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Treadmill vs. overground running gait during childhood: A qualitative and quantitative analysis

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ABSTRACT

Conventional gait labs are limited in their ability to study running gait due to their size. There is no consensus in the literature regarding the ability to extrapolate results for adult treadmill running to overground. This comparison has not been studied in children. Twenty-four healthy children (mean age 11.7) ran overground at a slow running speed while motion capture, ground reaction force, and surface electromyography (EMG) data were obtained. The same data were then collected while participants ran for 6 min on an instrumented treadmill at a speed similar to their overground speed. The kinematic, kinetic, and EMG data for overground and treadmill running were compared. Sagittal plane kinematics demonstrated similar hip and knee waveforms with the exception of more knee extension just before toe off. Ankle kinematic waveforms were similar during stance phase but treadmill running demonstrated decreased dorsiflexion during swing. Kinetic data was significantly different between the two conditions with treadmill running having a more anterior ground reaction force compared to overground. Due to the numerous differences between overground and treadmill gait demonstrated in this study, it is felt that the use of an instrumented treadmill is not a surrogate to the study of overground running in a pediatric population. This data set will function as a normative data set against which future treadmill studies can be compared.

1. Introduction

Historically running gait analysis was limited to cinematographic analysis of two or three gait cycles as limited by the size of a gait lab. In recent years, instrumented treadmills have provided the opportunity to study many more gait cycles. As a result, more variables can be standardized. In addition, inclination can be varied on treadmills allowing variation in test designs. However, it is not clear whether treadmill running biomechanics are comparable to overground gait.

Studies comparing overground running to treadmill running are not new. As early as 1976, cinematographic analysis determined that treadmill runners decreased their stride length, which resulted in an increased stride rate and decreased time in swing [1]. Another study demonstrated that treadmill runners have decreased ankle dorsiflexion at heel strike compared to their overground stride [2]. Other kinematic comparison studies demonstrated similarity for overground and treadmill runners in adult populations [3–6]. One of the only studies to do so, Riley et al. [4] concluded that overground and treadmill kinetic variables were similar enough to utilize treadmill-based research protocols for the study of overground running gait despite statistically significant kinematic and kinetic differences which were not felt to be clinically important.

Due to the less developed neuromuscular systems in children, it is unknown how children adapt their gait to treadmill running. To the best of our knowledge, there are no studies in the literature comparing treadmill and overground running gaits in a pediatric population. The ability to study pediatric running gait on a treadmill would not only vastly increase the understanding of normal pediatric running gait, but also serve as a baseline against which abnormal gait patterns can be compared.

The purpose of this study was to compare overground and instrumented treadmill pediatric running gait in order to

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determine whether or not treadmill gait data can be extrapolated to overground running data. If similarity is found, then this study will serve as a baseline data set for future studies on pediatric running gaits. Based on previous literature, we hypothesize that the kinematics and kinetics will be qualitatively similar and that any quantitative differences will be clinically insignificant.

2. Methods

Twenty four healthy children (8 female, 16 male) with a mean age of 11.7 (range 6–18, SD 3.6) were included in the study. Participants were free of chronic musculoskeletal pathology, moderate to severe asthma, or history of cardiopulmonary disease. Informed consent for participation in the study was obtained from the parents of the participants and assent from the participants themselves. The participants were recruited from employees of Gillette Children's Specialty Healthcare. The University of Minnesota Institutional Review Board approved the testing protocol. The study was self-funded by the Center for Gait and Motion Analysis at Gillette Children's Specialty Healthcare.

Each participant underwent gait analysis at the James R. Gage Center for Gait and Motion Analysis over level ground as well as on a treadmill. For the overground condition, the participants ran along a 17 m path. A 12-camera Vicon MX system (Vicon, Oxford, UK) was used to capture motion data at 120 Hz while 6 AMTI force plates (AMTI, Watertown, MA) were synchronized and used to collect the ground reaction forces at 1080 Hz. Simultaneously surface EMG signals were collected for the rectus femoris, medial hamstrings, vastus lateralis, anterior tibialis, and gastrocnemius-soleus complex (Motion Lab Systems, Baton Rouge, LA), also at 1080 Hz. A modified Vicon Plug-in-Gait model was used to calculate the kinematics and kinetics. The modification allowed for functional definitions of the hip centers and knee axes [7,8]. Participants wore their own shoes and were asked to jog at a slow comfortable speed for five trials. Without removing any motion capture markers or EMG sensors, the participants were directed to an instrumented tandem treadmill (AMTI, Watertown, MA). A similar 12-camera Vicon MX system was used for motion capture for the treadmill condition. To mitigate any risk associated with trips and falls while on the treadmill, an overhead harness was used. After a short acclimation period, the treadmill was set to match each participant's individual overground running speed. Data was collected over a 6 min timespan, with samples lasting approximately 10 s and taken at 1 min intervals. Many participants reported that the treadmill "felt faster" than overground. In order to be able to complete the 6 min running portion of the test, participants were encouraged to run slowly during the overground portion of the test. The treadmill speed was adjusted if the participants felt they would not be able to continue otherwise. Data was averaged over all trials for each participant for each condition. Running speed, step length, and cadence were made non-dimensional using the method described by Hof [9]. The kinetics and ground reaction forces were normalized by body mass.

Paired sample *t*-tests were used to test the significance of the differences in gait parameters such as running speed, cadence, step-length, toe-off time, and maximums and minimums of the kinematics and kinetics. A sub-sample of the data was identified in which the participants' overground and treadmill speeds matched to within 10%. The same statistical tests were run on this speed

Table 1
Gait cycle averages and statistical comparisons between overground and treadmill running. Parameter names in bold indicate $p < 0.05$ for the paired samples *t*-test for the full data set. Bolditalics parameter names indicate $p < 0.05$ for the paired samples *t*-test for the speed-matched and full data sets.

Parameter name	Full data set								Speed-matched sub-set							
	Overground		Treadmill		Diff.	95% CI		*p*	Overground		Treadmill		Diff.	95% CI		*p*
	Avg.	*N*	Avg.	*N*		Low	High		Avg.	N	Avg.	N		Low	High	
Speed	1.0	374	0.9	2110	0.1	0.1	0.2	**0.000**	0.94	48	0.92	195	0.02	0.00	0.05	0.082
Cadence	49.3	374	49.6	2110	−0.3	−1.5	0.9	0.586	48.76	48	49.79	195	−1.03	−2.98	0.93	0.276
Step length	1.2	374	1.1	2110	0.2	0.1	0.2	**0.000**	1.16	48	1.12	195	0.05	−0.01	0.10	0.097
Toe off	38.3	374	43.0	2110	−4.7	−6.3	−3.1	**0.000**	39.34	48	40.81	195	−1.47	−2.85	−0.09	**0.039**
Opp. foot contact	49.9	374	50.0	2110	0.0	−0.2	0.1	0.507	50.01	48	49.94	195	0.08	−0.18	0.34	0.530
Kinematics (°)																
Trunk tilt max	30.2	321	29.8	1769	0.5	−1.9	2.8	0.676	31.51	48	31.19	186	0.32	−3.69	4.33	0.866
Trunk tilt min	16.3	321	16.9	1769	−0.7	−3.3	2.0	0.611	18.23	48	19.35	186	−1.12	−5.77	3.53	0.610
Pelvic tilt max	20.5	374	21.3	2110	−0.8	−1.9	0.3	0.164	19.52	48	19.37	195	0.15	−1.66	1.96	0.859
Pelvic tilt min	12.2	374	12.7	2110	−0.5	−1.5	0.5	0.331	11.37	48	11.43	195	−0.07	−1.70	1.56	0.929
Hip flexion max	49.8	374	48.5	2110	1.2	−1.5	4.0	0.352	46.50	48	47.25	195	−0.75	−5.42	3.92	0.733
Hip flexion min	−2.5	374	−1.7	2110	−0.7	−2.3	0.8	0.331	−2.48	48	−3.17	195	0.69	−1.16	2.55	0.431
Knee Flexion max	88.5	374	85.6	2110	2.8	−2.6	8.2	0.290	83.94	48	84.46	195	−0.53	−7.55	6.49	0.873
Knee Flexion min	9.9	374	11.8	2110	−1.9	−3.2	−0.6	**0.007**	8.43	48	11.12	195	−2.69	−4.68	−0.70	**0.012**
Ankle dorsiflexion max	25.9	374	24.7	2110	1.1	0.1	2.1	**0.030**	24.83	48	24.77	195	0.06	−1.28	1.40	0.924
Ankle dorsiflexion min (plantarflexion max)	−21.7	374	−22.5	2110	0.8	−0.9	2.4	0.333	−21.86	48	−22.83	195	0.97	−2.05	3.99	0.498
Moments (Nm/Kg)																
Hip extension max	1.4	208	2.4	1912	−1.0	−1.1	−0.9	**0.000**	1.32	28	2.43	181	−1.11	−1.32	−0.90	**0.000**
Hip extension min	−0.9	208	−0.9	1912	0.0	−0.1	0.0	0.269	−0.80	28	−0.84	181	0.05	−0.03	0.13	0.210
Knee extension max	1.9	208	1.0	1912	0.9	0.7	1.0	**0.000**	1.82	28	0.96	181	0.87	0.70	1.04	**0.000**
Knee extension min	−0.5	208	−0.8	1912	0.3	0.2	0.3	**0.000**	−0.47	28	−0.72	181	0.24	0.15	0.34	**0.000**
Ankle plantarflexion max	2.0	208	2.8	1912	−0.8	−0.9	−0.6	**0.000**	2.02	28	2.88	181	−0.87	−1.14	−0.59	**0.000**
Ankle plantarflexion min	−0.4	208	−0.2	1912	−0.2	−0.3	−0.1	**0.001**	−0.36	28	−0.19	181	−0.17	−0.28	−0.05	**0.007**
Powers (W/Kg)																
Hip max	2.8	208	5.1	1912	−2.2	−2.8	−1.7	**0.000**	2.38	28	4.68	181	−2.30	−3.19	−1.41	**0.000**
Hip min	−2.6	208	−2.0	1912	−0.6	−1.1	−0.1	**0.030**	−2.08	28	−1.94	181	−0.14	−0.74	0.46	0.621
Knee max	4.4	208	4.2	1912	0.1	−0.7	0.9	0.734	4.24	28	3.93	181	0.31	−0.84	1.45	0.573
Knee min	−7.5	208	−3.6	1912	−3.9	−4.8	−3.0	**0.000**	−7.34	28	−3.37	181	−3.97	−5.27	−2.68	**0.000**
Ankle max	11.7	208	9.2	1912	2.5	1.6	3.3	**0.000**	10.32	28	10.02	181	0.30	−0.79	1.39	0.558
Ankle min	−4.1	208	−7.8	1912	3.7	3.1	4.4	**0.000**	−3.74	28	−7.73	181	3.99	2.43	5.56	**0.000**