EFFECT OF FATIGUE ON KINEMATIC AND KINETICS OF YOUTH RUNNERS: A PILOTSTUDY

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The purpose of this study was to investigate the vertical ground reaction forces and heel acceleration of young runners and how they change with fatigue. Young distance athletes (n=4) completed a fatiguing run on a treadmill while kinematic and kinetic data were recorded at the beginning, middle, and ends of their runs. Changes in ground reaction forces and limb acceleration were highly runner-specific, but demonstrate the need for a larger-scale study on the effects of fatigue on developing runners.

KEY WORDS: biomechanics, running, adolescents, injury prevention

INTRODUCTION: Running is an increasingly popular sport and recreational activity for youths, and more young athletes are training for and competing in longer distance events worldwide. In the US, it is estimated that at least 70,000 youths between the ages of six and 17 participated in half or full marathons in the year 2013 alone ("Running USA's Annual Marathon Report | Running USA," n.d.). Despite its increased popularity, there is little consensus regarding safe levels of running volume and frequency with regards to age. Injury risk factors for long distance runners continue to be well studied in the adult population, and include leg acceleration, asymmetry, (Mercer et al., 2010; Mercer, Vance, Hreljac, & Hamill, 2002), step length, and step rate (Gehring, Mornieux, Fleischmann, & Gollhofer, 2013; Milner, Hamill, & Davis, 2007). While adult research is useful in guiding research hypotheses for children and adolescents, special considerations like evolving motor control strategies, imbalances in the maturation rate of bone and soft tissues, and sudden changes in weight and height, mean that these adult studies cannot be assumed to be directly generalizable to paediatric populations. Part of the concern is that maturational factors, such as rapid growth and hormonal changes, and fatigue can interact in unique ways to influence injury risk. In addition, if changes in mechanics are found to occur with fatigue, further research may be necessary to provide volume guidelines similar to the type implemented with pitch counts in youth baseball to protect growing athletes from potentially harmful overuse injuries.The purpose of this study was to investigate the vertical ground reaction forces and heel acceleration of young runners and how they change with fatigue.

METHODS: Four subjects between the ages of 12 and 14 (13.5 ± 1.0), with body mass 46 ± 11.6 kg and height 160 ± 13.4 cm were recruited from running programs and teams based in and around Auckland, New Zealand. All were currently on school or local running clubs, had prior experience running for at least forty consecutive minutes, and had not experienced an injury that prevented them from running in the prior six months.

VO_2 max testing protocol*:* In order to determine a pace that would be sustainable for forty minutes yet still allow for the athletes to become fatigued, each subject underwent a VO_2 max test. VO_2 max protocol involved 3 minutes at a comfortable pace as determined by subject's current training and race times at 1% gradient. The speed of the treadmill was increased by 1 $km \cdot hr^{-1}$ each minute thereafter and the subject was asked their perceived exertion according to the Borg Rating of Perceived Exertion (RPE) Scale (Borg, 1982). Data collected included heart rate and velocity at VO_2 max and respiratory exchange ratio. After the VO_2 max test, anatomical measurements including sitting and standing height, knee width, and ankle width (mm), were taken. Subjects were also asked about their running histories, including the age at which they started running and their weekly training volume. Subjects then performed a familiarization run on a dual force plate treadmill.

kinematic analysis*:* Subjects returned to the lab at least 24 hours but no more than seven days after the treadmill familiarization, and were outfitted with 16 reflective markers in accordance with the lower body Plug-in Gait™ model (Vicon Motion Systems Limited, UK). Kinematic data was obtained using a 9 camera Vicon motion analysis system, and data was sampled at a frequency of 200 Hz. Vertical ground reaction forces (GRF) were measured with side-by-side force plates in the treadmill at a sampling frequency of 1000 Hz. After a warm-up, the subjects performed a run at a velocity of 70% of their VO_2 max. Kinetic and kinematic data were collected at time periods of 3, 19, and 38 ± 2 minutes of the run. Information was collected in 10 second increments, to allow for collection of at least 5 full strides per time period. Data was averaged over 3 clean footfalls, defined as instances where the foot made complete contact with only one of the dual force plates, and all force data was normalized by body weight. Marker trajectories and kinematic data were filtered using a low pass Butterworth filter with a cut-off of 8 Hz and analyzed in MATLAB™. Percent difference in heel acceleration between limbs, as a measure of asymmetry, was calculated as ((Left-Right)/Right)*100%,

RESULTS: Maturation level was calculated as time from peak height velocity (PHV) as predicted by the equation developed by Mirwald et al, and ranged from 2.0 past PHV to 0.7 years before PHV.

Table 1
Subject running history

Subject	Years Running	Weekly Mileage (km)	Runs/Week	Time/Week (min)	PB Distance	PB Time (min)
001	1.5	40	6	270	800m	2:18
002	8	12	2	75	5km	23:58
003	5	10	2	45	-	-
004	4	-	5	200	1500m	5:22

Table 2
VO_2 max test results

Subject	VO_2Max (L/min/kg)	Velocity @ VO2Max (km/hr)	HR	RER	RPE (Borg)
001	62	18	200	1.142	19
002	43.4	14	200	1.196	19
003	51.4	15	203	1.206	18
004	50.92	17	201	1.203	17

ground reaction forces: During the VO_2 max test, subject 1 presented as a prominent forefoot striker; as such, there was no impact transient in the early section of his run. However, a heel strike transient developed midway through the trial. The three other subjects were heel strikers, which remained constant throughout their trials. Two of the four subjects showed a significant increase in peak vertical ground reaction force between the beginning (2.10 ± 0.539BW; 2.43 ± .161BW) and end (2.23 ± .038BW; 2.27 ± .02323BW), $p<.05$ of the run.

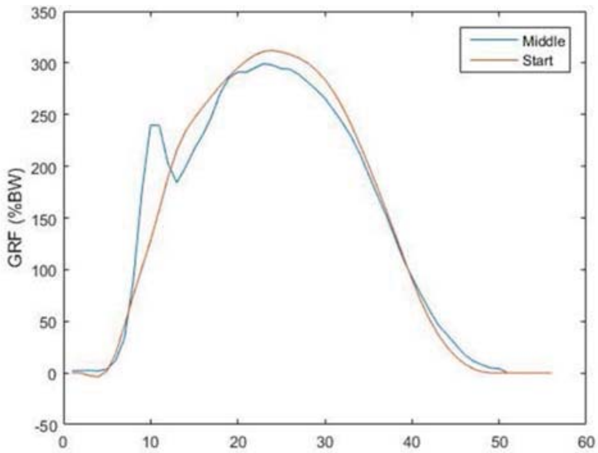

Figure 1: Development of a heel strike transient with fatigue in subject 1.

limb acceleration: Limb acceleration did not change significantly across time as determined by a paired t-test. There was also no significant change in cadence or step length between the beginning and end of the run for any of the subjects. A 2 (side) X 3 (time period) X 4 (subject) mixed model ANOVA showed that the non-dominant peak heel acceleration in mm/sec^2 (24.91 ± 3.38) was significantly greater than that of the dominant side (23.32 ± 3.66), and at the beginning (24.66 ± 3.76) as opposed to the end (22.55 ± 3.59) of the run. There were also significant interaction effects for both subject and time (F = 16.307, $p<.01$) and subject and side (F = 5.989, $p = .022$).

DISCUSSION: Development of the heel strike transient in the forefoot runner with fatigue was similar to the findings of larger scale studies looking at strike patterns over the course of half and full marathons (Larson et al., 2011). This information could be used as a marker for fatigue in this particular runner. Conversely, a coach may want to make the runner more aware of his form throughout a race, although there is no clear correlation between foot strike pattern and performance. Active ground reaction peak averages for all subjects were comparable to those found for adults, ranging from 2.12 to 3.05 BW. The relatively low values for the only subject that had yet to reach PHV points to a need for further investigation into the mechanics of runners pre and post adolescence.

Recommended alterations to the protocol would be to have the subjects run at a slightly higher RPE, even if it meant running for a shorter period, as they might not have been sufficiently fatigued to produce significant results. In addition, use of a full body marker set would allow for calculations of leg stiffness, which is another potential marker for injury.

CONCLUSION: As this was a pilot study, the sample size was too small to detect significant differences in kinematic variables such as knee flexion, stride, and step length. The sample size also requires reservation regarding the statistical power. However, this study demonstrates the potential for investigations into the kinetics and kinematics of youth distance runners. There is potential on the group level, for characterization and injury correlation. There is also potential for individual advancement, through use by coaches and trainers to improve performance. Future studies utilizing a larger subject pool would allow for comparisons across factors including gender, maturation level as well as training based factors, like weekly mileage and years of engagement.

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