ACUTE EFFECTS OF STRENGTH TRAINING ON RUNNING ECONOMY

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Sequencing strength training before aerobic conditioning is practised without empirical support. This study explored the acute effects of strength training on running economy and 3-D kinematics in five males. Running was performed on a treadmill at 12 and 14 km/h on three separate occasions. Trial 1 and 2 involved no strength training with data used to assess response stability of the variables. Before Trial 3, three sets of three repetitions at 85% of 1 repetition maximum of squat, bench press and deadlift with 3-5 minutes of rest were performed. Compared to Trial 2 no significant differences were observed when strength training was performed. Only a tendency of increased knee flexion (4.5°) at foot strike at the higher running velocity was observed. This suggests that running kinematics were changed exposing participants to long-term chronic injuries.

KEYWORDS: kinematics, fatigue

INTRODUCTION: When endurance training is performed first, studies have shown that post-activity strength and power measurements are significantly impaired compared to baseline data (e.g., Gomez et.al., 2002; Lepers, Pousson, Maffiuletti, Martin, & Van Hoecke, 2000). The time for full restoration of strength measures can take at least eight hours following the end of the endurance training (Gomez et al., 2002). Based on this prolonged time period required to recover, some authors recommend organising strength training before aerobic conditioning to avoid the aforementioned negative effects (e.g., Zatsiorsky & Kraemer, 2006). The practise of organising training in such a manner is now becoming popular within the professional team sport domain. The purported advantages are that it permits training to be completed under conditions more appropriate to improve strength in athletes and that both strength and endurance sessions are performed within a relatively short time-frame affording more time for the athletes to recover for the next day. Yet, within the literature there is a lack of supporting evidence for such practise. Moreover, when the strength training workload is too heavy (e.g., high volume typically used for hypertrophy) it can also illicit negative effects on proceeding actives. To date no previous research has investigated such decrements in running demands and movement coordination following a strength training protocol. From running induced fatigue it is known that movement coordination of running can change, increasing energetic demands and injury risk during the aerobic training (Derrick, Dereu & Mclean, 2002). This preliminary study explored the acute responses to a high-intensity, low volume strength training session in terms of running economy and kinematics. The aim was to identify any changes caused by the strength training to support or refute the emerging practise of organising strength training before endurance focussed conditioning.

METHOD: Five males (age = 23.6 ± 4.8 years; stature = 173.2 ± 5.8 cm; mass = 70.9 ± 1.3 kg; 1RM squat = 120 ± 9 kg; 1RM bench press = 80 ± 18 kg; 1RM deadlift = 112 ± 16 kg) with a minimum training age of six months volunteered. All were screened for injuries and medical conditions which could deem unfit for testing. For all trials they wore the same pair of running shoes and to standardise metabolic states during the testing they were asked to refrain from each of the following for the indicated time periods before testing: eating (≥2 hours), caffeine ingestion (≥4 hours), and vigorous or uncustomary exercise (≥24 hours) (Turner, Owings & Schwane, 2003). The testing schedule is shown in Figure 1. The maximum strength test included 3RM for the bench press and squat. These values were then used to estimate a 1RM for the bench press and squat (Wathen, as cited in LeSuer et.al., 1997, p. 211). Upon determination of the 1RM squat, another calculation was used (Ebben et.al., 2008) to determine the 6RM value for the deadlift. The 6RM values and Wathen's equation were again used to determine the 1RM value for the participant's deadlift. In total, three testing sessions were performed. Trial 1 and Trial 2 (completed with at least 48 hours between) were used for reliability purposes. Trial 3 consisted of a strength training program and occurred at least 48 hours after the second testing session. Immediately following the intervention session, participants performed another testing session on the treadmill

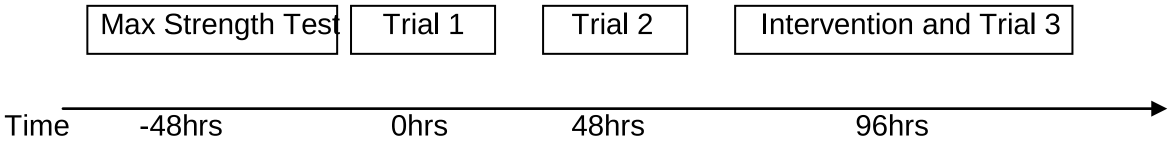

Figure 1. Time course of testing procedure.

Upon arriving for Trial 1, anthropometric characteristics were measured as described by Norton et.al. (1996, p. 33-75). This included stature, mass, and limb lengths. These measurements were later entered into the VICON Nexus (version 1.2) computer program. Bony landmarks were identified for the placement of retro-reflective ball markers for kinematic assessment using the Vicon MX motion analysis. Six Vicon cameras captured (500Hz) 3D motion of the participants when running on the treadmill. The study used the Plug-in-Gait lower limb marker set. A metabolic cart (MOXUS Modular VO2 System) was used to obtain running economy by dividing the VO_2 consumed during the final minute of each running stage by the participant's body mass. All running was performed on a Cosmos treadmill. Treadmill velocities were calibrated prior to commencement of testing, to ensure that the belt revolves at the same velocity as that displayed on the control panel. The participant then followed an 11 minute treadmill running protocol, with the treadmill set to a 1% grade incline to reflect the energy cost of outdoor running (Jones, 2007). The 11 minute protocol involved 3 mins at 10 km/h; 4 mins at 12 km/h; and 4 mins at 14 km/h. Data collection began in the final minute of each stage, where pulmonary gas exchange and lower limb kinematics were collected using the relevant equipment. For Trial 3, resistance exercise order was squat, bench press and deadlift. To replicate a strength training session to improve maximal strength participants performed 3 warm-up sets at 60, 70 and 80% 1RM, and 3 working sets of 3 repetitions at 85% 1RM in order to maximally stimulate motor units. Finally, rest intervals of 3-5 minutes duration were used (Kraemer et al., 2002).
Data from the right side were analysed only. The first two trials were used to assess test-retest stability of the dependent variables using typical error (TE), the 95% confidence intervals (CI) and the smallest worthwhile change (SWC) calculated by multiplying the standard deviation of the trials by a value of 0.2. T-tests, TE (95%CI) and Cohen's *d* were used to assess differences between Trial 2 and Trial 3. Angle-angle plots were visually inspected for each participant, at each velocity, across the three trials.

RESULTS: As shown in Table 1, TE ranged between 2.2 - 6.8° for kinematic measures while it was 1.7 - 2.3 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ for O_2 consumption. The SWC for all variables were less than their respective TE. Furthermore, based on the TEs and their respective 95%CI, test-retest stability was relatively poor for all variables. For all variables, no significant differences were found between Trial 2 and Trial 3. Only the knee angle at foot strike displayed a notable difference when the mean difference (Trial 3-2) was compared to respective TE and ES. On inspection of the angle-angle plots for each individual no systematic changes between Trials 2 and 3 were observed.

Table 1. Descriptive statistics across all three Trials.

			Trial 1 Mean(SD)	Trial 2 Mean(SD)	Trial 3 Mean(SD)	Trial 1-2 diff	SWC	TE	(95%CI)	Trial 3-2 diff	Effect Size
Foot Strike	12km/h	Hip (º)	41.8(4.4)	37.3(4.5)	38.6(5.1)	4.5	0.9	2.9	(1.7-8.3)	1.3	0.3
		Knee (º)	19.1(6.0)	19.6(7.5)	21.4(4.3)	-0.5	1.2	3.4	(2.1-9.8)	1.8	0.3
		Ankle (º)	6.7(3.8)	6.8(3.8)	7.5(4.1)	-0.1	0.8	3.7	(2.2-10.8)	0.7	0.2
	14km/h	Hip (º)	42.2(5.4)	40.4(6.1)	41.4(5.8)	1.9	1.1	2.4	(1.4-6.9)	1.0	0.2
		Knee (º)	17.9(6.7)	20.6(7.9)	25.1(5.2)	-2.6	1.3	2.3	(1.4-6.6)	4.5	0.7 *
		Ankle (º)	4.7(3.3)	6.0(4.6)	7.9(3.3)	-1.3	0.7	3.6	(2.2-10.4)	1.9	0.5
Toe Off	12km/h	Hip (º)	-5.5(4.9)	-8.4(2.8)	-6.8(2.6)	2.9	1.0	3.8	(2.3-11.0)	1.6	0.5
		Knee (º)	15.6(4.7)	13.7(2.2)	16.0(4.1)	1.9	0.9	4.1	(2.4-11.7)	2.3	0.6
		Ankle (º)	-20.5(2.3)	-17.3(5.8)	-18.2(4.0)	-3.2	0.5	4.5	(2.7-12.9)	-0.9	-0.2
	14km/h	Hip (º)	-8.3(4.4)	-10.0(2.7)	-9.0(3.0)	1.7	0.9	4.3	(2.6-12.3)	1.0	0.3
		Knee (º)	11.8(3.4)	14.7(0.9)	15.1(3.3)	-2.9	0.7	2.2	(1.3-6.2)	0.4	0.2
		Ankle (º)	-21.5(4.3)	-15.7(5.8)	-18.5(1.8)	-5.8	0.9	6.8	(4.1-19.6)	-2.8	-0.7
VO_2 ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$)	12km/h		44.1(1.8)	42.1(4.5)	43.2(2.3)	2.0	0.4	2.3	(1.4-6.5)	1.1	0.4
	14km/h		48.0(4.6)	49.3(5.0)	49.7(2.5)	-1.2	0.9	1.7	(1.0-4.9)	0.4	0.1

Note. SD = standard deviation, VO2 = volume of oxygen, SWC = smallest worthwhile change, TE = typical error, CI = confidence interval.

DISCUSSION: Strength training had no significant effect to subsequent measures of running economy at either velocity. However, at 14 km/h there was a tendency by the group to foot strike with a more (4.5˚) flexed knee. This observation suggests participants were fatigued, since similar (4.4°) changes in knee flexion have been previously reported when running under a fatigued state (Derrick et al., 2002). Previously a greater knee flexion at foot strike has been identified as a potential injury risk, since it increases tibial shock (Lafortune, Hennig & Lake, 1996). Given this increase in knee flexion and the purported increase in risk injury it was interpreted that strength training prior to running may place athletes at a greater risk of injury. Explanations for a lack of change found (other than sample size) in running economy may be due to the assessment. This sub-maximal protocol was employed to assess the oxygen cost, as it has consistently been identified as a more sensitive assessment than aerobic power (i.e., VO2max). In addition, running economy was selected instead of a maximal aerobic assessment based on the difficulty for controlling motivation when asking participants to perform three maximal tests within a short time-frame. Perhaps a more 'performance' based measure such as a time-trial reflecting aerobic training would have been a more appropriate measure. It should be noted that an individual's genetics and training history is a significant factor determining how prone to fatigue an athlete may be (Chiu et.al., 2003).

CONCLUSION: Possible evidence for increased injury risk was observed following a high intensity, low volume, full body strength training session. This was demonstrated by an increased knee flexion observed at foot strike (only at 14 km/h running velocity). It is likely that following the strength training participants were experiencing fatigue that changed the movement coordination. Despite the change in movement coordination running economy was preserved. These findings warrant a further more in-depth analysis using a larger, more experienced group of athletes.

REFERENCES:

Chiu, L.Z.E., Fry, A.C., Weiss, L.W., Schilling, B.K., Brown, L.E., & Smith, S.L. (2003). Postactivation potential response in athletic and recreationally trained individuals. *Journal of Strength and Conditioning Research, 17*(4), 671-677.

Derrick, T.R., Dereu, D., & Mclean, S.P. (2002). Impacts and kinematic adjustments during an exhaustive run. *Medicine & Science in Sports & Exercise, 34*(6), 998-1002.

Ebben, W.P., Feldmann, R.C., Dayne, A., Mitsche, D., Chmielewski, L.M., Alexander, P.,& Knetgzer, K.J. (2008). Using squat testing to predict training loads for the deadlift, lunge, step-up, and leg extension exercises. *The Journal of Strength and Conditioning Research, 22*(6), 1947-1949.

Gomez, A.L., Radzwich, R.J., Denegar, C.R., Volek, J.S., Rubin, M.R., Bush, J.A., Doan, B.K., Wickham, R.B., Mazzetti, S.A., Newton, R.U., French, D.N., Hakkinen, K., Ratamess, N.A., & Kraemer, W.J. (2002). The effects of a 10-kilometer run on muscle strength and power. *Journal of Strength and Conditioning Research, 16*(2), 184-191.

Jones, A.M. (2007). Middle- and long-distance running. In E.M. Winters, A.M. Jones, R. Davison, P.D. Bromley & T.H. Mercer (Eds.), *Sport and exercise physiology testing guidelines: the British Association of Sport and Exercise Sciences guide* (pp. 147-154). London : Routledge.

Kraemer, W.J., Adams, K., Cafarelli, E., Dudley, G.A., Dooly, C., Feigenbaum, M.S., Fleck, S.J., Franklin, B., Fry, A.C., Hoffman, J.R., Newton, R.U., Potteiger, J., Stone, M.H., Ratamess, N.A., & Triplett-McBride, T. (2002). Progression models in resistance training for healthy adults. *Medicine & Science in Sports & Exercise, 34*(2), 364-380.

Lafortune, M.A., Hennig, E.M., & Lake, M.J. (1996). Dominant role of interface over knee angle for cushioning impact loading and regulating initial leg stiffness. *Journal of Biomechanics, 29*(12), 1523-1529.

Lepers, R., Pousson, M.L., Maffiuletti, N.A., Martin, A., & Van Hoecke, J. (2000). The effects of a prolonged running exercise on strength characteristics. *International Journal of Sports Medicine, 21*(4), 275-280.

LeSuer, D.A., McCormick, J.H., Mayhew, J.L., Wasserstein, R.L., & Arnold, M.D. (1997). The accuracy of prediction equations for estimating 1-rm performance in the bench press, squat, and deadlift. *The Journal of Strength and Conditioning Research, 11*(4), 211-213.

Norton, K., Whittingham, N., Carter, L., Kerr, D., Gore, C., & Marfell-Jones, M. (1996). Measurement Techniques in Anthropometry. In K. Norton & T. Olds (Eds.), *Anthropometrica* (1st ed., pp. 25-76). Sydney: University of New South Wales Press.

Turner, A.M., Owings, M., & Schwane, J.A. (2003). Improvement in running economy after 6 weeks of plyometric training. *Journal of Strength & Conditioning Research, 17*(1), 60-67.

Zatsiorsky, V.M., & Kraemer, W.J. (2006). *Science and practice of strength training* (2nd Ed.). Champaign: Human Kinetics.