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The association between gait and physical fitness in adults with intellectual disabilities

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Abstract

Background Gait deviations are often seen in adults with intellectual disabilities (ID). Their low physical fitness levels may be associated with these deviations. Understanding the impact of fitness on gait in this population is important for developing interventions to improve gait. In a cross-sectional study, we assessed the association between multiple physical fitness components and spatiotemporal gait parameters in adults with ID.

Method Gait characteristics of 31 adults (42.77 ± 16.70 years) with ID without Down syndrome were assessed with the GAITRite at comfortable (CS) and fast speed (FS), along with fitness assessments (body composition, muscular endurance, strength, balance, Short Physical Performance Battery).

Results At CS, adults with ID with higher BMI and/or waist circumference spent more time in double support. At FS, those with better muscular endurance took steps faster, those with better balance took bigger steps and strides and those with better Short Physical Performance Battery scores took bigger steps and strides at higher velocity.

Conclusions Body composition was mostly associated with gait at CS, while the other physical fitness components were mostly associated with gait at FS. Better fitness may therefore be more important in more challenging conditions. These insights are useful for developing interventions to improve gait in adults with ID.

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Keywords developmental disabilities, motor control, nervous system diseases, physical condition, walking

Introduction

In order to be able to walk, the lower limbs and pelvis generate a propulsive force, maintain an upright stability, minimise the shock of floor impact and conserve energy by reducing the amount of muscular force required (Perry 1992). This requires functioning neural mechanisms, stability and elasticity of musculoskeletal elements and adequate physical fitness, such as sufficient strength and balance to be able to stand upright, bear body weight and move oneself forward (Rubino 2002). The major determinants of the gait pattern are pelvic tilt, rotation and lateral displacement, knee flexion and foot and knee mechanisms (Saunders *et al.* 1953). The upper body does not directly contribute to walking and serves to maintain a neutral alignment with minimal postural changes (Perry 1992).

Deviations in gait can be caused by deformities, muscle weakness, sensory loss, pain and impaired motor control (Perry 1992). Gait deviations are often seen in people with intellectual disabilities (ID; IQ < 70) (Almuhtaseb *et al.* 2014). This is not surprising because motor and cognitive functioning are fundamentally interrelated, and their cognitive limitations may influence their motor development and motor control throughout life (Diamond 2000).

In addition to good motor control, adequate physical fitness levels are needed for a proper gait, that is not causing any problems such as pain, instability, injury or a higher energy expenditure, which may lead to falls, fatigue and future disability and institutionalisation (Verghese *et al.* 2006; Verghese *et al.* 2007; Abellan van Kan *et al.* 2009). Higher levels of cardiorespiratory fitness, lower extremity strength, balance and reaction time were found to be associated with better gait in several populations, such as community dwelling older adults (Ploutz-Snyder *et al.* 2002; Tiedemann *et al.* 2005; Callisaya *et al.* 2010), patients with multiple sclerosis (Sandroff *et al.* 2013) and stroke survivors (Eng & Tang 2007; Taylor-Piliae *et al.* 2012). Physical exercise has also been found effective to improve gait and walking capacity in multiple populations, such as older adults (Gill *et al.* 2004; Eggenberger *et al.* 2015; Bouaziz *et al.* 2016), stroke survivors (Saunders *et al.* 2016) and people with dementia (Bossers *et al.* 2015; Kemoun *et al.* 2010). Because low physical fitness levels have been demonstrated in people with ID (Lahtinen *et al.* 2007; Hilgenkamp *et al.* 2010), this may also influence their gait.

However, little research regarding gait in adults with ID has been done (Almuhtaseb *et al.* 2014), and only few studies have looked at the relationship between physical fitness and gait. Results from previous studies in other populations may not be transferable to this population, because besides low physical fitness levels (Lahtinen *et al.* 2007; Hilgenkamp *et al.* 2010), adults with ID also have lifelong impairments in cognition and motor development/control (Enkelaar *et al.* 2012; Almuhtaseb *et al.* 2014; American Association on Intellectual and Developmental Disabilities 2018), which influence gait and thereby may alter the association between fitness and gait. In the general, population gait continues to mature until age 13–15 years (Froehle *et al.* 2013). With increasing age, cognition and physical fitness start to decline, which both impact gait. However, in adults with ID, maturation of gait does not reach the same level as in the general population (Enkelaar *et al.* 2012), and cognition is impaired throughout life, not just at older age. Because of this, the relative contribution of physical fitness to gait may be greater in this population than in the general population.

Cowley *et al.* (2010) found that lower extremity strength was significantly associated with gait speed in people with Down syndrome (DS) (Cowley *et al.* 2010). However, a progressive resistance training that was effective in increasing leg strength did not result in an increase in gait speed (Cowley *et al.* 2011). On the contrary, other exercise training programmes (treadmill training, obstacle course training, combined aerobic and resistance training) were found to be effective in improving gait in adolescents and adults with ID both with and without DS (Mendonca *et al.* 2011; Enkelaar *et al.* 2012; Hanegem *et al.* 2013; Lee *et al.* 2014). In addition, in a previous study, we found that the physical fitness components manual dexterity, balance, grip strength, muscular endurance and cardiorespiratory fitness were predictive for a decline in mobility (limitations in walking inside and outside the house) in older adults with ID, over a 3-year period (Oppewal *et al.* 2014).

These studies suggest that physical fitness may be related to gait in this population, and we hypothesise that physical fitness may play an important role in having proper gait. However, to our knowledge, the association between multiple physical fitness components and gait parameters has not yet been studied in adults with ID. This is important for understanding the impact of physical fitness on gait and for developing interventions to improve gait in this population. Therefore, we aim to assess the association between physical fitness and spatiotemporal gait parameters in adults with ID. We will assess this for walking at comfortable speed and in a more challenging condition, walking at fast speed.

Methods

Study design and participants

This cross-sectional study was performed in a consort of three ID care organisations and the Chair of Intellectual Disability Medicine of the Erasmus MC University Medical Center Rotterdam in the Netherlands. Inclusion criteria for the study were aged 20 years and older, mild [IQ = 50–69] or moderate [IQ = 35–49] ID and being able to walk without a walking aid. Exclusion criteria were having a diagnosis of Down syndrome, Parkinson's disease, cerebrovascular accident, dementia, Cerebral palsy or a severe visual impairment (vision <0.3). We included individuals aged 20 years and older because this study focuses on adult gait, and gait maturation does not seems to reach the same levels as in the general population or at least not at the same age. Therefore, we included individuals aged 20 years and older to decrease the risk of seeing a gait pattern that is still developing. We excluded individuals with DS because of their distinct gait patterns associated with the physical characteristics of this genetic syndrome (ligament laxity and muscle hypotonia), and this has already been studied extensively in previous research. We excluded individuals with the mentioned neurological diagnoses because we wanted to exclude the specific gait patterns related to these diseases.

Participants were selected from three central locations of these care organisations based on the inclusion and exclusion criteria. We first selected group homes housing this target population. Medical doctors and behavioural therapists of the participating ID care organisations then selected individuals from these homes that met the inclusion criteria. Two hundred individuals met the above mentioned criteria and were invited to participate, resulting in a study sample of 31 participants. Due to a period of reorganisations in the participating care organisations, consent rate was lower than expected, because participating in the study was often considered to be too much of a burden at that time. Informed consent was provided by individuals themselves or by their legal representatives.

Data were collected between December 2014 and July 2015. This study was approved by the Medical Ethical Committee of the Erasmus MC, University Medical Center Rotterdam (MEC-2014-201) and conducted according to the guidelines of the declaration of Helsinki (World Medical Association 2013).

Measurements

Personal characteristics

Sex and age were obtained from the medical doctors and level of ID of behavioural therapists. Level of ID was categorised according to the International Classification of Diseases as mild (IQ = 50–69) and moderate (IQ = 35–49) (World Health Organization 1996). To be able to normalise the gait parameters, leg length was measured from the greater trochanter to the floor, bisecting the lateral malleolus, while the participant was wearing the same shoes as while performing the gait measurements.

Medical information

To describe the study population in detail, the following medical information was collected from medical files: genetic syndrome, use of orthopaedic shoes, medication use (which was then scored into polypharmacy, defined as using five or more medications) and the presence of a visual impairment, diabetes, osteoarthritis, spasticity and contractures of the arms and/or legs.

Prior to the measurements, the Revised Physical Activity Readiness Questionnaire was administered (Thomas *et al.* 1992; Cardinal *et al.* 1996). If any questions were answered with 'yes' or 'unknown' by the professional caregivers of the participants, the medical doctor was contacted to determine whether the participant could safely participate.

Physical fitness

Physical fitness was measured with the ID-fitscan, a standardised physical fitness test battery we composed of tests that were found to be feasible and reliable for people with mild to moderate ID (Hilgenkamp *et al.* 2012, 2013; Oppewal *et al.* 2013). The following fitness tests are part of the ID-fitscan:

Body composition

Body composition was measured with height, weight and waist circumference. Height was measured with a stadiometer (Seca) with the participant wearing no shoes, weight with a digital floor scale (Seca) with participants wearing light clothes and no shoes and waist circumference at the narrowest point between the costal margin and iliac crest over the abdomen without clothes. Body mass index (BMI) was calculated by weight divided by squared height and divided into normal (<25 kg/m^2), overweight (25–30 kg/m^2) and obese (≥30 kg/m^2) (WHO 1995).

Muscular endurance

Muscular endurance was measured with the 30-s chair stand (30sCS) and the 5 times chair stand (5×CS) (Guralnik *et al.* 1994; Rikli & Jones 2001). For the 30sCS, participants had to stand up and sit down again as often as possible in 30 s, without using their hands. The number of complete stances was the test result. For the 5×CS, participants had to stand up and sit down again 5 times as fast as possible. The time needed to complete five stances was the result (in seconds). Validity and reliability of both tests have been confirmed in the general population (Guralnik *et al.* 1994; Jones *et al.* 1999; Rikli & Jones 2001; Freire *et al.* 2012). In addition, test–retest reliability of the 30sCS was moderate to good in older adults with ID (same-day interval ICC = 0.72 and 2-week interval ICC = 0.65) (Hilgenkamp *et al.* 2012).

Strength

We measured grip strength with the Jamar Hand Dynamometer (#5030J1, Sammons Preston Rolyan, USA) in seated position, following the recommendations of the American Society of Hand Therapists (Fess & Moran 1981). Participants had to squeeze the dynamometer with maximum force 3 times for both hands, with 1-min rest between attempts. The maximal score of the six attempts was the test result (in kg). Validity and reliability have been confirmed in the general population (Stark *et al.* 2011; Abizanda *et al.* 2012). In older adults with ID, test–retest reliability was good (same-day interval ICC = 0.94 and 2-week interval ICC = 0.90) (Hilgenkamp *et al.* 2012).

Balance

Static balance was measured with four stances with increasing difficulty: side by side stand, semi-tandem stand, tandem stand and one-leg stand. If the participant was able to maintain the position for 10 s, the participant was further evaluated with the next stand. If needed, carpet feet were used to mark the required position. Validity and reliability have been confirmed in the general population (Guralnik *et al.* 1994; Rossiter-Fornoff *et al.* 1995; Franchignoni *et al.* 1998; Giorgetti *et al.* 1998; Wolinsky *et al.* 2005). In adolescents and young adults with ID, test–retest reliability has also been confirmed (Blomqvist *et al.* 2012). As in the Short Physical Performance Battery (SPPB; described in the section below), a summary score for the three balance stances side by side, semi-tandem and tandem was also calculated, with scores ranging from 0 to 4 points with 4 being the best performance.

Short Physical Performance Battery

Based on the tests in the ID-fitscan, the SPPB score can be calculated. The SPPB is a battery of tests widely used in the general population and is a strong predictor for disability, institutionalisation and mortality (Guralnik *et al.* 1994; Guralnik *et al.* 1995; Guralnik *et al.* 2000). The SPPB total score was calculated based on the results for gait speed, three stances (side by side stand, semi-tandem stand and tandem stand) and the 5×CS. Scores range from 0 to 12 points, with 12 being the best performance.

Gait measurements

Gait was measured with the GAITRite Electronic Walkway, (CIR Systems, Inc., USA; 5.79 m with 4.88 m active area, 120 Hz scan rate). The GAITRite reliably and validly measures temporal and spatial gait parameters (Bilney *et al.* 2003; Menz *et al.* 2004; van Uden & Besser 2004; Kressig *et al.* 2006). Reliability was also confirmed in people with DS (Gretz *et al.* 1998) and elderly with mild cognitive impairment (Montero-Odasso *et al.* 2009). Spatial and temporal parameters were measured over multiple steps at the individual comfortable and fast gait speed of the participants, and the variability over these steps was measured as standard deviations (see Table 2 for the list of calculated parameters).

Procedure

Data collection took place in a large room or a gym at the ID care organisations, and the tests were conducted by a human movement scientist and physiotherapist with experience with people with ID. All gait measurements were performed by the same test instructor.

The GAITRite was placed with 2-m space in front of, and at the end of it, according to the guidelines, to avoid acceleration and deceleration on the GAITRite (Kressig *et al.* 2006). Gait was measured in two conditions: (1) walking at comfortable speed (CS) and (2) walking at fast speed (FS). For condition 1, participants were instructed to walk at the speed they would normally walk; for condition 2, participants were instructed to walk as if they were in a hurry, without running. In each condition, four walks were performed, of which the first walk was considered a practice walk. Participants walked with shoes. The test instructor was not allowed to walk with the participant or support the participant while walking because this could influence gait. After the gait measurements, the physical fitness tests were performed.

Statistical analyses

Personal characteristics, medical information, physical fitness results and gait parameters were described for the study sample. With regard to the gait parameters, the practice walk was excluded from the analyses, and all the gait parameters were calculated as the means of both legs across the three remaining walks.

Normality of the gait parameters was checked and considered sufficient for the CS condition, and spatial and temporal parameters of the FS condition, but not for variability parameters of the FS condition. Parametric tests were used for normal distributed parameters and nonparametric tests for the non-normal distributed parameters.

Differences between the gait parameters in the CS and FS condition were analysed with paired *t*-tests and Wilcoxon signed-rank tests. Effect sizes were calculated with Cohen's *d* (Cohen 1992). Effect sizes of 0.2, 0.5 and 0.8 were used as benchmarks for small, medium and large effects, respectively. Bonferroni correction was used to correct for multiple testing, resulting in $p < 0.002$ (0.05/27 gait parameters) to be considered statistically significant.

To assess the association between physical fitness and the gait parameters, Pearson's and Spearman's correlation coefficients were calculated between each physical fitness test and each gait parameter. For these analyses, all gait parameters were adjusted for leg length by dividing the gait parameters by the mean leg length of both legs. *R* values of 0.1, 0.3 and 0.5 were categorised as benchmarks for small, medium and large effects, respectively (Cohen 1992). From our previous study and preliminary analysis, we know that sex was associated with the gait parameters 'stance' and 'double support as a percentage of the gait cycle' and the standard deviations of 'step time', 'stride time', 'swing time' and 'single support' in the CS condition and with 'stance as a percentage of the gait cycle' in the FS condition. For these parameters, we also assessed the association between each physical fitness test and the gait parameters adjusted for sex with multiple linear regression analyses. Age and level of ID were not associated with gait parameters (Oppewal *et al*. in press).

Analyses were performed with the Statistical Package for Social Science version 21 (IBM Corporation, New York).

Results

Descriptives of the study sample

Table 1 shows the personal characteristics, medical information and physical fitness results of the study sample. The mean age of the study sample was 42.77 ± 16.70 years, 48.4% of the participants had a mild ID, and 77.4% was male.

Gait parameters

The gait parameters at CS and FS are presented in Table 2. Two participants were excluded for analyses in the FS condition, because they did not understand the task condition of walking as if they were in a hurry. In comparison with the CS condition, a significant increase was seen in step and stride length, velocity, stride velocity, cadence and swing and single support time as a percentage of the gait cycle (medium to large effect sizes), along with a significant decline in step time, stride (cycle) time, stance time, swing time, single and double support time and stance time as a percentage of the gait cycle (medium to large effect sizes) in the FS condition. The parameters regarding the width of the gait pattern (base of support and toe in/toe out) did not differ significantly between conditions and neither did the variability parameters.

Associations between physical fitness and gait parameters

Results regarding the associations between physical fitness and the gait parameters are presented in Table 3. A higher BMI and waist circumference was significantly associated with a higher double support

Table 1 Personal characteristics, medical information and physical fitness results of the study sample

		Total study sample (*N* = 31)
Personal characteristics		
Age	Years, *M* ± SD, range	42.77 ± 16.70, 20–68
Sex	Female, *n* (%)	7 (22.6%)
	Male, *n* (%)	24 (77.4%)
Level of ID	Mild (IQ = 50–69), *n* (%)	15 (48.4%)
	Moderate (IQ = 35–49), *n* (%)	16 (51.6%)
Medical information		
Genetic syndrome	No genetic syndrome, *n* (%)	9 (29.0%)
	PKU, *n* (%)	1 (3.2%)
	Mosaic mutation XLIS gene, *n* (%)	1 (3.2%)
	Smith–Magenis syndrome, *n* (%)	1 (3.2%)
	Williams syndrome, *n* (%)	1 (3.2%)
	Perlman syndrome, *n* (%)	1 (3.2%)
	Unknown, *n* (%)	17 (54.8%)
Diabetes	Yes, *n* (%)	2 (6.5%)
Osteoarthritis	Yes, *n* (%)	4 (12.9%)
Visual impairments†	Yes, *n* (%)	4 (12.9%)
Spasticity arms	Yes, *n* (%)	0
Spasticity legs	Yes, *n* (%)	1 (3.2%)
Contractures	Yes, *n* (%)	0
Orthopaedic shoes	Yes, *n* (%)	6 (19.4%)
Polypharmacy (≥5 medications)	Yes, *n* (%)	13 (41.9%)
Physical fitness		
Height	cm, *M* ± SD	170.18 ± 9.22
Weight	kg, *M* ± SD	78.97 ± 14.81
BMI	kg/m^2, *M* ± SD	27.24 ± 4.51
	Normal, *n* (%)	9 (29.0%)
	Overweight, *n* (%)	15 (48.4%)
	Obese, *n* (%)	7 (22.6%)
Waist circumference	cm	95.89 ± 11.91
Muscular endurance 30sCS	No. of reps	11.46 ± 3.91
Muscular endurance 5×CS	s	11.63 ± 4.82
Strength	kg	29.1 ± 11.6
Balance one leg	s	7.1 ± 3.83
Balance SPPB	Points out of 4	3.38 ± 0.98
SPPB total	Points out of 12	10.92 ± 1.38

n = number of participants; *M*, mean; SD, standard deviation; ID, intellectual disability; SPPB, Short Physical Performance Battery.
†Participants with a visual impairment but still with a vision >0.3.

time and double support time as a percentage of the gait cycle at CS. A better muscular endurance, as measured by the 5×CS, was significantly associated with a shorter step time and stride (cycle) time at FS. A better SPPB balance score was significantly associated with a higher step and stride length at FS. A better total SPPB score was significantly associated with a higher step and stride length, velocity and stride velocity at FS. No significant associations were found for the 30sCS, grip strength and one-leg stand. All significant associations represented a large effect size. All other correlations with a *p*-value <0.05 were also medium to large effect sizes; however, after correction for multiple testing, these correlations did not remain significant.

Discussion

In this study, we assessed the association between physical fitness and spatiotemporal gait parameters in

Table 2 Gait parameters at comfortable and fast speed, with the comparison between the two conditions

	Comfortable speed (CS) (n = 31)		Fast speed (FS) (n = 29)		CS vs. FS
	M ± SD	95% CI	*M* ± SD	95% CI	*d*
Spatial parameters					
Step length (cm)	65.28 ± 10.14	[61.56, 69.0]	74.90 ± 12.66	[70.08, 79.71]	−0.84** (large)
Stride length (cm)	130.88 ± 20.25	[123.45, 138.31]	150.23 ± 25.34	[140.59, 159.87]	−0.84** (large)
Base of support (cm)	11.88 ± 3.51	[10.59, 13.17]	11.96 ± 3.54	[10.61, 13.31]	−0.02 (small)
Toe in/toe out (degrees)	7.06 ± 7.17	[4.43, 9.69]	5.39 ± 6.65	[2.86, 7.92]	0.24 (small)
Temporal parameters					
Velocity (cm/sec)	118.36 ± 23.43	[109.76, 126.95]	156.68 ± 41.23	[141.00, 172.36]	−1.14** (large)
Stride velocity (cm/sec)	118.98 ± 23.47	[110.37, 127.59]	157.29 ± 41.10	[141.66, 172.93]	−1.14** (large)
Cadence (steps/min)	108.36 ± 10.19	[104.62, 112.10]	123.94 ± 16.71	[117.58, 130.30]	−1.13** (large)
Step time (sec)	0.56 ± 0.05	[0.54, 0.58]	0.49 ± 0.07	[0.47, 0.52]	1.15** (large)
Stride (cycle) time (sec)	1.12 ± 0.11	[1.08, 1.15]	0.99 ± 0.13	[0.93, 1.04]	1.08** (large)
Stance time (sec)	0.66 ± 0.08	[0.63, 0.69]	0.57 ± 0.09	[0.53, 0.60]	1.06** (large)
Swing time (sec)	0.46 ± 0.04	[0.44, 0.47]	0.42 ± 0.05	[0.40, 0.44]	0.88** (large)
Single support time (sec)	0.46 ± 0.04	[0.44, 0.47]	0.42 ± 0.05	[0.40, 0.44]	0.88** (large)
Double support time (sec)	0.20 ± 0.06	[0.18, 0.22]	0.16 ± 0.06	[0.14, 0.19]	0.67** (medium)
Phasic parameters					
Stance, %GC	58.97 ± 1.99	[58.24, 59.70]	57.47 ± 2.62	[56.47,58.46]	0.64** (medium)
Swing, %GC	41.03 ± 1.99	[40.30, 41.76]	42.54 ± 2.62	[41.54, 43.53]	−0.65** (medium)
Single support, %GC	41.03 ± 1.99	[40.30, 41.76]	42.54 ± 2.62	[41.54, 43.53]	−0.65** (medium)
Double support, %GC	18.08 ± 4.08	[16.58, 19.57]	16.20 ± 4.04	[14.66, 17.74]	0.46* (small)
Variability parameters					
Step length SD	2.99 ± 0.89	[2.66, 3.32]	3.42 ± 1.11	[3.00, 3.84]	−0.43 (small)
Stride length SD	5.29 ± 1.90	[4.59, 5.99]	5.60 ± 2.35	[4.71, 6.49]	−0.15 (small)
Base of support SD	2.51 ± 1.07	[2.12, 2.91]	2.58 ± 1.10	[2.16, 3.00]	−0.06 (small)
Stride velocity SD	7.07 ± 2.84	[6.03, 8.11]	9.66 ± 4.70	[7.87, 11.44]	−0.67 (medium)
Step time SD	0.02 ± 0.01	[0.02, 0.03]	0.02 ± 0.01	[0.02, 0.03]	0
Stride time SD	0.04 ± 0.02	[0.03, 0.04]	0.04 ± 0.03	[0.03, 0.05]	0
Stance time SD	0.03 ± 0.01	[0.026, 0.034]	0.04 ± 0.02	[0.03, 0.05]	−0.63 (medium)
Swing time SD	0.02 ± 0.01	[0.02, 0.03]	0.03 ± 0.02	[0.02, 0.03]	−0.63 (medium)
Single support time SD	0.02 ± 0.01	[0.02, 0.03]	0.03 ± 0.02	[0.02, 0.03]	−0.63 (medium)
Double support time SD	0.03 ± 0.02	[0.02, 0.03]	0.03 ± 0.02	[0.02, 0.04]	0

M = mean; SD = standard deviation; CI = confidence interval; % GC = percentage of the gait cycle, *d* = Cohen's d as effect size (small (0.2), medium (0.5) and large (0.8) effect), a positive effect size means that the mean value in the comfortable speed condition is higher than in the fast speed condition.
*$p < 0.05$.
**$p < 0.002$ (Bonferroni correction).

adults with ID during walking at both comfortable and fast gait speed. At CS, adults with ID with a higher BMI and/or waist circumference spent more time in the double support phase of the gait cycle. At FS, those with better muscular endurance took steps faster (in less time), those with better balance took bigger steps and strides and those with better SPPB total scores took bigger steps and strides at a higher velocity. Thus, body composition was seen to affect gait at CS, but the other physical fitness components mostly affected gait at FS. Body composition may more directly influence gait, while the other physical fitness components may be more important at more challenging conditions, such as while increasing gait speed.

As in the general population, we found that people with ID who were more obese spent more time in double support (Wearing *et al.* 2006). Children with DS who were obese also spent more time in the stance phase than those who were not obese (Galli *et al.* 2015). Additionally, in the general population, it was also seen that people who were obese had a lower

Table 3 Associations between the physical fitness tests and gait parameters.

	BMI		Waist circumference		Muscular endurance (30sCS)		Muscular endurance (5×CS)		Strength		Balance – one leg		Balance – SPPB score		SPPB total score	
	CS	FS	CS	FS	CS	FS	CS	FS	CS	FS	CS	FS	CS	FS	CS	FS
Spatial parameters																
Step length (cm)						0.42*			0.36*	0.47*	0.46*	0.53*	0.56*	0.67**		0.64**
Stride length (cm)						0.42*		−0.45*		0.47**	0.45*	0.52*	0.56*	0.67**		0.64**
Base of support (cm)											−0.44*		−0.37*			
Toe in/toe out (degrees)																
Temporal parameters																
Velocity (cm/sec)					0.43*	0.44*		−0.54*		0.47*		0.44*	0.42*	0.56*		0.64**
Stride velocity (cm/sec)					0.42*	0.44*		−0.53*		0.47*		0.44*	0.42*	0.56*		0.64**
Cadence (steps/min)			−0.50*													0.48*
Step time (sec)								0.61**		−0.44*						
Stride (cycle) time (sec)								0.61**		−0.44*						
Stance time (sec)	0.42**		0.44*					0.57*		−0.39*				−0.39*		−0.43*
Swing time (sec)								0.59*		−0.45*						
Single support time (sec)								0.59*		−0.45*						
Double support time (sec)	0.67**		0.70**	0.52*									−0.37*	−0.55*		−0.51*
Phasic parameters																
Stance, %GC	0.42*‡															
Swing, %GC			−0.51*	−0.48*									0.41*	0.51*		0.42*
Single support, %GC			−0.50*	−0.47*									0.41*	0.51*		0.42*
Double support, %GC	0.73**†	0.48*	0.66**†	0.52*										−0.51*		
Variability parameters																
Step length SD										−0.39*		−0.47*				
Stride length SD										−0.42*		−0.42*				
Base of support SD												−0.40*				
Stride velocity SD																
Step time SD									−0.48*†	−0.47*						

Table 3. *(Continued)*

	BMI		Waist circumference		Muscular endurance (30sCS)		Muscular endurance (5×CS)		Strength		Balance – one leg		Balance – SPPB score		SPPB total score	
	CS	FS	CS	FS	CS	FS	CS	FS	CS	FS	CS	FS	CS	FS	CS	FS
Stride time SD									−0.38*‡	−0.44*						
Stance time SD																
Swing time SD																
Single support time SD																
Double support time SD	0.45*		0.43*													

SD, standard deviation; SPPB, Short Physical Performance Battery; CS, comfortable speed; FS, fast speed.
*$p < 0.05$.
**$p < 0.002$ (Bonferroni correction).
†p still <0.05 after correction for sex.
‡p not <0.05 after correction for sex.

velocity, spent more time in stance phase and less time in swing phase and had a larger base of support (Wearing *et al.* 2006). Except for base of support, we also saw medium to large correlations with these variables; however, these did not remain significant after correction for multiple testing. These gait alterations are thought to be compensation strategies to maintain balance.

People with ID with better physical fitness (muscular endurance, balance and the SPPB total score) seem to have a more favourable gait pattern, implying the importance of physical fitness for gait in this population. A better strength and muscular endurance were associated with walking at higher velocity and thereby a shorter stride (cycle) time and related temporal parameters and with bigger steps and strides, which were taken faster. People with better balance and SPPB total scores tend to take bigger steps and strides, walk at higher velocity and spend less time in stance and double support phase and more in swing and single support phase. In addition, variability of the gait parameters also seemed to be less in those with better strength and balance. However, not all of these correlations remained significant after correcting for multiple testing. Therefore, results need to be replicated in larger samples, but all effect sizes were moderate to large.

Although not all correlations were significant, the size of the correlations between physical fitness and gait seemed to be higher than those seen in community dwelling older adults (Ploutz-Snyder *et al.* 2002; Tiedemann *et al.* 2005; Callisaya *et al.* 2010). The correlations in people with multiple sclerosis and stroke survivors also seem to be higher than those in community dwelling older adults (Eng & Tang 2007; Taylor-Piliae *et al.* 2012; Sandroff *et al.* 2013). Although such a comparison is difficult to make due to differences in the methods and measurements, this supports our hypothesis that physical fitness may be more important for gait in adults with ID than in the general population. These associations found between the physical fitness components and gait parameters provide valuable information for developing interventions to improve gait in this population. Focusing specifically on improving aspects of physical fitness, which are impaired, instead of just increasing physical activity, may result in improvements in gait and thereby decrease negative outcomes associated with gait deviation, such as pain, instability, injury and high energy expenditure.

Looking at norm referenced values for physical fitness for the general population, the physical fitness levels of this study sample are comparable with those of the general elderly population (mostly falling in 70+ years categories) (Guralnik *et al.* 1994; Rikli & Jones 1999; Bohannon *et al.* 2006; Michikawa *et al.* 2009). These low physical fitness levels may not be discriminative enough to be associated with gait at CS in this study sample, because we found the strongest correlations at FS. In the FS condition, we saw that participants walked significantly faster, with bigger steps and strides and that they spent less time in stance phase and more time in swing and single support phase of the gait cycle than in the CS condition. When the condition becomes more challenging, as in walking at faster speed, physical fitness may be more important and discriminating between those who are and those who are not able to adapt their gait. This is an important factor in daily life, for example, when one needs to react to traffic or obstacles in the surroundings. In addition, being able to better increase gait speed may leave more room for maintaining a higher comfortable gait speed for a longer period of time, which is important because comfortable gait speed declines with increasing age (Alexander 1996; Verghese *et al.* 2006), and this is an important predictor for negative health outcomes in the general population, such as future disability, falls, cognitive impairment, institutionalisation and mortality (Verghese *et al.* 2006; Verghese *et al.* 2007; Abellan van Kan *et al.* 2009).

The participants were able to perform the physical measures and overall had good understanding of the tests. Providing clear instructions and taking time to assure understanding are important. Especially, the fast walking speed condition needed some extra time to explain in some cases. A practice walk to assure the participants understand the task is therefore recommended. The GAITRite can have good usability to analyse gait in this population and is more practical and feasible over analyses in a laboratory setting.

This study assessed the association between physical fitness and gait in adults with ID without DS, a group not often studied regarding this topic although gait deviations are often seen in this population. A strong aspect of this study is that the associations between multiple fitness components and a large amount of gait parameters were investigated, to provide insight into which fitness components are important for which gait parameters. However, these results may not be representative for the total population of adults with ID due to the small sample size, the limited number of females and the fact that all participants lived in residential settings of ID care organisations. To facilitate interpretation and comparison with future studies, we provided participant characteristics and medical information that may influence gait. Finally, the small sample size may have led to a low statistical power to find significant associations; therefore, effect sizes were also reported to provide insight in the magnitude of the effect.

In summary, this study was the first to present the association between physical fitness and spatiotemporal gait parameters in adults with ID. Body composition was mostly associated to gait parameters at CS, while the fitness components muscular endurance, balance and the total SPPB score were mostly associated to gait parameters at FS. Insights in these associations can be useful for developing interventions to improve gait in this population. Further research is needed to replicate results, assess the effectiveness of training physical fitness on improving gait in this population and assess the causal relationship between physical fitness and gait deviations.

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Conflict of Interest

The authors report no conflicts of interest.

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