JIDR Journal of Intellectual Disability Research
Published on behalf of mencap and in association with IASSID

Journal of Intellectual Disability Research doi: 10.1111/jir.13132

VOLUME PART 2024

# Effects of a 12-week telehealth exercise intervention on gait speed and gait deviations in adults with Down syndrome

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## Abstract

*Background* Altered gait patterns and reduced walking speed are commonly reported in adults with Down syndrome (DS). Research on the effects of DS-specific exercise programmes on adults with DS is lacking. The purpose of this quasi-experimental study was to evaluate the changes in gait deviations and walking speed in adults with DS after a DS-specific exercise programme.
*Methods* Twenty participants underwent a 12-week, DS-specific exercise programme in a telehealth format. Before and after the intervention, gait deviations were assessed with the Ranchos Los Amigos Observational Gait Analysis form, and comfortable walking speed was evaluated with the 4-m walk test.
*Results* We observed increased comfortable walking speed and reduced gait deviations in the whole gait cycle in adults with DS after the intervention. There were fewer gait deviations during single-leg stance and swing-limb advancement and at the hip, knee and ankle joints after the 12-week exercise programme.
*Conclusions* Gait speed and observable gait impairments in adults with DS significantly improved following a 12-week telehealth exercise programme.

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**Keywords** Down syndrome, exercise, gait, intellectual disabilities, physical therapy, telehealth

## Introduction

Down syndrome (DS) is one of the most common genetic conditions, which results from an additional full or partial copy of chromosome 21 (Trisomy 21) and is known to occur in 1 in 800 births (Hayes & Batshaw 1993; Bull 2020). Individuals with DS present with specific cognitive, musculoskeletal, cardiovascular and endocrine characteristics, which can influence their overall health and motor development (Bull 2020). Due to improvements in childhood survival rates, individuals with DS can now be expected to live well into their 5th and 6th decades of life (de Graaf *et al.* 2017). Although life expectancy has improved, the prevalence of impairments secondary to DS requires further development of interventions, care plans and lifestyle changes to maximise their health and motor development from childhood to older age.

In the musculoskeletal system, individuals with DS often present with skeletal muscle hypotonicity (Foley & Killeen 2019) and systematic ligamentous laxity (Dey *et al.* 2013), which often lead to a barrier to participating in physical activities (Foley & Killeen 2019). Reduced physical activity and a

sedentary lifestyle can contribute to low bone mass, obesity and an inability to develop and maintain maximal muscle strength (Foley & Killeen 2019). In addition, ligamentous laxity can cause hip instability, patellar dislocations, ligamentous injuries, digital deformity of the foot and scoliosis, which ultimately lead to postural and gait deviations (Foley & Killeen 2019). Individuals with DS may also show developmental neurological abnormalities, including reduced volume of the cerebellum, delayed myelination and proprioceptive and vestibular deficits. Taken together, these impairments can cause difficulties in the planning, organisation and sequencing of movement patterns during gait (Cimolin *et al.* 2010).

In the general population, gait speed is directly important for community participation and instrumental activities of daily living; it is also a strong predictor of falls, future loss of mobility, morbidity and mortality (Abellan van Kan *et al.* 2009). Although longitudinal studies on gait speed are lacking for adults with DS specifically, adults with DS were included in a longitudinal study in adults with intellectual disabilities that confirmed the predictive ability of gait speed with adverse outcomes (decline in instrumental activities of daily living, falls and mortality) in this population (Oppewal *et al.* 2014; Oppewal *et al.* 2015; Oppewal & Hilgenkamp 2019). However, DS-specific musculoskeletal concerns impact gait and gait speed in adults with DS. With respect to walking deviations, it has been shown that adults with DS demonstrated a wider base of support and decreased step width, step length and stride length by 20–25% when compared with adults without DS (Rigoldi *et al.* 2011; Horvat *et al.* 2012). The current literature also reports that adults with DS have a 25% slower walking speed when compared with adults without DS (Agiovlasitis *et al.* 2009; Rigoldi *et al.* 2011; Horvat *et al.* 2012). Individuals with DS also show reduced sagittal-plane range of motion in the hip, knee and ankle during the gait cycle when compared with their age-matched controls (Rigoldi *et al.* 2011). Due to the reduced sagittal-plane movements during gait, a compensatory strategy that incorporates more frontal-plane hip range of motion is developed, thereby diminishing the efficiency of gait propulsion and progression in adults with DS (Rigoldi *et al.* 2011). During gait initiation, adults with DS showed reduced postural control when compared with controls, as evidenced by increased centre of mass excursions in the medial–lateral and anterior–posterior directions (Corsi *et al.* 2019). In addition, adults with DS showed slower responses during gait initiation when compared with controls without DS, which may be related to the presence of motor disturbances (Corsi *et al.* 2019). Despite the importance of gait and gait speed for community participation and independence, research on interventions to optimise gait in adults with DS is lacking.

Exercise intervention has been proven to improve gait in children and adolescents with DS. Smith *et al.* (2007) reported improved stiffness and impulse during walking after a 4-day treadmill training programme in preadolescents with DS. In another intervention study, an 8-week balance exercise programme was shown to improve the temporospatial gait parameters in adolescents with intellectual disabilities (Lee *et al.* 2014). However, the literature regarding the effects of exercise interventions on gait speed and deviations in adults with DS is somewhat limited. One study investigated the effects of Nordic walking training on gait in adults with DS (Skiba *et al.* 2019), and another study investigated a treadmill walking intervention (Carmeli *et al.* 2004). Both showed positive effects on walking speed and duration. However, these interventions were quite specialised, and it is unknown whether a combined aerobic and resistance exercise programme focused on DS-specific musculoskeletal issues would elicit the same effects. Thus, the purpose of this study was to evaluate the effects of a 12-week exercise programme on gait impairments in adults with DS. This study was conducted using a telehealth protocol due to stay-at-home orders during the COVID-19 pandemic. Telehealth has been shown to be a feasible delivery method for adults with DS in recent studies (Ptomey *et al.* 2018; Santoro *et al.* 2021). Our exercise programme incorporated a number of elements that specifically address the needs for DS, including foundational movements, hip strengthening, visual/vestibular activities and cardiovascular activity, which has been shown to improve balance in adults with DS (Guerrero *et al.* 2022). We hypothesised that a 12-week telehealth exercise intervention would improve gait speed and reduce the number of gait deviations found in individuals with DS.

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## Methods

### Participants

The participants were recruited between 2020 and 2021 by distributing flyers among local organisations involved in furthering research and supporting DS awareness, attending events for individuals with DS and through social media sharing. Eligibility criteria for participation in this study were checked by self-report in an online Zoom meeting using the Health Insurance Portability and Accountability Act (HIPAA)-compliant version. Inclusion criteria were age 18–35 years, generally healthy (no chronic diseases), sedentary or low-active lifestyle (less than 30 min of moderate-intensity physical activity per day), functioning thyroid [normal thyroid function or stable thyroid function (and medications) for at least 6 months] and a diagnosis of DS. The exclusion criteria for this study included a history of atherosclerosis or any other cardiovascular disease, hypertension or hypotension, diabetes, severe obesity (body mass index $> 40$ kg/m$^2$), current smoking, the presence of asthma or any other pulmonary disease, as well as current pregnancy. Additionally, participants were screened for safe participation in exercise with the Physical Activity Readiness Questionnaire, as recommended by the American College of Sports Medicine (ACSM 2022). It was estimated that a sample size of 18 was required to detect a difference with a repeated design using a power of 0.8, an alpha level of 0.05 and an assumed correlation between pre and post of 0.7. This was based on changes in peak $VO_2$ in adults with DS after a training programme (Rimmer *et al.* 2004), as our study of gait deviations was part of a larger study concerning the effects of exercise in individuals with DS. For this study, we recruited a total of 20 participants to account for an estimated 5% dropout rate. During a Zoom meeting, the informed consent form was discussed, which specifically included video recording of the data collection. Participants and their parents/legal representatives then signed the informed consent form and sent the original form by mail to the research team. This study was approved by the Institutional Review Board of the University of Nevada, Las Vegas (#1442844-EXP).

### Procedure

For each participant, comfortable walking speed and observational gait analysis were obtained before and after a 12-week remote exercise intervention programme. Given the circumstances surrounding the COVID-19 pandemic in the USA and to maintain the health and safety of our participant population, this study was conducted via Zoom Video Communications (Zoom Inc. 2020, San Jose, CA, USA) software. Utilising Zoom with a HIPAA-compliant licence, the research team organised three trained researchers to remotely instruct the participants in each of the tests and measures conducted. Participants were given supplies needed for accurate and reliable testing measurements, which included a 4-m length of string, a tripod mount, a wide-view lens camera that can be attached to a smartphone or tablet, a stopwatch and painter's tape. Additionally, written instructions and supplemental demonstration videos were provided to both the caregiver (i.e. assistant) and participant to familiarise them with the expectations of the testing session and to reduce possible confusion or anxiety related to testing procedures.

The participants attended one testing session prior to the intervention as well as one testing session after the intervention concluded. During each testing session, a facilitating researcher would provide instructions, while a secondary researcher would collect data and measurements remotely. The secondary researcher would have audio and video disabled to ensure the comfort of the participant. The participants had a caretaker present at the test time, and they would assist with collecting times, setting up equipment or providing safety supervision for the tasks. For this study, we measured comfortable walking speed using the 4-m walk test (4mWT) (Fritz & Lusardi 2009; Goldberg & Schepens 2011; Bohannon & Wang 2019) and gait deviations using the Ranchos Los Amigos Observational Gait Analysis (OGA) full body form (Center 2001). To achieve this, all sessions were recorded to allow for double-checking of walking speed and measurement of OGA.

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## Outcome measures

### *Comfortable walking speed*

The 4mWT was chosen to measure comfortable walking speed due to previous research showing the efficacy of using this test to analyse an individual's functional mobility level in a home setting. Fritz & Lusardi (2009) reported that gait speed is a reliable, sensitive and specific measure that provides valuable insights on two important factors of overall health, including an individual's functional capacity and balance confidence. Age-related cut-off scores for gait speed can be used as predictive measures for health status, functional decline, risk of future falls, fear of falling and quality of life across all ages and health conditions (Fritz & Lusardi 2009). Therefore, gait speed can be used to reliably track the progression of speed during exercise interventions and can be compared with specific, reliable cut-offs. Due to the safety concerns of the COVID-19 pandemic, the outcome measures used had to be feasible in the home environment (Fritz & Lusardi 2009). Fritz and Lusardi also produced evidence that a 10-ft walking test can be considered both reliable and valid. Therefore, the 4mWT was used as a short walking test (Fritz & Lusardi 2009; Bohannon & Wang 2019). Previous research has shown that assessing gait speed over shorter distances has high reproducibility across trials, further supporting the 4mWT as a reliable measurement tool (Graham *et al*. 2008; Goldberg & Schepens 2011).

Participants and their assistants used the pre-measured 4-m string to mark the beginning and end of the 4mWT on a hard, level surface. Each end of the string was demarcated with blue tape to cue the participant as well as provide a clear point for the research team to reference when analysing the video. The participant and their assistant were provided detailed instructions for setting up camera angles to allow for an anterior and posterior view of the participant walking at a comfortable walking speed. The camera and tripod were positioned to view the entire walkway and whole body of the participant. Participants occasionally required cueing and pre-trial attempts to walk at a comfortable walking speed. The facilitating researcher would, at times, prompt the participant's assistant to determine if the gait quality appeared typical for their function. The time required for 4mWT was recorded by the assistant with a stopwatch that had an audio function to ensure accurate timing. When the participant was ready, they began walking at their comfortable speed across the 4 m, and the stopwatch was stopped once participants crossed the tape and the time was recorded. Both the research team and caregiver recorded times for each trial. The participants were asked to complete a total of three trials. Breaks were allowed in between trials if needed but did not exceed 1 min. For each trial, the comfortable walking speed was calculated as 4 m divided by the time required for the trial. The average time of the three trials was calculated for each participant to be used in the statistical analyses.

### *Observational Gait Analysis*

The Rancho Los Amigos OGA was selected because of its usability to observe kinematic changes in gait over time, its reproducibility and its easy application in video analysis (Center 2001). A previous study indicated that the OGA conducted through video observation had both high intra-observer and inter-observer reliability while assessing the gait mechanics of the push-off phase of the foot in individuals post-stroke (McGinley *et al*. 2003). The OGA has also demonstrated a moderate to substantial intra-rater reliability and a fair-to-moderate inter-rater reliability and concurrent validity at the ankle, knee and hip in the sagittal plane when analysing the gait of people with spastic cerebral palsy (Groth & Novak 1999).

The OGA is separated into distinct functional task periods of gait during gait, including weight acceptance (WA), single-limb support (SLS) and swing-limb advancement (SLA) (Center 2001) (Appendix 1). Each functional task period is further divided into specific phases of gait in which deviations can be observed and clinically evaluated. WA includes the phases of initial contact (IC) and loading response (LR), in which the reference limb is outstretched and contacts the ground and weight is loaded onto the limb. SLS includes mid-stance (MSt) and terminal stance (TSt), in which the weight is transferred from one leg to the metatarsal heads and the heel raises from the ground. SLA includes pre-swing (PSw), initial swing (ISw), mid-swing (MSw) and terminal swing (TSw), in which the reference limb prepares and leaves the ground behind the body and then swings to the front of the body

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(Martin *et al.* 2009). The OGA consists of descriptive data points to determine if specific gait deviations were present or not in different body regions (trunk, hip, knee, ankle and foot) during different parts of the gait cycle.

Participants and their assistants were given detailed instructions for a proper camera set up on the provided tripod to observe the whole body of the participant in anterior, posterior and lateral views, as well as proper attire. Due to the nature of flat-foot prevalence in this population, this study requested that participants wear their most comfortable and supportive shoes/insoles, as this would be consistent with community ambulation conditions. The camera captured the participants walking at least one complete gait cycle on each limb in the anterior, posterior and lateral views. Participants first performed the first three trials at their comfortable walking speed while recorded in an anterior/posterior view, which was recorded as the participant walked away from the camera and towards the camera. This provided the research team with three video samples of the anterior aspect of the participant and three video samples of the posterior aspect of the participant. Three additional trials were performed in a lateral view, in which the participant walked at least one gait cycle past the camera with the camera positioned on the right or left side of the participant. This provided the research team with three video samples of the right lateral side of the participant and three video samples of the left lateral side of the participant. When the camera was unable to capture the participant's entire body throughout the gait cycle, a wide-angle lens was attached to the camera to expand the frame of the recorded video.

## Intervention

The Mann Method™ PT exercise programme used for this study was an online, 12-week integrative exercise programme developed and provided by a PT with extensive experience working with adults with DS (Sarah Mann, PT, DPT, MBA, NSCA-CPT) (Guerrero *et al.* 2022; Mann *et al.* 2023). Participants attended three virtual, live and interactive exercise sessions per week for a total of 12 weeks through the HIPAA-compliant version of Zoom. The exercise sessions were approximately 1 h in duration. Attendance was recorded every session, and participation was monitored through a heart rate monitor around the upper arm (Polar OH1), which was connected to a mobile app (Polar Beat). Heart rate data were saved after each session in a personal account created for this study, and this allowed the research team to access these data remotely. Within each session, 10 min was allotted to foundational movements, 15 min to hip strengthening, 15 min to visual/vestibular activities, 20 min to cardiovascular exercise and 5 min to cool down. See Table 1 for a more detailed description of the exercises in each session. The rationale for the exercise programme and a visual chart of all the exercises and instructions are provided elsewhere (Mann *et al.* 2023).

Each session of the exercise intervention included a warm-up, and the session was concluded with a cool-down period of stretching the lower and upper extremities. Participants and assistants of participants were provided time to ask questions, share their experiences and receive additional information if needed.

## Data processing

To extract data from the OGA form, a binary coding system was used to numerically characterise the qualitative characteristics of gait (McConnell & Silverman 2015). A digitised adaptation of the original OGA used in this study can be found in Appendix 1. The OGA consists of descriptive data points to determine if specific gait deviations were present or not; within, there were deviations that were classified by the OGA as 'minor deviations' and 'major deviations'. If a particular gait deviation was observed at least once throughout the sample videos of participant gait, a '1' was attributed to that deviation. For deviations not observed, the deviation would be attributed a '0' (McConnell & Silverman 2015). Data were summarised by major deviations, minor deviations and total deviations of body regions (trunk, pelvis, hip, knee and ankle) and phases of gait (IC, LR, MSt, TSt, PSw, ISw, MSw and TSw). The OGA examined changes in trunk and pelvic deviations, but these findings were omitted due to the variability in participant clothing. This study also omitted toe deviations present in the original OGA as they were not observable with shoes. Therefore, we only used the total number of deviations of the body regions (hip, knee and ankle), total gait cycle and functional

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**Table 1** Overview of the exercises in each session of the exercise programme

| Component | Description | Exercises included in each session |
|---|---|---|
| Cardiovascular endurance | Sequencing exercises and progressions that enhance cardiovascular endurance over the course of the session | Dancing warm-up and second dance bout at the end of the session prior to the cool-down, repeated forward jumps and medial/lateral jumps, and hip abduction/adduction jumps |
| Foundational movement exercise | Multi-joint movements targeting activation and strength of abdominals, gluteals, hip musculature, trunk musculature, upper extremity musculature and improving neuromuscular sequencing | Squats, squats with the assistance of exercise balls, planks, modified planks, push-ups and gluteal bridges |
| Hip strengthening | Specific exercises targeting gluteal and lateral hip musculature, transfer patterns and stability | Hip abduction, standing marches, quadruped exercises, transfers, tall-kneeling tasks, half kneeling tasks, clamshells and single-leg balance |
| Visual–vestibular exercises | Balance and coordination exercises targeting the visual–vestibular systems and integrating stabilisation challenges | Weight shift progressing to single-leg balance, righting reactions, lateral tilts, rotational ball passes (horizontal and diagonal), anterior/posterior tilts in standing (sagittal-plane weight shift in modified tandem stance) and over–under passes |
| Stretches | Targeted positions and movements addressing muscle tightness, postural asymmetry, postural musculature and decreased muscle length of gastrocnemius/soleus complex, hamstrings, hip flexors and lumbar extensors | Chest openers, overhead reaches, single knee to chest (supine), seated hurdler stretch and calf stretch (supine) |

tasks of gait (WA, SLS and SLA) for statistical analysis. The student researcher who performed the observations and data collection using OGA was trained and educated previously on gait analysis in the Doctor of Physical Therapy programme and had prior experience utilising the OGA analysis form. To reduce possible bias in OGA data collection, pre-intervention data were collected and processed by the research team prior to the collection and subsequent processing of post-intervention OGA data. All videos were analysed and scored by the same student researcher (R. L.).

### Statistical analysis

The normality of the 4mWT data was checked with the Shapiro–Wilk test. Paired *t*-tests were then performed to compare the comfortable walking speed before and after the remote exercise intervention. Observational gait data from the OGA from before and after the intervention were compared with Wilcoxon signed-rank tests as the data were not normally distributed. For all analyses, IBM SPSS Statistics for Windows version 26.0 by IBM Corp. (Armonk, NY, USA) was used.

## Results

Eighteen participants completed both pre-intervention and post-intervention data collection sessions (Table 2). Of the original 20 participants recruited, one was lost due to a dropout for reasons unrelated to the programme. The other participant was omitted from these results due to an injury that occurred outside of the exercise intervention and ultimately prevented OGA analysis in post-testing. The overall attendance rate of the programme was 93% for the 19 participants who completed it.

Comfortable walking speed was significantly faster after the exercise intervention (Table 3). There was also a statistically significant lower number of total deviations in the gait cycle after the intervention (Table 3). While there was no change in the WA task after intervention, significantly fewer deviations were found in the SLS and SLA tasks (Table 3). When examining the gait deviations of the body parts,

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**Table 2** Participant characteristics

| | Mean ± SD | Range |
|---|---|---|
| Age (years) | 25.7 ± 4.7 | 19–34 |
| Height (m) | 1.6 ± 0.1 | 1.3–1.8 |
| Weight (kg) | 73.1 ± 14.8 | 51.3–101 |
| Sex | 13 males and 5 females | |
| Waist circumference (cm) | 93.4 ± 12.5 | 78.5–119.0 |
| Hip circumference (cm) | 106.7 ± 11.8 | 91.0–128.5 |
| Calf circumference (L, cm), (R, cm) | (37.8 ± 4.5), (37.9 ± 4.7) | 31.0–47.0, 30.5–46.0 |

SD, standard deviation.

**Table 3** Comparisons of the numbers of gait deviations in the gait cycle, three functional tasks and three joints, and comfortable gait speed before and after intervention

| | Pre Mean ± SD | Post Mean ± SD | *P*-value |
|---|---|---|---|
| Gait cycle | 79.9 ± 25 | 58.2 ± 27.1 | 0.003* |
| Weight acceptance (WA) task | 11.8 ± 4.9 | 9.7 ± 5.7 | 0.088 |
| Single-limb support (SLS) task | 22.6 ± 6.4 | 16.2 ± 6.7 | 0.004* |
| Swing-limb advancement (SLA) task | 45.4 ± 15.7 | 32.3 ± 15.9 | 0.006* |
| Hip | 18.5 ± 5.3 | 12.8 ± 7.9 | 0.005* |
| Ankle | 13.9 ± 5.58 | 8.5 ± 6.6 | 0.000* |
| Knee | 10.4 ± 4.1 | 6.9 ± 4.4 | 0.009* |
| Comfortable walking speed (m/s) | 0.82 ± 0.21 | 0.98 ± 0.22 | 0.004* |

*Significant *P*-value $< 0.05$.
SD, standard deviation.

significantly fewer deviations were found after intervention in the hip, knee and ankle (Table 3). The primary deviations most frequently observed were the presence of hip external rotation and/or hip abduction and ankle eversion throughout the gait cycle of the ankle. Additionally, insufficient knee extension was observed during MSt, TSt and/or PSw periods.

## Discussion

The purpose of this study was to evaluate the changes in gait performance of adults with DS after a 12-week, remote, DS-specific exercise intervention. Overall, improvements in gait were seen in a faster comfortable walking speed and decreased total deviations in the whole gait cycle. When looking into specific functional tasks and joints in a gait cycle, we observed fewer deviations in SLS and SLA and in all three joints in the lower extremity after the intervention. Our findings support our hypothesis that a 12-week exercise intervention programme can increase gait speed and reduce the number of gait deviations in adults with DS.

The importance of gait speed has been thoroughly investigated with regard to its impact on mortality and the incidence of cardiovascular disease (Veronese *et al.* 2018). Gait speed has also been described in the literature as the sixth vital sign as it is related to an individual's functional mobility (Middleton *et al.* 2015). Bohannon & Wang (2019) demonstrated that the mean gait speed of adults aged 18–85 years measured using a 4mWT is 1.12 ± 0.23 m/s. Even though gait speed was significantly faster after the intervention, it was still

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slower than the average of the Bohannon and Wang study. In addition to the improvement in gait speed being statistically significant, it is important to assess how clinically relevant this change is. Although our study included a younger population, comparison with research on older adults in the general population can be relevant because of the early aging process in adults with DS (Bull 2020). A systematic review analysed gait speed with the 4mWT and found that the minimal clinically important difference from 0.10 to 0.20 m/s may be significant across different patient populations (older adults with multiple sclerosis, hip fracture and stroke) (Bohannon & Glenney 2014). Similarly, a previous study used the 4mWT to assess gait speed in older adults and reported that the minimum detectable change in gait speed must exceed 0.11 m/s to account for any measurement errors (Goldberg & Schepens 2011). In this study, we observed a 0.16 m/s increase in walking speed (pre: 0.82 ± 0.21 m/s; post: 0.98 ± 0.22 m/s) in persons with DS after the 12-week exercise intervention, which exceeds both the minimum detectable change and the minimal clinically important difference from those previous studies. For adults with DS, this increase in gait speed directly impacts their community participation and independence (Oppewal *et al.* 2015) and will likely lower their risk of future negative health outcomes and sarcopenia (Oppewal *et al.* 2014; Coelho-Junior *et al.* 2019; Oppewal & Hilgenkamp 2019). Overall, our data highlight the importance of a DS-specific exercise programme in improving gait speed in the adult population with DS.

Prior to the intervention, gait deviations in participants with DS were most frequently noted at the hip joint, followed by the ankle and knee joints. Regarding the hip joint, the primary deviations observed were the presence of hip external rotation and/or hip abduction throughout the gait cycle. In the ankle joint, the prominent deviation noted was ankle eversion during the gait cycle. In terms of the knee joint, the primary deviation identified was insufficient extension during MSt, TSt and/or PSw periods. These findings are consistent with the results reported by Rigoldi *et al.*, which demonstrated that adults with DS exhibited inadequate sagittal-plane knee range of motion throughout the gait cycle. This diminished range of sagittal-plane movements may result in the adoption of a compensatory strategy involving the utilisation of range of motion from alternative joints in different planes (Rigoldi *et al.* 2011).

With respect to gait deviations in adults with DS, our data showed reductions in gait deviations after the 12-week training programme in the whole gait cycle, SLS and SLA tasks and all three joints of the lower extremity. As described previously, altered spatiotemporal parameters (Rigoldi *et al.* 2011; Horvat *et al.* 2012), lower extremity kinematics (Rigoldi *et al.* 2011), reduced gait speed (Rigoldi *et al.* 2011; Horvat *et al.* 2012) and quality of postural control/reactions during gait (Corsi *et al.* 2019) may contribute to disturbance in gait initiation and progression, leading to a high number of gait deviations observed in this population before intervention. Improvements in gait, with fewer deviations at the level of the hip, knee and ankle, may attenuate the risk of lower extremity musculoskeletal issues. For example, research indicates that increased deviations in knee movement in the frontal and sagittal planes are associated with knee osteoarthritis (Kobsar *et al.* 2019). Furthermore, minimising these deviations has been shown to improve knee pain and function in adults with knee osteoarthritis (Cheung *et al.* 2018). The improvement in the gait deviations after the 12-week intervention may be attributed to the exercise components that specifically targeted core, hip and lower extremity strengthening, as well as balance and postural controls in DS, which allow the neuromuscular system to execute the movements more efficiently during gait. Interestingly, while there was a trend towards reduced gait deviations, we did not observe a difference in gait deviation before and after intervention in the WA, which is a double-limb support phase. It is likely that our exercise programme primarily improved SLS and SLA, which require higher balance control and muscle strength demand. Another explanation of why there was no difference in gait deviation change in the WA task was that WA only consists of IC and LR, which allows for much fewer deviations available for observational analyses.

While this study provides support for the benefits of DS-specific exercise interventions for improving gait speed and gait deviations in adults with DS, several limitations should be acknowledged. First, we did not include a control group (e.g. adults without DS and/or adults with DS that do not receive the intervention). This limits our ability to definitively attribute any

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changes to the exercise programme. Future studies that include both experimental and control groups will be beneficial to validate the effects of DS-specific exercise programmes in adults with DS. Second, the data analysis was observed through different recording devices by participants, which created variability in the quality of some images. Video analysis was limited at times by frame rates and resolution related to the variability in participant devices and internet connectivity, resulting in reduced clarity of images. Third, this study lacked the standardisation typically seen in experimental studies, which was seen in the variability in each participant's clothing, surface compliance that each participant ambulated on and background distractions that are unique to each participant's home environment. Participants were consistently asked to wear comfortable shoes and to wear shorts and t-shirts of differing colours for ease of analysis. These variables may have affected the reproducibility of our tests and measures.

In conclusion, gait speed and observable gait deviations were significantly improved after a 12-week remote combined exercise programme for adults with DS. The results of this study support clinicians using remote exercise interventions addressing foundational movement, hip strengthening, visual–vestibular training and cardiovascular endurance to improve gait speed and reduce gait deviations in individuals with DS. The success of the telehealth protocols used in this study further indicates that telehealth may continue to be a valid intervention and data collection method in future research that involves adults with DS.

## Acknowledgements

We would like to thank the participants and their families for participating in this research study.

## Source of Funding

This research was funded by the Eunice Kennedy Shriver National Institute of Child Health and Human Development (R00HD092606).

## Conflict of Interest

None of the authors have any conflict of interest to disclose, except author S. M., who is the founder of Mann Method PT and Fitness.

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## Ethics Statement

The Institutional Review Board of the University of Nevada, Las Vegas, approved this study (#1442844-EXP). All participants and their legally authorised representatives provided written informed consent before participating in this study.

## Clinical Trial Registration

This study was registered as a clinical trial on ClinicalTrials.gov, identifier: NCT04647851.

## Data Availability Statement

Data are available upon request.

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## Appendix: Observational Gait Analysis score sheet (Google Sheets 2021)

| | | IC | LR | MSt | TSt | PSw | ISw | MSw | TSw | Total major deviations | Total minor deviations | Total deviations | Trunk deviations |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Trunk | Lean: B/F | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Major: 0 |
| | Lateral lean: L/R | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | N/A | 0 | Minor: 0 |
| | Rotates: B/F | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | N/A | 0 | 0 | Total 0 |
| Pelvis | Hikes | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Pelvis deviations |
| | Tilt: PA | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | N/A | 0 | 0 | Major: 0 |
| | Lack forward rotation | | 0 | | | | | | 0 | 0 | 0 | 0 | Minor: 0 |
| | Lack backward rotation | | | | 0 | 0 | 0 | | | 0 | 0 | 0 | Total: 0 |
| | Excess forward rotation | | 0 | 0 | | | | 0 | 0 | N/A | 0 | 0 | |
| | Excess backward rotation | | | 0 | 0 | 0 | 0 | 0 | | N/A | 0 | 0 | |
| | Ipsilateral drop | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | Contralateral drop | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Hip | Flexion: Limited | | 0 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Hip deviations |
| | Flexion: Excess | | 0 | | | | 0 | 0 | 0 | 0 | 0 | 0 | Major: 0 |
| | Inadequate extension | | | 0 | 0 | 0 | | | | 0 | 0 | 0 | Minor: 0 |
| | Past retract | | | | | | | | 0 | 0 | N/A | 0 | Total: 0 |
| | Rotation: IR/ER | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | N/A | 0 | 0 | |
| | Ad/abduction | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | N/A | 0 | 0 | |
| Knee | Flexion: Limited | | 0 | | | 0 | 0 | | | 0 | N/A | 0 | Knee deviations |
| | Flexion: Excess | | 0 | | | 0 | 0 | 0 | | 0 | 0 | 0 | Major: 0 |
| | Inadequate extension | | | 0 | 0 | | | | 0 | 0 | N/A | 0 | Minor: 0 |
| | Wobbles | | 0 | 0 | 0 | | | | 0 | 0 | N/A | 0 | Total: 0 |
| | Hyperextension | | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | |
| | Extension thrust | | 0 | 0 | 0 | 0 | | | 0 | 0 | 0 | 0 | |
| | Varus/valgus: Vr/Vl | | 0 | 0 | 0 | 0 | | | | 0 | 0 | 0 | |
| | Excess contralateral flex | | | | | 0 | 0 | 0 | 0 | 0 | N/A | 0 | |
| Ankle | Forefoot contact | 0 | | | | | | | | 0 | N/A | 0 | Ankle deviations |
| | Flat-foot contact | 0 | | | | | | | | 0 | N/A | 0 | Major: 0 |
| | Foot slap | | 0 | | | | | | | 0 | N/A | 0 | Minor: 0 |
| | Excess plantar flexion | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Total: 0 |
| | Excess dorsiflexion | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | Inversion/eversion: Iv/Ev | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | Heel off | | 0 | 0 | | | | | | 0 | N/A | 0 | |
| | No heel off | | | | 0 | 0 | | | | 0 | N/A | 0 | |
| | Drag | | | | | | 0 | 0 | 0 | 0 | N/A | 0 | |
| | Contralateral vaulting | | | | | 0 | 0 | 0 | 0 | 0 | N/A | 0 | |
| | Major deviations (phases) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| | Minor deviations (phases) | N/A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |
| | Total deviations (phases) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | |

IC, initial contact; LR, loading response; MSt, mid-stance; TSt, terminal stance; PSw, pre-swing; ISw, initial swing; MSw, mid-swing; TSw, terminal swing; N/A, not applicable.

*Accepted 21 February 2024*

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