NEUROMUSCULAR, BIOCHEMICAL, ENDOCRINE AND PHYSIOLOGICAL RESPONSES OF ELITE RUGBY LEAGUE PLAYERS TO COMPETITIVE MATCH-PLAY.

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A thesis submitted in fulfilment of the requirements of the degree of Doctor of Philosophy.

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DECLARATION

This work has not previously been submitted for a degree or diploma in any University. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

Signed: ______________________

Christopher P. McLellan
In 2009, the National Rugby League (NRL) was the most watched sport on Australian television (TV) (403). A review of TV ratings at the completion of the 2009 NRL season revealed that 60 of the top 100 rating subscription TV programs were NRL matches (403), exceeding TV ratings of all other football codes in Australia. In particular, NRL matches out-rated Australian Football League (AFL) matches on both free to air and subscription TV (403). The NRL is experiencing unprecedented popularity with improved TV ratings for Friday night and Sunday afternoon matches and an average crowd attendance of 16,051, an increase of 2.93% on 2008 figures. In 2009, the Telstra premiership recorded the highest regular season attendance in the history of Rugby League with 3,081,839 people attending the 26 rounds of regular season matches. NRL matches on subscription TV reached more than 3.6 million viewers in 2009, while on average, each regular season round in the NRL reached more than 2.7 million viewers with more than 220,000 listeners tuning into Rugby League on radio every weekend throughout the season (403).

To assist the NRL to remain the centre piece in the fee to air and subscription TV schedule, there is a considerable need for a substantial and ongoing commitment to excellence by coaches, sports scientists and strength and conditioning practitioners to advance the knowledge base regarding match preparation, match-play performance and best practice methodologies during the post-match recovery period. Despite the professional status of the NRL as an international sport with a global viewing audience, there remains a lack of research in the key areas of player response to the demands of match-play and the pattern of neuromuscular, endocrine and biochemical recovery in elite Rugby League in comparison to other football codes such as AFL, Rugby Union and Soccer. With the exception of Dr Dan Baker from the Brisbane Broncos, who has set the bench mark for applied strength and power research in professional Rugby League for over 10 years, the majority of research has consisted of retrospective reporting of player anthropometric data, injury rates and comparisons of junior, amateur, and semi-professional player performance characteristics.

The motivation for the present body of work arose from a conversation with Olympic weightlifting coach, Mr Lyn Jones at a Sports Power Coaching accreditation course attended by the author in Brisbane in 2005. During the course of one of many conversations regarding athlete recovery and preparation, Lyn pondered the age-old question of how can a coach determine when an athlete has recovered sufficiently from a workout or competitive performance to enable that athlete to return to training in preparation for subsequent performance? The lack of information pertaining to the physiological demands of Rugby League match-play under current defensive rules, interchange
limitations and the introduction of two on-field referees is evident in any systematic review of the literature. Furthermore a review of the literature revealed no study had examined the neuromuscular, endocrine or biochemical response of elite Rugby League players to competitive match-play. No study has investigated the time course associated with a return to pre-match neuromuscular, endocrine or biochemical measures during the post-match recovery period following NRL match-play.

The present body of work was therefore undertaken to establish the neuromuscular, endocrine, biochemical and physiological demands of match-play in the NRL and to determine the anabolic:catabolic endocrine behaviour, neuromuscular fatigue and muscle damage immediately post-match and for a period of up to 5 days post-match. By determining the time course associated with a return to pre-match hormonal homeostasis and neuromuscular function, the effectiveness of recovery strategies could be established. An increased knowledge base in relation to the neuromuscular, endocrine, biochemical and physiological pattern of response following elite Rugby League match-play may enable a more accurate identification of when players could return to training without interfering with the short term post-match recovery period to be recognised, and preparation for subsequent performance optimised.
This thesis “by publication” comprises five experimental studies presented as five individual chapters. Each of the five experimental studies are “In press”. All papers are presented in the format accepted for publication and include an introduction, review of the literature, methods, results and discussion sections. Each experiment builds on the previous experiment to increase the knowledge of short-term and long-term post-match physiological, neuromuscular, endocrine, and biochemical responses of elite players as they relate to elite Rugby League match-play.

There are eight Chapters which make up the present thesis. Chapter 1 provides an introduction of the purpose and significance of the research, presents hypothesis associated with each study and outlines the research questions. Chapter 2 provides an overview of the literature with specific reference to the physiological demands and movement patterns associated with Rugby League match-play. The reader is introduced to Global Positioning System (GPS) technology for performance analysis in sports and the validity and reliability of portable GPS units is considered. Chapter 2 also contains a review of neuromuscular fatigue and sports performance with a particular focus on the assessment of movements incorporating the stretch shortening cycle (SSC) to determine neuromuscular fatigue and the role of muscle force, power and the rate of force development in team sports. A review of the literature pertaining to endocrine indices of fatigue, muscle damage and recovery following contact sport concludes Chapter 2.

Chapter 3 is Experimental Study 1, and has been accepted for publication as:


Chapter 4 is Experimental Study 2, and has been accepted for publication as:


Chapter 5 is Experimental Study 3, and is presented in the format accepted for publication:

Chapter 6 is Experimental Study 4, and has been accepted for publication as:


Chapter 7 is Experimental Study 5, and has been accepted for publication as:


The Journal of Strength and Conditioning Research was specifically selected as the refereed Journal to receive the results of Experiments 1 – 5. It was reasoned that if clinical practice was to improve then the results of Experiments 1 – 5 should be presented in sources that were widely read by Strength and Conditioning and Sports Science practitioners. There was a clear intent that research should inform practice and the Journal of Strength and Conditioning Research was therefore the journal of choice.

In addition to the “In press” papers listed in Chapters 3, 4, 5, 6, and 7, the research conducted in completion of the present thesis also contributed to the preparation of the following poster presentations:


Chapter 8 presents the overall discussion and conclusions that summarise the findings of the experimental studies and outlines recommendations for future research to increase our understanding of elite Rugby League match-play.
ACKNOWLEDGEMENTS

I would like to acknowledge a number of people for their support and encouragement throughout the period of my doctoral candidature. Throughout my entire professional career I have received unwavering support from my wife Vanessa and my very understanding children, Ronan and Remi. My family have sacrificed much to allow me to pursue my career and for that words cannot express my gratitude.

To my supervisor, Dr Dale Lovell, thank you for your consistent support and for providing the element of perspective in all aspects of this research. To my associate supervisor, Dr Bon Gray, thank you for your attention to detail and critical review throughout the construction of the thesis in its final form.

Sincere thanks also to a number of colleagues within the Faculty of Health Sciences and Medicine at Bond University, in particular, Professor Lars McNaughton, Assistant Professor Michael Pahoff and Ms Jenny Dimento. The encouragement and support provided by Lars, Michael and Jenny has been tremendous.

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ABSTRACT

The primary aim of this thesis was to advance our knowledge of the neuromuscular, endocrine, biochemical and physiological responses of elite Rugby League players during competitive match-play. The secondary aim of this thesis was to examine the effects of the short term recovery phase post-match and the associated time-course for a return to hormonal homeostasis, neuromuscular function and musculoskeletal recovery following match-play.

Chapter 3 (Experimental Study 1 – Paper 1)

The purpose of this study was to examine i) the relationship between rate of force development (RFD) and vertical jump (VJ) performance during a counter movement jump ii) the reliability of RFD recorded during the counter movement jump (CMJ) and squat jump (SJ) forms of the VJ. Twenty three physically active men aged 23 ± 3.9 yr participated in the study. Subjects completed three unloaded CMJ and three unloaded SJ in random order on a force plate. RFD was measured during CMJ and SJ movements with vertical jump displacement (VJD) measured simultaneously during the CMJ only. Subjects incorporated arm swing to their CMJ technique to reach up as high as possible and VJD was measured. All SJ were executed with both hands on the hips throughout the full range of movement. Peak rate of force development (PRFD), peak force (PF) and time to peak force (TPF) were significantly correlated to VJD during the CMJ (r = 0.68, r = 0.51 and r = -0.48 respectively). The RFD and TPF during the CMJ and SJ were associated with low test re-test reliability (coefficient of variation [CV]: 11.8 – 17.9 %). Peak and average power, PF and VJD produced high test retest reliability (CV: 2.8 – 5.1 %) during both the CMJ and SJ movements. However, caution must be used when interpreting data using PRFD due to low re-test reliability. The results indicate that PRFD, a measure of explosive strength, and PF, a measure of maximal strength are the primary contributors to VJD during the CMJ. Measurement of selected force-time variables during the CMJ and SJ demonstrate acceptable levels of reliability for inclusion in functional assessment protocols to determine the influence of acute or chronic exercise on SSC performance in physically active men.

Chapter 4 (Experimental Study 2 – Paper 2)

The aim of the present study was i) to examine the physiological demands of competitive Rugby League match-play using portable Global Positioning Systems (GPS) to monitor player’s movement
patterns and heart rate (HR) and ii) examine positional comparisons to determine if a player’s physiological requirements are influenced by their playing position during Rugby League match-play. Twenty two elite male Rugby League players were monitored during five regular season competition matches using portable GPS software. There was no significant difference in the total distance travelled between backs (5573 ± 1128 m) and forwards (4982 ± 1185 m) during match-play. Backs and forwards had an average HR of approximately 80 % of their maximum HR (162 ± 11 and 165 ± 12 b·min\(^{-1}\) respectively) throughout each match. Backs achieved greater maximum running speed (8.6 ± 0.7 m·sec\(^{-1}\)), completed a greater number of sprints (18 ± 6), had less time between sprints (3.2 ± 1.1 min), achieved a greater total duration of sprinting (44.7 ± 9.1 s) and covered more distance sprinting (321 ± 74 m) than forwards (6.8 ± 0.7 m·sec\(^{-1}\), 11 ± 5, 5.2 ± 2.2 min, 25.8 ± 9.2 s and 153 ± 38 m respectively). The present study provides insight into the high intensity nature of elite Rugby League competition incorporating real-time accelerometer and GPS technology to establish key performance indicators of match-play. The results identify significant positional differences in total distances covered, running speed profiles and the physiological demands of match-play. Position specific demands on aerobic and anaerobic energy systems during elite Rugby League match-play should be considered when planning post-match recovery protocols and training activities to optimise subsequent performance.

Chapter 5 (Experimental Study 3 – Paper 3)

The purpose of the present study was to i) examine player movement patterns to determine total distance covered during competitive Rugby League match-play using GPS and ii) examine pre, during and post-match plasma creatine kinase (CK) and endocrine responses to competitive Rugby League match-play. Seventeen elite Rugby League players were monitored for a single game. Player movement patterns were recorded using portable GPS units (SPI-Pro, GPSports, Canberra, Australia). Saliva and blood samples were collected 24 hr pre-match, 30 min pre-match, 30 min post-match and then at 24 hr intervals for a period of 5 days post-match to determine plasma CK and salivary testosterone (sTest), cortisol (sCort) and testosterone:cortisol ratio (sT:C). The change in the dependent variables at each sample collection time was compared to 24 hr pre-match measures. Backs and forwards travelled distances 5747 ± 1095 m and 4774 ± 1186 m respectively throughout the match. The sCort and plasma CK increased significantly \((p < 0.05)\) from 30 min pre-match to 30 min post-match. Plasma CK increased significantly \((p < 0.05)\) post-match, with peak plasma CK concentration measured 24 hr post-match \((889.25 ± 238.27 \text{ U.L}^{-1})\). Cortisol displayed a clear pattern of response with significant \((p < 0.05)\) elevations up to 24 hr post-match, compared with 24 hr pre-
match. The GPS was able to successfully provide data on player movement patterns during competitive Rugby League match-play. The plasma CK and endocrine profile identified acute muscle damage and a catabolic state associated with Rugby League match-play. A return to normal testosterone:cortisol ratio within 48 hr post-match indicates that a minimum period of 2 days is required for endocrine homeostasis post-competition. Plasma CK remained elevated despite 120 hr of recovery post-match identifying that a prolonged period of at least 5 days of modified activity is required to achieve full recovery following muscle damage during competitive Rugby League match-play. The results support the inclusion of plasma CK and salivary endocrine measures as objective markers of muscle damage and stress experienced by elite Rugby League players pre, during and post-match. Furthermore, the results indicate that plasma CK, sCort, sTest and sT:C ratio are meaningful measures to monitor individual player tolerance to training and competitive loads and should be considered when developing recovery and training plans over the course of an extended season of weekly elite Rugby League competition.

Chapter 6 (Experimental Study 4 – Paper 4)

The aim of the present study was to identify neuromuscular, biochemical and endocrine markers of fatigue following Rugby League match-play. Seventeen elite Rugby League players were monitored for a single match. Peak rate of force development (PRFD), peak power (PP) and peak force (PF) were measured during a countermovement jump (CMJ) on a force plate pre and post match-play. Saliva and blood samples were collected 24 hr pre-match, 30 min pre-match, 30 min post-match and then at 24 hr intervals for a period of 120 hr to determine plasma creatine kinase concentration ([CK]) and salivary cortisol concentration ([sCort]). There were significant ($p < 0.05$) decreases in PRFD and PP up to 24 hr post-match with PF significantly ($p < 0.05$) decreased immediately post-match. The [sCort] significantly ($p < 0.05$) increased from 24 hr pre-match to 30 min pre-match and up to 24 hr post-match compared to 24 hr pre-match. Plasma [CK] significantly ($p < 0.05$) increased 30 min post-match with a peak occurring 24 hr post-match and remained elevated above 24 hr pre-match for at least 120 hr post-match. There were significant ($p < 0.05$) correlations between the increase in plasma [CK] and reduction in PRFD 30 min post-match and 24 hr post-match. The [sCort] was significantly ($p < 0.05$) correlated with the reduction in PF 30 min post-match. Results demonstrate that neuromuscular function is compromised and results in significant impairment of PRFD, PF and PP for up to 48 hr following elite Rugby League match-play. Elevated plasma [CK] despite 120 hr recovery indicates that damage to muscle tissue following Rugby League match-play may persist for at least five days post-match. Despite the prolonged presence of elevated plasma [CK] post-match, strength
training 48 hr post-match may have resulted in a compensatory increase in PRFD supporting the inclusion of strength training during the short-term post-match recovery period. The CMJ offers a functional analysis measure of neuromuscular fatigue and exercise induced muscle damage and should be considered to establish a comprehensive profile of individual adaptation and recovery following elite Rugby League match-play.

**Chapter 7 (Experimental Study 5 – Paper 5)**

The purpose of the present study was to investigate the relationship between the pre-match and short term post-match biochemical and endocrine responses to the intensity, number and distribution of impact forces associated with collisions during elite Rugby League match-play. Seventeen elite male Rugby League players each provided blood and saliva samples 24 hr pre-match, 30 min pre-match, 30 min post-match and then at 24 hr intervals for a period of 5 days post-match to determine plasma creatine kinase concentration ([CK]) and salivary cortisol concentration ([sCort]). The intensity, number and distribution of impact forces experienced by players during match-play were recorded using portable Global Positioning Systems (GPS) and integrated accelerometer. The change in the dependent variables at each sample collection time was compared to 24 hr pre-match and 30 min pre-match measures. Plasma [CK] and [sCort] increased significantly \( p < 0.05 \) during match-play. Significant correlations \( p < 0.05 \) were observed between the number of hit-ups and peak plasma [CK] 24 hr post-match, 48 hr post-match and 72 hr post-match \( p < 0.05 \). The number of impacts recorded in Zone 5 (8.1 – 10.0 G) and Zone 6 (> 10.1 G) during match-play were significantly correlated \( p < 0.05 \) to plasma [CK] 30 min post-match, 24 hr post, 48 hr post and 72 hr post-match. The GPS and integrated accelerometer was able to provide data on the intensity, number and distribution of impacts resulting from collisions during match-play. Elite Rugby League match-play resulted in significant skeletal muscle damage, and was highly dependent on the number of heavy collisions > 8.1G. Plasma [CK] remained elevated 120 hr post-match identifying that at least five days of modified activity is required to achieve full recovery following elite Rugby League match-play. A gradual reduction in plasma [CK] during the five day post-match recovery phase coincided with reduced training loads and no additional physical trauma indicting plasma [CK] can be used to monitor acute recovery from elite Rugby League match-play.
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LIST OF SYMBOLS AND ABBREVIATIONS

Dot [ · ] above any symbol indicates a time derivative
Dash [ - ] above any symbol indicates a mean value

SYMBOLS

α \hspace{1em} \text{alpha}
β \hspace{1em} \text{beta}
r \hspace{1em} \text{Pearsons product moment correlation coefficient}
p \hspace{1em} \text{statistical significance}
µ \hspace{1em} \text{micro}
°C \hspace{1em} \text{temperature in degrees celsius}
± \hspace{1em} \text{plus or minus}
% \hspace{1em} \text{percent}
> \hspace{1em} \text{greater than}
< \hspace{1em} \text{less than}

UNITS OF MEASUREMENT

ANOVA \hspace{1em} \text{analysis of variance}
b·min\(^{-1}\) \hspace{1em} \text{beats per minute}
cm \hspace{1em} \text{centimetres}
CV \hspace{1em} \text{coefficient of variation}
ES \hspace{1em} \text{effect size}
ft \hspace{1em} \text{feet}
g \hspace{1em} \text{grams}
G \hspace{1em} \text{gravitational force}
h \hspace{1em} \text{hours}
hr·wk\(^{-1}\) \hspace{1em} \text{hours per week}
HR \hspace{1em} \text{heart rate}
HR\(_{\text{max}}\) \hspace{1em} \text{maximum heart rate}
Hz \hspace{1em} \text{Hertz}
HSD \hspace{1em} \text{Tukey’s honestly significant difference}
ICC  intraclass correlation coefficient
kg  kilogram
km·hr$^{-1}$  kilometres per hour
km·wk$^{-1}$  kilometres per week
m  metres
min  minutes
m·min$^{-1}$  metres per minute
mm  millimetre
ms  millisecond
m·sec$^{-1}$  metres per second
ms$^2$  metres per second squared
N  Newton
ng·mL$^{-1}$  nanogram per millilitre
nm·L$^{-1}$  nanomole per litre
N·s$^{-1}$  Newton per second
pg·mL$^{-1}$  picograms per millilitre
rpm  revolutions per minute
s  seconds
SD  standard deviation
SEE  standard error of estimate
SEM  standard error of mean
TE  typical error
VO$_2$ max  maximum oxygen uptake
U·L$^{-1}$  units per litre
W  Watts
wk  week
yr  years
µg·dL$^{-1}$  micro-gram per decilitre
µL  micro litre
ENZYMES / METABOLITES

ACTH  adrenocorticotrophic hormone
ADP  adenosine diphosphate
ATP  adenosine triphosphate
Ca²⁺  calcium
CGB  cortisol binding globulin
CK  creatine kinase
[CK]  creatine kinase concentration
CK-BB  brain creatine kinase isoform
CK-MB  cardiac muscle creatine kinase isoform
CK-MM  skeletal muscle creatine kinase isoform
[Cort]  cortisol concentration
FSH  follicle stimulating hormone
GOT  glutamic oxaloacetic transaminase
H⁺  hydrogen ion
K⁺  potassium
LDH  lactate dehydrogenase
LH  leutenising hormone
Na⁺  sodium
NH³  ammonia
PCr  phosphocreatine
Pi  inorganic phosphate
sCort  salivary cortisol
[sCort]  salivary cortisol concentration
SHBG  sex hormone binding globulin
sT:C  salivary testosterone:cortisol ratio
sTest  salivary testosterone
[sTest]  salivary testosterone concentration
T:C  testosterone:cortisol ratio
### VARIABLES AND ABBREVIATED TERMS

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<td>1RM</td>
<td>one repetition maximum</td>
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<tr>
<td>AFL</td>
<td>Australian Football League</td>
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<td>ARFD</td>
<td>average rate of force development</td>
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<td>AF</td>
<td>average force</td>
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<td>AP</td>
<td>average power</td>
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<td>BT</td>
<td>bench throw</td>
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<td>BUHREC</td>
<td>Bond University Human Research Ethics Committee</td>
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<td>CHO</td>
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<td>CMJ</td>
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<td>CNS</td>
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<td>EE</td>
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<td>e.g.</td>
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<td>EIMD</td>
<td>exercise induced muscle damage</td>
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<td>EMG</td>
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<td>EMS</td>
<td>electromyostimulation</td>
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<td>ES</td>
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<td>F</td>
<td>force</td>
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<td>FTV</td>
<td>force-time variable</td>
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<td>GCT</td>
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<td>GPS</td>
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<td>ground reaction force</td>
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<td>HFF</td>
<td>high frequency fatigue</td>
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<td>HPA</td>
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<td>H-reflex</td>
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MHC  myosin heavy chain
MIVC  maximum isometric contraction
MMG  mechanomyography
MN  motor neuron
MPF  mean power frequency
MRFD  maximum rate of force development
M-wave  skeletal muscle action potential
MU  motor unit
MVC  maximum voluntary contraction
n  number of subjects
NCAA  National Collegiate Athletic Association (USA)
NM  neuromuscular
NPC  National Provincial Championship (New Zealand Rugby Union)
NRL  National Rugby League
NSWPL  New South Wales Premier League
P  power
PF  peak force
PP  peak power
RFD  rate of force development
PRFD  peak rate of force development
RBE  repeated bout effect
Reps  repetitions
RIA  radioimmunoassay
RM  repetition maximum
ROM  range of movement
RSA  repeated sprint ability
RSAT  repeated sprint ability test
RT  resistance training
SA  selective availability
SJ  squat jump
SR  sarcoplasmic reticulum
SSC  stretch shortening cycle
SPSS  statistical package for the social sciences
T1  first thoracic vertebrae
TMA  time motion analysis
TMS  transcranial magnetic stimulation
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<tr>
<td>TPF</td>
<td>time to peak force</td>
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<tr>
<td>T-tubule</td>
<td>transverse tubule</td>
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<tr>
<td>TV</td>
<td>television</td>
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<tr>
<td>US</td>
<td>United States</td>
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<tr>
<td>USA</td>
<td>United States of America</td>
</tr>
<tr>
<td>USG</td>
<td>urine specific gravity</td>
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<tr>
<td>UV</td>
<td>ultraviolet</td>
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<tr>
<td>VA</td>
<td>voluntary activation</td>
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<tr>
<td>VJ</td>
<td>vertical jump</td>
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<tr>
<td>VJD</td>
<td>vertical jump displacement</td>
</tr>
<tr>
<td>VL</td>
<td>vastus lateralis</td>
</tr>
<tr>
<td>VM</td>
<td>vastus medialis</td>
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<td>WiFi</td>
<td>wireless fidelity</td>
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