[Athletic Training]

Influence of Stride Frequency and Length on Running Mechanics: A Systematic Review

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Context: A high number of recreational runners sustain a running-related injury each year. To reduce injury risk, alterations in running form have been suggested. One simple strategy for running stride frequency or length has been commonly advocated.

Objective: To characterize how running mechanics change when stride frequency and length are manipulated.

Data Sources: In January 2012, a comprehensive search of PubMed, CINAHL Plus, SPORTDiscus, PEDro, and Cochrane was performed independently by 2 reviewers. A second search of the databases was repeated in June 2012 to ensure that no additional studies met the criteria after the initial search.

Study Selection: Inclusion criteria for studies were an independent variable including manipulation of stride frequency or length at a constant speed with outcome measures of running kinematics or kinetics.

Study Design: Systematic review.

Level of Evidence: Level 3.

Data Extraction: Two reviewers independently appraised each article using a modified version of the Quality Index, designed for assessing bias of nonrandomized studies.

Results: Ten studies met the criteria for this review. There was consistent evidence that increased stride rate resulted in decreased center of mass vertical excursion, ground reaction force, shock attenuation, and energy absorbed at the hip, knee, and ankle joints. All but 1 study had a limited number of participants, with several methodological differences existing among studies (eg, overground and treadmill running, duration of test conditions). Although speed was held constant during testing, it was individually self-selected or fixed. Most studies used only male participants.

Conclusion: Despite procedural differences among studies, an increased stride rate (reduced stride length) appears to reduce the magnitude of several key biomechanical factors associated with running injuries.

Keywords: systematic review; stride rate; cadence; step length

Running is a popular activity because of its accessibility, minimal equipment, and health benefits. Over 28 million people in the United States run weekly.[14] Approximately 56% of recreational runners and as many as 90% of those training for a marathon sustain a running-related injury each year.[20] With such a large number of people running and a high incidence of injury, there is a need to provide adequate care for the running population.

There are many intrinsic and extrinsic risk factors for running-related injuries, including age, sex, running volume, and hill or speed training.[18,19,21] Lower extremity running kinematics play a role in overuse injuries, such as patellofemoral pain. Studies have examined rearfoot eversion, knee valgus, hip adduction, and tibial internal rotation with inconclusive results.[4,21] More recently, running cadence and foot strike patterns have been measured with the popularity of minimalist running, warranting further analysis of cadence and running efficiency. Running injuries may be associated with the magnitude and rate of impact force loading during the stance phase.[12] Running velocity and stride length can influence impact shock.[3] Changes to running form (stride frequency or length) at a fixed speed can alter electromyography and kinetics.[1]

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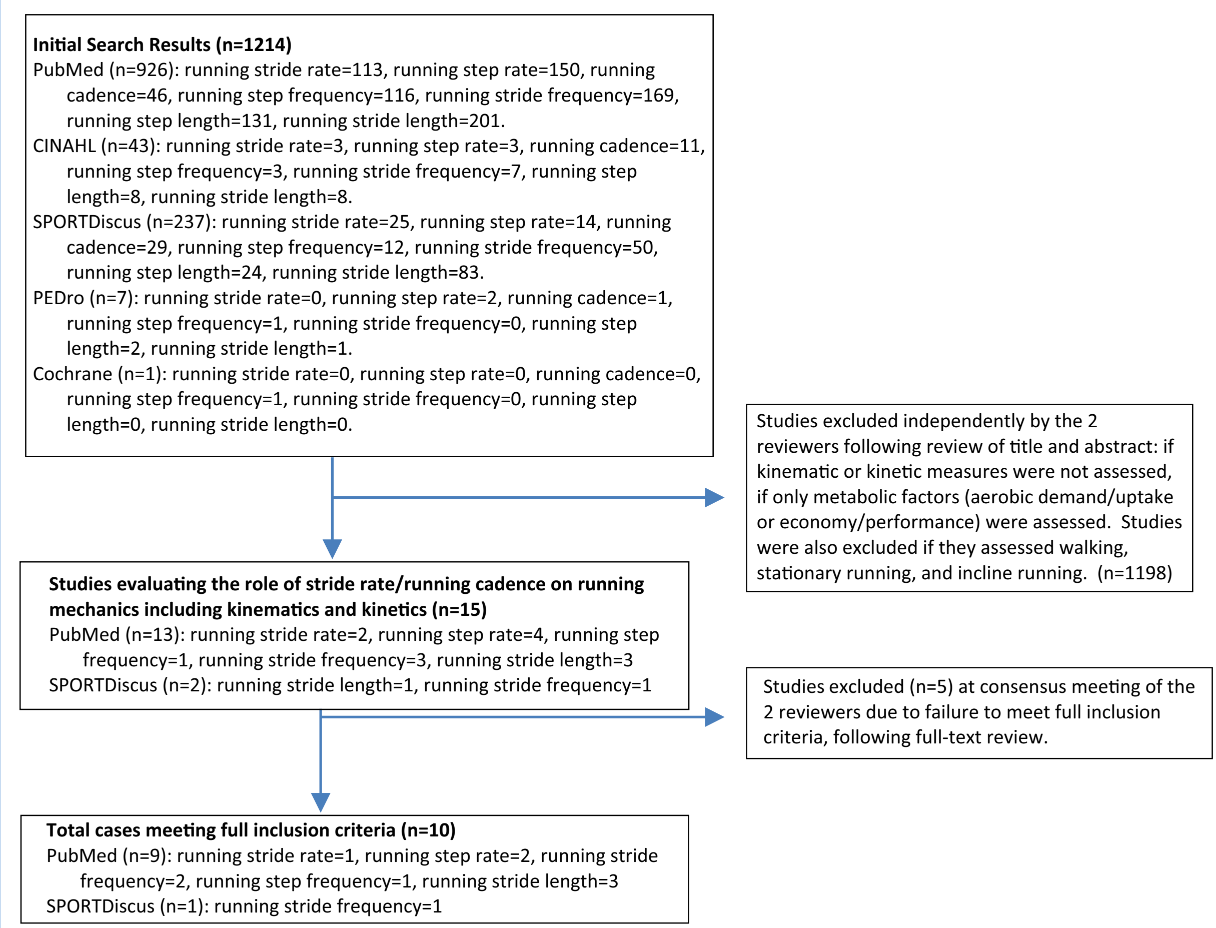

Figure 1. Summary of search and selection process.

This review is a comprehensive summary of the kinematic and kinetic effects that stride frequency and length can have on running.

METHODS

Data Sources

In January 2012, a Cochrane database search was completed, and no systematic reviews regarding the effects of stride frequency and length on running mechanics were found. A search was then conducted in PubMed, CINAHL Plus, SPORTDiscus, PEDro, and Cochrane databases up to January 2012 using the following keywords: *running stride rate, running step rate, running cadence, running step frequency, running stride frequency, running step length*, and *running stride length*. "Step rate" refers to the total number of running steps per minute, with "step frequency," "stride rate," and "stride frequency" commonly used to reflect the same or similar measure. The search was restricted to articles in English; abstracts, meeting proceedings, dissertations, and theses were excluded. A second search of the databases was performed in June 2012 to ensure that no additional studies met the criteria after the initial search.

Study Selection

Studies were included if they involved healthy individuals who were able to run with no lower extremity pain. Both sexes and all ages were included. Also, studies needed to have a repeated-measures design that altered running stride frequency or length at a constant speed across all conditions. The dependent variables needed to include kinematic or kinetic data during running, such as ground reaction forces (GRFs), shock attenuation, joint angles, joint moments, or powers. Studies that focused solely on metabolic factors, such as aerobic demand and oxygen uptake or running economy, were excluded, as well as those that assessed walking, stationary running, or incline running.

Two authors (AGS and JMK) independently screened titles and abstracts of the studies retrieved. If no abstract was available or uncertainty existed, full-text articles were retrieved. Reference lists of included articles were checked for additional studies. A summary of the search strategy and selection results is provided in Figure 1.

A consensus meeting was held to resolve differences in inclusion, with the third author (BCH) making the final determination. No disagreements occurred that required mediation by the third author. The full text of the 12 selected articles was reviewed, with 2 studies being excluded based on predetermined criteria. The 2 independent reviewers fully agreed on the articles included in the systematic review.

Quality Assessment

Quality was assessed independently by both reviewers using the Quality Index developed by Downs and Black.[5] The original scale was reported to have good test-retest (r = 0.88) and interrater (r = 0.75) reliability and high internal consistency (KR-20 = 0.89). The only items shown to have poor reliability were those pertaining to external validity (items 11 and 12); however, we opted to include those items since the subject criteria involved only healthy individuals, which minimizes external validity concerns with a clinical population. Disagreements between the 2 reviewers were resolved by further discussion and agreement.

RESULTS

Studies were included only if the dependent variables included kinematic or kinetic data during running, such as GRFs, shock attenuation, joint angles, joint moments, or powers. Ten studies met the inclusion/exclusion criteria (Table 1). Four studies assessed running kinematics using 2- or 3-dimensional video motion capture systems.[2,9,15,16] Seven articles addressed GRF and kinetics.[3,7,9,10,13,15,16] Four studies analyzed acceleration and impact attenuation,[3,8,10,12] and 2 studies assessed leg stiffness.[7,13]

Stride frequency was manipulated in 6 articles,[2,7-10,13] while stride length was manipulated in 4.[3,12,15,16] Most changes in stride frequency and length were based on a specific percentage, which ranged from ±5% to ±36%. One study manipulated stride length by 1 length of the runner's foot.[16] Stride frequency was controlled with use of a metronome for auditory cueing in 7 articles[2,7-10,12,13]; stride length was controlled with markers on a runway in the other 3.[3,15,16] Speed was held constant in all 10 studies, making manipulation of stride frequency or length yield an inverse change in stride length or frequency, respectively.

Quality Assessment

The reported scores were those reached by consensus, with the reliability coefficients reflective of each reviewer's original score (Table 2). The percentage agreement between the 2 independent reviewers was 50%. All but 2 of the 14 items had 90% or 100% agreement. Disagreements in these 2 items were based on whether the study indicated that the participants were men or women and, based on that, whether the participants were considered representative of the entire population.

DISCUSSION

During running, there are no periods of double-limb support and, instead, periods when both feet are off the ground simultaneously (flight phase), meaning that there is never an overlap between the stance phases of the right and left legs. For a single lower extremity, initial contact in the gait cycle begins the period of loading response, which is then followed by midstance, terminal stance, and preswing during running. Loading response is most commonly understood as the time when weight is accepted onto the lower extremity. Midstance is the point where the body's weight passes directly over the supporting leg. The swing phase then consists of the periods initial swing, midswing, and terminal swing. Running injuries may be associated with the magnitude and rate of impact force loading during the stance phase of running.[12] Stride length and, thereby, rate can influence impact shock.[3]

Kinematics

The knee was the most affected by manipulation of step frequency. A significantly more flexed knee at initial contact, as well as less peak knee flexion during stance, was noted when step rate was increased.[9] Changes at the ankle joint were observed, with the ankle demonstrating a more plantar flexed position at initial contact with increased stride rate.[2,9] Kinematic changes at the hip included significantly less hip peak flexion and adduction during loading response when the step rate increased.[9]

Other findings include a significant inverse relationship between step rate (omit "and step length") and horizontal distance between center of mass and heel at initial contact.

GRF and Joint Kinetics

GRFs were measured using force platforms mounted on the ground or in combination with a treadmill. A significant inverse relationship was noted with reduced peak vertical GRF when stride rate was increased.[9,13] Table 1 presents additional results involving peak impact force, axial reaction force, and breaking impulse (the posteriorly directed component of the GRF vector from initial contact to midstance).

Significant changes in vertical displacement of the body's center of mass were noted. A significant inverse relationship between step rate and center of mass vertical excursion was found; as step rate increased, the runner's center of mass excursion was reduced.[9]

Hip and knee extension moments increased significantly at touchdown and during impact as stride length increased.[15] A significantly increased maximum angular velocity difference was reported at the knee and rearfoot between the overstride condition and the normal and understride conditions.[2]

Table 1. Description of selected studies

Intervention	Outcomes	Results
Hobara et al[10]: 10 healthy moderately active men (28.8 ± 3 y)		
PSF, ±15%, ±30% at constant speed (2.5 m/s) on treadmill	Ground reaction impact force (and thereby VIP, VILR, and VALR)	Differences in VIP ($P < 0.01$), VILR ($P < 0.05$), and VALR ($P < 0.05$) among conditions, with decreases noted as step rate increased
Clarke et al[2]: 10 healthy runners (25-135 km/wk)		
PSF, ±5%, ± 10% at constant speed (3.8 m/s) on treadmill	Peak shank deceleration and 2-dimensional sagittal kinematics	Decreased peak shank deceleration as stride rate increased; differences between all conditions except –5% and preferred ($P < 0.05$) Knee and ankle joint angles at touchdown were similar across conditions Decrease in vertical velocity of the foot ($P < 0.05$) as stride rate increased from –10% compared with preferred, +5%, and +10% and –5 compared with preferred, +5, and +10%
Derrick et al[3]: 10 healthy male university students		
PSL, ±10%, ±20% at constant speed (3.8 m/s) over ground	Head and leg accelerations, impact attenuation, joint powers	Leg and head accelerations increased as stride length increased ($P < 0.05$) Impact attenuation was greater in +20% PSL compared with –20% PSL Progressive increase in mechanical energy absorbed during impact phase in all 3 lower extremity joints with stride length; significance (alpha = 0.05) noted at the hip at –10% and –20% conditions
Heiderscheit et al[9]: 45 healthy recreational runners (25 men), ran minimum of 24.1 km/wk for ≥3 mo		
PSF, ±5%, ±10% at constant speed (preferred) on treadmill	Step length, stance duration, vertical excursion of center of mass, foot inclination angle at initial contact, horizontal distance between center of mass and heel at initial contact, ground reaction force, 3-dimensional kinematics, and kinetics of the hip and knee	Step length, center of mass vertical excursion, braking impulse, and peak knee flexion angle decreased with increased step rate ($P < 0.01$) Less mechanical energy was absorbed at the knee during +5% and +10% conditions and the hip during +10%; hip, knee, and ankle absorbed significantly more energy at –10% ($P < 0.01$) Peak hip adduction angle and peak hip adduction and internal rotation moments decreased at +10% ($P < 0.01$)
Seay et al[15]: 10 healthy physically active adults (22-32 y)		
PSL, ±20% at constant speed (3.8 m/s) over ground	Kinematics and kinetics of the lumbosacral (L5-S1) and thoracolumbar (T12-L1) regions	As stride length increased, L5-S1 and T12-L1 vertical reaction forces at touchdown and during impact increased ($P < 0.00$), as well as peak sagittal L5-S1 moment during impact ($P = 0.02$)

(continued)

Table 1. (continued)

Intervention	Outcomes	Results
Stergiou et al[16]: 6 healthy male recreational runners, ran minimum of 16.1 km/wk for at least 1 y		
PSL ± length of runner's foot	Ground reaction impact force, kinematic data of rearfoot and knee	Ground reaction impact force was greater in the elongated stride condition ($P = 0.00$) Rearfoot and knee angular velocities were altered with increased stride length due in part to the appearance of a bimodal curve (2 distinct minimums and a well-defined maximum) for the rearfoot
Hamill et al[8]: 10 healthy, physically active college-aged men		
PSF, ±10%, ±20% at constant speed (preferred) on treadmill	Head and tibial acceleration	Decreased power of leg acceleration at impact and active peak between −20% and +20% ($P < 0.05$) Shift to higher frequency at impact and active peak between −20% and +20% ($P < 0.05$) Head accelerations were maintained at a constant level across all conditions
Mercer et al[12]: 10 healthy male recreational runners		
PSL, ±15% with PSF maintained on treadmill at varying speed PSF, ±15% with PSL maintained on treadmill at varying speed +10% PSL/−10% PSF and −10% PSL/+10% PSF at constant speed (3.8 m/s) on treadmill	Shock attenuation	Shock attenuation decreased as stride length decreased with stride frequency held constant ($P < 0.05$) No change in shock attenuation with stride frequency manipulated and stride length held constant; shock attenuation significantly greater during +10% PSL/−10% PSF compared with −10% PSL/+10% PSF condition at constant speed ($P < 0.05$)
Morin et al[13]: 10 healthy physically active men		
PSF, ±10%, ±20%, ±30% at constant speed (3.3 m/s) on treadmill	Contact time, vertical ground reaction force, center of mass vertical displacement, and leg stiffness	Contact time decreased and leg stiffness increased from preferred to +20% and +30% ($P < 0.05$) Peak vertical force decreased from −30% to preferred ($P < 0.05$) Center of mass vertical displacement decreased with increased step frequency ($P < 0.05$)
Farley and Gonzalez[7]: 4 healthy men (21-29 y) experienced with treadmill running		
PSF, −26%, −18%, −11%, −5%, +17%, +25%, +30%, +36% at constant speed (2.5 m/s) on treadmill	Contact time, vertical ground reaction force, leg spring stiffness, vertical stiffness	Between the lowest and highest possible stride frequencies: the stiffness of the leg spring more than doubled ($P < 0.01$), vertical stiffness of the spring-mass system increased by 3.5-fold, vertical displacement of the center of mass during ground contact phase reduced more than 50%, and contact time decreased ~30% ($P < 0.01$)

PSF, preferred stride frequency; PSL, preferred stride length; VIP, vertical impact peak; VILR, vertical instantaneous loading rate; VALR, vertical average loading rate.

Table 2. Modified Downs and Black[5] quality index results, interrater reliability for each item, and total score[a]

	1	2	3	4	6	10	11	12	16	17	18	20	22	25	Total
Clarke et al[2]	1	1	1	1	1	1	0	0	1	1	1	1	1	1	12
Derrick et al[3]	1	1	1	1	1	1	0	0	1	1	1	1	1	1	12
Farley and Gonzalez[7]	1	1	0	1	1	0	0	0	1	1	0	1	1	1	9
Hamill et al[8]	1	1	1	1	1	1	0	0	1	1	1	1	1	1	12
Heiderscheit et al[9]	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
Hobara et al[10]	1	1	1	1	0	1	0	0	1	1	1	1	1	1	11
Mercer et al[12]	1	1	1	1	1	1	0	0	1	1	1	1	1	1	12
Morin et al[13]	1	1	1	1	1	1	0	0	1	1	1	1	1	1	12
Seay et al[15]	1	1	0	1	1	1	0	0	1	1	1	1	1	1	11
Stergiou et al[16]	1	1	1	1	1	1	0	0	1	1	1	1	1	1	12
Reliability	1.00	1.00	0.00	1.00	0.00	1.00	0.62	0.09	1.00	1.00	0.62	1.00	1.00	1.00	0.53
Agreement, %	100	100	60	100	90	100	90	40	100	100	90	100	100	100	50

1, clear aim/hypothesis; 2, outcome measures clearly described; 3, patient characteristics clearly described; 4, interventions clearly described; 6, main findings clearly described; 10, actual probability values reported; 11, participants asked to participate representative of entire population; 12, participants prepared to participate representative of entire population; 16, analysis completed was planned; 17, time between intervention and outcome is the same; 18, appropriate statistics; 20, valid and reliable outcome measures; 22, participants recruited over same period; 25, adjustment made for confounding variables.

[a]All studies are prospective. 0, no; 1, yes.

Segment Accelerations and Shock Attenuation

With regard to acceleration, the body functions in a way that maintains head acceleration regardless of the stride rate condition.[3,8] Mean peak tibial acceleration showed a significant linear trend as stride length increased ($P < 0.05$), indicating that peak tibial acceleration increased as stride length increased.[3] Similarly, impact attenuation (shock absorption at impact) increased as stride length increased.[3]

Leg Stiffness

The musculoskeletal system alters the mechanical behavior of its spring system when step frequency is manipulated during running. The effect of ground contact time specifically appears to be a strong and direct determinant of leg stiffness.[13] Decreasing ground contact time yielded a significant ($P < 0.05$) increase in leg stiffness; conversely, increasing ground contact time significantly ($P < 0.05$) decreased leg stiffness.[13] Increased step frequency results in decreased ($P < 0.05$) ground contact time, vertical displacement of center of mass, and leg length variation (compression).[13]

Limitations

Limitations, although present, did not inhibit the ability to assess the comparative analysis among the studies. The number of participants was limited in the studies by Farley and Gonzalez[7] (n = 4) and Stergiou et al[16] (n = 6). All other articles had 10 participants, with the exception of Heiderscheit et al,[9] who had 45.

How "runners" were defined differed among the articles. Many of the study participants were described as "active," not necessarily indicating that their main sport was running. Other articles that specified the participants as "runners" did not specify average mileage per week of training or had varying mileage per week of training ranging from 16 to 135 km (roughly 10-84 miles) (Table 1).

Possible differences in running mechanics between ground and treadmill running should also be considered a limitation, and the articles included were nearly split in this regard. Although proper measures were taken to effectively ensure that running velocity was controlled, there may be opportunity for participants to modify running mechanics slightly if a true steady state was not reached. The short duration of the test condition could perhaps also affect the pattern observed during the studies.

Another potential limitation is the constant speed used. Some studies allowed runners to self-select speed and then calculated preferred stride frequency at that speed.[8,9] Other studies specifically chose a fixed speed and manipulated stride frequency based on preferred stride frequency at that speed.[2,3,7,10,12,13,15] The preselected speed in these studies may have altered the kinematics and kinetics, even at the preferred cadence, for runners in studies where it was not clearly stated what their prior volume, intensity, and speed of training was or whether they were experienced runners. One common concern was that runners had limited exposure running at the manipulated stride rates; therefore, it is unclear whether the kinematic and kinetic changes observed would change after extensive training with the altered cadence. Only immediate changes were reported.

Although limitations may include running surface and speed, these should not affect the validity of the findings, as there is still a comparison between the different step rate and length conditions. In addition, narrowing a search with more stringent inclusion criteria (eg, running surface or speed) would have further limited the number of articles included.

Changes in technology over time likely contributed to differences observed. Several studies employed a 2-dimensional analysis to assess running kinematics,[2,16] whereas more recent studies used a 3-dimensional approach.[9,15]

None of the articles included in this systematic review specifically addressed injury prevention or recovery. Outcome data involved biomechanical changes, including kinematic and kinetic data, in a healthy population. Therefore, the external validity of the findings remains unknown.

Clinical Relevance

A clinician may consider gait manipulation in a symptomatic patient who is having pain with running; pain may be used as an outcome measure to help determine whether the biomechanical changes are contributing to the patient's symptoms. If the runner is symptomatic, the response to a change in gait may be immediate and provide a basis to judge effectiveness. Auditory cueing with the use of a metronome was most commonly used for feedback. In the clinical setting, minimal time for motor change and carryover effect must be considered, as studies have not reassessed mechanics beyond the immediate timeframe. In addition to practice, motor learning is influenced by the type and timing of feedback provided, which should vary as a patient progresses through phases of motor learning (skill acquisition vs skill refinement vs skill retention).[6,11,17,22]

CONCLUSION

The findings suggest that increased stride rate (decreased stride length) affects impact peak, kinematics, and kinetics and therefore may be considered as a mechanism with which to influence injury risk and recovery of a runner. Specifically, similarities are seen across all studies, with decreased center of mass vertical excursion, GRF, impact shock and attenuation, and energy absorbed at the hip, knee, and ankle as step rate is increased or step length is decreased at a constant speed. Furthermore, some studies showed changes in axial reaction forces at the lumbar spine[15] and angular velocity differences between the knee and rearfoot.[16] The minimum change in step frequency required to observe biomechanical change was 10% in most cases[2,3,8,9,12,13]; however, changes were noted with as little as a 5% increase in step rate.[2,9]

REFERENCES

1. Chumanov ES, Wille CM, Michalski MP, Heiderscheit BC. Changes in muscle activation patterns when running step rate is increased. *Gait Posture*. 2012;36:231-235.
2. Clarke TE, Cooper LB, Hamill CL, Clark DE. The effect of varied stride rate upon shank deceleration in running. *J Sports Sci*. 1985;3:41-49.
3. Derrick TR, Hamill J, Caldwell GE. Energy absorption of impacts during running at various stride lengths. *Med Sci Sports Exerc*. 1998;30:128.
4. Dierks TA, Manal KT, Hamill J, Davis I. Lower extremity kinematics in runners with patellofemoral pain during a prolonged run. *Med Sci Sports Exerc*. 2011;43:693-700.
5. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health*. 1998;52:377-384.
6. Doyon J, Penhune V, Ungerleider LG. Distinct contribution of the cortico-striatal and cortico-cerebellar systems to motor skill learning. *Neuropsychologia*. 2003;41:252-262.
7. Farley CT, Gonzalez O. Leg stiffness and stride frequency in human running. *J Biomech*. 1996;29:181.
8. Hamill J, Derrick TR, Holt KG. Shock attenuation and stride frequency during running. *Hum Move Sci*. 1995;14:45-60.
9. Heiderscheit BC, Chumanov ES, Michalski MP, Wille CM, Ryan MB. Effects of step rate manipulation on joint mechanics during running. *Med Sci Sports Exerc*. 2011;43:296-302.
10. Hobara H, Sato T, Sakaguchi M, Sato T, Nakazawa K. Step frequency and lower extremity loading during running. *Int J Sports Med*. 2012;33:310-313.
11. Korman M, Raz N, Flash T, Karni A. Multiple shifts in the representation of a motor sequence during the acquisition of skilled performance. *Proc Natl Acad Sci U S A*. 2003;100:12492-12497.
12. Mercer JA, Devita P, Derrick TR, Bates BT. Individual effects of stride length and frequency on shock attenuation during running. *Med Sci Sports Exerc*. 2003;35:307.
13. Morin JB, Samozino P, Zameziati K, Belli A. Effects of altered stride frequency and contact time on leg-spring behavior in human running. *J Biomech*. 2007;40:3341-3348.
14. Running USA. 2012 State of the Sport Part II: Running Industry Report. 2012. http://www.runningusa.org/2012-state-of-sport-part-2?returnTo=annual-reports. Updated July 15, 2012, Accessed November 30, 2012.
15. Seay J, Selbie WS, Hamill J. In vivo lumbo-sacral forces and moments during constant speed running at different stride lengths. *J Sports Sci*. 2008;26:1519-1529.
16. Stergiou N, Bates BT, Kurz MJ. Subtalar and knee joint interaction during running at various stride lengths. *J Sports Med Phys Fitness*. 2003;43:319.
17. Swinnen SP, Schmidt RA, Nicholson DE, Shapiro DC. Information feedback for skill acquisition: instantaneous knowledge of results degrades learning. *J Exp Psychol Learn Mem Cogn*. 1990;16:706-716.
18. Taunton JE, Ryan MB, Clement DB, McKenzie DC, Lloyd-Smith DR, Zumbo BD. A prospective study of running injuries: the Vancouver Sun Run “In Training” clinics. *Br J Sports Med*. 2003;37:239-244.
19. Taunton JE, Ryan MB, Clement DB, McKenzie DC, Lloyd-Smith DR, Zumbo BD. A retrospective case-control analysis of 2002 running injuries. *Br J Sports Med*. 2002;36(2):95-101.
20. van Gent RN, Siem D, van Middelkoop M, van Os AG, Bierma-Zeinstra SM, Koes BW. Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review. *Br J Sports Med*. 2007;41:469-480.
21. Wen DY. Risk factors for overuse injuries in runners. *Curr Sports Med Rep*. 2007;6:307-313.
22. Winstein CJ. Knowledge of results and motor learning: implications for physical therapy. *Phys Ther*. 1991;71:140-149.