Literature Review: Is there an Acute Hormonal Response to Resisted Sprint Training?

Eric MacLean, B.HK, CSCS, CK, CFC

School of Exercise, Biomedical, and Health Sciences, Edith Cowen University, Perth, Australia

Specificity of training is considered to be a fundamental component of any detailed, goal oriented conditioning program. Whether one is training to improve functional ability, rehabilitate a musculoskeletal injury, or develop sport specific physiological attributes, the specific nature of the prescribed training regimen, and the exercises contained within, will dictate the magnitude of the adaptive response expressed at the myofibular level.

Sport-specific time motion and physical demands analysis indicates that successful performance in field and court sport are based on an athlete's ability to generate single and repetitive explosive linear and multidirectional sprint efforts during the course of a competitive match (15,36,42).

Cronin and Hansen (14) report that for many sporting activities, maximum velocity is not always reached, and that short burst of speed; 'sprints', are more common. Cronin and Hansen (14) further suggest that 'the ability to develop velocity in as short a time as possible may be of most importance to sport performance'.

The quantification of a sprint effort, measured through the kinetic and kinematic functions of velocity and acceleration; more specifically, a product of stride length and stride rate (frequency), is significant in evaluating its performance (24).

Recently, there has been a large volume of peer reviewed empirical and anecdotal evidence published investigating the biomechanic movement patterns, and the kinetic and kinematic variables of sprint training performed across diverse, and often innovative training modalities and techniques (5-7,17,22,24,27,29,32,34,43).

This volume of research indicates that several different 'sprint' training techniques are associated with improving an athlete's explosive speed profile (5-7,17,22,24,27,27,31,43). The techniques reviewed each incorporate an element of 'resistance', whereby each study subjected participants to performing sprints of various lengths under some form of external loaded condition; up hills (17,29), wearing weighted vests (5-7,29) or weight belts at distal end of limb segments (24,43), or pulling/towing a weight (17,27,31,32). A review of this research indicates that the addition of resistance alters sprint mechanics, and the resultant movement kinetic and kinematic values.

An inherent characteristic of labratory and field investigation is the diversification of trial results, and analytical conclusions. Elements of subject variability, experimental design and training protocol, have a multifactoral interaction with the reliability and validity of the data collected and the results reported. As a result, the general consensus regarding resisted sprint training as an effective methodology for improving one's linear speed is, at present, equivocal.

By summarizing the current body of resisted sprint training literature, and applying the known force velocity relationships, sprint training induced neurological, morphological musculoskeletal, and anaerobic exercise induced hormonal adaptations and their regulating mechanisms, new theories speculating the dose and response mechanisms of resisted sprint training can be synthesized.

Several researchers (38,39) have quantified with statistical significance, and concluded, that linear acceleration and power output; the reported purpose of sprint training (14), is a function of force production.

If this positive force production and sprint performance relationship is accepted, than it is logical to deductively investigate the mechanisms of force production and to elucidate them as a potential adaptive response to resisted sprint training.

Cronin and Hansen (14) and Harridge et al. (23) report that an athlete's ability to accelerate their body during sprinting is dependant upon several factors; technique (14), the force production capability of the body, particularly, force production capability of the lower limb musculature (14,23), and the speed at which the muscle contracts (Harridge). Mann et al (34) support Cronin and Hansen's contention by concluding that the ability to perform well in sprints over short distances is dependant on the ability to produce large amounts of force at crucial times.

A wealth of published research identifies a strong positive correlation between force output and power performance, and that they are is directly related to the rate of force development, and myofibular hypertrophy, suggesting that sprint performance could be related to, and have a positive relationship to, androgen hormones and their muscle cell interactions, as there is a large body of published literature supporting an androgen hormone force production relationship (12,19,20,28,30,33,35,41,44,50).

If this relationship is accepted, and so is the relationship between sprint training induced positive force production adaptations, it can be speculated that sprint training stimulates a hormonal response, and that this hormonal response contributes to the performance increases reported in the literature.

At present, following an extensive review, this young researcher was unable to locate any published literature investigating the acute hormonal response to resisted sprint training. It is speculated that the known anabolic-androgenic hormonal response that accompanies acute anaerobic high intensity exercise, plays a significant role in the improvements in sprint performance reported following resisted sprint training.

The basis of resisted sprint training techniques; loading of limbs at the distal ends, uphill running, weighted vests, and resisted towing as a modality to improve sprint and consequently, sport, performance, is that it is movement pattern specific and appropriate for training the velocity and acceleration phases of sprinting (17).

Following the postulates of the SAID (Specific Adaptations to Imposed Demands) principle (2), which Cronin and Hansen (14) state justifies resisted sprint training, one can propose that the hormonal response to 'resisted' sprint training, would be greater than that of 'non-resisted' sprint training, and that the associated specific hormone induced adaptations would be greater, and advantageous to a competitive athlete.

The following report is a literary review of the published adaptive responses associated with the resisted sprint training techniques currently found within the literature. A summarization of the resisted sprint techniques reported by Faccioni (17) will attempt to illustrate how the addition of 'resistance' to single and repetitive high intensity linear sprint performances contributes to the positive training adaptations expressed at the neuromuscular and myofibular level.

Further, this report will attempt to illustrate how resisted sprint training induces an acute hormonal response, and that it is this response which significantly contributes to the reported performance improvements.

More specifically, this review will illustrate the causal relationship between fast-release (49) hormones; epinephrine (E), norepinepherine (NE), testosterone (T), growth hormone (GH), insulin, insulin like growth factor-1 and resisted sprints.

It is the author's intention that the research presented in this article be used as justification and foundation for the future quantitative investigation into the potential acute hormonal response to resisted sprint training, and to quantify the magnitude of that response.

Such investigation has direct practical relevance to the strength and conditioning professional attempting to enhance the linear speed and acceleration profiles of the athlete's they consult. An understanding of the acute hormonal response will provide the conditioning professional with the ability to prescribe training protocols with greater adaptation specificity, improving training efficiency and efficacy, and athletic performance.

Resisted Sprint Training Techniques

Faccioni (17) identifies 4 resisted sprint techniques; wearing weighted vests, adding weight to distal limb segments, running up hills, and pulling/towing weights are commonly practiced forms of resisted sprints.

The reported adaptive responses to these methods, to this point, have been limited to biomechanical, through kinetic and kinematic analysis, evaluation.

Each of the resisted sprint measures identified by Faccioni (17) are reported to influence stride length (14,17,29,40), stride frequency (14,43), stance times (14,29), and the regulating neuromuscular activation and synchronization (6,27) patterns.

The following is a review of each of the 4 methods of resisted sprint training, and the biomechanic, composition, and neuromuscular adaptations.

Distal Limb Loading

A review of the literature revealed two studies investigating the effects of limb loading (43). Ropret et al. (43) reported that leg loading of 0.6, 1.2, and 1.8kg had an effect on performance, where a load of 1.8kg significantly decreased sprint velocity. It was concluded that the increase in speed was a result of a decrease in stride frequency.

A much earlier study by Martin showed similar results. It was reported that foot and thigh loading increased stride length and decreased stride frequency.

The difference between the Martin and Ropret et al. (43) studies is that Martin concluded that the increase in inertial forces induced by the distal loading decreased sprint velocity.

Cronin and Hansen (14) suggest that long-term study is required to further investigate distal loading before assumptions of it's efficacy can be confidently made.

Uphill Running

The basis for uphill running is that it will induce an increase in stride length to maintain peak velocity while overcoming the resistance provided by the angle of inclination.

Faccioni (17) suggests that uphill running places an increased load on the thigh extensor muscles as the athlete tries to push themselves up the grade, and maximize stride length. It is thought (17,29) that this training induced increase in extensor activity will trigger biomechanical adaptations, specifically, an increase in stride length, that when applied to flat surface sprinting, will translate into higher linear sprint velocities.

Knuz and Kaufman (29) tested this concept by evaluating run performance on flat and ^{3o} grade surfaces. They reported that a grade of 3^o resulted in a decrease in velocity of 1m/s, no change in step frequency, a decrease in step length, and an increase in trunk thigh angle. Further, they concluded that uphill running may result in increases in stride length and decreases in stance phase length when applied to flat surface running.

In a more recent investigation of the kinetics and kinematics of 3^o slope and flat surface running, Paradisis and Cooke (40) conclude that uphill running resulted in increased contribution from the propulsive phase.

It is reported that the propulsive phase of sprinting is associated with the greatest acceleration, force, and power outputs (14,24).

Further, Paradisis and Cooke (40), and Knuz and Kaufman (27) further report significant changes in the trunk (27,40) and shank angle are decreased at both foot strike and toe off during sloped (3^o) running.

A summarization of these 2 studies indicate that uphill running triggers a biomechanic and muscle activation adaptation that attempts to increase stride length.

It is suggested (14) that this training modality requires additional long-term investigation to validate its reported performance effect.

Weighted Vests

The use of weighted vests is another mode of resisted sprint training that has received investigative attention (5-7.29). The practice of using weighted vests is in attempts to create what Bosco et al. (5) refer to as, a 'hypergravity' condition.

Hansen et al. (22) supports the positive weighted vest induced force development adaptations concluded by Bosco et a. (5-7), by reporting that vest sprinting with loads of 15 and 20% of body mass increased 10-, and 30m sprints by 7.5 and 10%, and 9.3 and 11.7% respectively. The authors speculated that the subjects had less force to overcome in the early stages of the sprint when the vest was removed (14). It was concluded that the increase in sprint time was attributed to decreased step length and step frequency and to increased stance times (22).

Bosco et al. (5-7) applied 'hypergravity' conditions to investigate its effect on drop jump (5-7), squat jump (6), and sprint performances (7). While individual study designs differ, all 3 concluded that wearing a weighted vest significantly increased lower limb power (5), force development (6), and produced a rightward shift in the force velocity curve (5-7).

Further, Bosco et al. (6) suggest that the improvement in force development was a function of an increase in stretch-shortening cycle (SSC) performance and an increase in leg extensor myotendinous stiffness.

Cronin and Hanson (14), following their own review of the literature, suggest that wearing a weight vest during sprinting may increase the vertical force at each ground contact, increasing the eccentric load on the extensor muscles during the braking phase. They speculate that this effect 'may serve to increase the muscle's capacity to store elastic energy and improve power output.

The strong relationship between wearing a weighted vest and force development leads one to assume that the muscular efforts required to overcome the 'hypergravity' condition would trigger, and adaptively respond to, increased hormone secretion. Further investigation into this area is highly encouraged.

Resisted Pulling/Towing

Resisted pulling/towing refers to the pulling or towing of weighted instruments; sleds, tires, parachutes, elastic tubing supported objects, and the like. Faccioni (17) suggests that the using towing as a form of resistance may increase the load on the athlete's torso, and may require them to initiate greater torso and pelvic stabilization.

Letzelter et al. (31) studied the effect of resisted towing (pulling a weighted sled) on a group of female sprinters and found that as the resistance increased (2.5kg to 10kg load) that performance over 30m decreased. They concluded that as resistance increased step length decreased, and that it was this decrease in step length that accounted for the decreased performance.

In another study investigating resisted pulling, Kafer et al. (27) studied the effects of resisted, and assisted sprinting on sprint times over 20-, 40-, and 60m distances. It was reported that the resisted group recorded an average improvement of 0.08 seconds ($p<0.001$), and 0.35 seconds ($p<0.001$) over 20-, and 60m distances. The mechanisms regulating the improvements were not provided, however, it was speculated that the performance improvements was that the increased resistance from the sled resulted in increased force production to develop and maintain velocity. Kafer et al. (27) speculated that this effect would increase the load associated with the SSC, increasing muscle stiffness and vertical force at each ground coupling point.

In review of the above reported resisted sprint techniques, it can be seen that all modalities significantly induce biomechanical changes, which positively influence force production outputs.

While the current volume of research has been limited to investigating the kinetic and kinematic variables. The above noted force production and muscle activation adaptive responses necessitate physiological investigation into the hormonal response that is associated with these changes.

In addition to the research presented, Harridge et al. (23) report that sprint training can alter the myosin heavy chain expression of muscle fibres. Harridge et al. (23) further report that sprint training, might be considered the most likely condition in which increases in speed, either through a shift in fibre-type distribution, or through altered coupling between fibre type and speed of shortening, might contribute to increased power generation. After testing this hypothesis across 6 weeks of sprint training, it was found that increases in whole muscle performance occurred without any significant change in myosin heavy chain isoform or fibre-type distribution.

Proposed Hormonal Response to Resisted Sprint Training

Sprint training is typically undertaken as an anaerobic practice. It involves a series of repetitive, high intensity, explosively powerful outputs (2,14,24,39). For the exception of certain training phases (peak speed) where full recovery is optimal before initiating a subsequent effort, sprint training specific to sport situations, involves repetitive peak efforts, with work to rest intervals specific to time motion analysis data individual to the particular sport, position, competitive level etc.

Further, time motion analysis indicates that sprinting is a short-term anaerobic effort, that primarily utilizes the phosphagen and glycolytic energy systems (2,36,40,42), and as such, is subject to the hormonal responses associated with anaerobic exercise.

Several researchers (8,9,11,26,48-50) report that hormone responses are evoked by sprint and short-term power exercise.

Viru (49) proposed that exercise induced hormonal changes are classified as fast-, moderate-, and slow-rate responses, where fast-rate responses are characterized by significant hormonal changes appearing within the 1st minute after the onset of exercise.

Viru and Viru (50) and Kindermann et al. (28) reports that these responses trigger activation of the sympathoadrenal system (rapid increase of blood levels of epinephrine and norepinepherine) as well as the pituitary-adrenocortical system (rapid increase of corticotrophin followed by a less rapid but longer lasting cortisol response.

Further, Viru and Viru (50) report that fast-rate hormonal responses are related to the effect of the central motor command, whereby impulsation from cortical pyramidal neurons communicate directly with the spinal motornuerons. They propose that, this way, highly intensive supramaximal exercise and very short muscle efforts of explosive effort (sprint and resisted sprints) are capable of triggering increased activity of several endocrine systems.

It is this ‘fast-response’ effect that is of particular relevance to understanding the hormonal response of resisted sprint training as the efforts last no longer than several seconds (39).

Viru and Viru (50) reports that neurotransmitter concentrations increase after 6 seconds of cycling at maximal power, concluding that anaerobic exercise lasting only a few seconds are capable of activating the sympathoadrenal system. Viru and Viru (50) continue to report that 4- to 7-fold increases in neurotransmitter release have been reported immediately 30s following maximal pedaling rate, or within 30-90 seconds following a 30-second sprint. (Wingate assessment is an effective, valid, and reliable method of assessing anaerobic maximal power performance, and as such, can be applied to simulate maximal sprint induced power performance).

Epinepherine and norepinepherine are fast-rate sympathetic nervous system responses that cause the release of acetylcholine from nerve endings (50). As a result epinepherine and norepinepherine blood concentrations increase rapidly at the beginning of exercise.

The improved functional capacities of the endocrine system are apparent by the increased concentration of blood catecholamines. Particularly important are the exaggerated catecholamine responses after sprint training. In the sprint-trained person, the immediate increase of growth hormone (GH), as well as an increases of cortisol and insulin concentration are, after 30 seconds of sprint, more pronounced than endurance-trained persons (28,50).

Hughes et al. (26) and Hoffman (25) report testosterone concentrations have been shown to increase at 90 seconds, and 120 seconds maximal and submaximal intermittent anaerobic exercise, whereby increased levels of testosterone (T) are based on exercise intensity.

Testing testosterone levels following treadmill run Hughes et al. (22) found serum T levels a 20.7% increase over base line ($p<0.05$) 20min following submaximal treadmill exercise, with levels 27.4% above base line immediately post, 25.7 and 21.6% above baseline 10-, and 20-min post.

T is reported to induce several physiological responses, all of which can be related to the responses promoted by resisted sprint training.

A review of anaerobic exercise stimulated T adaptations are multifactoral, and highly integrative. Cardinale and Stone (11), citing, animal based studies, suggest that T has a strong influence on skeletal muscle excitation-contraction coupling and on phenotypization of fast twitch fibres, and states that it seems reasonable to suggest that T levels play an important role in developing high rate of force in muscular activity with a short contraction time.

Bosco et al (8,9) support the conclusion made by Cardinale and Stone (11) reporting that a significant relationship between T levels and power output, suggesting the influence of this anabolic hormone on the development of type II fibres, reporting that his positive correlation identified between vertical jump and basal T levels supports their hypothesis that T plays an important role in explosive performance.

Bosco et al. (8,9) further support the role of T in sprint performances, in reporting, after investigating the serum T levels and sprinting performances of soccer players, that T influences speed and power.

In addition to T, GH, is reported to increase in response to anaerobic exercise. VanHelder et al. (48) and Kindermann et al. (28) report that single bouts of short-term high intensity exercise elicits minor increases in growth hormone. VanHelder et al. (48) further report that growth hormone is significantly related ($r=0.93$, $p<0.001$) to the oxygen demand / availability ratio (D/A) during intermittent anaerobic exercise.

Viru and Viru (50) report that near- or supramaximal exercise intensities, similar to those potentially induced during resisted sprint training, may lead to an increase in insulin levels.

The significance of this is that insulin functions as a carrier protein, aiding in the transfer of hormones and substrates throughout the blood stream and across cellular membranes, particularly that of the sarcolemma, allowing it’s bound ligand to interact with the nucleus (in terms of anabolic hormone, influence transcription and increase protein synthesis).

Further, Stone (44), reports that GH levels are regulated by insulin like growth factor-

1 (IGF-1), suggesting that GH concentrations are a function of IGF-1 concentrations.

More spefically, Amir et al. (1) report that growth hormone/insulin like growth factor 1 (IGF-1) axis is an important physiological regulator of muscular growth and development. This axis maintains muscle mass by suppressing protein degredation, increasing amino acid uptake, and stimulating protein synthesis. The bioavailability of IGF-1 is dependant upon circulating IGF-1, where physical exercise is reported to have a significant impact on the GH/IGF-1 axis during anaerobic exercise (30-seconds all-out Wingate) promotes a transient increase in IGF-1, promoting muscle and capillary growth, and muscle hypertrophy

In summary of the biomechanic alterations noted by (5-7,17,22,24,27,29,32,34, 43), the enhanced muscle activation response in the thigh extensor muscles noted by Knuz and Kaufman (29), the SSC alterations reported by Kafer et al. (27) and Bosco et al. (6), and the program design modalities of resisted sprint work to rest ratios, it can be assumed that there the short-burst, anaerobic nature induces an acute hormonal that triggers an increase in T, GH, insulin, and IGF-1.

The known anabolic factors of these agents, increasing protein synthesis, type I and II fibre cross-sectional area, fat acid mobilization and sparring of muscle glycogen and glycolysis, that there is an acute hormonal effect regulating the performance response to resisted sprint training.

While this contention is based upon theoretical review, it is this authors recommendation that further scientific and investigation be carried out to quantitatively evaluate the acute hormonal response to resisted sprint training.

Specifically, to measure the acute catecholamine, T, GH, insulin, IGF-1, responses at 30, 60, 90, and 120 seconds post sprint trial, and 1-, 10-, 15-, and 30minutes post training session to assess plasma concentrations in relation to basal values so that as practicing strength and conditioning professionals, we can better understand the hormonal influence contributing to the kinetic and kinematic results we measure.

Practical Applications

Review of the research and conclusions presented is intended to provide the current conditioning professional with a foundation of the factors that govern sprint, and resisted sprint training induced adaptations.

Further, the review of hormonal interactions to short duration, high intensity anaerobic exercise should promote critical thought into understanding the regulating mechanisms of resisted sprint training, and to begin to shift the current paradigm that performance improvements in ‘sprint’ or ‘resisted sprint’ training are solely technically or biomechanically based, but that they have physiological and hormonal origins.

Recognition of this interaction should allow the practicing conditioning coach to better understand the mechanisms of change and provide them with the foundation to more effectively establish set to repetition and work to rest ratios and loads based on the known anabolic responses to the various training modalities that exist.

It is the hope, that this review, will lead to further investigation into this topic, and that it becomes an area that experiences rapid growth in the near future.

References

Amir, Ruthie., Ben-Sira, David., and Sagiv, Moran. IGF-1 and FGF-2 Responses to Wingate Anaerobic Test in Older Men. Journal of Sports Science and Medicine. 2007. 6:227-232.

Baechle, Thomas R., and Earle, Roger W. Essentials of Strength Training and Conditioning, 2nd Edition. Human Kinetics Publishers. 2000.

1. Blanco, C.E., Popper, P., and Micevych, P. Anabolic-Androgenic Steroid Induced Alterations in Choline Acetyltransferase Messenger RNA Levels of Spinal Cord Motor Neurons in the Male Rat. *Neuroscience*. 1997. 78:873-882.

2. Bleisch, W.V., Harrelson, A.L., and Luine, V.N. Testosterone Increases Acetylcholine Receptor Number in the "Levator Ani" muscle of the Rat. *Journal of Neurobiology*. 1982. 13:153-161,

3. Bosco, C., Zanon, S., Rusko, H., Dal Monte, A., Bellotti, P., Latteri, F., Candoloro, N., Locatelli, E., Azzaro, E., Pozzo, R., and Bonomi, S. The Influence of Extra Load on the Mechanical Behavior of Skeletal Muscle. *European Journal of Applied Physiology*. 1984. 53: 149-154.

4. Bosco, C. Adaptive Response of Human Skeletal Muscle to Stimulated Hypergravity Condition. *Acta Physiolo. Scand*. 1985. 124: 507-513.

5. Bosco, C., Rusko, H., and Hirvonen, J. The Effect of Extra-Load on Muscle Performance in Athletes. *Med. Sci. Sports Exerc*. 1986. 18:415-419.

6. Bosco, C., Tihanyi, J., Rivalta, L., Parlato, G., Pulvirenti, C., Foti, C., Viru, M., and Viru, A. Hormonal Responses in Strenuous Jumping Effort. *Japanese Journal of Physiology*. 1996. 46: 93-98.

7. Bosco, C., Tihany, J., and Viru, A. Relationships between Field Fitness Level Test and Basal Serum Testosterone and Cortisol Levels in Soccer Players. *Clinical Physiology*. 1996. 16:317-322.

8. Bigland, B., and Jehring, B. Muscle Performance in Rats, Normal and Treated with Growth Hormone. *Journal of Physiology*. 1952. 1167. 129-136.

9. Cardinale, Marco., and Stone, Michael H. Is Testosterone Influencing Explosive Power Performance. *Journal of Strength and Conditioning Research*. 2006. 20(1), 103-107.

10. Chang, F.E., Dodds, W.G., Sullivan, M., Kim, M.H., and Malarkey, W.B. The Acute Effects of Exercise on Prolactin and Growth Hormone Secretion: Comparison between sedentary women and women runners with normal and abnormal menstral cycles. *Journal of Endocrinology and Metabolism*. 1986. 62. 551-556.

11. Crist, D.M., Peake, G.T., Eagan, P.A., and Waters, D.L. Body Composition Response to Exogenous GH during Training in Highly Conditioned Adults. *Journal of Applied Physiology*. 1988. 65. 579-584.

12. Cronin, John., and Hansen, Keir T. Resisted Sprint Training for the Acceleration Phase of Sprinting. *Strength and Conditioning Journal*. 2006. 28(4). 42-51.

Dobson, Bryan P. and Keogh, Justin W.L. Methodological Issues for the Application of Time-Motion Analysis Research. *Strength and Conditioning Journal*. 2007. 29(2). 48-55.

13. Evans, Nick A. Current Concepts in Anabolic-Androgenic Steroids. *American Journal of Sports Medicine*. 2004. 32. 534-542.

14. Faccioni, A. Resisted and Assisted Methods for Speed Development. *Strength and Conditioning Coach*. 1993. 1:10-11.

15. Fry, Andrew C., Kraemer, William J., Stone, Michael H., Warren, B.J., Kearney J.T., Maresh, C.M., Weseman, C.A., and Fleck, S.J. Endocrine and Performance Responses to High Volume Training and Amino-Acid Supplementation in Elite Junior Weight Lifters. *International Journal of Sport Nutrition*. 1993. 3. 306-322.

16. Fry, Andrew C., Kraemer, William J., Stone, Michael H., Koziris, Perry L., Thrush, John T., and Fleck, Steven. Relationships Between Serum Testosterone, Cortisol, and Weight Lifting Performance. *Journal of Strength and Conditioning Research*. 2000. 14(3), 338-343.

17. Fryberg, D.A., Gelfeld, R.A., and Barrett, E.J. Growth Hormone Acutely Stimulates Forearm Muscle Protein Synthesis in Normal Adults. American *Journal of Physiology (Endocrinology Metabolism). 1991. 23(E). 499-504.*

18. Gater, D.R., Gater, D.A., Uribe, J.M., and Bunt, J.C. Impact of Nutritional Supplements and Resistance Training on Body Composition, Strength, and Insulin-Like Growth Factor-1. *Journal of Applied Sports Science*. 1992. 6. 66-76.

19. Hansen, K., Cronin, J., and McNair, P. *Acute Kinematic Adaptations to Resisted Sprint Training*. Auckland, New Zealand: Auckland University of Technology, Division of Sport and Recreation. 2005.

Harridge, S.D.R., Bottinelli, R., Canepari, M., Pellegrino, M., Reggiani, C., Esbjornsson, M., Balsom, P.D., and Saltin, B. Sprint Training, In Vitro and In Vivo Muscle Function, and Myosin Heavy Chain Expression. *Journal of Applied Physiology*. 1998. 84:442-449.

20. Hay, J.G. *The Biomechanics of Sports Techniques*. (2nd Edition). Englewood Cliffs, NJ: Prentice Hall, 1985. p.539.

21. Hoffman, Jay. Testosterone: A Review of Physiological Effects and Exercise Responses. *National Strength and Conditioning Association Journal*. 1992. 14(4). 10-17.

22. Hughes, Rommie J., Johnson, Glen O., Housh, Terry J., Weir, Joe P., and Kinder, James E. The Effect of Submaximal Treadmill Running on Serum Testosterone Levels. *Journal of Strength and Conditioning Research*. 1996. 10(4), 224-227.

23. Kafer, R., Adamson, G., O'Conner, M., and Faccioni, A. Methods of Maximizing Speed Development. *Strength and Conditioning Coach*. 1993. 1:9-11.

24. Kindermann, W., Schnabel, A., Schmitt, W.M., and Biro, G. Catecholamines, Growth Hormone, Cortisol, Insulin, and Sex Hormones in Anaerobic and Aerobic Exercise. *European Journal of Applied Physiology*. 1982. 49. 389-399.

25. Knuz, H., and Kaufman, D.A. Biomechanics of Hill Sprinting. *Track Tech*. 1981. 82:2603-2605.

26. Kraemer, William, J. Marchitellim, L., Gordon, S.E., Harman, E., Dziaos, J.E., Mello, R., Frykman, P, McMurray, D., and Fleck, S.J. Hormonal and Growth Factors Responses to Heavy Resistance Training Protocols. *Journal of Applied Physiology. 1990*. 69. 1442-1450

27. Letzelter, M., Sauerwein, G., and Burger, R. Resistance Runs in Speed Development. *Mod. Athl. Coach*. 1995. 33:7-12.

28. Lockie, R.G., Murphy, A.J., and Spinks, C.D. Effects of Resisted Sled Towing on Sprint Kinematics in Field Sport Athletes. *Journal of Strength and Conditioning Research*. 2003. 17:760-767.

29. Lombardo, J.A., Hickson, R.C., and Lamb, D.R. Anabolic/androgenic steroids and growth hormone. *Perspectives in Exercise Science and Sports Medicine (Volume 4: Erogenics: Enhancement of Performance in Exercise and Sport*. Indianapolis: Brown & Benchmark, 1991, 249-284.

30. Mann, R.V., Herman, J., Johnson, B., Schultz, C., and Kotmel, J. *The Elite Athletes Project: Sprints and Hurdles*. Colorado Springs: United States Olympic Committee, 1982. Publication 1-11.

31. McMillan, J.L., Stone, M.H., Sartin, J., Keith, R., Marple, D., Brown, C., and Lewis, R.D. 20-Hour Physiological Responses to a Single Weight-Training Session. *Journal of Strength and Conditioning*. 1993. 7. 9-21.

Meir, R., D., Arthur., and M. Forest. Time Motion Analysis of Professional Rugby League: A Case Study. *Strength and Conditioning Coach*. 1996. 1-5.

32. Murad, F., and Haynes, R.C. Adenohypophyseal Hormones and Related Substances. *The Pharmaceutical Basis of Therapeutics (6th ed.)*. New York: Macmillan. 1980. 1369-1396.

Newman, Mark A., Tarpenning, Kyle M., and Frank Marino E. Relationships Between Isokinetic Knee Strength, Single Sprint Performance, and Repeated-Sprint Ability in Football Players. *Journal of Strength and Conditioning Research*. 2004. 18(4). 867-872.

Palmeiri, Jerry. Speed Training for Football. *NSCA Journal*. 1993. 15(6). 12-17.

Paradisis, G.P., and Cooke, C.B. Kinematic and Postural Characteristics of Sprint Training on Sloping Surfaces. *Journal of Sport Sciences*. 2001. 19:149-159.

33. Raeburn, Peter., Logan, Peter., and Mackinnon, Laurel. Serum Testosterone Response to High Intensity Resistance Training in Male Veteran Sprint Runners. *Journal of Strength and Conditioning Research*. 1997. 11(4). 256-260.

Rhea, Matthew R., Hunter, Randy, L., and Hunter, Tad J. Competition Modeling of American Football: Observational Data and Implications for High School, Collegiate, and Professional Player Conditioning. *Journal of Strength and Conditioning Research*. 2006. 20(1). 58-61.

34. Ropret, R., Kukloj, M., Ugarkovic, D., Matavulj, D., and Jaric, S. Effect of Arm and Leg Loading on Sprint Performance. *European Journal of Applied Physiology*. 1998. 77:547-550.

35. Stone, Michael H. Human Growth Hormone: Physiological Functions and Ergogenic Efficacy. *Strength and Conditioning*. August 1995. 72-74.

36. Shepard, R. Hormonal Control of Systems. *Physiology and Biochemistry of Exercise*. New York: Praeger, 1982.

37. VanHelder, W.P., Radomski, M.W., and Goode, R.C. Growth Hormone Responses during Intermittent Weight Lifting Exercise in Men. *European Journal of Applied Physiology*. 1984. 53. 31-34.

38. VanHelder, W.P., Radomski, M.W., Goode, R.C., and Casey, K. Hormonal and Metabolic Response to Three Types of Exercise of Equal Duration and External Work Output. *European Journal of Applied Physiology*. 1985. 54. 337-342.

39. VanHelder, W.P., Casey, K., and Radomski, M.W. Regulation of Growth Hormone During Exercise by Oxygen Demand and Availability. *European Journal of Applied Physiology*. 1987. 56. 628-632.

40. Viru, A. Exercise Metabolism and Endocrine Function. In Biochemistry of Exercise. H.G. Knuttgen, J.A. Vogel., and J. Poortmans, eds. Champaign, IL: Human Kinetics. 1983. 83-86.

41. Viru, Atko., and Viru, Mehis. Hormones in Short Term Exercises: Anaerobic Events. *Strength and Conditioning Journal*. 2003. 25(4), 31-37.

42. Walberg-Rankin, J., Hawkins, C, E, Fild, D.S., Sebolt, D.R. The Effect of Oral Arginine During Energy Restriction in Male Weight Trainers. *Journal of Strength and Conditioning Research.* 1994. 8. 170-177.

43. Weltman, A., Weltman, J.Y., Schurrer, R., Evans, W.S., Veldhuis, J.D., and Rogol, A.J. Endurance Training Amplifies the Pulsatile Release of Growth Hormone: Effects of Training Intensity. *Journal of Applied Physiology*. 1992. 72. 2188-2196.

44. Wilkerson, J.E., Horvath, S.M., and Gutin, B. Plasma Testosterone during Treadmill Exercise. *Journal of Applied Physiology*. 1980. 49: 249-253.