ABSTRACT

**Background:** Several strategies have been proposed to reduce loading of the lower extremity while running including step rate manipulation. It is unclear however, whether step rate influences the incidence of lower extremity injuries.

**Purpose:** To examine the association between step rate and risk of injury in an adult recreational runner population.

**Study Design:** Prospective Cohort

**Methods:** A total of 381 runners were prospectively followed for an average of nine months. Two-dimensional video was used to assess preferred step rate during a timed two-mile run or a 5K race. Injury surveillance to record sub-clinical injuries (those for which medical treatment was not sought) was performed via semi-monthly email surveys over the course of one year. Injury surveillance for clinical injuries (those for which medical treatment was sought) was performed via a full medical record review using the Armed Forces Health Longitudinal Technology Application. Clinical, sub-clinical and combined clinical and sub-clinical injury incidence were assessed in separate analyses. Injury was operationally defined as seven or more days of reduced activity due to pain. To assess the predictive validity of running step rate, the step rate of participants who did not develop a musculoskeletal injury during the observation period were compared with the running step rate of participants who did develop an injury during the observation period.

**Results:** Out of 381 runners, 16 sustained a clinical overuse injury for which medical treatment was sought. Mean step rate for clinically un-injured runners was 172 steps/min and mean step rate for clinically injured runners was 173 steps/min which was not statistically significantly different (p = 0.77). Out of 381 runners, 95 completed all four sub-clinical injury surveys (95/381 = 25%). Out of those 95 runners, 19 sustained a clinical (n = 4) or sub-clinical injury (n = 15). The step rate of sub-clinically injured and non-injured runners in this sub-sample was also not statistically significantly different (p = 0.08), with a mean of 174 steps/min for the uninjured group and a mean step rate of 170 steps/min for those in the sub-clinical injured group.

**Conclusion:** Preferred step rate was not associated with lower extremity injury rates in this sample of DoD runners. Additional research is needed to justify preferred step rate manipulation as a means to reduce lower extremity injury risk.

**Level of Evidence:** Level 3

**Key Terms:** step rate, cadence, running injuries
INTRODUCTION
Forty-five percent of military sport-related injuries occur due to running.¹ Several strategies have been proposed to reduce loads to the lower extremity while running, including the alteration of the running form.²⁻⁴ One strategy that has been employed is increasing step rate, which subsequently results in a decrease in stride length. It has been proposed that shortening one’s stride length may decrease the propensity for running injuries.⁵ Thompson et al⁶ reported that decreasing stride length whether in barefoot or shod conditions, reduced both vertical ground reaction force and joint moments. Advocates of a running style with an increased step rate claim that employing this technique will reduce loading of the knee and hip joints and has potential to reduce running injuries.²⁻⁴,⁷,⁸

Minimizing the forces associated with ground contact is thought to be important to prevent injury. Heiderscheit et al² reported that with as little as a 5% increase in step rate there was a 20% decrease in load to the hip and knee. Willson et al⁹ reported that there was a significant reduction in patellofemoral (PF) joint stress per step, and a 9-12% reduction in cumulative PF joint stress in a 1 kilometer run. In the laboratory setting, altering step rate has demonstrated a reduction in biomechanical stress to the hip and knee,²⁰ however the relationship between self-selected step rate and lower extremity injuries in recreational runners has not been reported.

Though step rate has been proposed as a method to decrease lower extremity loading while running, there have been few prospective studies observing step rate and its relationship to lower extremity injuries. To the authors’ knowledge, Luedke et al⁹ are the only authors to observe this relationship in high school cross country runners. Those authors reported that cross country runners with a step rate less than or equal to 164 were 6.7 times more likely to sustain a shin injury compared to runners who ran greater than or equal to 174 steps per minute.⁹ However, the Luedke et al⁹ study had a sample of 68 high school cross country runners, which makes the generalizability to all runners difficult. Luedke et al’s⁹ study also focused only on shin and knee injuries as opposed to all lower extremity injuries.

Due to the limited body of research observing step rate and its relationship to lower extremity injuries, more research is needed in this area. Therefore, the primary aim was to examine the association between step rate and risk of injury. It was hypothesized that runners with a greater step rate would have a decreased incidence of injury.

METHODS
A total of 407 Department of Defense (DoD) beneficiaries (includes service and family members) were screened for inclusion/exclusion criteria (Table 1) prior to the Army Physical Fitness Test and 5K. The study protocol was approved by the Keller Army Community Hospital Institutional Review Board (KACH IRB). All subjects provided informed consent. Initial intake forms collected information including: date of Army Physical Fitness Test (APFT), age, sex, height (inches), weight (lbs), and average running mileage per week. A total of 381 runners met the inclusion/exclusion criteria and continued with the study, see Figure 1.

The 381 runners were prospectively followed for an average of nine months. (270 men, 111 women, age

| Table 1. Study Inclusion and Exclusion Criteria. |
|-----------------------------------------------|
| **Inclusion**                                   | **Exclusion**                                      |
| Department of Defense (DoD) Beneficiary who were able to respond to surveys for 8 months post data collection | Known pregnancy currently or in the previous 6 months |
| Between 18-50 years old                        | Lower extremity or low back surgery in the previous 6 months |
| Run at least 6 miles per week                  | Any lower extremity or low back exercise limitations |
| Read and speak English well enough to provide informed consent and follow study instructions | Retrospective injury identified on AHLTA within the current calendar year |

The International Journal of Sports Physical Therapy | Volume 15, Number 2 | April 2020 | Page 222
an average age of 22.6 ± 6 years, height 174.59 ± 10.34 centimeters, weight 75.65 ± 11.1 kilograms. At baseline, participants' average weekly running mileage was 9.49 ± 8.74 miles per self-report.

An a-priori power analysis was performed in G Power version 3.1. A two-tailed t-test was utilized with alpha set to 0.05, and a power of 0.80. U.S. Military Academy collaborators recently completed a study in a sample of 40 runners, and determined that the Minimal Detectable Difference (MDD) in step rate, utilizing the method employed in this study, was six steps with a standard deviation of 12 steps. Effect size for this study was determined by dividing the MDD of six steps by the standard deviation of 12 steps, resulting in an effect size of 0.50. G Power analysis determined a sample of 210 runners was estimated to be needed to show a statistically significant relationship between step rate and injury. However, due to poor survey response rates reported in previous studies, a sample of 400 runners were recruited for this study.

**PROCEDURES**

To determine preferred step rate, subjects were asked to run at their self-selected run pace for two-miles or 5K. Runners participating in the study were identified by wearing numbered running bibs. To determine step rate, two-dimensional video (frontal plane) was collected during over ground running from two stationary high-speed cameras (Casio Exilim EX-ZR200, Tokyo Japan) sampling at 30 frames per second (Hertz) with a resolution of 640 x 480 pixels and shutter speed of 1/1000s. Stationary cameras were mounted to two Vivitar (Edison, NJ, USA) tripods set to a height of 80 centimeters on a level surface. During the APFT performed on a paved route, 2 cameras were set to capture preferred step rate at approximately 800 meters, 1200 meters, 1800 meters, and 2200 meters. (Figures 2 and 3) During the APFT performed on a standard track, a stationary camera was placed on each of the straight-aways to capture preferred step rate continuously over the two-mile event. During the 5K, one camera was positioned at approximately 1200 meters.

Running videos were cut down into 10 second video clips from which participants were identified by their running bib. Step rate data were first reduced from each runner’s 1800 m running video. If 1800 m video data quality were poor, the 1200 m video was used instead. Videos taken at 800 m and 2200 m were only used if both the 1800 and 1200 videos were unusable. Videos were determined to be unusable if the reviewer was unable to identify the runner’s bib number or there was not a full 10 second (s) video clip where each step could be visualized.

Preferred step rate was calculated from each 10s video segment by counting every time a runner’s foot hit the ground in the 10s video clip and then multiplying this number by six. This method of step rate analysis used in this study (10s method) has been shown to be a reliable and valid method.
In the current study, step rate analysis was performed by two separate medical professionals, a physical therapist (Rater 1) and an athletic trainer (Rater 2). Rater 1 and Rater 2 were both experienced in the use of high-speed video for the evaluation of running mechanics. Inter-rater reliability was established between these raters prior to step rate analysis. Each rater evaluated the first 20 participant's high-speed video clips, once, independently and blinded to each other’s assessments. The inter-rater reliability between the two raters was excellent (ICC (2,1) = 0.98). After confirming inter-rater reliability, the remaining subject videos were analyzed.

**INJURY SURVEILLANCE**
Subjects consented to a retrospective and prospective medical record review. Sub-clinical injury surveillance (injuries for which medical treatment was not sought) was performed by collecting semi-monthly email self-report injury surveys. Clinical injury surveillance (injuries for which medical treatment was sought) was performed via full medical record review using the Armed Forces Health Longitudinal Technology Application (AHLTA), a secure and closed DoD medical documentation system. AHLTA was used to query lower extremity injury diagnoses related to hip, knee, ankle, foot and low back. This was done eight to 10 months after the initial running assessment. AHLTA medical records are available DoD wide, therefore if a subject moved during the study year their medical records were still able to be reviewed.

All participants received a simple email survey every other month asking them to provide their weekly running mileage and if they had pain and/or had limited their activity due to pain or an injury for seven or more days

\[12\] during the survey reporting period. If the answer was yes, the runner was deemed as having a sub-clinical injury and received additional questions regarding the location, severity, and nature of the injury. The email surveys were necessary to maximize accuracy of weekly running
mileage and injury information for which the runners did not seek medical attention. A sub-clinical injury was defined as an injury reported on one of the surveys, and not documented in AHLTA (an injury for which medical treatment was not sought).

**STATISTICAL ANALYSIS**
All data were entered into Microsoft Excel and analysed by the statistical package, SPSS V 24 (SPSS Inc; Chicago, IL). Descriptive statistics were calculated to describe the socio-demographic (age, sex, etc.) and health characteristics of the entire sample. Means and standard deviations were computed for continuous data and frequency distributions were analysed for categorical data. To assess the influence of running step rate on injury, the step rate of participants who did not develop a clinical or sub-clinical musculoskeletal injury during the observation period was compared with the running step rate of participants who did develop an injury during the observation period utilizing a two tailed t-test. Effect size utilizing Cohen’s $d$ (small; $d=0.2$, medium; $d=0.5$, large; $d=0.8$) was also calculated between the participants who did not develop a clinical or sub-clinical musculoskeletal injury and those runners who did develop an injury during the observational period.

**RESULTS**
Over the course of nine months 7% (25 out of 381) of runners sustained a clinical injury for which medical treatment was sought. Of these injuries 64% (16 out of 25) were overuse in nature. A total of 15 runners or 16% reported a sub-clinical injury via email survey (15 out of 95). Total number of injuries and the corresponding average step rate per body region are presented in Table 2. Descriptive statistics of step rates in clinically non-injured and clinically overuse injured runners, as well as the sub-clinical non-injured and sub-clinical injured runners are presented in Table 3; step rate distributions by groups are represented in Figure 4. Mean step rate for non-injured runners was 172 steps/minute and mean step rate for clinically injured runners was 173 steps/minute. An independent t-test comparing step rate of clinically injured and non-injured runners demonstrated that these rates were not statistically significantly different ($p=0.77$). Only one subject was excluded from the clinical injury analysis due to being unable to find them in AHLTA.

Ninety-five out of 381 runners (25%) completed all four sub-clinical injury surveys. Nineteen out of those 95 runners sustained a clinical ($n=4$) or sub-clinical injury ($n=15$). An independent t-test comparing step rate of sub-clinically injured and non-injured runners in this sub group demonstrated that these rates were not statistically significantly different ($p=0.08$), with a mean of 174 steps/minute for the uninjured group and a mean step rate of 170 steps/minute for those in the combined injury group. A small effect size was observed between both the clinically injured and non-injured runners (0.08) and the sub-clinically injured and non-injured runners (0.41).

**DISCUSSION**
The primary purpose of this study was to observe if step rate influenced lower extremity injury rates in

| Table 2. Overuse Injuries and Step Rate by Body Region. |
|----------------------------------------------------------|
|                | Clinical Injuries* | Subclinical Injuries** | Total Combined Injuries | Mean Step Rate (steps/minute) | Standard Deviation (steps/minute) |
| Foot           | 2                  | 4                      | 6                       | 174                           | 4.89                             |
| Ankle          | 2                  | 3                      | 5                       | 177                           | 12.44                            |
| Shin           | 3                  | 2                      | 5                       | 169                           | 5.01                             |
| Calf           | 0                  | 3                      | 3                       | 170                           | 9.17                             |
| Knee           | 6                  | 1                      | 7                       | 170                           | 8.38                             |
| Quadriceps     | 1                  | 1                      | 2                       | 168                           | 0                                |
| Hamstring      | 1                  | 1                      | 2                       | 180                           | 25.46                            |
| Low Back       | 1                  | 0                      | 1                       | 156                           | 0                                |
| **Total number** | **16**            | **15**                 | **31**                  | **172**                       | **9.59**                        |

*Clinical Injuries defined as injuries identified in Armed Forces Health Longitudinal Technology Application (AHLTA)
**Subclinical injuries defined as injuries identified via email surveys.
Running injuries can be complex and multifactorial. There are several internal and external risk factors to consider in regards to running injuries. Intrinsic risk factors include: sex, body mass index, previous injuries, weekly running distance, and/or lack of running experience. Extrinsic risk factors to consider include: training frequency, ground stiffness, Department of Defense personnel. This relationship was analyzed by examining self-selected step rate during a timed two-mile run test or a 5K, and then collected injury data prospectively for an average of nine months. Overall, results of this study suggest that step rate did not have a significant impact on lower extremity injury rates in this population.

### Table 3. Step Rate Statistics in Non-Injured and Injured Runners.

|                        | Non-Injured via AHLTA | Clinical Injury | Non-Injured via Survey* | Sub-clinical Injury* |
|------------------------|-----------------------|-----------------|-------------------------|----------------------|
| Number of subjects     | 356                   | 16              | 76                      | 15                   |
| Average step rate      | 172 steps/min         | 173 steps/min   | 174 steps/min           | 170 steps/min        |
| Median step rate       | 174 steps/min         | 171 steps/min   | 174 steps/min           | 168 steps/min        |
| Standard Deviation     | 10.39                 | 11.48           | 12.32                   | 7.09                 |
| Independent t-test p   |                       |                 |                         |                      |
| value                  | 0.76                  | 0.08            |                         |                      |
| 95% Confidence         |                       |                 |                         |                      |
| Intervals              | -7.08, 5.30           | -0.55, 8.86     |                         |                      |
| Effect Size (Cohen’s d)| 0.08                  | 0.41            |                         |                      |
| Observed Power         | 0.19                  | 0.61            |                         |                      |

*95 runners responded to all four email surveys.

Figure 4. Box plots showing the distributions of step rates between the injured and non-injured runners. The upper and lower margins of the box indicate the interquartile range, demarcating the 25th and 75th percentiles. The center line represents the median score (ie. 50th percentile). The outer bars indicate the range of scores at each end of the distribution, with circles indicating outliers beyond 3 standard deviations from the mean.
always running on the same side of the road, and/or running shoe.\textsuperscript{13} One or a combination of these internal and external risk factors could also contribute to a running related injury.

Though step rate has been proposed as a method to decrease load to the lower extremity while running, there have been few prospective studies observing preferred step rate and its relationship to lower extremity injury rates. To the authors’ knowledge Luedke et al\textsuperscript{9} is the only other published study to observe this relationship in high school cross country runners. In Luedke et al\textsuperscript{9} study, it was reported that runners with a step rate less than or equal to 164 were 6.7 times more likely to sustain a shin injury compared to runners who ran greater than or equal to 174 steps per minute. Luedke et al\textsuperscript{9} reported 63.6% of their injuries were classified as minor and resulted in only 1-7 days lost of running. In the current study, injury was defined as pain limiting running for seven or more days. Therefore, minor injuries were not captured in this study that limited running for less than seven days, which represented a majority of the injuries reported in Luedke et al's study\textsuperscript{9}.

Analysis included all lower extremities injuries whereas, Luedke et al\textsuperscript{9} analyzed step rate separately for knee or shin pain. In the current study, both the shin and knee injured body regions had lower mean step rates (169 and 170 steps/minute) when compared to the other lower extremity injured body regions (Table 2). This could potentially indicate that these specific body regions, the shin and knee, might have a higher relative risk in regards to lower step rates as compared to other lower extremity body regions such as the hip and foot. This would be consistent with Luedke et al\textsuperscript{9} who reported cross country runners with a step rate less than or equal to 164 were 6.67 times more likely to sustain a shin injury compared to runners who ran greater than or equal to 174 steps per minute.

In an attempt to capture injuries sustained over the course of the year that participants did not seek medical care for, four online surveys were sent out in total. Unfortunately, survey compliance rate was only 25%. Therefore, all injuries where runners could self-select not to run may not have been captured. This could explain the low rate of injury over the course of one year. However, though the compliance rate of the surveys over all was low, of our 31 overuse injuries reported, 15 or 48% were reported only via survey.

Preferred step rate was calculated using the 10s method. Though this method made it feasible to count step rate during a two-mile-run, it may have limited the sensitivity of step rate calculations. Utilizing this method, the minimal detectable difference in step rate was six steps. Luedke et al\textsuperscript{9} utilized the Polar S3+ Stride Sensor which has been shown to be an accurate and reliable tool to measure step rate with a 1.4% error rate (2-3 steps per minute). Presently, there are several reliable wearable technologies available to measure step rate that would negate this limitation.

This study captured step rate during the Army Physical Fitness Test two-mile run event. This is a timed and graded event for cadets or active duty soldiers. Currently, it has not been reported in the literature whether step rate varies between a maximal effort two-mile run and a recreationally paced two-mile run. Luedke et al\textsuperscript{9} captured step rate during two separate 400 meter runs, one self-paced and one with a pace set at 3.3 m/s performed with a pacer. For the self-selected pace, runners were instructed to run with 80% of their 5K pace effort or 15 of 16 points on the Borg Rating of Perceived Exertion. Self-paced step rate of the sample was 171.3 steps per minute, and step rate at the set 3.3 m/s would be 169.7 steps per minute, which is most likely not a clinically meaningful difference.\textsuperscript{9}

Step rate is often manipulated in runners undergoing gait retraining, but only one study to date has demonstrated that cross country runners with greater step rate experienced fewer anterior shin injuries.\textsuperscript{9} In the current study, running with a greater step rate was not protective of running related injuries in recreational runners. Injury was defined as pain limiting running for seven or more days, and therefore did not capture more minor injuries. In laboratory settings as little as a 5% increase in step rate significantly decreases the load to the lower extremity.\textsuperscript{2} This would represent approximately an eight steps per minute increase. Therefore, though step
rate modifications may still be effective at treating running related injuries, self-selected step rate was not predictive of those runners who will sustain a running injury in this population.

CONCLUSIONS
The results of the current study indicate that self-selected step rate in DoD runners did not influence subclinical (self-reported) or clinically documented lower extremity injury rates. Future studies are needed to further investigate the relationship of step rate and lower extremity injuries, further examine step rate by specific injury locations, and whether step rate can be a useful screening tool to prevent lower extremity injuries in runners.

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