Michael Johnston[1], Julie Johnston[4], Christian J. Cook[1], Lisa Costley[2], Mark Kilgallon[3], Liam P. Kilduff[1]

1.Applied Sports Technology, Exercise and Medicine (A-STEM) Research Centre, College of Engineering, Swansea University, Swansea, United Kingdom
2. Ulster Sports Academy, University of Ulster, Jordanstown, United Kingdom
3. Welsh Rugby Union, National Centre of Excellence, Vale of Glamorgan, United Kingdom.
4. Department of Sport Science, Nottingham Trent University, Nottingham, United Kingdom.

Keywords: Testosterone; Cortisol; Creatine Kinase; Neuromuscular fatigue; Speed; Strength

Word count: 2860

Abstract word count: 250

Number of tables: 3

Number of figures: 0

The effect of session order on the physiological, neuromuscular, and endocrine responses to maximal speed and weight training sessions over a 24-hour period

Abstract

Objectives: Athletes are often required to undertake multiple training sessions on the same day with these sessions needing to be sequenced correctly to allow the athlete to maximize the responses of each session. We examined the acute effect of strength and speed training sequence on neuromuscular, endocrine, and physiological responses over 24 hours. *Design:* 15 academy rugby union players completed this randomized crossover study. *Method:* Players performed a weight training session followed 2 hours later by a speed training session (WS) and on a separate day reversed the order (SW). Countermovement jumps (CMJ), perceived muscle soreness (MS), and blood samples were collected immediately prior, immediately post, and 24 hours post sessions one and two respectively. Jumps were analyzed for power, jump height, rate of force development, and velocity. Blood was analyzed for testosterone (T), cortisol (C), lactate and creatine kinase (CK). *Results:* There were no differences between CMJ variables at any of the post training time points ($p > 0.05$). Likewise, CK, T, C, and MS were unaffected by session order ($p > 0.05$). However, 10 meter sprint time was significantly faster (Mean ± SD; SW 1.80s ± 0.11 vs. WS 1.76 ± 0.08s; $p > 0.05$) when speed was sequenced second. Lactate levels were significantly higher immediately post speed sessions versus weight training sessions at both time points ($p < 0.05$). *Conclusions:* The sequencing of strength and speed training does not affect the neuromuscular, endocrine, and physiological recovery over 24 hours. However, speed may be enhanced when performed as the second session.

1. Introduction

Elite athletes will often undertake a training program involving multiple daily training sessions being repeated over the course of a week [1]. In order for the athlete to adapt to such a program, the loads must be applied in an order or spacing that allows the athlete to have recovered to a point where they are able to meet or exceed the requirements of the next training session [2]. One potential factor that will influence this is the order in which the sessions are performed. For example, it has been reported that performing endurance training six hours before strength training resulted in greater fatigue the following day than when the order was reversed [3], possibly due to variation in both the type of fatigue generated and the time taken to recover from each session. In addition, running performance has been shown to be impaired eight hours after a weight training session [4], thereby affecting session quality and, potentially, the adaptive process. In contrast, a morning weight training session, but not a speed session, has been shown to have a positive effect on afternoon sprint performance [5].

Furthermore, the residual fatigue associated with both speed [6] and weight [7] training has been reported to persist beyond the initial hours following the training session, and therefore this timeframe needs to be investigated, as it will have important implications for training design. While several studies have examined the order effect on weight and endurance training sessions [3,8,9], to date, no studies have examined the order effect of speed training and strength training, highlighting a vital gap in our understanding of program design given many sports perform both types of sessions on the same training day. Therefore, the aim of this study was to compare the neuromuscular, endocrine, and biochemical responses of a training day during which maximal speed training was followed two hours post by weight training, to a training day with the reverse order. Specifically, the study set out to compare morning performance to afternoon performance where it was preceded by a second session, and to assess whether session order affected recovery at 24 hours post.

2. Methods

Ethical approval for the study was granted from a university research ethics committee. Fifteen academy level rugby players provided written informed consent to participate in this study (mean ± standard deviation: age 21 ± 1 years; 100.5 ± 10.5 kg; height 185.7 ± 6.6 cm). The study was undertaken at the end of the regular playing season, and participants were performing physical training four days per week. The study utilized a randomized crossover design, and each experimental protocol was completed over two days, one consisting of maximal speed training followed by a weight training session two hours later (SW), and one consisting of a weight training session followed by a maximal speed training session two hours later (WS) (Figure 1). The two-hour break was chosen as previous research has suggested that this is sufficient to recover from both speed [6] and weight training [7,] and is a common recovery time used in elite sport settings.

INSERT FIGURE 1 AROUND HERE

Prior to arriving on day one of each protocol, participants were given two days off training. Each participant was given an arrival and start time that was maintained throughout the study to account for circadian variation in hormones and body temperature [10]. Upon arrival (immediately pre session one), participants filled out a questionnaire on perceived muscle soreness (MS), and a blood sample was collected for subsequent analysis for testosterone (T), cortisol (C), creatine kinase (CK), and lactate. Participants then performed a 10-minute standardized warm-up before reporting to the testing area where they performed three countermovement jumps (CMJs), after which they performed either the SW or WS protocol.

In the SW protocol, participants proceeded to an indoor track to perform a maximal speed training session. This session consisted of a running specific warm up followed by 6 x 50m maximal sprints with 5 minutes recovery between each trial [6]. This speed training session reflected a normal training sessions for team sport athletes, and is in line with the volume of maximal speed running per session suggested by elite track coaches [6,11]. After completion of the final sprints, the participants again provided blood samples, and information on MS before performing three CMJs (immediately post speed session time-point). Two hours later, blood, MS, and CMJs were collected again (immediately pre weights session time point), after which, the participants proceeded to the gym to undertake a weight training session consisting of 5 sets of 4 repetitions of the back squat and the Romanian dead lift (RDL), all at 85%1RM, and with 4 minutes recovery between sets and exercises. After completion of this session, the CMJs were repeated, and blood lactate was taken once again (immediately post weights session time-point). Due to time constraints, it was not possible to collect blood samples at this time point. Lactate, MS, CMJs, and blood were collected again for a final time the following morning (24 post speed session time-point).

In the WS protocol, the exact same training sessions were performed, however, the order was reversed with the weight training session being performed in the morning, and the speed session in the afternoon.

During each protocol, the first day's breakfast, lunch, snacks, and dinner along with the following day's breakfast were provided (Soulmate food, Lancashire, UK).

All CMJs were performed on a force platform (Type 9287CA, Kistler Instruments Ltd., Farnborough, United Kingdom). After collection, the vertical component of the ground reaction force-time history was exported for analysis, and peak power (PP), average rate of force development (aRFD), jump height (JH), and peak velocity (PV) were calculated as per previously published literature [6]. The participants were fully familiarised with CMJs, and performed them weekly within the academy.

Blood samples were collected from the antecubital vein after 10 minutes of lying supine. After collection, the samples were centrifuged at 3000 rpm for 10 minutes at room temperature. Plasma was analysed for T, C, and CK activity (Roche Diagnostic Limited, Charles Avenue, Burgess hill) on a Cobas C8000 analyser (Roche Diagnostics, Switzerland). The inter-assay CVs for T, C, and CK were 5.3, 3.7, and 1.4% respectively. The intra-assay CVs for T, C, and CK were 4.5, 3.3, and 1.7% respectively. Lactate was analysed using a lactate analyser (Lactate pro, Arkray). The CV for lactate was 2.8%.

Perceived muscle soreness (MS) was recorded at each data collection point, using a 7-point Likert scale designed to measure soreness in the lower body. The scale ranged from very, very good (1) to very, very sore (7) [12].

The participants recorded weights lifted during each of the squat and Romanian deadlift work sets, and total tonnage was calculated from this information. Each participant also provided a Rate of Perceived Exertion, using the Borg 10 grade scale, for the weight training sessions performed during each protocol upon completion [13].

Sample size was determined using the methods of Hopkins [14], and 15 subjects was found to be adequate to determine changes with sufficient statistical power. All statistical analysis was performed using the IBM SPSS (Version 20.0, SPSS Inc., Chicago, IL) statistical data package. CK values were log transformed due to large inter-participant variability. Differences between and within protocol were assessed using a two way (time point and protocol) repeated measure analysis of variance. Bonferroni adjustments were run where relevant. Differences between the afternoon and morning sprint and weight training performances were also investigated to see if session order affected performance. These differences were assessed using one-way t-tests. Effect size (ES) was determined using partial eta-squared. The level of significance was set at $p \leq 0.05$. Data is presented as the mean ± standard deviation.

3. Results

There was no significant time-protocol interaction for 50 m sprint times (effect size eta2 = 0.070, $p > 0.05$) during the sprint training session confirming that performance did not differ across the protocols. The protocols did differ with regard to peak 10 m time, with performance in the afternoon (1.76 ± 0.08s) being faster than performance in the morning (1.80 ± 0.11s) ($p > 0.05$). There was no significant different in the rate of perceived effort or total volume lifted for the weight training sessions between the protocols ($p > 0.05$) (Table 1).

INSERT TABLE 1 AROUND HERE

There was a significant time effect on T (effect size eta2 = 0.349, $p < 0.05$), and C (effect size eta2 = 0.751, $p < 0.05$) (Table 2), but no time-protocol interaction for T (effect size eta2 = 0.115, $P > 0.05$) or C (effect size eta2 = 0.026, $P > 0.05$).

Both protocols had a significant time effect on lactate (effect size eta2 = 0.923, $p < 0.05$), MS (effect size eta2 = 0.650, $p < 0.05$) and CK (effect size eta2 = 0.882, $p < 0.05$), and there was a significant time-protocol interaction for lactate (effect size eta2 = 0.932, $p < 0.05$), with lactate levels being significantly different immediately post session one ($p < 0.05$), and immediately post session two (p <

0.05), but not at any other time point (Table 2) between protocols. No time-protocol interaction was found for MS (effect size eta2 = 0.024, $P > 0.05$) or CK (effect size eta2 = 0.063, $P > 0.05$).

INSERT TABLE 2 AROUND HERE

Time effects were found for CMJ PP (effect size eta2 = 0.636, $p < 0.05$), JH (effect size eta2 = 0.629, $p < 0.05$), aRFD (effect size eta2 = 0.454, $p < 0.05$), and PV (effect size eta2 = 0.645, $p < 0.05$) (Table 3). However, there was no significant time-protocol interaction for CMJ PP (effect size eta2 = 0.114, $P > 0.05$), JH (effect size eta2 = 0.061, $P > 0.05$), aRFD (effect size eta2 = 0.081, $P > 0.05$), and PV (effect size eta2 = 0.143, $P < 0.05$).

INSERT TABLE 3 AROUND HERE

4. Discussion

To our knowledge, this is the first study to examine the influence of manipulating the order of maximal speed training and weight training on the same day on acute neuromuscular, physiological, and endocrine responses. The primary finding from this investigation was that, while the two sessions individually resulted in significantly different metabolic responses, training order did not result in different endocrine responses, patterns of muscle soreness, muscle damage, or neuromuscular performance over a 24-hour period.

In the current study, both the initial maximal speed training, and weights sessions were found to result in similar depressions in neuromuscular performance immediately post session. The response to the morning maximal speed training session in the SW protocol is in line with previous findings [6]. However, given that the acute fatigue response to exercise has been reported to vary depending on the nature of the activity [8,7], the finding that both types of sessions resulted in similar declines in performance is somewhat unexpected, especially given the different post session metabolic responses (9.41 ± 1.38 mmol/l post speed vs. 3.15 ± 1.07 mmol/l post weights). Therefore, while a link between metabolic fatigue and loss in neuromuscular performance has previously been reported [15], it does not seem to have differentiated the sessions in the current study. Instead, it is possible that the strength levels (Squat 1RM 170 ± 20 kg, Bench 1RM 135 ± 10 kg) of the participant group in the current study contributed to the findings as it has been demonstrated that strength-trained participants experience significantly more neural fatigue than untrained participants [16] and, therefore, the participants in this study may have experienced greater depressions in neuromuscular performance immediately after a maximal strength focused weight-training session than would have been expected from a non-elite population.

Immediately after both the morning maximal speed training and weight training sessions, C decreased significantly while T increased significantly after the maximal speed training, and non-significantly after the weight training session, with no difference in the testosterone response between the protocols (Table 2). This lack of difference in T occurred even though the sessions differed significantly in terms of the metabolic response they inducted. While several studies report a relationship between training-induced elevations in lactate and post-exercise changes in T [17,18], others have found elevations to occur in the absence of lactate [19]. The results of the current study suggest that metabolic accumulation does not affect either T or C in an obvious dose response manner.

When performance was reassessed two hours after the morning sessions and immediately prior to the start of the afternoon sessions, all of the countermovement jump variables had recovered in both protocols. While the time frames required for recovery from different types of resistance training have previously been demonstrated [7,20], to our knowledge, this is the first study to compare the time frames for recovery from maximal speed training to a maximal strength-focused weight-training session.

Given the relationship between exercise intensity and neuromuscular adaptation [21], it is important that the second session of the day is not performed in a fatigued state. The results showed no difference in either total tonnage lifted or rate of perceived effort when the weight training sessions were compared (Table 1), suggesting that performing a strength-training protocol two hours post maximal speed training does not result in decreased performance. In contrast, 10m-sprint time was significantly faster when performed two hours after a weights session versus the morning (0.04 second). While this improved performance may have been a result of normal circadian patterns associated with body temperature [22], it is also possible that the weight training itself played a role in improving sprint performance 2 hours post. Cook et al. [5] reported morning weight training to result in a change in the normal circadian pattern of T, resulting in it being significantly elevated prior to the speed testing versus the same time-point on a day where no morning session was performed. In the current study, T was unchanged from its baseline levels two hours post weight training, while in contrast C had declined significantly by this time point (Table 2). While C does appear to degrade at a faster rate during the day than T [22,23], the lack of a significant decline in T coupled with the changes in C further suggests that the morning training had an effect on normal endocrine circadian rhythm, and that weight training may have affected the normal circadian pattern associated with T. In doing so, it is possible the non-genomic effects, notably increased aggression and muscle function, associated with T [24] accentuated the normal circadian patterns associated with performance, and contributed to sprint performance at this time-point.

The performance of a morning exercise session did not affect metabolic response to either session in the current study, with similar responses regardless of whether the session was performed in the morning or afternoon. This conflicts with the findings of Coffey et al.[25] who reported the metabolic response to a second session was affected by the first session of the training day. The most likely explanation for the difference between these results and the current study is the difference in the time between the sessions, with Coffey et al.[25] performing their sessions with a 15-minute recovery between them. In contrast, a two-hour recovery between sessions was utilized in the current study and, as a result, sufficient time was available for lactate concentrations to return to baseline, in turn, allowing the participants to sufficiently recover from the first session.

At the 24 hours post time-point, neuromuscular performance was found to be significantly declined versus initial baseline measurements in both protocols, however, there was no difference between the protocols suggesting that session order does not affect the neuromuscular system at this time point (Table 3). While previous research has reported similar findings when the two sessions were identical in make-up [26,27], this is the first study to suggest that, at least on weights and speed training days, session order does not seem to be a factor in neuromuscular performance the following day. However, this finding conflicts with Doma and Deakin[3] who found a strength session followed six hours later by an aerobic run to have a significantly greater negative effect on running performance 24 hours post compared to when the order was reversed. One possible explanation for the difference between the studies is the readiness of the neuromuscular system to undertake the second session of the day. While in the current study neuromuscular performance had returned to baseline prior to the start of second session of the day, Doma and Deakin[3] reported that maximal voluntary contraction (MVC) was still depressed six hours after the strength training session, and immediately prior to the start of the run session. This was in contrast to the running-strength training sequence were MVC had fully recovered between sessions. While the fact that the participants in Doma and Deakin [3] lacked a resistance training background in resistance training, and this may have contributed to the depressed MVC at 6 hours, their findings still highlight the importance of ensuring neuromuscular recovery prior to beginning session two as training in a fatigued state may result in greater depressions 24 hours post.

5. Conclusion

In conclusion, this study demonstrated that two protocols with different session order resulted in similar neuromuscular, endocrine, and biochemical responses over a 24-hour period in a well-trained population. This was the case even though the metabolic response was different between the sessions. This was potentially due to the two-hour time period allowing the participants to have fully recovered from the first session of the day.

6. Practical implications

- Two hours is sufficient for the recovery of neuromuscular performance after both maximal speed training and weight training sessions.
- Providing sufficient recovery from the first training session, the coach and athlete can structure their sessions in either order without negatively affecting recovery 24 hours post.
- There was a significant improvement in 10m-sprint performance in the afternoon when preformed 2 hours after the weights session. While several factors could have contributed to this, it is possible the morning session enlisted some degree of priming.

7. Acknowledgments

We acknowledge with gratitude the contributions of the players who partook in this study, the staff from the Sports Institute Northern Ireland, and Ulster hospital who provided their time and expertise.

8. References

1. Cormack SJ, Newton RU, McGuigan MR. Neuromuscular and endocrine responses of elite players to an Australian rules football match. *Int J Sports Physiol Perform.* 2008; 3(3):359-374.
2. Bishop PA, Jones E, Woods AK. Recovery from training: a brief review: brief review. *J Strength Cond Res.* 2008; 22(3):1015-1024.
3. Doma K, Deakin GB. The effects of strength training and endurance training order on running economy and performance. *Appl Physiol Nutr Metab.* 2013; 38(6):651-656.
4. Palmer CD, Sleivert GG. Running economy is impaired following a single bout of resistance exercise. *J Sci Med Sport.* 2001; 4(4):447-459.
5. Cook CJ, Kilduff LP, Crewther BT, et al. Morning based strength training improves afternoon physical performance in rugby union players. *J Sci Med Sport.* 2013; 17(3): 317-321.
6. Johnston M, Cook CJ, Crewther BT, et al. Neuromuscular, physiological and endocrine responses to a maximal speed training session in elite games players. *Eur J Sport Sci.* 2015:1-7.
7. McCaulley GO, McBride JM, Cormie P, et al. Acute hormonal and neuromuscular responses to hypertrophy, strength and power type resistance exercise. *Eur J Appl Physiol.* 2009; 105(5):695-704.
8. Cadore EL, Izquierdo M, dos Santos MG, et al. Hormonal responses to concurrent strength and endurance training with different exercise orders. *J Strength Cond Res.* 2012; 26(12):3281-3288.

9. Coffey VG, Pilegaard H, Garnham AP, et al. Consecutive bouts of diverse contractile activity alter acute responses in human skeletal muscle. *J Appl Physiol.* 2009; 106(4):1187-1197.

10. Hackney AC, Viru A. Research methodology: endocrinologic measurements in exercise science and sports medicine. *J Athl Train.* 2008; 43(6):631-639.

11. Francis C. *The Structure of Training for Speed*, Canada, Charliefrancis.com. 2008.

12. Andersson H, Raastad T, Nilsson J, et al. Neuromuscular fatigue and recovery in elite female soccer: effects of active recovery. *Med Sci Sports Exerc.* 2008; 40(2):372-380.

13. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc.* 1982; 14(5):377-381.

14. Hopkins WG. Estimating sample size for magnitude-based inferences. Sport Science. http://sportsci.org/resources/stats/xSampleSize.xls. October 2015

15. Walker S, Davis L, Avela J, et al. Neuromuscular fatigue during dynamic maximal strength and hypertrophic resistance loadings. *J Electromyogr Kinesio.* 2012; 22(3):356-362.

16. Ahtiainen JP, Hakkinen K. Strength athletes are capable to produce greater muscle activation and neural fatigue during high-intensity resistance exercise than nonathletes. *J Strength Cond Res.* 2009; 23(4):1129-1134.

17. Izquierdo M, Ibanez J, Calbet JA, et al. Cytokine and hormone responses to resistance training. *Eur J Appl Physiol.* 2009; 107(4):397-409.

18. Walker S, Taipale RS, Nyman K, et al. Neuromuscular and hormonal responses to constant and variable resistance loadings. *Med Sci Sports Exerc.* 2011; 43(1):26-33.

19. Fry AC, Lohnes CA. Acute testosterone and cortisol responses to high power resistance exercise. *Fiziol cheloveka.* 2010; 36(4):102-106.

20. Raastad T, Hallen J. Recovery of skeletal muscle contractility after high- and moderate-intensity strength exercise. *Eur J Appl Physiol.* 2000; 82(3):206-214.

21. Tan B. Manipulating resistance training program variables to optimize maximum strength in men: A review. *J Strength Cond Res.* 1999; 13(3):289-304.

22. Teo W, McGuigan MR, Newton MJ. The effects of circadian rhythmicity of salivary cortisol and testosterone on maximal isometric force, maximal dynamic force, and power output. *J Strength Cond Res.* 2011; 25(6):1538-1545.

23. Hayes LD, Bickerstaff GF, Baker JS. Interactions of cortisol, testosterone, and resistance training: influence of circadian rhythms. *Chronobiol Int.* 2010; 27(4):675-705.

24. Crewther BT, Cook C, Cardinale M, et al. Two Emerging Concepts for Elite Athletes The Short-Term Effects of Testosterone and Cortisol on the Neuromuscular System and the Dose-Response Training Role of these Endogenous Hormones. *Sports Med.* 2011; 41(2):103-123.

25. Coffey VG, Jemiolo B, Edge J, et al. Effect of consecutive repeated sprint and resistance exercise bouts on acute adaptive responses in human skeletal muscle. *Am. J Physiol-Regul Integr Comp Physiol.* 2009; 297(5):R1441-R1451.

26. Skurvydas A, Kamandulis S, Masiulis N. Effects on muscle performance of two jumping and two cycling bouts separated by 60 minutes. *Int Sportmed J.* 2010; 11(2):291-300.

27. Skurvydas A, Kamandulis S, Masiulis N. Two series of fifty jumps performed within sixty minutes do not exacerbate muscle fatigue and muscle damage. *J Strength Cond Res.* 2010; 24(4):929-935.

Figure Legend

Figure 1: - Schematic outlining the design of the speed weights and weights speed protocols. Assessments performed immediately prior session one, immediately post session one, immediately pre session two, immediately post session two, and 24 hours post session one during each protocol.