the erector spinae muscles to produce enough force to overcome the weight of the load and the hip extensors generating much greater forces than the spinal erectors (3). Resulting in a typical flexion or kyphotic thoracic and lumbar curve, of which the kyphotic response can be reduced with regular strength training. Heavy or maximal loads for strength athletes results in slight flexion angles of vertebrae during deadlifts and does not elicit any unnatural range of motion (4). However, only a small portion of the population regularly engage in adequate resistance exercise training to safely perform a deadlift with heavy weight. For the majority of the population, these findings suggest that technique changes as the load increases and that this technique change may be inevitable without training, leading to increased injury risks. Therefore, simply lifting with heavy loads may be considered an unsafe lift if the movement pattern differs significantly from unweighted lifts. This highlights the need for monitoring technique during resistance exercise in order to accurately determine limits of safety, by identifying technique changes as loads increase. Therefore the aim of this research was to infer trends of weighted and unweighted conventional deadlift movement patterns. This was accomplished by monitoring movement of the spine during unweighted and weighted deadlift trials with inertial sensors, allowing for comparisons of movement patterns between lifting trials and between devices within trials.

METHODS

The adult pre exercise screening system (APSS) was used to identify the risk of performing high intensity exercise (5). Eleven participants completed five repetitions of three different lifting trial sets (unweighted, barbell and 80% of one repetition maximum (1RM) sets). All screening and data collection protocols were approved by the Charles Darwin University Ethics Committee for Human Research, ethical approval number: H14046. Participants completed signed consent and a self-reported questionnaire to assess their recent experience with resistance exercise. The included participants were considered experienced at performing resistance exercises with safe technique, specifically the conventional deadlift. Data collection was conducted at the Sport and Biomedical Engineering Laboratory (SABEL) at Griffith University (Nathan Campus), in a controlled environment to reduce environmental limitations. An inertial sensor was securely applied to participant’s skin with Physio tape at the spinal landmarks C7, T12 and S1 respectively. Participant’s movement patterns were monitored by a video camera and a tri axial accelerometer and gyroscope housed in the inertial sensor units. Comparisons between lifting trial inertial sensor angular rate of change data was completed in Matlab and Excel. The movement of the spine or trunk technique during the concentric phase of the deadlift was chosen as the segment of analysis. Determining the start and end points of the concentric phase for each trial was completed with the SABEL sense data analysis software program (SABEL Sense, Sabel Laboratory, Brisbane, Australia), which synchronised video and inertial sensor outputs for X, Y and Z axis, for observational assessment of movement patterns. All inertial sensor data was reduced into concentric lifting phases, for each repetition of each lifting trial, by manually picking the start point or first upward movement of the concentric phase and the end point or lockout of the concentric phase. This reduced data was normalised for time by interpolating data to 100 samples (N = 100), and a 5 Hz low pass hammering window filter was applied. The group mean of each reduced, normalised, filtered data set (each channel for each sensor for each lifting trial) was calculated and plotted in Excel and Matlab, to provide a model of deadlift technique. This model was interpreted by comparing each lifting trial and cross referencing video playback observations. For statistical comparisons of technique the final inertial sensor group means for Y axis angular rate of change for each sensor and each included lifting trial were extracted into Excel. Gyroscope Y axis data was the chosen channel of analysis due to spine flexion and extension data occurring in this axis, representing movement around the frontal axis and through the sagittal plane. The group means of gyroscope rate of change outputs from each lifting trial
were used for comparisons. Pearson's correlations and Student's T-tests were completed in Analyse-it (Analyse-it Software, Ltd, Leeds, United Kingdom) for Excel 2007, to determine the correlation and significant differences between each specified angular rate of change lifting trial relationship. Lifting trials included unweighted conventional deadlifts, conventional deadlifts with a 20 kg barbell and conventional deadlifts at 80% of 1RM. The angular rate of change relationships between lifting trials with and without weight demonstrated the influence that weight has on angular rate of change during deadlifts. The correlation between the Y axis angular rate of change outputs and the Student T test P values were reported with a level of significance set at 0.5.

RESULTS

The relationships between lifting trials was measured by a Pearson’s correlation and comparing group means in multiple Student’s T test analyses between deadlifts with no weight, deadlifts with a barbell, and deadlifts at 80% of 1RM (Table 1, Figure 1). This statistical analysis yielded nine separate Student's T tests demonstrating the Y axis angular rate of change correlation between the mean curves of the concentric phase for each included lifting variable pair (Table 1). Two significant differences were found. It was concluded that weight has a significant influence on lifting technique at the S1 segment of the spine at 20 kg absolute and at 80% of individual 1RM. All other trials demonstrated no significant differences. A model of deadlift technique was formulated in Excel for observational interpretation to infer real world trends. This model represents the time normalised mean lifting patterns or S1 Y axis angular rate of change for the concentric phase of each included lifting trial (Figure 1).

Table 1 - Influence of weight on technique rate of change. Nine Student's T tests demonstrating the Y axis angular rate of change correlation between the mean curves of the concentric phase for each included lifting variable pair. Bolded P values indicate statistical significance.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Pearson Correlation (95% CI)</th>
<th>Student T test P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unweighted C7 vs. Barbell C7</td>
<td>0.986 (0.980 - 0.991)</td>
<td>0.055</td>
</tr>
<tr>
<td>Unweighted C7 vs. 80% 1RM C7</td>
<td>0.697 (0.580 - 0.786)</td>
<td>0.418</td>
</tr>
<tr>
<td>Barbell C7 vs. 80% 1RM C7</td>
<td>0.742 (0.638 - 0.819)</td>
<td>0.383</td>
</tr>
<tr>
<td>Unweighted T12 vs. Barbell T12</td>
<td>0.994 (0.991 - 0.996)</td>
<td>0.142</td>
</tr>
<tr>
<td>Unweighted T12 vs. 80% 1RM T12</td>
<td>0.858 (0.796 - 0.903)</td>
<td>0.594</td>
</tr>
<tr>
<td>Barbell T12 vs. 80% 1RM T12</td>
<td>0.825 (0.750 - 0.879)</td>
<td>0.069</td>
</tr>
<tr>
<td>Unweighted S1 vs. Barbell S1</td>
<td>0.941 (0.914 - 0.960)</td>
<td>0.769</td>
</tr>
<tr>
<td>Unweighted S1 vs. 80% 1RM S1</td>
<td>0.807 (0.726 - 0.866)</td>
<td>0.010</td>
</tr>
<tr>
<td>Barbell S1 vs. 80% 1RM S1</td>
<td>0.937 (0.908 - 0.957)</td>
<td>0.009</td>
</tr>
</tbody>
</table>

Legend: C7 = Inertial sensor at cervical spine; T12 = Inertial sensor at thoracic spine; S1 = Inertial sensor at sacral spine.
DISCUSSION

The only significant difference between spine angular rates of change during deadlifts was at the S1 segment between the 80% of 1RM lifting trial and both other trials (unweighted and barbell). There was no significant difference between any T12 or C7 relationships or between unweighted deadlifts at S1 and barbell deadlifts at S1. These results suggest that weight has a significant influence on performing deadlifts, specifically at S1. This is evident when comparing the rate of change models between these lifting trials (Figure 1). There are three distinct phases in the mean curves for rate of change at S1 for all three conventional trials, which are synonymous with the LO, KP and LC phase defined from past research (1, 3). The first phase occurs from the first upward momentum usually just greater than 0°/sec to around 15-30°/sec. Based on observation from video playback, this phase was defined as the tension or tightening of the muscles to take up the load and increase force production, to increase upward momentum. In theory, increases in weight would slow down this process, due to more force production required, leading to a longer time taken to complete this phase. This is supported from the S1 normalised timing points (0 to 100) in which this phase was completed. The unweighted trial completed this phase at around time point 20-30, the barbell trial at time point 30-40, and the trial at 80% of 1RM at time point 40-50 (Figure 1). Based on observation from video playback, longer knee extension occurred in trials with heavy weight, without coupled trunk inclination, resulting in longer time periods to complete this phase. This is demonstrated as the 80% of 1RM had much larger knee extension rate of change in this first phase compared to the other two trials. The LO phase defined from past research also demonstrates greater rates of knee extension (1, 3). As weight increases, inertial sensors placed on the spine may be able to detect technique differences, specifically the knee extension changes measured from S1. Therefore knee extension needs to be evaluated quantitatively using these methods for future research. These conclusions are supported by related research that suggests technique changes as weight increases, even when attempting to perform the exercise adhering to guidelines (3, 4).

The second phase (KP) of the lift was defined as trunk inclination acceleration, occurring when knee extension begins reaching its limit and trunk acceleration from hip and spine extension occur more rapidly. This is represented in rate of change data increasing after the first phase ends up until a peak is achieved. Conventional deadlifts with a barbell achieved a higher peak acceleration compared to the other trials (Figure 1). In theory as weight increases it is more difficult to achieve higher rate of change, due to greater forces required from muscles to move the load. However lifting with a barbell resulted in the biggest rate of change data, suggesting greater acceleration can be achieved with weight up until a certain point. This may be an area for research to find an individual weight where power can be maximised. The final or third deceleration phase (LC) occurred as angular rate of change decreased rapidly back down to just above 0°/sec (Figure 1). This is when lockout occurred and movement stopped. No flexion occurred during any deadlifting trials, evident from peak angular rate of change values and observation, as flexion results in much greater angular rate of change peaks. These three identified phases are synonymous with past research (LO, KP and LC phases), suggesting that these phases can also be monitored by placing a single inertial sensor on the S1 segment of the spine.

Figure 1 - Mean comparison of conventional deadlift trials at S1. Three separate phases including lift off (LO), knee passing (KP) and lift completion (LC) phase.
Visual observation of plotted data demonstrated high variation between participants' lifting patterns and large standard deviations that may have influenced group means. This suggests that individuals may have different techniques and comparing technique between individuals may be an area for future consideration. Furthermore, it appeared that trials with heavier weight (80% of 1RM) had less variability, compared to trials with less weight or no weight, with more individual lifting patterns being closer to the mean and within the standard deviation. This presents a possible trend that the standard deviation or variability between participants becomes narrower as weight increases. Therefore it may be easier to complete a deadlift adhering to guidelines with weight, than without weight. Typical resistance exercise coaching techniques are taught for the purpose of lifting with weight, and technique changes as weight increases, as supported by past research (4, 6). Therefore, technique of a lift with no weight may be misrepresented and may actually present as a different lift entirely when compared to techniques during weighted lifts, and may require separate guidelines for defining safe or unsafe technique. The lighter data in heavier lifts may be due to the participants conforming more strictly to lifting guidelines that were developed for lifting with weights. Therefore, the variability of unweighted lifts may be explained by the experienced participants' lifting with habit, as opposed to lifting based on previously practiced guidelines and consistently training with heavy loads. Future research to measure this trend may be essential to decipher differences between resistance exercise with weight and with no weight, and may result in separate guidelines for technique based on the weight lifted. It is unknown at which specific weight (absolute or relative) that technique begins to change. However, based from these results, it is assumed to be between 20 kg absolute and 80% of 1RM, and may be dependent on the individual. Defining the weight limits when technique change occurs may have important applications for monitoring fatigue or safety. Furthermore, when considering performance, strength athletes regularly perform maximal lifts to 100% of 1RM, which may have further technique changes, when compared to 80% of 1RM. Maximal lifting was not completed for these results to ensure the safety of participants. However, the results warrant the need for future research to measure technique at maximal lifting capacity, for valuable knowledge of performance parameters, which may lead to changing standardised technique guidelines or defining new guidelines specific to lifting with heavy weight.

The variation between individuals may have been due to the method of manually picking start and end points of each individual lift to reduce the data into concentric phases. Thus, individuals that lift at differing speeds may have slight differences when key phases or peaks occur when the lifting data is normalised, despite the interpolation of time normalisation. This may have caused small errors in the results and could have been tested with confidence limits. Furthermore other methods may have been more appropriate to implement for synchronising the data. The method of template fitting may have reduced these limitations, where start and end points are chosen, with peaks and markers of technique lined up or synchronised between lifts. Thus, allowing the data between or on either side of these markers to be time normalised. Therefore, this method should be considered for future research when comparing group means of lifting data. However, despite these limitations, it was assumed that results from the Student's T tests were appropriate to infer trends of technique variations.

The participants in this research were all experienced at lifting weights, however did not include any professional athletes currently competing in strength sports. The most experienced and oldest participant had previously competed in strength sport competitions and exhibited observed differences in rate of change at S1, during the 80% of 1RM deadlift trials, compared to other participants. This difference was a faster initial phase of lifting up until around 30°/sec was achieved, due to less isolated knee extension and more coupled or simultaneous hip and knee extension, which relates more closely to lifting trials performed with lighter weights. This suggests that there may be a difference between individual’s capabilities of adhering to technique guidelines with heavy weight, when based on different experience levels. This is in line with previous research that has reported that more practice and experience results in higher levels of competence or skill execution (7, 8). Related research also supports this observation, demonstrating differences in squat press technique between individuals of differing experience levels (9). Therefore, measuring technique difference based on experience may be important for future practical applications. For example, strength athletes may require a completely specialised or different technique monitoring tool, compared to individuals with no prior lifting experience, such as those in workplace environments. Thus, future research that classifies or measures these technique differences and tailors research specific to sub-populations may be important to supply best practice technique monitoring tools.

PRACTICAL APPLICATIONS

This methodology can now be implemented practically to determine parameters of the three phases of a concentric deadlift using a single inertial sensor unit on the S1 segment of the spine. An athlete's angular rate of change and the time it took to complete the different phases of the lift may provide coaches with a valuable tool to monitor athlete progress or rehabilitation. This may also be a simple means of determining if an individual performed a lift as desired, eliminating any error of visual observation. The other major practical application from this research is the possibility of implementing and expanding the methodology to analyse previously discussed research areas of importance. These recommended future research applications included measuring movement during lifting with different loads on varied sub populations, to define lifting limits based on performance parameters such as angular rate of change. Future research based on the recommendations provided may lead to further practical applications and provide health professionals with a tool to monitor technique quantitatively with inertial sensors. In conclusion this research deconstructed a conventional deadlift and provided valuable insight into the movement pattern of the spine during weighted and unweighted variations, which lead to valuable research recommendations. The conclusion that kinematics
change as weight increases may pave the way for developing future research and guidelines for performance and safety.

REFERENCES

THE RELATIONSHIP BETWEEN TWO MEASURES OF PHYSICAL CAPACITY AND MATCH PERFORMANCE IN SEMI-PROFESSIONAL AUSTRALIAN RULES FOOTBALL

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1 University of Notre Dame, Fremantle, Australia
2 South Fremantle Football Club, Fremantle, Australia

INTRODUCTION

Australian Rules Football (ARF) is an invasive field-based team sport that requires athletes to have the ability to perform repeat high-intensity, intermittent exercise including frequent accelerations, decelerations and change of direction (2, 8). Each team is made up of 22 players with only 18 on the field at any one time with 4 players on the interchange bench. A game is played between 2 teams over 4 quarters that last approximately 30 minutes. The main objective is to invade the opposition territory to score a goal. The evolution of ARF in terms of rule changes, team tactics and professionalism have influenced the physical demands of athletes in matches (12). For example the mean running velocity of a professional ARF athlete has increased from 6.8 ± 0.6 km/h in 2005 to 7.3 ± 0.7 km/h in 2008 (12). These observations have led to some debate in regards to the relevance of traditional fitness testing practices. For example, traditionally a 3km time trial (3KM TT) is used to measure athletes’ aerobic capacity. This measure of aerobic capacity is used to identify elite talent at the national draft camp held each year (3). However, in professional ARF, Mooney et al. (8) recently discovered a significant relationship between Yo-Yo Intermittent Recovery Level 2 (YYIR2) score and match performance.

A study observing the factors affecting soccer performance suggested that technical, tactical and physical performance were relevant measures of match performance (6). The authors reported that physical match intensity, in particular high intensity activity was an indicator of individual match performance, and that field tests can provide an insight into the capacity of athletes to execute high intensity activity (6).

Specific to ARF, there is only a small body of research investigating the relationships between physical capacity measures and physical match performance (8, 10, 13, 14). These studies support the previous findings in soccer that high aerobic capacities are important qualities for an elite ARF athlete to possess. For example, Young et al. (14) reported that performance in the YYIR2 was significantly greater in starters compared to non-starters at the beginning of an ARF season. In addition, significant correlations between the YYIR2 test and match exercise intensities have been reported in elite ARF including average distance/minute and high-intensity distance/minute (>15 km/h) (8). This study also reported a significant relationship between the YYIR2 and total ball disposals. This relationship was mediated by high-speed distance/min, suggesting that increasing high-intensity running through improving YYIR2 score, will increase ball disposal count.

At a semi-professional level of ARF, there has been very limited research that directly investigates the relationship between physical capacity and match performance. The one study that has provided experimental evidence on the topic has found a significant association between 3KM TT and direct game involvement (DGI)/min (10). DGI/min was used to represent individual match performance and included the total number of kicks, handballs, marks and tackles a player had in competition (10). Although, their finding was significant, the analysis reported only a small association, suggesting the relevance of the 3KM TT is not as strong as previously thought (10). However, there are considerable differences in physical match demands between professional and semi-professional ARF that need to be considered (2). For example, professional ARF players cover 9% more distance/minute and perform 21% more high-intensity efforts/minute than semi-professional players (2). Therefore, specific physical capacity measures may differ in the relationship to match performance across competition levels. The Western Australian Football League (WAFL) is a semi-professional state based competition with players training 3 times per week and games played on weekends (10).

Literature shows that the YYIR2 and 3KM TT are relevant physical capacity measurements associated with individual match performance in professional and semi-professional ARF respectively. Currently, there is no empirical evidence investigating which measurement of physical capacity is best associated to individual match performance. Therefore the aim of this study was to identify which physical capacity measure is the best predictor of match performance in semi-professional ARF.

METHODS

Twenty-three semi-professional footballers (n=23) from the same WAFL Club were invited to participate in this study. Informed consent was gathered prior to the commencement of any data collection. Ethical approval was obtained through the University of Notre Dame Human Research Ethics Committee.
Physical capacity measurements were the 3KM TT and YYIR2. Match performance was measured via two methods: a direct game involvement measure (reflected by the summation of kicks, handballs, marks and tackles per minute) (DGI/min) and physical measures from GPS indices. Distance per minute (DIS/min) and high speed distance per minute (HS/min) (metres > 18km/h) were the physical match performance measures. All of these measures were collected on participants throughout the 2015 season.

A sample was collected for an individual player if they recorded a YYIR2 score, 3KM TT, GPS indices and a DGI/min for a match. Samples were collected throughout the 20 match season. Of the 23 footballers recruited to participate, only 20 recorded at least one sample (ranging from 1 – 17) due to team selection, the number of available GPS units and technical errors with GPS units. A total of 123 samples were collected.

Each participant completed both physical capacity measurements less than four weeks prior to the first game of the season. All participants had previously completed each test at the beginning of the pre-season to attain familiarisation. The YYIR2 was performed on a wooden indoor surface. This test has previously been reported to have typical errors ranging from 4.9 to 10.4% (1). The 3KM TT was performed on an outdoor grassed surface measured using a trundle wheel (Cresent Measuring Wheel). A typical error of 3.5% has been reported for this procedure (11).

Participants had their GPS indices recorded each match by a portable GPS unit sampling at 10 Hz (SPI Pro X, GPSports, Canberra, Australia). This data was downloaded and analysed post-match using an analysis software program (TEAM AMS, Canberra). Only the on-field playing duration for each participant was reported. Samples were only included if the participant played greater than 70% of total match time. This was to reduce reporting unusually high running intensities. Each participants DGI/min was calculated using statistics recorded each game by a commercial statistical analytics company (Champion Data, South Bank, Australia). Champion Data has been reported to provide 99% accuracy for match statistics (9).

Statistical analysis was conducted using SPSS (Version 22). Linear mixed models (LMM) were used to analyse the longitudinal data. LMM statistic is suitable where multiple measures are repeatedly taken from the same individuals, data is not necessarily normally distributed, and data may be missing at random (e.g. player was injured). Residual tests for normality on final model was used to ensure the assumption for the LMM is met. Statistical significance was set at p < 0.05. Players’ experience (reflected by number of senior games) were controlled for in the LMM model.

RESULTS

Participants had a mean (±SD) stature of 184.8 ± 5.5 cm, mass of 83.3 ± 7.0 kg and age of 23.2 ± 2.7 years. Physical capacity and match performance measures are described in Table 1.

Table 1 - Description of physical capacity and match performance measures.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>3km TT (sec)</td>
<td>676.87</td>
<td>31.59</td>
</tr>
<tr>
<td>YoYo (m)</td>
<td>651.06</td>
<td>101.95</td>
</tr>
<tr>
<td>DGI/min</td>
<td>0.26</td>
<td>0.07</td>
</tr>
<tr>
<td>DIS/min</td>
<td>132.11</td>
<td>12.17</td>
</tr>
<tr>
<td>HS/min</td>
<td>19.64</td>
<td>5.97</td>
</tr>
<tr>
<td>Experience</td>
<td>59.26</td>
<td>44.88</td>
</tr>
</tbody>
</table>

LMM results found significant associations between 3 KM TT and match performance variables investigated (Table 2). YYIR2 was investigated in each of the models but was removed as it was non-significant. Model 1 reported a significant association between 3 KM TT and DGI/min (p < 0.05). Experience was not significantly associated with DGI/min and removed from the final Model 1. Model 2 reported a significant association between 3 KM TT and DIS/min (p < 0.05), with Experience a significant contributor (p = .005). Model 3 reported a significant association between 3 KM TT and HS/min (p < 0.05), with Experience a significant contributor (p < .001). A summary of the final models is shown in Table 2.
Table 2 - LMM between physical capacity measurements and match performance variables.

<table>
<thead>
<tr>
<th>Model</th>
<th>Variable</th>
<th>Estimate</th>
<th>SE</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) DGI/min</td>
<td>Intercept</td>
<td>.918</td>
<td>.136</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>3 KM TT</td>
<td>-.001</td>
<td>.001</td>
<td>.000</td>
</tr>
<tr>
<td>2) DIS/min</td>
<td>Intercept</td>
<td>302.849</td>
<td>21.042</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>3KM TT</td>
<td>-.248</td>
<td>.027</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Experience</td>
<td>-.052</td>
<td>.018</td>
<td>.005</td>
</tr>
<tr>
<td>3) HS/min</td>
<td>Intercept</td>
<td>77.905</td>
<td>9.592</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>3KM TT</td>
<td>-.082</td>
<td>.014</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Experience</td>
<td>-.048</td>
<td>.009</td>
<td>.000</td>
</tr>
</tbody>
</table>

For Model 2, the prediction formula is as follows:

\[
\text{DIS/min} = \text{intercept} + 3 \text{ km TT} + \text{Experience}
\]

As an example, using mean values from Table 1 and parameter estimates from Model 2 in Table 2 DIS/min can be predicted.

\[
\begin{align*}
\text{DIS/min} &= 302.85 + 676.87(-.248) + 59.26(-.052) \\
&= 132.11 \text{ metres/min}
\end{align*}
\]

Figure 1 - Scatterplots and line of best fit of 3 km TT and match performance variables.

DISCUSSION

This study aimed to identify which physical capacity measure could best predict individual match performance in semi-professional ARF. The results show that 3KM TT performance and the number of senior games played are significant predictors of total distance and high speed distance covered per minute during a match. 3 km TT performance was also a predictor of the number of direct game involvements a player had per minute. Furthermore, the insignificance of the YYIR2 creates doubt to the efficacy of using this test in a semi-professional environment. This is surprising given the emphasis that has been placed on the importance of performance (and recovery) of high intensity efforts in previous research (2, 8, 6). These findings are important for coaches to consider as they highlight the physical mechanisms that contribute to individual match performance at the semi-professional ARF level.

The 3 km TT is not thought to be specific to the mechanics of ARF as it is a continuous aerobic test that requires pace judgement (4). However, the results of this study suggest that it can be used to predict semi-professional ARF match performance. The relationship between 3 km TT performance and each of the match performance variables can be seen in Figure 1. The inverse relationship identifies that better performance in the 3 km TT results in greater high speed, total distance and direct game involvement per minute in a match. This supports previous research in semi-professional ARF that also found a significant association between 3 km TT and the number of direct game involvements per minute in a match (10). Also, the 3 km TT test has been shown to be a better predictor of V02 max than other field tests (7).

In contrast to the 3 km TT, the YYIR2 measures the capacity to perform repeat high intense intermittent exercise with a significant aerobic component in combination with a large anaerobic contribution (1). The finding that the YYIR2 was not a significant predictor for any match performance variable differs from previous research involving professional ARF players (8). In this study the authors identified a significant correlation with the number of ball disposals that was mediated through high intensity running (> 15 km/h) per minute (8). However this is partly explained by noting that the
GPS parameters used to quantify high speed running in this study were different to the present study. In addition, the greater fitness levels and increased physical match demands of professional players compared with semi-professional players is another possible reason for the unexpected result (2).

This study also investigated the association between player experience and individual match performance. There were significant associations between player experience and total distance and high speed distance covered per minute suggesting that inexperienced players cover more ground than the more experience counterparts. This supports the finding in professional ARF that less experienced players had a greater movement output (5). Whilst speculative, it is proposed that more experienced players are able to read the play more effectively and are more efficient with their movements by placing themselves in a position to receive the ball (5, 8).

**PRACTICAL APPLICATIONS**

For coaches and strength and conditioning professionals the results indicate the importance of allocating sufficient time in the pre-season phase to develop physical capacity. In particular, improving the mechanics that contribute to 3 km TT performance as this measure is a significant predictor of match performance in semi-professional ARF. The results may also be useful for professional ARF, in particular for the 2016 season, as rule changes to the interchange system will require players to stay on the field longer. Communicating this information to the players could provide conditioning sessions and testing more relevance to individual match performance. This study also has practical applications to team selection for games as the number of senior games played is also a significant predictor of physical match performance and should be taken into account.

**REFERENCES**

The Journal of Australian Strength and Conditioning

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4. Roundtable Discussion: Commentary (<1000 words) on a relevant topic by 3-5 professionals (relevant to topic). Invitation by editorial board, based on topic selected for each issue.

5. Point-Counterpoint: Members are encouraged to submit a focused question or statement of interest to the strength and conditioning community, for the purposes of debate.

6. Case Study: Members are encouraged to submit a detailed analysis of a single subject or small group of subjects. This paper should have the same overall structure as the "Original Research Manuscripts" which have been outlined above, but not include any statistical analysis. The basic idea is to describe a specific case and hence the article will include the background of the subject(s), the exercise intervention(s) or techniques applied, the results achieved and practical applications with an emphasis on what would be done differently if a similar case was presented in the future.

REFERENCING

Referencing must conform to the guidelines, irrespective of the manuscript or article. Please check the new electronic referencing guidelines.

All references must be outlined at the end of the document and numbered. References are cited in the text by numbers (e.g., [4,9]). All references listed must be cited in the manuscript and be referred to by number therein. For original investigations, please limit the number of references to fewer than 40 or explain why more are necessary. Please follow the examples below.

**Journal Article**


**Book**


**Chapter in an edited book**


**References from Electronic Sources**

Referencing electronic sources poses problems due to the changing nature of websites. Please limit electronic references in peer-reviewed manuscripts to on-line refereed journals where possible. However, it is recognized that popular media websites (i.e. non-refereed) may also need to be referenced from time to time for some points in peer-reviewed manuscripts and will often be used in "From the Field" and other Applied Training manuscripts in JASC. In either case, please use the format below when referencing web based sources.

**Example**

**Refereed Online Journal**


**Popular media or Commercial Website**


‘From the field’ articles do not necessarily require referencing, though it is encouraged. If referencing is used, please ensure it conforms to the guidelines above.
TABLES, ILLUSTRATIONS, PHOTOGRAPHS, AND VIDEO CLIPS

The JASC encourages authors to submit tables, colour photographs, charts, video clips, and figures that help to illustrate aspects of the article.

Figures, Photographs and Video Clips
All figures should be professional in appearance. Electronic photographs are encouraged. Please use a digital camera with high resolution. Ensure images are clear and taken in a well-lit environment. The figure number and description should be placed below the figure on the same page. Please place your figures in the results section where possible.

All photographs and videos are required to demonstrate health and safety procedures in the training environment (i.e. wearing appropriate clothing and shoes, removing hats, using safety equipment such as collars on bars, spotters as required etc.). The focus of the photograph or video should not be on a commercial product or the identity of a school or business. The JASC reserves the right to remove or request new, revised photos if the original photos or video clips do not follow these guidelines or if the photo or video is not of acceptable quality.

Tables
Tables must be numbered, professional in appearance and include a brief title above the table. Do NOT submit tables as photographs. Please place your tables in the results section where possible.

Model Consent
Authors should have consent for use by all models appearing in figures, video clips, audio clips, and possibly other formats. It is the policy of the JASC to make every effort not to block out the faces of individuals in figures, etc. If a model is under 18 years of age, parental consent is required along with the consent of the model.

It is understood that all papers are somewhat unique and sensible deviations to the above guidelines will be tolerated where reasonable.

For further information or to submit articles to the ASCA for publication in the JASC please email -

info@strengthandconditioning.org