Effect of Lumbar Spine Manipulation on Asymptomatic Cyclist Sprint Performance and Hip Flexibility

Eric Olson BS^a, Michael Bodziony BS^a, John Ward DC, MA, MS^{b,*},
Jesse Coats DC, DAAPM^c, Bradley Koby DC^d, Doug Goehry BS^a

^a Graduate Student, Texas Chiropractic College, Pasadena, TX

^b Associate Professor/Research Fellow, Department of Physiology and Chemistry, Texas Chiropractic College, Pasadena, TX

^c Professor, Department of Clinical Specialties, Texas Chiropractic College, Pasadena, TX

^d Assistant Professor, Chair, Department of Principles and Practices, Department of Diagnosis, Texas Chiropractic College, Pasadena, TX

Received 11 June 2014; received in revised form 21 August 2014; accepted 23 August 2014

Key indexing terms:

Exertion;
Physical;
Rate;
Heart;
Exercise;
Manipulation;
Spinal;
Acupuncture;
Chiropractic

Abstract

Objective: The purpose of this study was to measure the impact of midlumbar spinal manipulation on asymptomatic cyclist sprint performance and hip flexibility.

Methods: Twelve cyclists were equally randomized into an AB:BA crossover study design after baseline testing. Six participants were in the AB group, and 6 were in the BA group. The study involved 1 week of rest in between each of the 3 tested conditions: baseline testing (no intervention prior to testing), condition A (bilateral midlumbar spine manipulation prior to testing), and condition B (sham acupuncture prior to testing, as a control). Testing was blinded and involved a sit-and-reach test followed by a 0.5-km cycle ergometer sprint test against 4-kp resistance. Outcome measures were sit-and-reach distance, time to complete 0.5 km, maximum heart rate, and rating of perceived exertion. An additional 8 cyclists were recruited and used as a second set of controls that engaged in 3 testing sessions without any intervention to track test acclimation. An analysis of variance was used to compare dependent variables under each of the 3 conditions for the experimental group and control group #1, and a repeated-measures analysis of variance was used to analyze test acclimation in control group #2.

Results: Lumbar spine manipulation did not demonstrate statistically significant between-group changes in sit-and-reach ($P = .765$), 0.5-km sprint performance time ($P = .877$), maximum exercise heart rate ($P = .944$), or rating of perceived exertion ($P = .875$).

Conclusions: The findings of this preliminary study showed that midlumbar spinal manipulation did not improve hip flexibility or cyclist power output of asymptomatic participants compared with an acupuncture sham and no-treatment control groups.

© 2014 National University of Health Sciences.

* Corresponding author. Texas Chiropractic College, 5912
Spencer Hwy, Pasadena, TX 77505. Tel.: +1 281 998 5704.
E-mail address: jward@txchiro.edu (J. Ward).

Introduction

Spinal manipulation and acupuncture are 2 forms of alternative medicine classified as mind and body practices.¹ The impact spinal manipulation and acupuncture have on exercise performance has been minimally studied, particularly among asymptomatic athletes. This is concerning considering that these 2 modalities are often used by athletes.^{2–8}

There is limited research on how spinal manipulation may impact athletic performance.^{9–22} Among asymptomatic participants, spinal manipulation has not been shown to acutely improve run time to exhaustion, maximum oxygen consumption, rating of perceived exertion (RPE), blood lactate, exercise heart rate, free throw accuracy, or 30-m sprint time.^{9–12} Spinal manipulation, however, has been shown to increase hip mobility among runners,⁹ how far golfers can drive a ball,¹⁴ and handgrip strength of judo athletes.²⁰ The mechanism by which spinal manipulation has impacted athletic performance in some research studies is unclear, but it may involve alterations in paraspinal muscle reflexes and motoneuron excitability²³ leading to increased force output.²⁴ As a result, to gain better clarity on how manipulation could impact athletes, studies should focus on different topical attributes of exercise performance (eg, anaerobic power, aerobic performance, plyometrics, agility) to demonstrate clear trends. This study differs from the work of other researchers in this field in that it focuses on anaerobic power of athletes.

In addition, there is a paucity of research demonstrating that acupuncture may have some role in enhancing exercise performance.^{25–27} Acupuncture has preliminarily been shown to improve quadriceps maximum isometric voluntary force in athletes, but not drop jump height.²⁸ The exact mechanism by which acupuncture could impact exercise performance is unclear and needs further analysis with methodologically strong studies.²

Cyclists rely on power to help them climb hills and accelerate past other racers. Wingate-like tests are popular short-duration, all-out cycling sprint tests against high resistance that measure power.^{29–33} Typically, these sprint tests last 30 seconds²⁹; but there are modified versions that last longer.^{34,35} In general, anaerobic capacity tests, like Wingate tests, should be very physically challenging and completed by participants in 30 to 90 seconds.^{36–39} Supramaximal tests like these rely heavily on both the creatine phosphate system and glycolysis to provide energy.^{40,41}

The purpose of this study was to determine if midlumbar spine manipulation could positively impact asymptomatic cyclist sprint performance and hip flexibility.

Methods

This study was reviewed and approved by the Texas Chiropractic College Institutional Review Board for human subjects in accordance with the Declaration of Helsinki. All subjects were provided a written and oral explanation of the study procedures prior to participation. This trial was registered with the University Hospital Medical Information Network Clinical Trials Registry, trial no. UMIN000014899.

Study Design and Setting

This was a blinded, randomized, controlled study of the impact that lumbar spine manipulation had on cycle ergometer sprint performance and hip flexibility. Twenty cyclists were involved in this study and underwent testing once per week over a 3-week period (Fig 1). Participants were tested under 3 possible conditions: baseline condition (no intervention prior to testing), condition A (bilateral lumbar spine manipulation prior to testing), and condition B (sham acupuncture to arbitrary points). During each test iteration, participants performed a sit-and-reach test 15 minutes postintervention (if they were scheduled for an intervention that week) followed by a 0.5-km cycle ergometer sprint against 4-kp resistance. This study used an AB:BA crossover design⁴² to reduce exercise test acclimation as a covariate between the 2 compared main conditions, A vs B.

Participants, Randomization, and Blinding

Twenty-eight asymptomatic cyclists were recruited via word of mouth for this study (Fig 2). All study applicants provided an informed written consent on college-approved documents. They were then screened against inclusion and exclusion criteria. Two participants were dropped from the study. One male participant dropped out of the study after his baseline test session because of scheduling conflicts. One female participant was dropped from the study because her baseline cycle ergometer test took longer than 100 seconds, demonstrating that she was not fit enough for the study. Their data are not included in any analysis. Twenty participants (Table 1) completed the study.

Fig 1. Illustration of the study design.

A computer-generated randomization list was developed prior to beginning the study and used to assign participants to groups: AB, BA, and control #2. Participants were all given a verbal description of the study procedures prior to testing to reduce anxiety during the test. Upon arrival to a given test session, participants changed into appropriate exercise attire.

Each research assistant involved in all data recording was blinded as to the study intervention. Blinding was performed by having the research assistant stand outside while the intervention or lack thereof took place. Study inclusion and exclusion criteria are listed in Fig 3.

Sit-and-Reach Test

Participants took off their shoes and placed their feet against the sit-and-reach box (Baseline, White Plains, NY). Participants kept their knees extended and placed one hand over the other as they flexed forward as much as they could as they breathed out (Fig 4A). The greatest distance the participants pushed the top metal measuring board was recorded in centimeters. Each participant made 2 attempts during each test session, and the greater test value was recorded.

Cycle Ergometer Sprint Test Protocol

The seat height on the cycle ergometer was adjusted for each participant based on comfort level during their baseline test. For uniformity, the chosen seat height was recorded and used for each given participant for their 2 remaining test iterations during weeks 2 and 3. During cycle ergometer testing, participants wore an RS 300X SD Polar heart rate monitor chest strap (Polar Electro Inc, Lake Success, NY). Prior to beginning their sprint test, participants warmed up for 2 minutes against 1-kp resistance. Then, the resistance was raised to 4 kp; and within approximately 3 seconds, similar to other researchers,²⁹ the participants were vocally instructed to begin their sprint test as a stopwatch marked their exact start time as the odometer on the cycle ergometer was zeroed (Fig 4B). The resistance setting of 4 kp was arbitrarily chosen as a challenging Wingate-like test setting that would take most cyclists 30 to 90 seconds to complete the cycling sprint test. This was chosen as opposed to engaging in a true 30-second Wingate test because of the model of cycle ergometer available to researchers—Monark Ergomedic 828E (Monark AB, Varberg, Sweden) vs the Monark Ergomedic 894E—for Wingate testing. The Monark

Fig 2. Flow diagram of study progression.

Ergomic 828E does not keep track of total flywheel revolutions per minute, a variable needed to determine Wingate power-related attributes like peak power output, anaerobic fatigue, and anaerobic capacity.³⁰ The test concluded once the participant reached 0.5 km based on the Monark cycle ergometer digital display. During the sprint test, participants received strong verbal encouragement to ensure maximal effort by a blinded research assistant. At the conclusion of the 0.5-km cycle ergometer test, completion time was recorded, in addition to their maximum exercise heart rate and RPE. Participants were required to hold onto the cycle ergometer handlebars in an upright position and keep their buttocks on the bike seat throughout the test. In addition, their feet were fastened to the pedals by means of racing-style toe clips.

Acupuncture

Acupuncture was performed in this study by a doctor of chiropractic who received a 1-year postdoctoral certification in acupuncture, had 450 postdoctoral continuing education hours in acupuncture, and had 17 years of acupuncture practice experience. Acupuncture was not performed by a licensed acupuncturist. In this study, acupuncture was used as a sham control (control #1). The doctor of chiropractic performing acupuncture attempted to place acupuncture needles near or directly on the following acupuncture points as shown in Fig 5A to C without using a guide tube: Yang Ling Quan (gall bladder 34), Sanyinjiao (spleen 6), Qihai (conception vessel 6), and Shenmen (ear point 55).²⁸ All participants

Table 1 Comparison of Baseline Attributes Between the Intervention Arm (AB Group and BA Group) and Control Arm (Control #2) of the Study

	12-Cyclist Intervention (AB + BA) Arm	8-Cyclist Control Arm	<i>P</i> Value
Sex (M/F)	5/7	1/7	
Age (y)	36.3 ± 7.4	28.4 ± 11.1	.219
Mass (kg)	81.4 ± 25.2	65.8 ± 7.7	.141
Height (m)	1.72 ± 0.10	1.65 ± 0.07	.249
Body mass index (kg/m ²)	27.1 ± 6.7	24.3 ± 2.6	.221
Age range (y)	22-51	20-48	

Most data listed as mean ± SD. Between-groups data were compared with an independent-samples *t* test.

were supine for 15 minutes during the acupuncture treatment. Tai Chi 0.16–Chinese gauge × 13-mm sterile, single-use acupuncture needles (Tai-Chi single acupuncture needles, Lhasa OMS inc., Weymouth MA) were used. All acupuncture points were bilateral with the exception of Qihai. Yang Ling Quan was inserted approximately 10 to 12 mm. Sanyinjiao was inserted approximately 6 to 8 mm. Qihai was inserted approximately 8 to 12 mm. Shenmen was inserted approximately 2 to 3 mm. All acupuncture needles were single use and were disposed of in a biohazard container after use. The acupuncture points and the location and angle of needle placement were not intended to impact exercise performance or hip flexibility. The chiropractic acupuncturist did not attempt to achieve DeQi.

Spinal Manipulation

Spinal manipulation for this study was performed by a doctor of chiropractic with more than 15 years of experience. The spinal manipulation involved a side-posture mammillary push at L3, performed bilaterally, in an attempt to impact the majority of the lumbar spine and lumbar plexus (Fig 5D).^{44,45} The spinal manipulative therapy (SMT) consisted of a high-velocity, low-amplitude force applied at the L3 mammillary process as described by Bergman and Peterson.⁴⁶ Following manipulation, participants sat in a chair for 15 minutes to allow for a similar rest period as the sham acupuncture condition.

Statistical Analysis

Data were analyzed in SPSS version 20.0 (IBM, Armonk, NY). Results were reported as mean ± SD unless otherwise specified. An independent-samples *t* test was used to compare between-group differences at

Inclusion criteria were:
1) participant had a Body Mass Index (BMI) under 30
2) between the ages of 18-55 years of age
3) informed written consent was provided
4) answering "no" to all exercise contraindication sections on a Physical Activity Readiness-Questionnaire (PAR-Q) ⁴³
5) reported regularly engaging in at least 3 days per week of moderate (moderate-resistance moderate-velocity cycling) to intense (high-resistance high-velocity sprint cycling) aerobic cycling activity for 30 minutes or more per session
6) complete all cycle sprint tests in under 100 seconds per test

Study participants with any of the following were excluded from the study:
1) diagnosis of any cardiovascular, respiratory, neurological, or muscular disorder
2) caffeine consumption 6 hours before cycling test (participants were also repeatedly reminded to avoid caffeine six hours prior to each testing session)
3) participants in the intervention arm were not (or have ever been) an acupuncture or chiropractic college student or faculty member
4) participant received acupuncture or spinal manipulation in the previous 2 weeks
5) participant reported adverse reactions to acupuncture or spinal manipulation at any time in their life
6) participant was on any medications that would make exercise potentially dangerous for them (e.g., beta-agonists)
7) daily pain rated greater than a 3 on a 0-10 Numeric Rating Scale (NRS)

Fig 3. List of study inclusion and exclusion criteria.

baseline for the 12-cyclist intervention arm and 8-cyclist control arm. The Levene test for equality of variance was used and followed for homogeneity of variance violation. An analysis of variance (ANOVA) was used to compare dependent variables under each of the 3 tested conditions: baseline condition, condition A, and condition B for the 12 cyclists that received an intervention. A repeated-measures ANOVA was used to track within-group test adaptation over time for the 8-cyclist control arm. The Mauchly test was used to monitor sphericity, and the Greenhouse-Geisser correction was used during instances of sphericity violation.⁴⁷ A Bonferroni post hoc test was conducted on statistically significant data among all ANOVAs to determine which condition was significant. The α level of $P < .05$ was considered statistically significant for all tests.

Results

Preliminarily, the results for the study (Table 2) demonstrated that there were no statistically significant differences between the 3 conditions. However, the spinal manipulation group demonstrated the fastest sprint times and the greatest hip flexibility

when compared with the sham acupuncture and baseline testing groups in the intervention arm. The 8-cyclist control group test attributes did not change to a significant level; thus, there was minimal test acclimation.

Discussion

Sprint performance values for the manipulation condition may have been due to slight test acclimation. For example, during each of the 3 sprint tests, control group #2 became slightly faster. It is probable that, because the manipulation condition occurred during week 2 or 3 in the intervention arm, a small amount of test improvement was due to acclimation. However, spinal manipulation has been shown to improve force output transiently²⁴; and that may have also contributed to the improvements observed.

The spinal manipulation group was found to have the greatest improvement in hip motion, similar to the work by Sandell et al,⁹ except they measured hip extension in runners. In another study, Costa et al¹⁴ found that, following spinal manipulation, golfers were able to hit the ball farther. It is feasible that, in their study, spinal manipulation increased the body's ability

Fig 4. Sample female participant performing the sit-and-reach test (A), followed by the 0.5-km cycle ergometer sprint test against 4-kp resistance (B).

to stretch tissue, muscle, and/or ligament to recoil more in the localized region manipulated.¹⁴ The benefit of spinal manipulation at increasing flexibility and how that relates to sport performance warrant further review. Increased flexibility can be useful in some sports like gymnastics and diving.⁴⁸ Another issue to consider is if spinal manipulation can reduce muscle force transiently if it is increasing muscle flexibility. Several studies have shown that stretching before resistance training can reduce strength transiently.^{49–53}

Limitations and Future Studies

This study is only analyzing the impact lumbar spine manipulation may have had on cyclist sprint performance and hip flexibility. These results would not necessarily apply to resistance training, plyometrics, aerobic endurance exercise, agility, fartleks, or other modes of exercise training.

Researchers did not recruit a set number of participants based on a power analysis because of this

intentionally being a pilot study. Following a post hoc power analysis using G*Power version 3.1.3 (Universität Kiel, Kiel, Germany),^{54,55} researchers determined that study power was 0.3528. This analysis was in accordance with a desired effect size of 0.5, α of .05, 2 tails, and 12 participants per group condition compared in the main arm of our study. In consideration of this analysis, the current study was underpowered and the possibility of type II error exists. Ideally, to have a power of 0.80, researchers would need 34 participants per group with a 2-tailed analysis. Despite this, it is normal in exercise science research to engage in underpowered studies involving 10 to 20 participants per compared study group to observe data trends.^{56–60}

The findings of this study cannot be extrapolated to participants with low back pain. It is reasonable to suggest that cyclists with low back pain, who did receive manipulation, would have reacted differently than asymptomatic participants in this study.

Researchers did not use any form of blood/urine test to corroborate that participants did not have excessive amounts of caffeine or its metabolites in their system during any of the given exercise test sessions. Despite this, participants were repeatedly reminded to avoid caffeine 6 hours before testing; but it is conceivable that some participants may have accidentally ingested caffeine before one of their test sessions, and that could have confounded study findings.^{61–65}

The timing and nutritional content of meals were not regulated in this study. The diet of the participants may have changed throughout the study and impacted their performance. Ideally, future studies should have participants test in the morning after an overnight fast to make testing as similar as possible between sessions.

The intention of this study was not to focally impact one vertebra (L3) but to impact multiple vertebrae above and below the midlumbar region manipulated. Manipulation studies demonstrate that manual spinal manipulation impacts multiple nerve root levels.^{44,45} However, the regional location of spinal manipulation chosen for this study to improve lower limb performance may not have been optimal. It is unclear if manipulating other regions of the spine would have a more positive impact on exercise performance.

Directions for future studies would be to evaluate how spinal manipulation impacts athlete performance for patients with neck and/or low back pain. To harvest a reasonable sample size for comparison, this may require a broader inclusion of participants. For example, if sports chiropractic researchers limit inclusion for an experiment to football quarterbacks with neck pain, their sample size will likely be very

Fig 5. Sample female participant receiving acupuncture (A-C) and lumbar spine manipulation (B) on different test weeks.

Table 2 Changes Noted for Hip Flexibility and Cycle Sprint Test

12 Participants	Baseline	Sham Acupuncture	Manipulation	<i>P</i> Value
0.5-km sprint time (s)	51.9 ± 14.8	49.9 ± 13.9	49.1 ± 13.0	.877
RPE (Borg 6-20 scale)	16.7 ± 1.6	17.0 ± 1.3	16.8 ± 1.9	.875
Max HR (beats per min)	172.4 ± 11.6	173.7 ± 11.5	174.0 ± 13.0	.944
Sit-and-reach (cm)	30.4 ± 6.7	31.4 ± 6.9	32.0 ± 7.1	.765
8 Participants	Control Test #1	Control Test #2	Control Test #3	<i>P</i> Value
0.5-km sprint time (s)	70.4 ± 23.8	68.1 ± 21.5	67.9 ± 19.8	.540
RPE (Borg 6-20 scale)	15.6 ± 1.9	16.5 ± 3.5	16.1 ± 3.3	.576
Max HR (beats per min)	174.8 ± 9.4	178.6 ± 8.9	173.3 ± 20.0	.526
Sit-and-reach (cm)	36.8 ± 5.7	37.0 ± 5.2	37.1 ± 4.7	.802

Control tests #1 to #3 represent each of the 3 consecutive rounds of testing as shown in Fig 1 for the control arm (control #2). Data listed as mean ± SD. Between-groups data (baseline, sham acupuncture, manipulation) were analyzed with an ANOVA. Within-groups data (control tests #1-#3) were analyzed with a repeated-measures ANOVA.

HR, heart rate; RPE, rating of perceived exertion.

small. If they broaden their inclusion criteria to include multiple types of throwing athletes with neck pain and develop set criteria to track sport-specific performance, then that will help enhance sample size. Lastly, future research is also warranted on how acupuncture may impact sports performance using experienced licensed acupuncturists.

Conclusions

The findings of this preliminary study showed that midlumbar spinal manipulation did not improve hip flexibility or cyclist power output of asymptomatic

participants compared with an acupuncture sham and no-treatment control groups.

Funding Sources and Conflicts Of Interest

This study was supported by a grant from NCMIC. No conflicts of interest were reported for this study.

References

1. NCCAM. Complementary, alternative, or integrative health: what's in a name? [Internet] Bethesda (MD): US Department of Health & Human Services; 2014 [[cited 2014 Aug 1]. Available from: nccam.nih.gov/health/whatisacam].

2. Ahmedov S. Ergogenic effect of acupuncture in sport and exercise: a brief review. *J Strength Cond Res* 2010;24:1421–7.
3. Lin Z, Lan L, Hübscher L, et al. Effects of acupuncture stimulation of recovery ability of male elite basketball athletes. *Am J Chin Med* 2009;37:471–81.
4. Julian C, Hoskins W, Vitiello A. Sports chiropractic management at the World Ice Hockey Championships. *Chiropr Osteopat* 2010;18:32.
5. Pollard H, Hoskins W, McHardy A, et al. Australian chiropractic sports medicine: half way there or living on a prayer? *Chiropr Osteopat* 2007;15:14.
6. Uchacz G. 2010 Olympic winter games, chiropractic: the making of history. *J Can Chiropr Assoc* 2010;54:14–6.
7. Kazemi M, Shearer H. Chiropractic utilization in taekwondo athletes. *J Can Chiropr Assoc* 2008;52:96–102.
8. Konczak C. Chiropractic utilization in BMX athletes at the UCI World Championships: a retrospective study. *J Can Chiropr Assoc* 2010;54:250–6.
9. Sandell J, Palmgren P, Björndahl L. Effect of chiropractic treatment on hip extension ability and running velocity among young male running athletes. *J Chiropr Med* 2008;7:39–47.
10. Ward J, Ramcharan M, Coats J, Chu C, Zuniga J. Lumbar spine manipulation impact on running performance. *J Am Chiropr Assoc* 2013;21–34.
11. Ward J, Coats J, Ramcharan M, Humphries K, Tong T, Chu C. Thoracolumbar spinal manipulation impact on exercise performance. *J Chiropr Med* 2012;11:233–41.
12. Humphries K, Ward J, Coats J, Norbert J, Amonette W, Dyess S. Lower cervical spine manipulation impact on handgrip strength and free-throw accuracy of asymptomatic recreational basketball players: a pilot study. *J Chiropr Med* 2013;12:153–9.
13. Brolinson P, Smolka M, Rogers M, et al. Pre-competition manipulative treatment and performance among Virginia Tech athletes during 2 consecutive football seasons: a preliminary, retrospective report. *J Am Osteopath Assoc* 2012;112:607–15.
14. Costa S, Chibana Y, Giavarotti L, et al. Effect of spinal manipulative therapy with stretching compared with stretching alone on full-swing performance of golf players: a randomized pilot trial. *J Chiropr Med* 2009;8:165–70.
15. Waters K, Boone W. The relationship of spinal misalignment elements to muscle imbalance in dance performance. *J Chiropr Res Clin Investig* 1988;1:49–58.
16. Schwartzbauer J, Kolber J, Schwartzbauer H, Zhang J. Athletic performance and physiological measures in baseball players following upper-cervical chiropractic care: a pilot study. *J Vertebral Subluxation Res* 1997;1:33–9.
17. Grimston S, Engsberg J, Shaw L, Vetanze N. Muscular rehabilitation prescribed in coordination with prior chiropractic therapy as a treatment for sacroiliac subluxation in female distance runners. *Chiropr Sports Med* 1990;4:2–8.
18. Shrier I, Macdonald D, Uchacz G. A pilot study on the effects of pre-event manipulation on jump height and running velocity. *Br J Sports Med* 2006;40:947–9.
19. Lauro A, Mouch B. Chiropractic effects of athletic ability. *J Chiropr Res Clin Investig* 1991;6:84–7.
20. Botelho M, Andrade B. Effect of cervical spine manipulative therapy on judo athletes' grip strength. *J Manipulative Physiol Ther* 2012;35:38–44.
21. Hillerman B, Gomes A, Korporeal C, Jackson D. A pilot study comparing the effects of spinal manipulative therapy on quadriceps muscle strength. *J Manipulative Physiol Ther* 2006;29:145–9.
22. Wang S, Meadows J. Immediate and carryover changes of C5-6 joint mobilization on shoulder external rotator muscle strength. *J Manipulative Physiol Ther* 2010;33:102–8.
23. Pikar J. Neurophysiological effects of spinal manipulation. *Spine* 2002;27:357–71.
24. Grindstaff T, Hertel J, Beazell J, Magrum E, Ingersoll C. Effects of lumbopelvic joint manipulation on quadriceps activation and strength in healthy individuals. *Man Ther* 2009;14:415–20.
25. Frago A, Ferreira A. Immediate effects of acupuncture on biceps brachii muscle function in healthy and post-stroke subjects. *Chin Med* 2012;7:7.
26. McDonough S, Liddle S, Hunter R, et al. Exercise and manual auricular acupuncture: a pilot assessor-blind randomised controlled trial. The acupuncture and personalized exercise programme Trial. *BMC Musculoskelet Disord* 2008;9:31.
27. Nascimento R, Hossri C, Berwanger O, Carvalho V. Acupuncture and exercise capacity: a case report. *Clinics* 2012;67:193–4.
28. Hübscher M, Vogt L, Ziebart T, Banzer W. Immediate effects of acupuncture on strength performance: a randomized, controlled crossover trial. *Eur J Appl Physiol* 2010;110:353–8.
29. Amir R, Ben-Sira D, Sagiv M. IGF-I and FGF-2 responses to Wingate anaerobic test in older men. *J Sports Sci Med* 2007;6:227–32.
30. Driss T, Vandewalle H. The measurement of maximal (anaerobic) power output on a cycle ergometer: a critical review. *BioMed Res Int* 2013 [Article ID 589361].
31. Franco B, Signorelli G, Trajano G, Costa P, Oliveira C. Acute effects of three different stretching protocols on the Wingate test performance. *J Sports Sci Med* 2012;11:1–7.
32. Ozkaya O. Familiarization effects of an elliptical all-out test and the Wingate test based on mechanical power indices. *J Sports Sci Med* 2013;12:521–5.
33. Souissi H, Chtourou H, Chaouachi A, Chamari K, Souissi N, Amri M. Time-of-day effects on EMG parameters during the Wingate test in boys. *J Sports Sci Med* 2012;11:380–6.
34. Katch V, Weltman A, Traeger L. All out versus a steady paced cycling strategy for maximal work output of short duration. *Res Q Am Assoc Health, Phys Ed Recr* 1976;47:164–8.
35. Katch V, Weltman A, Martin R, Gray L. Optimal test characteristics for maximal anaerobic work on the bicycle ergometer. *Res Q* 1977;48:319–27.
36. Altug Z, Altug T, Altug A. A test selection guide for assessing and evaluating athletes. *Natl Str Cond Assoc J* 1987;9:62–6.
37. Gotshalk L. Discipline and strictness in testing and training. *Natl Strength Cond Assoc J* 1985;7:72–3.
38. Kraemer W, Fleck S. Anaerobic metabolism and its evaluation. *Natl Strength Cond Assoc J* 1982;4:20–2.
39. Tesch P. Bridging the gap: anaerobic testing. *Natl Strength Cond Assoc J* 1984;6:44–67.
40. Katch V, McArdle W, Katch F. Essentials of exercise physiology. 4th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2007:255.
41. McArdle W, Katch F, Katch V. Exercise physiology. 6th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2007:217–20.
42. Mills E, Chan A, Wu P, Vail A, Guyatt G, Altman D. Design, analysis, and presentation of crossover trials. *Trials* 2009;10:27.

43. Thomas S, Reading J, Shephard R. Revision of the physical activity readiness questionnaire (PAR-Q). *Can J Sport Sci* 1992;17:338–45.
44. Herzog W. The biomechanics of spinal manipulation. *J Bodyw Mov Ther* 2010;14:280–6.
45. Pickar J. Neurophysiological effects of spinal manipulation. *Spine J* 2002;2:357–71.
46. Bergman T, Peterson D. *Chiropractic techniques: principles and procedures*. 3rd ed. St. Louis: Elsevier-Mosby; 2011:258–61.
47. Field A. *Discovering statistics using SPSS*. 2nd ed. Thousand Oaks: Sage; 2005:296–303 [309–60,428–82].
48. Gremion G. Is stretching for sports performance still useful? A review of the literature. *Rev Med Suisse* 2005;27:1830–4.
49. Behm D, Bambury A, Cahill F, Power K. Effect of acute static stretching on force, balance, reaction time, and movement time. *Med Sci Sports Exerc* 2004;36:1397–402.
50. Evetovich T, Nauman N, Conley D, Todd J. Effect of static stretching of the biceps brachii on torque, electromyography, and mechanomyography during concentric isokinetic muscle actions. *J Strength Cond Res* 2003;17:484–8.
51. Kokkonen J, Nelson A, Cornwell A. Acute muscle stretching inhibits maximal strength performance. *Res Q Exerc Sport* 1998;69:411–5.
52. Cramer J, Housh T, Coburn J, Beck T, Johnson G. Acute effects of static stretching on maximal eccentric torque production in women. *J Strength Cond Res* 2006;20:354–8.
53. Power K, Behm D, Cahill F, Carroll M, Young W. An acute bout of static stretching: effects on force and jumping performance. *Med Sci Sports Exerc* 2004;36:1389–96.
54. Faul F, Erdfelder E, Buchner A, Lang A. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behav Res Methods* 2009;41:1149–60.
55. Faul F, Erdfelder E, Lang A, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* 2007;39:175–91.
56. Crecelius A, Kirby B, Voyles W, Dinunno F. Augmented skeletal muscle hyperaemia during hypoxic exercise in humans is blunted by combined inhibition of nitric oxide and vasodilating prostaglandins. *J Physiol* 2011;589:3671–83.
57. Froyd C, Millet G, Noakes T. The development of peripheral fatigue and short-term recovery during self-paced high-intensity exercise. *J Physiol* 2013;591:1339–46.
58. Gavin T, Ruster R, Carrithers J, et al. No difference in the skeletal muscle angiogenic response to aerobic exercise training between young and aged. *J Physiol* 2007;585:231–9.
59. Kim E, Gregg L, Kim D, Sherk V, Bembien M, Bembien D. Hormone responses to an acute bout of low intensity blood flow restricted resistance exercise in college-aged females. *J Sports Sci Med* 2014;13:91–6.
60. Paschalis V, Theodorou A, Panayiotou G, et al. Stair descending exercise using a novel automatic escalator: effects on muscle performance and health-related parameters. *PLoS One* 2013;8:e56218.
61. Silva-Cavalcante M, Correia-Oliveira C, Santos R, et al. Caffeine increases anaerobic work and restores cycling performance following a protocol designed to lower endogenous carbohydrate availability. *PLoS One* 2013;8:e72025.
62. Simmonds M, Minahan C, Sabapathy S. Caffeine improves supramaximal cycling but not the rate of anaerobic energy release. *Eur J Appl Physiol* 2010;109:287–95.
63. Bridge C, Jones M. The effect of caffeine ingestion on 8 km run performance in a field setting. *J Sports Sci* 2006;24:433–9.
64. Doherty M, Smith P. Effects of caffeine ingestion on rating of perceived exertion during and after exercise: a meta-analysis. *Scand J Med Sci Sports* 2005;15:69–78.
65. Bazzucchi I, Felici F, Montini M, Figura F, Sacchetti M. Caffeine improves neuromuscular function during maximal dynamic exercise. *Muscle Nerve* 2011;43:839–44.