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Investigation of treadmill and overground running: Implications for the measurement of oxygen cost in children with developmental coordination disorder

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Differences in the kinematics and kinetics of overground running have been reported between boys with and without developmental coordination disorder (DCD). This study compared the kinematics of overground and treadmill running in children with and without DCD to determine whether any differences in technique are maintained, as this may influence the outcome of laboratory treadmill studies of running economy in this population. Nine boys with DCD (10.3 ± 1.1 year) and 10 typically developing (TD) controls (9.7 ± 1 year) ran on a treadmill and overground at a matched velocity (8.8 ± 0.9 km/h). Kinematic data of the trunk and lower limb were obtained for both conditions using a 12-camera Vicon MX system. Both groups displayed an increase in stance time ($p < 0.001$), shorter stride length ($p < 0.001$), higher cadence ($p < 0.001$) and reduced ankle plantar flexion immediately after toe-off ($p < 0.05$) when running on the treadmill compared with overground. The DCD group had longer stance time ($p < 0.009$) and decreased knee flexion at mid-swing ($p = 0.04$) while running overground compared to their peers, but these differences were maintained when running on the treadmill. Treadmill running improved ankle joint symmetry in the DCD group compared with running overground ($p = 0.019$). Overall, these findings suggest that there are limited differences in joint kinematics and lower limb symmetry between overground and treadmill running in this population. Accordingly, laboratory studies of treadmill running in children with DCD are likely representative of the energy demands of running.

1. Introduction

Developmental coordination disorder (DCD) is a common childhood condition that is characterised by impaired motor coordination that may affect activities of daily living and participation in physical activity [1,2]. Running, which is vital for participation in many sports and games, is a fundamental movement skill that has been reported to be poorly executed by children with DCD [3]. We have recently shown that children with DCD have a higher cadence and a tendency to spend a longer time in stance and take shorter strides whilst running compared with their peers [4]. Children with DCD also display less knee extension immediately prior to foot contact and have lower knee extensor moments, peak knee absorption power and ankle power generation during the stance phase of running [4].

Given that joint kinematics, stride length, stance time and ground reaction forces have been found to influence running economy [5–7], the differences in running gait identified in children with DCD may have implications for the oxygen cost of running. Yet studies by our group comparing the oxygen cost of running at standardised speeds in boys with and without DCD have reported no difference [8,9], suggesting that the kinematic and kinetic differences in running in children with DCD may not be large enough to affect the oxygen cost of running. However, it is important to note that such studies of oxygen cost have been conducted on a treadmill to precisely control the running speed, as well as to allow for the collection of expired air, whereas the quantitative differences in running gait were identified while running overground. This raises the question; does running on a treadmill modify the natural overground gait of children with DCD, thereby minimising any differences from TD children, and therefore mitigate any differences in the oxygen cost of locomotion?

Previous studies comparing overground and treadmill running in trained adults have reported shorter stride length, higher stride rate and longer stance time with the latter [10,11]. Treadmill running has also been associated with kinematic differences at the hip [11], knee [12] and ankle [13] compared with overground

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running. Furthermore, treadmill running is associated with reduced ground reaction forces [12] and treadmill walking improves lower limb symmetry in hemiparetic patients due to the assistance of the treadmill belt in moving the stance limb backwards [14]. Whether the differences in overground running gait between boys with and without DCD are preserved during treadmill running is not known and any alterations may influence the oxygen cost of locomotion. Accordingly, the aim of the present study was to compare the kinematic characteristics of running gait and lower limb symmetry of children with and without DCD while running overground and on a treadmill.

2. Methods

2.1. Participants

Nineteen boys aged 7–11 years participated in this study; 9 with DCD and 10 typically developing (TD) controls matched for age, height and body mass (Table 1). All children with DCD had a formal diagnosis from a paediatrician and low motor proficiency was confirmed using an age standardised movement assessment (<15% on the Movement Assessment Battery for Children-2, MABC-2) [15]. The controls were volunteers from the community with movement proficiency well within the normative range (>25% on the MABC-2). Exclusion criteria were musculoskeletal injury, co-occurring disorders, or an overweight body mass index [16]. Boys were studied given that DCD is more prevalent in boys than girls [17] and to control for any differences in running gait between genders [18]. Ethical approval was obtained from the Institutional Human Research Ethics Committee (RA/4/1/4444) and informed consent was obtained from the child and parent/guardian.

2.2. Experimental design

Participants completed the MABC-2 to confirm their level of motor proficiency [15]. Each child then completed an analysis of overground running gait at a standardised speed of 8.8 km/h alongside an adult pacemaker on a 15 m runway with a 12-camera Vicon MX 3D motion analysis system operating at 250 Hz (Oxford Metrics, Oxford, UK). Participants were required to perform three successful trials whereby the speed attained was within ±0.9 km/h of the target. The speed of 8.8 km/h was chosen to compare previous studies which investigated the running gait [4] and oxygen cost of running in children with and without DCD [9]. Following this, the procedure for mounting and dismounting the treadmill (RTM600, Biodex Medical Systems, Shirley, NY) was explained. The participant then mounted the treadmill with an investigator standing behind as a safety precaution and began walking at a slow speed of 2.4 km/h. Once the participant was comfortable, the speed was gradually increased to 6.8 km/h, and was maintained for 5 min for familiarisation with treadmill running. Once participants were familiarised, they were asked to run on the treadmill at 8.8 km/h for 4 min, with kinematic data recorded in the last 30 s of this period.

Table 1
Characteristics of participants with developmental coordination disorder (DCD) and typically developing control children (TD), mean (SD).

	TD ($n=10$)	DCD ($n=9$)
Age (year)	9.7 (1.0)	10.3 (1.1)
Height (cm)	142.6 (7.7)	141.2 (9.4)
Body mass (kg)	33.7 (4.5)	33.3 (7.3)
Body mass index (kg/m^2)	16.5 (1.1)	16.5 (1.9)
MABC-2 (‰)	70.8 (17.8)	3.9 (3.3)[a]
MABC-2 score range (‰)	50–91	0.5–9

[a] Significant difference from TD group ($p < 0.01$).

2.3. Data collection and analysis

Prior to performing the running trials, each participant was fitted with 34 retro-reflective markers (14 mm) on the trunk and lower body in accordance with the UWA lower body marker set [19]. Data was filtered using a fourth-order, 14 Hz zero-lag, low-pass Butterworth filter, with the filter frequency determined by residual analysis. Kinematic calculations were performed in Vicon Nexus using the UWA lower body model [19]. Kinematic parameters included joint angles of the thorax, pelvis, hip, knee and ankle. Six strides (three for each lower limb) were analysed for both running conditions. These six strides were consecutive strides randomly selected from the 30 s recording period. Stride length on the treadmill was calculated using stride time and the speed of the treadmill belt [20]. The left and right stride of each running trial were individually temporally normalised to 101 points where a complete gait cycle was defined from initial foot contact to the next foot contact of the same foot. Three cycles of each leg were averaged to produce a typical running gait pattern for each participant. Data was then collated to determine the ensemble average output for the DCD and TD groups for both the overground and treadmill run. The degree of symmetry between the lower limbs while running on a treadmill and running overground was analysed using waveform correlations of joint angles over the gait cycle. Coefficients of multiple determination (CMD) were then calculated, producing a single correlation value between two waveforms, with a CMD value of ±1.00 indicating perfect symmetry/asymmetry between the left and right limbs [21].

Spatiotemporal parameters and minimum and maximum peak joint angle values from each gait cycle were analysed for the thorax, hip, knee and ankle joints using three-way repeated measures analysis of variance (ANOVA; 2 groups × 2 modes of running × 6 trials (strides)), with post hoc testing as appropriate to determine where any differences lay. Intra-individual kinematic variability (the SD of the mean of the 6 trials for each participant) at specific points of the gait cycle (heel strike, mid-swing and toe-off) and waveform CMD's values were used to compare between groups and running modes using repeated measures ANOVA across the hip, knee and ankle joints. All statistical analyses were performed using SPSS version 19.0 (SPSS, Inc., Chicago, IL) at an alpha level of 0.05. All results are presented as mean ± SD.

3. Results

3.1. Spatiotemporal parameters

The average running speed for the overground trials was well-matched between groups and similar to the speed of treadmill running (Table 2). There was a main effect of the mode of running on stance time, stride length and cadence. Both groups displayed increased stance time ($F_{(1,8)}=63.8$, $p<0.001$), decreased stride length ($F_{(1,8)}=47.7$, $p<0.001$) and increased cadence ($F_{(1,8)}=44.4$, $p<0.001$) when running on the treadmill compared with overground. There was no effect of group on stride length ($F_{(1,8)}=0.6$, $p=0.44$) or cadence ($F_{(1,8)}=1.8$, $p=0.214$) while running overground or on the treadmill. In contrast, there was a main effect of group on stance time ($F_{(1,8)}=20.6$, $p=0.002$), with the DCD group spending a longer time in stance compared with the TD group while running overground and on the treadmill (overground, $F_{(1,8)}=11.5$, $p=0.009$; treadmill, $F_{(1,8)}=24.7$, $p=0.001$). There was no effect of running trials on stance time, stride length and cadence.