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The stability of step rate throughout a 3200 meter run

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ABSTRACT

Step rate has been studied in controlled laboratory settings due to its association with biomechanical parameters related to running injuries. However, the stability of step rate in a run over ground when speed is not controlled remains unclear. In this observational cohort study, 30 subjects were asked to run 3200 meters (m) over ground at their self-selected pace during an Army Physical Fitness Test. Stationary cameras were placed along the paved course to capture step rate at 800 m, 1200 m, 1800 m, and 2200 m. For analysis of step rate at four different time points, a repeated measures analysis of variance (ANOVA) with a Bonferroni-Holm correction was utilized to determine statistical difference with a significance level set at $p < 0.05$ (95% confidence intervals). There was a statistically significant ($p = 0.04$) difference between step rate at two different time points; however, the mean group difference in step rate was approximately 1–2 steps per minute, which is not likely clinically meaningful. There was no difference in average weekly miles trained or performance time in those who demonstrated a change in step rate versus those who maintained a steady step rate. Clinicians and researchers may be able to expect step rate to be consistent from 800 m–2200 m during a 3200 m timed run regardless of the runner's training mileage or performance time. This may be valuable for observing over ground running characteristics when the full course of a run cannot be viewed as it could within a laboratory setting.

1. Introduction

Running is a primary method of endurance training in all four military branches (Air Force, Army, Marines, and Navy). In a recent survey of over 10,000 service members, running was reported to account for 45% of all exercise and sports related injuries [1]. Therefore, methods attempting to reduce the injury rates in service members must be considered to reduce health-care costs and time away from work. In observational studies, runners with a lower habitual step rate have been observed to be at an increased risk for lower extremity injuries [2,3]. Luedke et al. observed that runners with a step rate of 164 steps per minute (spm) or less were 6.67 times more likely (95% CI, 1.2–36.7) to experience a shin injury compared to runners with a step rate of greater than or equal to 174 spm [2]. Furthermore, Morgan et al. observed that recreational runners training for a half-marathon with a step rate less than 163 spm had an injury rate of 66.7% compared to a 22.2% injury rate in those with a step rate greater than 168 spm [3]. Therefore, observing step rate may be an important gait characteristic to consider when identifying individuals at risk for running related injuries.

Increasing preferred step rate by as little as 5–10% at a constant speed has been shown to reduce the biomechanical parameters associated with running related injuries [4–8]. With an increase in step rate at a constant speed, there is an associated decrease in step length [5,9–11] causing the foot to land closer to center of mass [12] with an increase in knee flexion [5] and ankle plantarflexion [5,6] at impact. Kinetic changes associated with an increase in step rate include reduced peak vertical ground reaction forces [5,8], vertical loading rates [8–10,12], and braking impulse [5,8]. Reductions in load to the knee and hip [4,5,11], peak plantar pressure [7,13], peak hip adduction angle [5,10,14], and hip internal rotation moments [5] have been reported with an increase in step rate. These associated biomechanical changes with increasing step rate may be helpful in the prevention and rehabilitation of running-related injuries. Furthermore, this suggests that step rate is an important metric to measure for laboratory and in-field gait analysis.

Reliable measure of step rate count is key for gait analysis or interventions targeting step rate manipulation. Step rate count can be achieved using high speed two-dimensional (2D) video analysis [15,16]. 2D video analysis is a practical and cost-effective technique that requires little time or experience to perform. Miller et al. validated a 10 second (s) method for step rate count when using cameras sampling at 30 Hertz (Hz) with excellent agreement compared to a 60 s

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method [16]. This method allows for feasibility in step rate count when observing runners over ground when the full course of the run cannot be viewed or when observing a large group of runners. With advances in personal electronics, phones and other handheld devices are capable of capturing video at 30 Hz or greater providing most clinicians and coaches with the ability to assess step rate. Furthermore, 2D video analysis is reliable for experienced and novice providers [15], allowing this technique to be used for clinicians or coaches without need for additional training.

To our knowledge, no study has observed the stability of video analysis step rate count with a run over ground when speed is not controlled. With treadmill running, step rate appears to be clinically stable throughout a run [17,18] and demonstrates good day to day reliability [19]. The objective of this observational cohort study was to determine if step rate would change at different time points throughout a 3200 m run over ground. Our hypothesis was that step rate would not change during the run.

Fig. 1. Set up of camera on the Army Physical Fitness Test route.

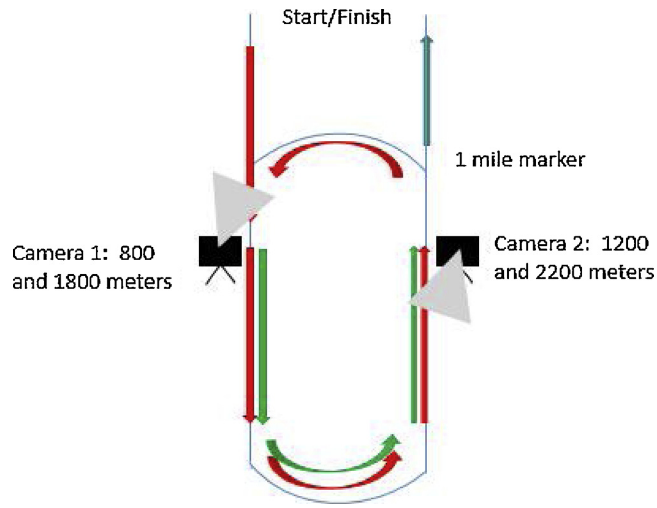

Fig. 2. Army Physical Fitness run route.
Camera 1 captured step rate at 800 and 1800 m, and Camera 2 captured step rate at 1200 and 2200 m. Lap 1 represented by red, Lap 2 represented by green. Cameras represented by black rectangles. Line of sight of camera represented by gray triangles. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Methods

2.1. Participants

Thirty Department of Defense (DoD) Beneficiaries (Active Duty Soldiers or Cadets) were recruited as subjects. Individuals were included in the study if they were between the ages of 18–50 years, ran on average 6 miles per week, and could read and speak English to provide consent and follow study instructions. Subjects were excluded if they were currently pregnant or had been pregnant within the past 6 months, had a lower extremity or lower back surgery within the previous 6 months, or were on a profile given by a healthcare provider to limit exercise due to lower extremity or low back injury. See Table 1 for subject eligibility requirements. Eligible subjects were asked to run over ground at their self-selected pace during an Army Physical Fitness Test timed 2 mile (3200 m) run.

2.2. Study protocol

This study is a secondary analysis of data collected from a Keller Army Community Hospital Institutional Review Board (KACH IRB) approved study. Subjects were recruited prior to the Army Physical Fitness Test (APFT) and written informed consent was obtained. Subjects completed an intake form reporting information such as gender, age, height, weight, self-reported average weekly mileage, and self-reported step rate count. Participants were asked to wear a numbered race bib (15.24 cm x 27.94 cm in size) on the front of their shirts prior to running the 3200 m run at their self-selected pace. Two stationary cameras (Casio Exilim EX-ZR200, Tokyo, Japan) sampling at 30 Hz with a resolution of 640 × 480 pixels and shutter speed of 1/1000s were placed along the running course to capture two-dimensional frontal plane video, see Fig. 1. Stationary cameras were mounted to Vivitar tripods (Edison, NJ, USA) set to a height of 80 centimeters (cm) above the running surface. Cameras were placed along the flat paved running course to capture the subject's preferred step rate at 800 m, 1200 m, 1800 m, and 2200 m, see Fig. 2. Camera placement was chosen to assess step rate in the middle of the run to mitigate potential changes in running pace. Performance time was recorded at the completion of the run.

2.3. Video analysis

Windows Movie Maker 2012 (available for free download at http://www.microsoft.com) was used to assess each of the subject's running videos. Subjects were identified by the race bib number on the front of their shirts. Videos were edited to 10 s clips to capture the number of foot strikes at the 800 m, 1200 m, 1800 m, and 2200 m marks.

Step rate count was calculated from an edited 10 s video clip by counting the number of total steps taken by the left and right feet, then multiplying by 6 to calculate the step rate count for 1minute. This method is referred to as the 10 s method for step rate count [16]. For

Table 1
Study Inclusion and Exclusion Criteria.

Inclusion	Exclusion
Department of Defense (DoD) Beneficiary between the ages of 18-50 years old	Known pregnancy currently or in previous 6 months
Run at least 6 miles per week	Lower extremity or low back surgery in previous 6 months
Read and speak English to provide informed consent and follow study instructions	Profile given by a healthcare provider to limit exercise due to a lower extremity or low back injury

example, if 30 steps were counted during the 10 s video clip, then the total step rate count would be 30 × 6 = 180 steps per minute.

2.4. Statistical analysis

Data were entered into Microsoft Excel 2016 and then analyzed by statistical package, R V 3.1.2 (R Foundation; Vienna, Austria) and/or SPSS V 24 (SPSS Inc; Chicago, IL). For analysis of step rate at four different time points, a repeated measures analysis of variance (ANOVA) with a Bonferroni-Holm correction was utilized to determine statistical difference with a significance level set at $p < 0.05$ (95% confidence intervals). An independent *t*-test with significance level set at $p < 0.05$ was used to analyze mean group differences between those who had a change in step rate and those who did not have a change in step rate for weekly miles trained and performance time. Overall group marginal means in steps per minute were analyzed using multiple comparison tests.

3. Results

3.1. Baseline characteristics

Of 30 subjects, 18 were male and 12 were female. The mean age of the subjects was 20.6 ± 1.8 years, mean height was 174.4 ± 10.5 cm, and mean weight was 73.6 ± 8.9 kg. Subjects ran an average of 11.8 ± 11.2 miles per week.

3.2. Step rate stability over two-mile run

Fourteen (46.7%, 11 male and 3 female) subjects demonstrated a change in self-selected step rate between 800 m and 2200 m of a timed 3200 m run observed on 2D video analysis. Table 2 demonstrates the mean step rate at each camera view. There was a statistically significant ($p = 0.04$) difference between step rate at 1200 m and 1800 m (173.6 ± 9.8 and 172.2 ± 10.2 steps per minute (spm)), as well as at 1200 m and 2200 m (173.6 ± 9.8 and 172.2 ± 9.9 spm). Table 3 describes the overall mean difference in step rate in steps per minute as well as percent change at each view. The mean difference in step rate ranged from 0 to ± 1.4 steps per minute, and the percent change ranged from 0 to 0.81% change.

3.3. Step rate stability versus performance

There was no statistical difference in average weekly miles trained ($p = 0.46$) or performance time ($p = 0.80$) in those who had a statistical change in step rate versus those who maintained a steady step rate. Table 2 describes the mean weekly mileage and performance time for subjects.

4. Discussion

To our knowledge, there are no studies assessing the stability of step rate during over ground running when using 2D video analysis. The primary aim of this study was to determine if step rate changes at different time points throughout a timed 3200 m run over ground. Despite a statistically significant difference ($p = 0.04$) at the 1200 m versus 1800 m as well as at the 1200 m versus 2200 m time points, mean group differences of 1–2 spm do not likely demonstrate a clinically meaningful difference in step rate, supporting our hypothesis. Recent literature suggests at least a 5–10% change in step rate to see clinically meaningful changes in running kinetics [4–8]. Based on this population, a change in step rate by approximately 9–17 steps would reflect a 5–10% change or a likely clinically meaningful difference. Table 3 demonstrates a less than 1% change in overall group step rate throughout the run.

These results support the work of others who have shown non-clinically significant changes in step rate during treadmill running [17,18]. Jewell et al. observed during an exhaustive run, defined as running at a pace that could be maintained for 15 min, but not 20 min on a treadmill, that step rate did not significantly change despite a significant change in contact time [17]. Although the Jewell et al. study included only habitual forefoot runners, over half of the runners changed to a rearfoot strike by the completion of the run without altering their step rate frequency [17]. Moreover, participants running for 1hour on a treadmill only showed a 1–2% reduction in step rate as the runners became fatigued [18]. Although minimal change in step rate was detected, these studies were performed with runners on a treadmill, and running mechanics on a treadmill may not be generalizable to over ground running [20,21]. Runners have been observed to use a higher step rate on a treadmill compared to over ground running at similar speeds [22].

Unlike treadmill running, with over ground running, speed is not constant allowing the runner to vary speed based on fatigue or environmental conditions. Speed may be weakly correlated although higher step rates have been observed at faster speeds [23–25]. Weyand et al. observed no significant change in step rate as runners increased speed from 2 m/s to 4 m/s; however, step rate was a primary function of

Table 3
Multiple Comparisons Tests Based on Marginal Means.

View	View	Mean Difference (steps per minute)	Percent Difference (%)	Significance (p value)
1	2	−.20	−.12	1.00
	3	1.20	.69	.13
	4	1.20	.69	.17
2	1	.20	.12	1.00
	3	1.40*	.81	.04*
	4	1.40*	.81	.04*
3	1	−1.20	−.70	.13
	2	−1.40*	−.81	.04*
	4	.00	.00	1.00
4	1	−1.20	−.70	.17
	2	−1.40*	−.81	.04*
	3	.00	.00	1.00

Based on overall marginal means.
* The mean difference is significant at the 0.05 level. Adjustment for multiple comparisons: Bonferroni-Holm.

Table 2
Analysis of Step Rate- Means and Standard Deviations.

Change in Step Rate Throughout 3200 meter Run	# of subjects	View 1 Step Rate (spm)	View 2 Step Rate (spm)	View 3 Step Rate (spm)	View 4 Step Rate (spm)	3200 meter time (min)	Average Weekly Mileage	% of female
No	16	171.8 ± 11.6	171.8 ± 11.6	171.8 ± 11.6	171.8 ± 11.6	14:00 ± 2:03	10.3 ± 8.6	50%
Yes	14	175.3 ± 7.5	175.7 ± 7.2	172.7 ± 8.9	174.1 ± 7.9	13:50 ± 1:44	13.4 ± 13.7	29%
All subjects	30	173.4 ± 9.9	173.6 ± 9.8*,+	172.2 ± 10.2*	172.2 ± 9.9+	13:55 ± 1:52	11.8 ± 11.2	40%

Step rate expressed in steps per minute (spm).
Views 1–4 represent step rate at 800 m (m), 1200 m, 1800 m, and 2200 m respectively.
* statistical difference between view 2 and view 3 (P = 0.04).
+ statistical difference between view 2 and view 4 (P = 0.04).

speed when running at speeds at 8 m/s [25]. In the current study, runners averaged a pace around 3–4 m/s based on overall performance time. Speed changes may be more correlated with changes in step length [18,24,25]. Because speed was not measured in the present study, we cannot conclude what effect speed had on step rate at the four time points. Negative correlations between change in step length and knee and hip muscular endurance have been observed during an exhaustive run without changes in step rate [26]. This may suggest that runners select a step rate for self-optimization of running efficiency [27].

Furthermore, our results show no statistical difference in average weekly miles trained ($p = 0.46$) or performance time ($p = 0.80$) in those who had a change in step rate versus those who maintained a steady step rate. At similar running speeds, step rate has not been associated with performance time [28,29]. Stability of step rate in elite runners on a treadmill has been established, with day to day good reliability ($r = 0.85$) and individual difference in daily step rate of 0.2–2.6% [19]. The current research demonstrates stability of step rate of non-elite runners during 800 m–2200 m of a timed 3200 m run over ground.

4.1. Limitations

Currently, there is no gold standard for assessing step rate. Step rate for the current study was calculated using the 10 s method based on running course and presence of other runners on the course. Also, this method was chosen due to ease of use and practicality for the clinical setting. Although this method has been shown to have excellent intra-rater and inter-rater reliability compared to a 60 s method [16], sensitivity of step rate count may have been limited with the minimal detectable difference of 6 steps. Others have calculated step rate visually by counting the number of right foot strikes in 30 s and multiplying by 4 [5,30]. Wearable technologies are available to calculate step rate, such as the wearable technology utilized in the Luedke et al. study for step rate calculation, with an error rate of 1.4% or 2–3 spm of runners on an outdoor track [2,31]. Other wearable technologies are available that provide reliable and valid step rate count for constant and varying velocities; however, many coaches, clinicians, and researchers may not have access to these technologies due to cost restrictions. For studies observing large groups of subjects during one run, supplying each subject with wearable technology may not be financially feasible. A second limitation of this study is that speed was not assessed at each view. We cannot assume that runners maintained a steady pace throughout the run based on overall performance time. To mitigate expected changes in running pace, we chose to capture step rate in the middle of the run versus at the start or completion of the run. Future studies should continue to investigate the correlation between speed and step rate variability during steady state running.

5. Conclusion

Clinicians and researchers may be able to expect step rate to be consistent from 800 m–2200 m of a 3200 m run despite a runner's training mileage or performance time. This may be valuable for observing over ground running when the full course of the run cannot be viewed as it could within a laboratory setting. Ultimately, more research is needed to generalize these results for other populations and longer distance running events.

Conflict of interest statement

The authors certify that they have no conflict of interest that would inappropriately influence this research. The opinions expressed herein are those of the authors and do not necessarily reflect the opinions of the Department of Defense, the United States Army, or other federal agencies.

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