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Kinetic and Spatiotemporal Gait and Running Parameters in Children with and without Intellectual Disabilities: The Role of Obstacle Crossing

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Abstract

Introduction: Children with intellectual disabilities (ID) often demonstrate slower gait patterns and reduced postural stability compared with their typically developing (TD) peers. Evidence on how these children negotiate complex tasks such as obstacle crossing, particularly during running, remains scarce. The present study aimed to compare the spatiotemporal and kinetic characteristics of walking and running in children with ID and TD children under normal and obstacle-crossing conditions.

Materials and Methods: In this descriptive-comparative study, 16 girls with ID (IQ: 50-70) and 17 age-matched TD girls (mean age≈11 years) completed four locomotor tasks: (1) walking on a level walkway without an obstacle (normal gait, NG), (2) walking while crossing an obstacle (OBS), (3) running on a level walkway (normal running, NR), and (4) running while crossing an obstacle (ROBS). Ground reaction forces (GRF) and selected spatiotemporal parameters were captured using two force plates and a motion analysis system. For each dependent variable, a three-factor mixed-model analysis of variance (ANOVA) was conducted.

Results: Running speed was the only spatiotemporal variable showing a significant group difference, with the ID group running slower than the TD group (P=0.008). The ID group also demonstrated reduced trailing-limb speed and increased lead-limb cadence compared to TD peers. Most GRF components differed between groups during walking, and obstacle crossing during running significantly modified GRF profiles.

Conclusion: Children with ID adopt distinct gait adaptations and GRF patterns when crossing obstacles, including slower running speeds and more conservative locomotor strategies. These adaptations likely reflect motor control and balance constraints, while elevated vertical and braking forces suggest reduced shock absorption capacity and limited use of propulsive force.

Key words: Intellectual Disability, Gait, Running

Introduction

Intellectual disability (ID) is a neurodevelopmental condition resulting from incomplete brain maturation (1). It leads to alterations in adaptive functioning that impact independent daily activities, social responsibility, communication, interpersonal relationships, and academic and/or occupational achievement (2). Walking and running are fundamental locomotor skills and serve as key indicators of coordinated whole-body development (3). Efficient, dynamic, and independent walking requires the continuous integration of the musculoskeletal, sensory, and nervous systems, supported by adequate muscle strength, joint mobility, and effective neuromuscular control (4).

Individuals with ID have a high prevalence of balance and gait impairments arising from multiple underlying mechanisms (5-7). The first involves arrested or incomplete development of the nervous

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system, which affects both cognitive and motor functions (8, 9). The second is premature aging of various body systems; mobility-related problems occur more frequently and at an earlier age in individuals with ID compared to age-matched peers without ID, potentially leading to reduced muscle strength and sensory function (vision, proprioception, and vestibular function) (10). The third factor is a predominantly sedentary lifestyle, which further reduces physical capacities such as endurance, balance, and strength relative to those of peers (11).

Previous research on gait variables in individuals with ID has primarily focused on those with Down syndrome (DS). However, findings have been inconsistent due to variations in the severity and type of intellectual impairment as well as differences in experimental protocols and testing conditions. Some studies have reported that, compared to typically developing (TD) peers, individuals with ID exhibit shorter swing times, step times, and step widths (12), along with reduced stride and step lengths, lower walking speed, and fewer steps per minute (13, 14). Conversely, other studies have found greater step and stride widths, longer stance times, increased double-support duration (15), longer stride and step lengths (12), and even higher walking speeds (16) in the ID group. Azadian et al. (2025) also observed no significant differences between the ID and TD groups in spatiotemporal gait variables during normal walking; however, when a challenging task such as placing an obstacle in the walking path was introduced, variability in spatiotemporal gait parameters increased (17). Running, compared to walking, is a more complex motor task that requires greater degrees of freedom and coordination of the lower limbs. Studying running characteristics may therefore provide deeper insights into motor control in individuals with ID. Losa et al. (2014) examined selected running variables in a population comprising children with DS, autism, and other developmental disorders. Their results indicated a significant difference in running speed between children with intellectual impairments and TD children (18). Similarly, Biber et al. (2024) reported that certain running parameters, such as stride length, step width, and swing-phase duration, differed significantly between children with DS and age-matched controls (19). To our knowledge, running characteristics in children with ID without genetic disorders have received little research attention. Thus, the first aim of this study was to examine and compare the kinetic and spatiotemporal characteristics of walking and running between children with ID and their TD peers.

Safe obstacle negotiation is one of the most challenging motor activities in daily life, requiring precise limb coordination, adjustment of step length and height, and maintenance of dynamic balance. Chen et al. (2016) reported that children with DS exhibited lower speeds and greater step widths during obstacle crossing, as well as increased lateral motion and pelvic rotation compared to TD peers. They tended to clear the obstacle with a larger safety margin by lifting their feet higher and taking longer steps (20). However, most previous studies have focused on walking in individuals with DS, and little is known about differences in running or obstacle crossing patterns in children with ID. Therefore, the second aim of this study was to investigate the kinetic and spatiotemporal characteristics of walking and running during obstacle crossing in children with ID compared to TD peers. Based on theoretical considerations, we hypothesize that, compared to TD children, those with ID will demonstrate slower walking and running speeds, shorter or more asymmetric steps, and different GRF patterns, particularly when faced with an obstacle.

Materials and Methods

Study Design

In this descriptive-comparative study, a total of 33 children participated, including 16 children with mild ID and 17 TD children.

Participants

All participants were between 9 and 13 years of age. Children in the ID group were recruited from special education schools and had a documented diagnosis of mild ID (IQ between 50 and 70) based on their school records. Typically developing children were matched to the ID group by age. Inclusion criteria for both groups were the ability to walk and run independently without assistive devices and the absence of any neurological or orthopedic conditions affecting gait. Exclusion criteria for all participants included neurological disorders (other than ID for the ID group), secondary genetic disorders such as DS or autism, chronic medical conditions, visual impairments, and physical disabilities affecting gait (2).

The objectives and assessment procedures of the study were explained to the parents, and informed consent forms were signed by the parents of all

participants. Data collection was conducted in the mornings in the presence of either parents or teachers. Height and weight were measured for all children. As shown in the results, the height of children in the ID group was significantly lower than that of the TD group (Table 1). Other demographic characteristics (age, weight, body mass index, and lower-limb length) did not differ significantly between the groups, except for ankle circumference, which was slightly smaller in the ID group (Table 1). Prior to the start of the study, written informed consent was obtained from all parents or guardians. The study protocol was approved by the Ethics Committee of Islamic Azad University (Ethics Code: IR.IAU.H.REC.1402.008) and was conducted in accordance with the principles outlined in the Declaration of Helsinki.

Table 1. Baseline characteristics in the TD and ID groups (Mean±SD)

	Groups		p-value
	ID	TD	
Age (year)	11.23 ± 1.34	11.77 ± 1.93	0.43
Mass (Kg)	45.3 ± 12.24	48.81 ± 9.09	0.24
Height (m)	1.44 ± 12.24	1.57 ± 0.96	0.003
BMI	19.39 ± 4.07	19.56 ± 2.55	0.88

Abbreviations: ID: intellectual disability; TD: typically developing; BMI: body mass index

Sample Size

The sample size was estimated a priori using G*Power software (version 3.1, Heinrich Heine University, Düsseldorf, Germany) for a mixed-model repeated-measures ANOVA design. Assuming a medium effect size (f=0.25), an alpha level of 0.05, and a statistical power of 0.80, the minimum required sample size was estimated to be approximately 30 participants. Based on these calculations and considering potential data loss, a total of 33 children were recruited, including 16 children with ID and 17 TD children.

Data sources/ measurement

This study was conducted in a biomechanics laboratory. Each individual was asked to perform four locomotor tasks: (1) walking on a level walkway without an obstacle (normal gait, NG), (2) walking while crossing an obstacle (OBS), (3) running on a level walkway (normal running, NR), and (4) running while crossing an obstacle (ROBS). The tests were carried out on a straight 10-meter walkway. To record ground reaction forces (GRFs), two force plates were installed in sequence at the midpoint of the walkway. The obstacle was an adjustable horizontal bar positioned so that, during crossing, the lead foot would land on the first force plate and the trailing foot would land on the second. The obstacle height for each child was set to 15% of their leg length to ensure proportional scaling (mean obstacle height≈12 cm) (21). Before data collection, participants completed several familiarization trials to adapt to walking/running on the force plates and crossing the obstacle. In each of the four conditions, three successful trials (with each foot fully contacting the force plate) were recorded, and the average values were used for analysis. The order of tasks was randomized for each participant to minimize sequence and fatigue effects. Children were encouraged to walk and run at their self-selected comfortable speeds, and during obstacle-crossing trials, to clear the obstacle without stopping and with a continuous rhythm. To prevent targeted foot placement during the no-obstacle tasks, participants were instructed to look forward rather than down at the force plates.

Movements were recorded using a six-camera motion analysis system (Vicon, Oxford Metrics, UK) at a sampling rate of 100 Hz. Reflective markers were placed on anatomical landmarks of the lower limbs (hips, thighs, knees, ankles, heels, and toes of both feet) to extract spatiotemporal parameters of walking and running. Ground reaction forces were collected via two force plates (Kistler, 1000 Hz). For vertical GRF, three peaks were identified during gait: the first peak (ZP1) following heel or forefoot contact, the second peak (ZP2) occurring near mid-stance, and the third peak (ZP3) associated with the trailing limb. During obstacle-crossing conditions, only the first vertical peak (ZP1) was analyzed. In the anterior–posterior direction, braking force (YP1) and propulsive force (YP2) were measured, while in the mediolateral direction, the lateral force peak (XP1) was recorded during foot contact (22). Vertical loading rate was calculated from the slope of the vertical force curve from initial contact to the first vertical peak. To account for differences in height between groups, spatiotemporal parameters such as speed and step length were normalized to each participant's stature. All GRF components were expressed as a percentage of body weight (BW). Motion and force data were processed using MATLAB software. For trials involving walking or running with an obstacle, the limb clearing the obstacle was defined as the lead limb, and the subsequent limb was designated as the

trailing limb.

Statistical Analysis

For each dependent variable, a three-factor mixed-model analysis of variance (ANOVA) was conducted. The between-subject factor was group (two levels: ID and TD), and the within-subject factors were task (two levels: normal walking or running and obstacle crossing) and limb (two levels: right vs. left limb for the normal condition, and lead vs. trailing limb for the obstacle-crossing condition). Analyses were performed separately for walking data and running data. When significant main effects or interactions were detected, post hoc pairwise comparisons with Bonferroni correction were applied. A P-value < 0.05 was considered statistically significant. Prior to conducting the ANOVA, assumptions such as normality of data distribution and homogeneity of variances were checked and met. All statistical analyses were performed using SPSS software (version 26, IBM, Armonk, NY, USA).

Results

Demographic information of the participants is presented in Table 1. Given the height differences between the two groups, walking speed and step length were normalized to each participant's stature.

The statistical analysis results for spatiotemporal variables are summarized in Table 2. Cadence in the ID group increased significantly for the leading limb during obstacle crossing, whereas walking speed for the trailing limb in the ID group was significantly lower than that of the leading limb (p=0.000) and the TD group (p=0.041). Step length was not significantly affected by any of the factors.

The results indicated that the group factor had a significant effect only on running speed (p=0.008), with pairwise comparisons showing that the ID group ran significantly slower than the TD group. Additionally, the task factor had a significant effect on step length. Pairwise comparisons revealed no significant difference in step length between running and obstacle-crossing conditions for the TD group, whereas the ID group exhibited a significantly greater step length during obstacle crossing compared to running.

Factorial analysis results for the vertical peak force ZP1 are presented in Table 3. All main factors had a significant effect on this variable. The ZP1 force in the ID group was significantly greater than in the TD group (p=0.003) (Fig.1). In the TD group, obstacle crossing led to a significant increase in vertical force at trailing limb contact (p=0.025), whereas in the ID group, neither task nor limb significantly influenced ZP1. As shown in Table 3, ZP2 values during NG were higher in the TD group than in the ID group. In the ID group, ZP2 for the trailing limb was significantly lower than for the leading limb. The ZP3 values in the TD group during obstacle crossing were also significantly higher compared to the ID group. For anterior–posterior forces, both the group and task factors significantly affected the braking force component YP1, with overall braking forces in the ID group significantly greater than those in the TD group (p=0.003). In the TD group, both braking force (YP1) and propulsive force (YP2) were significantly greater during obstacle crossing than during NG (p=0.009 for YP2, p=0.002 for YP1). Additionally, loading rate was significantly higher for the trailing limb compared to the leading limb in both groups during obstacle crossing.

Kinetic running data are shown in Table 4. Both ZP1 and YP1 increased significantly during obstacle crossing compared to running in both groups (p<0.001). For YP1, the increase was significantly greater in the trailing limb than in the leading limb (p<0.001). For YP2, the leading limb produced greater force than the trailing limb in both groups (p<0.001). In the mediolateral direction, as shown in Fig. 1, XP1 forces were generally higher in the ID group compared to the TD group (p=0.01). The task factor and its interaction with limb were also significant. Pairwise comparisons showed that, during ROBS, XP1 in the leading limb of both groups was significantly lower than in the trailing limb and also lower than in running (p=0.001). The task and limb factors did not significantly affect vertical loading rate (p>0.05).

Table 2. Factor Analysis of Spatiotemporal Variables for Walking and Running Under Normal and Obstacle-Crossing Conditions in the ID and TD Groups (F and *p* values)

Variables	Task	Foot	ID	TD	Group	Task	Task* group	Foot	Foot* group	task* foot
			Mean ± SD	Mean ± SD						
Gait Cadence	NG	Left	120.12±13.2	118.75±13.9	F=0.001	F=0.08	F=0.21	F=22.54	F=3.32	F=24.27
		Right	120.38±14.9	119.38±13.1	p=0.971	p=0.774	p=0.653	p=**0.000**	p=0.081	p=**0.000**
	OBS	Leading	124.27±17.1	117.31±18.0	Eta=0.001	Eta=0.003	Eta=0.007	Eta=0.421	Eta=0.091	Eta=0.439
		Trailing	118.31±18.8	121.63±14.7						
Gait Speed	NG	Left	0.77±0.16	0.77±0.10	F=0.22	F=0.72	F=0.92	F=2.66	F=1.74	F=4.77
		Right	0.78±0.17	0.78±0.10	p=0.643	p=0.402	p=0.344	p=0.113	p=0.197	p=**0.037**
	OBS	Leading	0.80±0.26	0.82±0.13	Eta=0.007	Eta=0.023	Eta=0.029	Eta=0.79	Eta=0.053	Eta=0.133
		Trailing	0.74±0.19	0.81±0.13						
Gait Stride length	NG	Left	1.44±0.22	1.48±0.15	F=0.62	F=0.45	F=0.53	F=0.001	F=0.16	F=0.016
		Right	1.45±0.19	1.48±0.14	p=0.439	p=0.510	p=0.473	p=0.890	p=0.695	p=0.902
	OBS	Leading	1.45±0.31	1.52±0.21	Eta=0.019	Eta=0.014	Eta=0.017	Eta=0.001	Eta=0.005	Eta=0.001
		Trailing	1.44±0.43	1.54±0.20						
Running Cadence	NR	Left	181.23 ±28.4	194.37±13.9	F=2.86	F=2.20	F=0.013	F=0.977	F=0.937	F=0.005
		Right	183.31±27.6	195.95±24.2	p=0.101	p=0.148	p=0.910	p=0.331	p=0.341	p=0.946
	ROBS	Leading	180.33±22.4	190.35±19.2	Eta= 0.085	Eta=0.066	Eta=0.001	Eta=0.031	Eta=0.029	Eta=0.001
		Trailing	174.68±24.1	188.85±25.6						
Running Speed	NR	Left	2.07±0.41	2.42±0.28	F=8.10	F=0.06	F=0.07	F=0.05	F=4.70	F=0.03
		Right	2.09±0.40	2.38±0.30	p=**0.008**	p=0.734	p=0.797	p=0.825	p=**0.038**	p=0.869
	ROBS	Leading	2.11±0.38	2.43±0.29	Eta= 0.207	Eta= 0.002	Eta= 0.002	Eta= 0.002	Eta= 0.132	Eta= 0.001
		Trailing	2.06±0.38	2.37±0.34						
Running Stride length	NR	Left	1.38±0.16	1.51±0.16	F=3.01	F=4.86	F=0.08	F=1.20	F=0.84	F=0.34
		Right	1.36±0.15	1.47±0.15	p=0.093	p=**0.035**	p=0.776	p=0.282	p=0.367	p=0.563
	ROBS	Leading	1.43±0.24	1.54±0.20	Eta= 0.088	Eta= 0.136	Eta= 0.003	Eta= 0.037	Eta= 0.026	Eta= 0.011
		Trailing	1.44±0.27	1.52±0.21						

Note: *ID*: intellectual disability; *TD*: typically developing; *NG: walking on a level walkway without an obstacle (normal gait); OBS: walking while crossing an obstacle; NR: running on a level walkway (normal running); ROBS: running while crossing an obstacle*; Bolded *p*-values indicate statistically significant differences ($p<0.05$)

Table 3. Factor Analysis of Ground Reaction Force (GRF) Variables During Walking Under Normal and Obstacle-Crossing Conditions in the ID and TD Groups (F and *p* values)

Variables	Gait	Foot	ID	TD	Group	Task	Task* group	Foot	Foot* group	task* foot
			Mean ± SD	Mean ± SD						
ZP1	NG	Left	1.25±0.12	1.15±0.16	F=10.67	F=9.23	F=5.52	F=4.68	F=4.58	F=4.77
		Right	1.30±0.12	1.11±0.07	p=**0.003**	p=**0.005**	p=**0.025**	p=**0.038**	p=**0.040**	p=**0.037**
	OBS	Leading	1.26±0.13	1.15±0.12	Eta= 0.256	Eta= 0.229	Eta= 0.151	Eta= 0.131	Eta= 0.129	Eta= 0.133
		Trailing	1.31±0.14	1.26±0.12						
ZP2	NG	Left	0.69±0.12	0.78±0.11	F=2.02	F=13.77	F=11.85	F=4.91	F=0.23	F=11.02
		Right	0.68±0.12	0.76±0.11	p=0.165	p=**0.001**	p=**0.002**	p=**0.034**	p=0.634	p=**0.002**
	OBS	Leading	0.71±0.10	0.73±0.13	Eta= 0.061	Eta= 0.308	Eta= 0.277	Eta= 0.137	Eta= 0.007	Eta= 0.262
		Trailing	0.65±0.13	0.69±0.13						
ZP3	NG	Left	1.15±0.12	1.19±0.08	F=3.84	F=6.68	F=9.34	F=0.28	F=0.13	F=2.10
		Right	1.19±0.13	1.19±0.10	p=0.059	p=**0.015**	p=**0.005**	p=0.602	p=0.721	p=0.157
	OBS	Leading	1.13±0.21	1.27±0.13	Eta= 0.110	Eta= 0.177	Eta= 0.232	Eta= 0.009	Eta= 0.004	Eta= 0.063
		Trailing	1.19±0.14	1.28±0.09						
YP1	NG	Left	0.44±0.11	0.32±0.08	F=10.08	F=40.21	F=11.78	F=0.61	F=0.36	F=6.15
		Right	0.51±0.13	0.34±0.08	p=**0.003**	p=**0.000**	p=**0.002**	p=0.442	p=0.555	p=**0.019**
	OBS	Leading	0.49±0.14	0.44±0.15	Eta= 0.245	Eta= 0.565	Eta= 0.275	Eta= 0.019	Eta= 0.011	Eta= 0.165
		Trailing	0.52±0.12	0.45±0.06						
YP2	NG	Left	0.50±0.12	0.43±0.05	F=1.82	F=36.10	F=7.73	F=0.185	F=0.08	F=0.503
		Right	0.50±0.10	0.42±0.05	p=0.187	p=**0.000**	p=**0.009**	p=0.670	p=0.780	p=0.483
	OBS	Leading	0.55±0.12	0.54±0.08	Eta= 0.055	Eta= 0.538	Eta= 0.20	Eta= 0.006	Eta= 0.003	Eta= 0.016
		Trailing	0.53±0.09	0.53±0.11						
XP1	NG	Left	0.08±0.04	0.07±0.04	F=0.64	F=1.24	F=5.24	F=1.99	F=0.85	F=0.05
		Right	0.09±0.04	0.07±0.01	p=0.428	p=0.274	p=**0.029**	p=0.168	p=0.364	p=0.823
	OBS	Leading	0.08±0.04	0.09±0.04	Eta= 0.02	Eta= 0.038	Eta= 0.145	Eta= 0.06	Eta= 0.027	Eta= 0.002
		Trailing	0.08±0.03	0.08±0.03						
Loading rate	NG	Left	34.29±10.91	35.73±9.45	F=0.28	F=0.92	F=1.14	F=9.96	F=0. 71	F=16.0
		Right	34.65±13.22	34.55±5.42	p=0.601	p=0.345	p=0.294	p=**0.004**	p=0.406	p=**0.000**
	OBS	Leading	31.74±10.34	33.46±8.87	Eta= 0.009	Eta= 0.029	Eta= 0.035	Eta= 0.243	Eta= 0.022	Eta= 0.34
		Trailing	36.99±13.66	40.73±8.67						

Note: *ID*: intellectual disability; *TD*: typically developing; *ZP1–ZP3*: first to third vertical ground reaction force peaks; *YP1*: braking force; *YP2*: propulsive force; *XP1*: mediolateral force; *NG*: normal gait condition; *OBS*: obstacle-crossing condition; Bolded p-values indicate statistically significant differences ($p<0.05$)

Table 4. Factor Analysis of Ground Reaction Force (GRF) Variables During Running Under Normal and Obstacle-Crossing Conditions in the ID and TD Groups (F and *p* values)

Variables	Gait	Foot	ID	TD	Group	Task	Task* group	Foot	Foot* group	task* foot
			Mean ± SD	Mean ± SD						
ZP1	NR	Left	1.77±0.42	1.85±0.19	F=1.83	F=30.88	F=0.000	F=0.02	F=0.05	F=0.82
		right	1.77±0.40	1.93±0.18	p=0.186	p=**0.000**	p=0.985	p=0.891	p=0.831	p=0.373
	ROBS	Leading	2.01±0.45	2.10±0.15	Eta= 0.056	Eta= 0.499	Eta= 0.000	Eta= 0.001	Eta= 0.001	Eta= 0.026
		Trailing	2.01±0.37	2.16±0.26						
YP1	NR	Left	0.35±0.10	0.33±0.09	F=0.05	F=50.03	F=0.897	F=60.28	F=1.36	F=28.94
		right	0.34±0.09	0.31±0.06	p=0.828	p=**0.000**	p=0.351	p=**0.000**	p=0.253	p=**0.000**
	ROBS	Leading	0.38±0.08	0.37±0.08	Eta= 0.002	Eta= 0.617	Eta= 0.028	Eta= 0.66	Eta= 0.042	Eta= 0.483
		Trailing	0.53±0.10	0.56±0.16						
YP2	NR	Left	0.42±0.11	0.42±0.07	F=0.117	F=2.15	F=0.02	F=64.96	F=3.47	F=20.67
		right	0.47±0.17	0.46±0.08	p=0.734	p=0.152	p=0.885	p=**0.000**	p=0.072	p=**0.000**
	ROBS	Leading	0.48±0. 10	0.51±0.11	Eta= 0.004	Eta= 0.065	Eta= 0.001	Eta= 0.677	Eta= 0.101	Eta= 0.40
		Trailing	0.37±0.10	0.32±0.06						
XP1	NR	Left	0.10±0.05	0.07±0.02	F=7.71	F=8.16	F=3.84	F=10.95	F=0.10	F=12.32
		right	0.09±0.04	0.07±0.03	p=**0.009**	p=**0.008**	p=0.053	p=**0.002**	p=0.754	p=**0.001**
	ROBS	Leading	0.05±0.02	0.04±0.02	Eta= 0.20	Eta= 0.208	Eta= 0.11	Eta= 0.261	Eta= 0.003	Eta= 0.284
		Trailing	0.09±0.04	0.08±0.03						
Loading rate	NR	Left	55.42±21.30	64.30±15.25	F=3.33	F=2.63	F=1.52	F=0.63	F=0.084	F=2.88
		right	63.53±37.34	70.73±22.97	p=0.078	p=0.115	p=0.227	p=0.435	p=0.774	p=0.100
	ROBS	Leading	59.29±30.00	74.87±16.98	Eta= 0.097	Eta= 0.078	Eta= 0.047	Eta= 0.02	Eta= 0.003	Eta= 0.085
		Trailing	62.21±20.52	78.90±22.02						

Note: *ID*: intellectual disability; *TD*: typically developing; *ZP1–ZP3*: first to third vertical ground reaction force peaks; *YP1*: braking force; *YP2*: propulsive force; *XP1*: mediolateral force; *NR*: normal running condition; R*OBS*: obstacle-crossing condition during running; Bolded p-values indicate statistically significant differences ($p<0.05$)

Discussion

The purpose of the present study was to examine differences in spatiotemporal characteristics and GRFs between children with ID and TD children during walking and running, under both normal and obstacle-crossing conditions. Our findings revealed several significant differences that may reflect the motor limitations of children with ID.

According to our results, the spatiotemporal characteristics of NG in children with ID were generally similar to those of the TD group. These findings are consistent with those of Horvat et al. (2012) (12) and Looper et al. (2006) (23), who also reported no substantial differences between ID and TD groups in basic spatiotemporal gait parameters. However, introducing an obstacle into the walking path altered certain gait variables, particularly in the ID group. Specifically, the trailing limb in the ID group showed a significantly lower walking speed compared to both the leading limb and the trailing limb in the TD group. The observed Group × Task × Limb interaction for walking speed suggests that this reduction was not a general slowing but a selective strategy affecting the trailing limb during obstacle crossing. This limb-specific modulation likely reflects increased reliance on anticipatory control and visuospatial working memory during trailing-limb clearance, a phase in which direct visual information about the obstacle is no longer available. The relationship between cognitive components and gait in individuals with ID during dual-task walking, obstacle crossing, or perturbed walking—where an additional cognitive challenge is introduced alongside the gait task—has been evaluated by Axer et al. (2010) (24). They reported that, under such conditions, individuals with ID adopt adaptive strategies such as reducing speed and increasing step width and length to enhance stability. To date, such cognitive challenges have received limited attention in research on gait abnormalities in the ID population. Moreover, studies have shown that visuospatial working memory plays a crucial role in obstacle crossing, especially for successful trailing-limb clearance, where direct visual perception of the obstacle is no longer possible (25, 26). Extensive research has also demonstrated that visuospatial working memory performance (27, 28) and spatial orientation skills (29) are significantly lower in children with ID compared to age-matched peers. Therefore, it appears that during obstacle-crossing gait, children with ID may adopt a strategy of reducing gait speed, particularly for the trailing limb, as an effective means of ensuring safe clearance of the obstacle. Beyond main effects, several significant Group × Task × Limb interactions indicate that gait adaptations in children with ID are context- and limb-specific rather than uniform. In particular, obstacle crossing elicited asymmetric adjustments between the leading and trailing limbs in the ID group, whereas TD children preserved more symmetrical limb behavior across tasks.

The results for spatiotemporal running variables showed that, among all evaluated parameters, running speed was lower in the ID group than in the TD group in both the running and obstacle-crossing conditions. In contrast, no notable between-group differences were observed in the walking task. These findings align with those of Losa et al. (2014), who also reported significantly lower gait speed in children with cognitive impairments during running compared with TD peers, but found no difference during NG (18). According to these authors, the reduced running speed in the ID group may be due to muscle weakness stemming from physical inactivity and a sedentary lifestyle throughout life (29). Consistent with the walking results, our findings also showed that during obstacle crossing, the trailing limb in the ID group exhibited a significant reduction in running speed compared to the leading limb. This may suggest that walking and running speeds are more sensitive to cognitive impairments than other spatiotemporal parameters. In fact, reducing the trailing limb speed may provide additional time for balance recovery after obstacle clearance. This behavioral pattern is similar to that reported in children with DS, who also reduce their crossing speed and adopt more cautious steps to increase stability (20). The presence of significant interaction effects further indicates that reduced running speed in children with ID was expressed differently across limbs, with the trailing limb being disproportionately affected during obstacle crossing. Such limb-dependent regulation of speed suggests a conservative locomotor strategy aimed at maintaining dynamic stability during high-demand tasks rather than a global impairment in running performance.

Ground reaction forces analysis during walking revealed that the vertical ZP1 force in the ID group was significantly greater than in the TD group. In the anterior–posterior direction, braking force (YP1) was also significantly higher in the ID group. According to Van De Walle et al. (2019), the "crouch" gait pattern, characterized by hamstring

shortening and increased knee flexion at initial contact, is commonly observed in children with ID (30). Hoang and Reinbolt (2012) further demonstrated that crouch posture, ranging from mild to severe, can lead to increased GRF during the stance phase of gait (31). Therefore, it is plausible that the crouch posture in the ID group may alter foot-strike mechanics, thereby contributing to the higher GRF values recorded during the initial stance phase. Importantly, the significant Group × Task × Limb interactions for vertical and braking forces indicate that TD children adjusted limb-specific loading patterns in response to obstacle crossing, particularly by increasing trailing-limb forces, whereas children with ID exhibited a more uniform force distribution across limbs and tasks. This reduced limb-specific adaptability may reflect limited flexibility in neuromuscular control when responding to external constraints.

The effect of the task factor (i.e., obstacle crossing) on GRF revealed increased ZP1 in the trailing limb, as well as increased ZP3, YP1, and YP2 in both the leading and trailing limbs of the TD group compared with NG. In contrast, no significant limb differences were observed between the obstacle-crossing and NG conditions in the ID group. The increase in early-stance force in the trailing limb, together with increased step length, may reflect the precision required for accurate foot placement before reaching the obstacle. Additionally, in TD participants, greater vertical and propulsive forces were observed during the final stance phase—forces that are essential for lifting the foot and successfully clearing the obstacle. By contrast, the ID group showed no meaningful difference in propulsive force (YP2) between obstacle crossing and NG. These findings align with those of Rigoldi et al. (2011), who reported that reduced lower-limb power and decreased strength in the hip, knee, and ankle muscles may limit the ability of individuals with ID to generate sufficient force to effectively raise the center of mass, thereby reducing propulsive forces (32).

In the running task, the only between-group difference was observed for XP1, with lateral shear forces generally higher in the ID group than in controls. Lateral force primarily results from medial–lateral shifts in the center of pressure and reflects the individual's effort to prevent sideways falls. Higher lateral forces in the ID group suggest that these children experience greater lateral instability while running and must exert more inward or outward forces through the foot to maintain balance. This observation is consistent with clinical reports indicating that children with motor impairments often display more unsteady walking and running, with increased lateral movements of the trunk and limbs (3). Interestingly, in both groups, obstacle crossing produced a distinct pattern in lateral force: XP1 in the leading limb during ROBS was lower than during running. This may be due to more forward-directed guidance and reduced speed of the leading limb, which plays a stabilizing role to enable successful trailing-limb clearance. Conversely, after clearing the obstacle, a slight lateral imbalance may occur, requiring corrective action by the trailing limb, which explains the higher XP1 values for the trailing limb in both groups. Overall, our data indicate that children with ID face challenges in controlling lateral balance, particularly at higher speeds, and that these difficulties become more apparent under complex conditions such as obstacle crossing. This underscores the importance of targeting dynamic balance and lateral control in rehabilitation programs for these children. The significant Group × Task × Limb interaction for mediolateral forces further supports this interpretation, indicating that obstacle crossing imposed asymmetric lateral control demands that were especially pronounced in the trailing limb. In children with ID, the amplified lateral forces across conditions suggest greater reliance on compensatory mediolateral stabilization mechanisms during complex, high-speed locomotion.

This study has several limitations. The sample size was relatively small and included only girls with mild ID, which may limit the generalizability of the findings to other populations. In addition, participants performed the tasks at self-selected speeds, and differences in running speed between groups may have influenced some kinetic and spatiotemporal outcomes. The study also focused mainly on discrete spatiotemporal and GRF variables and did not assess detailed kinematic, electromyographic, or continuous waveform characteristics.

Conclusion

In summary, the findings of this study indicate that children with ID display distinct gait and running patterns compared to their TD peers, particularly when negotiating obstacles. To maintain balance and safety, they adopt strategies such as reducing trailing-limb speed, increasing leading-limb

cadence, and taking longer steps. These children also exhibit differences in GRFs, characterized by higher initial contact and braking forces, along with reduced propulsive and push-off forces—suggesting impaired shock absorption and diminished forward propulsion. Additionally, greater lateral forces during running reflect poorer lateral balance control in children with ID. Collectively, these results suggest that when faced with dynamic and challenging tasks, children with ID adopt a conservative and less efficient movement pattern, which may increase their susceptibility to early fatigue and reduce their participation in physical activities.

Ethics Approval and Consent to Participate

The current study was approved by the Ethics Committee of Islamic Azad University, Hamedan Branch (Ethics Code: IR.IAU.H.REC.1402.008). All research procedures were performed in accordance with the ethical principles of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to their enrollment in the study.

Consent for Publication

Not applicable.

Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Author's Contribution

M.M. was responsible for data collection, data extraction and preprocessing. M.M. and E.A. contributed substantially to the study conception and design, data analysis and interpretation, and manuscript drafting. All authors reviewed the manuscript, provided feedback, and approved the final version for publication.

Conflict of Interest

All authors declared that there were no conflicts of interest to report.

Declaration of Generative Artificial Intelligence in Scientific Writing

During the preparation of this work, the authors used ChatGPT, an AI-assisted tool, to improve the readability and language of the manuscript. After using this tool, the authors carefully reviewed and edited the content as needed and take full responsibility for the content of the published article.

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