

THE EFFECT OF EXERCISE PROGRAMMES ON PHYSICAL AND PHYSIOLOGICAL HEALTH INDICATORS IN INDIVIDUALS WITH DOWN SYNDROME: A SYSTEMATIC SCOPING REVIEW

Ahmet Kurtoğlu^{A, B, C, D, E}

Department of Coaching Education, Faculty of Sport Science, Bandirma Onyedi Eylul University, Balıkesir, 10200, Turkey
e-mail: akurtoglu@bandirma.edu.tr
ORCID: 0000-0002-9292-5419

Bekir Çar^{B, C, D}

Department of Recreation, Faculty of Sport Science, Gazi University, Balıkesir, 06330, Turkey
ORCID: 0000-0001-7422-9543

Özgür Eken^{B, C, D}

Department of Physical Education and Sport Teaching, Faculty of Sport Science, Inonu University, Malatya, 44280, Turkey
ORCID: 0000-0002-5488-3158

Burçin Akçay^{B, D}

Department of Physiotherapy and Rehabilitation, Faculty of Physical Therapy and Rehabilitation, Dokuz Eylül University, İzmir, 35210, Turkey
ORCID: 0000-0002-0883-0311

Ertuğrul Kurtoğlu^{A, B}

Department of Cardiology, Medical Faculty, Malatya Turgut Ozal University, Malatya, 44210, Turkey
ORCID: 0000-0001-5835-087X

Ebru Kaya Mutlu^{B, C, D}

Department of Physiotherapy and Rehabilitation, Faculty of Health Science, Bandirma Onyedi Eylul University, Balıkesir, 10200, Turkey
ORCID: 0000-0002-8595-5513

Serhat Kılıçarslan^{B, C, D}

Department of Software Engineering, Faculty of Engineering and Natural Sciences, Bandirma Onyedi Eylul University, Balıkesir, 10200, Turkey
ORCID: 0000-0001-9483-4425

Emrah Dönmez^{A, B, D}

^{*}Department of Software Engineering, Faculty of Engineering and Natural Sciences, Bandirma Onyedi Eylul University, Balıkesir, 10200, Turkey
ORCID: 0000-0003-3345-8344

Zeynep Taçgın^{B, D}

Department of Finance, Banking and Insurance, School of Social Sciences, Marmara University, Istanbul, 34722, Turkey
ORCID: 0000-0001-7827-8238

Ozan Bahadır Türkmen^{A, B, D}

Department of Physiotherapy and Rehabilitation, Faculty of Health Science, Bandirma Onyedi Eylul University, Balikesir, 10200, Turkey
ORCID: 0000-0002-1799-3286

Musa Türkmen^{B, D}

Department of Physical Education and Sport, Institute of Health Science, Inonu University, Malatya 44280, Turkey
ORCID: 0000-0001-5606-444X

Mehmet Emek Koca^{B, D}

Department of Physical Education and Sport, Institute of Postgraduate Education, Bandirma Onyedi Eylul University, Turkey
ORCID: 0000-0002-5447-1030

^AStudy design; ^BData collection; ^CStatistical analysis; ^DManuscript Preparation; ^EFunds Collection

Abstract Aim: The aim of this two-stage systematic review is (1) to outline the scope of health problems commonly seen throughout the lives of individuals with Down syndrome (DS) and (2) to synthesise the effectiveness of exercise interventions implemented for these problems through multidimensional health outcomes. The review aimed to comprehensively evaluate the clinical value of exercise-based approaches for problems observed in individuals with DS in the cardiovascular, respiratory, metabolic, neuromotor, musculoskeletal, postural control, gait, and cognitive/psychosocial domains.

Methods: The review was conducted in accordance with the PRISMA 2020 guidelines, and the study selection/exclusion processes were managed using the Covidence programme. Searches were conducted in the Web of Science, Scopus, PubMed, and MEDLINE databases using relevant keywords. After removing duplicate records, two independent researchers performed title-abstract and full-text screenings. Experimental or observational studies describing health problems in DS or implementing exercise/physical activity interventions for these problems were included in the review.

Results: A total of 51 studies were included. In the first phase, individuals with DS demonstrated a high prevalence of congenital heart disease (CHD) (40–67%), predominantly ventricular septal defect (VSD), atrial septal defect (ASD), and atrioventricular septal defect (AVSD). CHD markedly increased mortality risk in complex cases, while early echocardiographic screening and timely surgery improved survival. Obesity and obstructive sleep apnoea were highly prevalent from early childhood, and aerobic capacity indicators (VO₂peak, HRpeak) were consistently reduced independent of adiposity. Musculoskeletal abnormalities—including pes planovalgus, impaired postural control, and altered gait patterns—were common and contributed to reduced functional performance.

In the second phase, exercise interventions demonstrated clear multidomain clinical benefits in DS. Core stability and treadmill-based training improved balance, whereas structured motor programmes enhanced fundamental motor skills. Resistance and multicomponent exercise improved muscle strength, functional fitness, and oxidative stress markers. Sports-based interventions (e.g., swimming, Nordic walking, basketball) enhanced locomotor capacity and participation. Respiratory-focused approaches such as proprioceptive neuromuscular facilitation (PNF) and chest physiotherapy improved pulmonary function. Technology-assisted modalities—virtual reality (VR) and transcranial direct current stimulation (tDCS)—supported neuroplasticity and yielded clinically meaningful motor and cognitive gains.

Conclusion: This systematic review demonstrates that health problems affecting multiple systems are common and determine quality of life in individuals with DS; however, appropriately planned exercise programmes provide meaningful benefits at biological, motor, cognitive and psychosocial levels. Early screening and follow-up, along with individualised, multi-component exercise approaches, are considered a fundamental intervention strategy for reducing cardiometabolic risks, maintaining functional independence, and increasing social participation in DS.

Key words: Down syndrome, health, exercise, physiology

Introduction

Down Syndrome (DS) is a genetic condition that occurs in approximately one in every 700 live births (de Graaf et al., 2015), is mostly associated with trisomy 21, and is characterised by a clinical picture affecting multiple systems. These individuals, who have certain distinctive physical and physiological differences, have a higher prevalence of accompanying health problems related to the cardiovascular (Dimopoulos et al., 2023), endocrine (Szczańska-Popłonyk et al., 2024), musculoskeletal and neuromotor systems compared to the general population (Gawel et al., 2024). Congenital heart disease (CHD) is at the centre of this burden; the prevalence of CHD in different cohorts is reported to be approximately 40–67%, with the most common lesions being ventricular septal defect, atrial septal defect and atrioventricular septal defect (Alkhushi, 2024; Nordklev et al., 2024; Uludag Alkaya et al., 2023; Yaqoob et al., 2019). The presence of CHD, particularly in complex lesions, has been shown to significantly increase mortality; long-term survival in the DS + CHD combination has been shown to be lower than both the general population and individuals with CHD but without DS (Villamil et al., 2025). It has also been reported that the relationship between cardiac structure and function and body composition follows a different pattern in DS, with left ventricular mass and diastolic function parameters differing significantly from healthy peers (Fitzpatrick et al., 2020; Kelly et al., 2019). Pulmonary hypertension and the accompanying haemodynamic overload further complicate the clinical picture from childhood onwards (Bush & Ivy, 2022).

In addition to cardiovascular problems, obesity, dyslipidaemia, obstructive sleep apnoea and low aerobic capacity emerge as significant health problems from early life onwards in individuals with DS. The prevalence of obesity in children and adolescents has been found to be significantly higher than in the general population; an increased body mass index has been shown to be associated with sleep apnoea, metabolic disorders, and low physical fitness (Basil et al., 2016; Pecoraro et al., 2024). It has been reported that $\text{VO}_{2\text{peak}}$ and maximum heart rate are significantly lower in both young and adult DS populations, independent of obesity, and that cardiorespiratory responses exhibit an inefficient pattern during submaximal and maximal exercise (Dodd et al., 2023; Mendonca et al., 2022; Oviedo et al., 2021). From a musculoskeletal perspective, pes planovalgus, joint hypermobility, decreased trunk and lower extremity muscle strength, postural control and balance disorders, and wide-based and variable gait patterns have been frequently reported (Foley & Killeen, 2019; Giustino et al., 2020; Leite et al., 2018; Masaki et al., 2021). It is emphasised that these impairments are decisive in terms of functional performance, daily living activities and long-term physical activity levels, and that gait disturbances and cognitive decline with age may contribute to the risk of dementia (Beqaj et al., 2018).

Given this complex morbidity profile, exercise and physical activity interventions stand out as a non-pharmacological primary treatment and rehabilitation tool for individuals with DS. Randomised controlled and controlled studies have shown that core stability and treadmill-based programmes significantly improve balance in children (Alsakhawi & Elshafey, 2019; Jain et al., 2022), the effects of structured exercise protocols on fundamental motor skills, balance, and lower extremity functional strength (Thein Tun et al., 2025), and that basketball and multi-component programmes yield significant gains in body composition and functional fitness (Cai & Baek, 2022). Resistance training has been reported to increase muscle mass, muscle strength and functional performance, while positively modulating oxidative stress markers (Rosety-Rodriguez et al., 2021). Aerobic and resistance-based cardiorespiratory programmes provide significant improvements in blood pressure, haemodynamic responses and submaximal exercise efficiency (Seron et al., 2015). Nordic walking, swimming and community-based strength training, such as sports-based approaches, increase walking parameters, locomotor functions and social

participation, while pulmonary rehabilitation and chest physiotherapy applications offer clinically meaningful gains in respiratory functions (Nahla et al., 2022). Additionally, it has been demonstrated that single-session moderate-intensity exercise can provide acute benefits on executive functions and inhibition, and that the combination of tDCS and virtual reality can support neuroplasticity on motor-cognitive outputs (Chen et al., 2015).

Upon reviewing the entire literature, it is evident that studies on individuals with DS generally consist of a mixture of studies with heterogeneous methodological quality, typically addressing a single clinical domain or a single exercise modality. It was concluded that there are a limited number of studies that analyse cardiac, pulmonary, metabolic, and musculoskeletal profiles in individuals with DS together, address the distribution and prevalence of health problems in individuals with DS, examine the effects of exercise applications on these health problems, and summarise them systematically. In this context, the planned systematic review has a two-stage structure: in the first stage, existing epidemiological and clinical evidence regarding CHD, pulmonary hypertension, obesity, cardiorespiratory capacity, musculoskeletal anomalies, postural control, balance, and walking characteristics in children, adolescents, and adults with DS will be synthesised. The second phase will evaluate the effects of exercise and physical activity-based interventions (aerobic, resistance, multi-component, sport-based, pulmonary, and technology-assisted programmes) on cardiorespiratory fitness, muscle strength, motor skills, balance, gait, respiratory function, oxidative stress, and cognitive outcomes. This review is expected to contribute to the evidence-based restructuring of clinical monitoring and rehabilitation strategies for individuals with DS and to provide a methodological roadmap for future exercise-based intervention studies. However, the current literature consists of a mosaic of studies with heterogeneous methodological quality, mostly addressing a single clinical domain (e.g., only CHD, only obesity, or only motor skills) or a single exercise modality. There is no comprehensive review that simultaneously addresses the cardiac, pulmonary, metabolic, and musculoskeletal profile in individuals with DS to define the distribution of health problems and systematically summarise the multidimensional clinical effects of exercise interventions in the same population. In this context, the planned systematic review has a two-stage structure: in the first stage, existing epidemiological and clinical evidence regarding CHD, pulmonary hypertension, obesity, cardiorespiratory capacity, musculoskeletal anomalies, postural control, balance, and gait characteristics in children, adolescents, and adults with DS will be synthesised. In the second phase, the effects of exercise and physical activity-based interventions (aerobic, resistance, multi-component, sport-based, pulmonary, and technology-assisted programmes) on cardiorespiratory fitness, muscle strength, motor skills, balance, gait, respiratory function, oxidative stress, and cognitive outcomes will be evaluated. This review is expected to contribute to the evidence-based restructuring of clinical monitoring and rehabilitation strategies for individuals with DS and to provide a methodological roadmap for future exercise-based intervention studies.

Methods

Study Selection

The protocol for this systematic review was registered in advance in PROSPERO (CRD420251046980), and the study selection process was conducted in accordance with the PRISMA 2020 guidelines (Page et al., 2021). This study has been pre-registered on the Open Science Framework (OSF) platform in accordance with the principles of transparency and reproducibility, and the methodological details are presented in a structured manner in the relevant registration file (<https://osf.io/nq68z>). Following the literature search, records were transferred to Covidence

(Veritas Health Innovation, Melbourne, Australia) software, and duplicate records were first automatically and then manually removed. As the review was planned in a two-stage structure, the identified studies were divided into two different eligibility sets: (i) observational studies reporting the profile and outcomes of common health problems (particularly in the areas of cardiac, obesity/metabolic, musculoskeletal, balance/gait, and cardiorespiratory fitness) in individuals with DS, and (ii) experimental/quasi-experimental studies examining the effectiveness of exercise, physical therapy/rehabilitation, or physical activity interventions targeting these problems. The Web of Science, PubMed, Scopus, and Medline databases were used in the research.

A targeted strategy combining four core concept blocks was used in electronic searches. The basic query used in Web of Science was as follows: Down syndrome' OR 'Trisomy 21' AND ('physical therapy' OR 'physiotherapy' OR "rehabilitation" OR 'neurodevelopmental treatment') AND ('exercise' OR 'physical activity' OR "sports" OR 'adaptive sports' OR 'functional training') AND ('motor skills' OR 'functional improvement' OR 'outcomes'). This configuration combines (1) the population (DS), (2) the treatment/rehabilitation context (physiotherapy, rehabilitation, neurodevelopmental approaches), (3) the type of intervention (exercise, physical activity, sports, functional training), and (4) the outcome domains (motor skills, functional improvement, outcomes). Corresponding MeSH/Thesaurus terms and free-text keywords in other databases were adapted while preserving this logical block structure. As language restrictions, only English and Turkish full-text, peer-reviewed journal articles were included; no restrictions were imposed on age, gender, or work environment.

Data Extraction

Two authors (A.K. and B.Ç.) performed the extraction of original bibliographic articles. The two authors independently searched and selected articles using the following criteria: characteristics of the target population, study type, and outcome. When necessary, the third and fourth authors (M.T. and Ö.E.) assisted in the inclusion or exclusion of articles.

Participants, intervention, comparators, outcomes, and study design (PICOS) criteria were used to identify included and excluded studies. These criteria have been systematically applied to both the observational studies in the first phase and the intervention studies in the second phase.

Table 1. Study inclusion and exclusion criteria based on PICOS

	Inclusion Criteria	Exclusion Criteria
Population	Children, adolescents or adults diagnosed with genetically confirmed DS (Trisomy 21, mosaic or translocation); there are no restrictions based on gender, age or living environment.	Participants without DS, mixed samples where DS is not reported separately, and studies providing only family/caregiver data.
Intervention	First stage: congenital heart diseases and cardiac outcomes, obesity/body composition, cardiorespiratory fitness, musculoskeletal findings, and balance/gait-functional performance. In the second stage: motor skills, balance and walking, muscle strength, cardiorespiratory responses, oxidative stress/antioxidants, pulmonary functions, and cognitive performance.	Studies in which the components of the intervention cannot be distinguished and the effect of exercise/physiotherapy cannot be analysed independently; studies focused solely on pharmacological or surgical treatment.
Comparator	In intervention studies, a passive control or active control group is not required in observational studies.	Single-arm experimental studies or case series without an appropriate comparator.
Outcome	First stage: cardiac status, obesity/body composition, cardiorespiratory fitness, musculoskeletal findings with balance, walking and functional performance. Second stage: motor skills, balance and walking, muscle strength, cardiorespiratory responses, oxidative stress/antioxidants, pulmonary functions and cognitive performance.	Studies that only report subjective perceptions such as attitude, knowledge, satisfaction; studies that do not provide clinical, functional or physiological health indicators; reports that do not contain sufficient quantitative outcome data.
Study Design	Observational studies and experimental/quasi-experimental intervention studies.	Case presentations, small case series, editorial articles, commentaries, conference abstracts, reviews and meta-analyses.
Additional Criteria	Original research articles published in peer-reviewed scientific journals, with full text available in Turkish or English.	Publications whose full text is unavailable; articles in languages other than Turkish/English; works that are solely theses, reports or grey literature.

Risk of Bias and Study Quality Assessment

For this review, the methodological quality and potential for bias of the included studies were independently assessed by two researchers. The Newcastle-Ottawa Scale (NOS) was used for observational studies (cohort, case-control, and cross-sectional designs), and the PEDro Scale was used for randomised and semi-randomised studies of exercise/physiotherapy interventions (Maher et al., 2003; Stang, 2010). Each study was assessed separately according to the criteria of the relevant scale, and a total score was calculated. For PEDro, 6–10 points were interpreted as 'high', 4–5 points as 'moderate', and 0–3 points as 'low' methodological quality; for NOS, 7–9 points were considered 'high', 5–6 points as 'moderate', and ≤4 points as 'low' quality. Discrepancies between the two independent evaluators were first resolved through consensus; in cases where consensus could not be reached, a third senior researcher was consulted to make the final decision.

As a result of database searches, a total of 7,844 records were obtained (Web of Science: n=4,050, Scopus: n=3,712, PubMed: n=82). No additional records were identified from supplementary sources or grey literature. Using Covidence software, 1,416 duplicate records were automatically removed, and 6,428 unique studies were screened at the title-abstract level. At this stage, 6,042 studies that did not meet the eligibility criteria were excluded. A total of 211 studies were evaluated for full-text review; no studies were inaccessible (n=0). In the full-text evaluation, the reasons for exclusion were incorrect outcome domain (n=92), incorrect indication (n=28), incorrect study design (n=15), incorrect intervention (n=5), incorrect setting (n=3), and sample incompatible with the target population (n=1). Ultimately, 51 studies meeting the inclusion criteria were included in the systematic review (Figure 1).

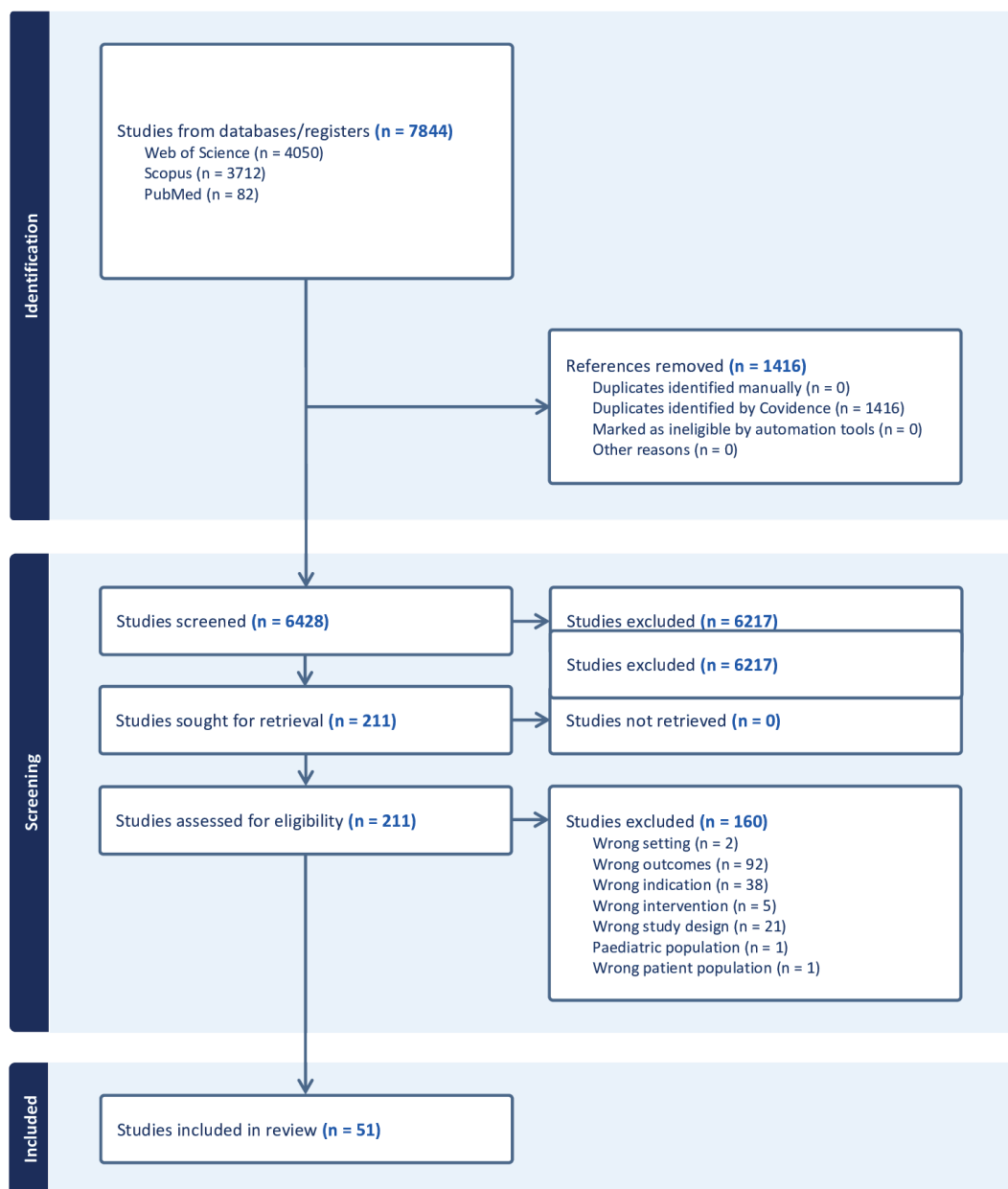


Figure 1. PRISMA diagram of study

No	Author, year	Study type	Sample (n)	Outcome Measurements	Key Findings	Conclusion
Congenital Heart Defects (CHD)						
1	(Uludag Alkaya et al., 2023)	Retrospective Cohort	1731 DS Female: 573 Male: 1158 Age: 1 day – 25 years follow-up: 36 years	CHD diagnosis was made by echocardiography. Congenital heart diseases, surgical intervention, neuromotor development, and mortality were analyzed.	CHD prevalence is 52.1% VSD: 35% ASD: 31.8% AVSD: 23.4% Five-year survival is 97.4% in patients without CHD, 95.6% in mild CHD, and 86.1% in moderate-severe CHD. CHD is more common in women than in men.	The prevalence of CHD, most commonly VSD, is higher in girls with DS and shows a significant association only with hypothyroidism, while no association has been found with neurodevelopmental outcomes and other risk factors.
2	(Yaqoob et al., 2019)	Retrospective	350 DS Female: 140 Male: 210 Age: 0–18 years follow-up: 6 years	CHD diagnosis was made by echocardiography Thyroid function (T3, T4, TSH) was measured. Chromosomal analysis was performed (trisomy 21, translocation, mosaicism)	CHD prevalence: 41.8% VSD: 41% PDA: 15.4% AVSD: 12% Thyroid dysfunction: 22% Compensated hypothyroidism: 12.5% Overt hypothyroidism: 5.8% Hyperthyroidism: 3.7% CHD was more common in males, while thyroid disorders were seen at similar rates in both genders.	Congenital heart disease and thyroid dysfunction are common in individuals with DS, and early diagnosis and intervention for these conditions, accompanied by routine screening and a multidisciplinary approach, significantly improve quality of life and survival.
3	(Alkhushi, 2024)	Retrospective	254 DS Female: 113 Male: 141 Age: 1–53 years Follow-up: NA	Echocardiography reports were used; the prevalence, type, hemodynamic significance, and surgical interventions of congenital heart diseases were evaluated.	CHD prevalence: 66.5% AVSD: 33.1% Perimembranous VSD: 18.9% Right ventricular pathologies: 10.2% Hemodynamically significant CHD was observed in 52.4% of cases.	Congenital heart disease is observed in 66.5% of children with DS, most commonly AVSD and perimembranous VSD. Surgery is required in 34.4% of cases; early diagnosis and regular follow-up have a positive effect on quality of life.
4	(Nordklev et al., 2024)	Cohort	702 DS Female: 113 Male: 141 Age: 1–53 years	Participants were examined using the Norwegian Birth and Heart Registries. CHD prevalence, subtypes of AVSD, congenital characteristics, and surgical outcomes were evaluated.	CHD prevalence: 57.4%; AVSD: 44.4%). The female ratio and prematurity were higher in infants with AVSD. The survival rate up to 1 year of age was 93.2%; it was 99.7% in those without AVSD. The survival rate of those who underwent surgery was 96%.	Early cardiac screening and timely surgical intervention in AVSD cases observed in babies with DS have been reported to increase survival rates. Furthermore, it has been reported that live birth rates in Norway have remained stable over the past 20 years and that the first-year mortality risk for these babies does not differ from that of AVSD cases without chromosomal abnormalities.

No	Author, year	Study type	Sample (n)	Outcome Measurements	Key Findings	Conclusion
Mortality Rate						
5	(Engsner et al., 2024)	Retrospective	67,814 CHD+DS: 3285 CHD: 64,529 Controls: 26,128 Follow-up: 16	Data were obtained from the Swedish National Health Records. All-cause mortality and cardiovascular mortality are analysed.	The mortality rate DS+CHD group: 17% CHD-only group: 8% Control group: 0.8% Survival was lower in individuals with DS and complex CHD. Mortality related to CHD was higher in individuals with DS, especially in the first years after birth. Although the mortality difference decreased with age, life expectancy was low, especially in the presence of complex CHD.	DS has been shown to significantly increase the mortality risk of congenital heart disease; therefore, early diagnosis, surgical intervention, and long-term follow-up of cases with complex CHD in particular are recommended.
6	(Alsaied et al., 2016)	Retrospective cohort	1092 DS Age: 0–18 years	The study examined the effect of cardiac surgery on neurodevelopmental and academic outcomes in children with DS using a retrospective cohort design. Assessments were conducted using clinical records and at least one of the following standardized tests: Bayley-III, PLS-5, PDMS-2, WJ-III, OWLS-II, BRIEF, and CBCL.	Infants with CHD scored significantly lower on language development compared to those without CHD. Preschool children with CHD scored lower on language and visual-motor tests, but the differences were not significant. In school-age children, the presence of CHD did not affect neurodevelopmental outcomes.	In children with DS and those requiring congenital heart surgery, although language development may be delayed in early childhood, these differences are observed to disappear by school age, highlighting the importance of early intervention.
Other Cardiac Problems						
7	(Fitzpatrick et al., 2020)	Retrospective cohort	2342 DS Female: 1257 Male: 1085 Age: ≥18 years Follow-up: 20 years	Analyzed from US health system records. Prevalence of heart disease (CHD, MI, heart failure), stroke, hypertension, diabetes, and obesity was determined using ICD codes.	CHD: 0.38%, MI: 0.04%, Hypertension: 2.69%, Diabetes: 5.00%, Hypercholesterolemia: 2.69% were lower than in the general population. Stroke rates were similar. The rates of overweight (73.4%) and obesity (43.0%) were higher. Cardiovascular risk factors were generally less common in the DS group.	Although obesity is common in individuals with DS, the prevalence of cardiovascular disease is lower than in the general population, highlighting the importance of restructuring health policies and screening strategies specific to this group.

No	Author, year	Study type	Sample (n)	Outcome Measurements	Key Findings	Conclusion
8	(Claus et al., 2019)	Cross-sectional study	149 DS Age: 10–20 years	Cardiac structure and function were assessed using echocardiography. New cardiac findings were identified in individuals who had not previously been diagnosed.	New cardiac anomalies were detected in 6% of individuals who had not previously been diagnosed, and these findings included PDA, aortic insufficiency, mitral valve deformities, pericardial effusion, left ventricular hypertrophy, ventricular premature beats, and VSD; these new anomalies were observed in both individuals with and without a history of CHD.	Asymptomatic cardiac anomalies can be detected in adolescents with DS, independent of known CHD history, supporting the need for re-evaluation of cardiac function during adolescence.
9	(Kelly et al., 2019)	Cross-sectional study	136 DS Female: 76 Male: 60 102 healthy Female: 60 Male: 42 Age: 13–29 years	Body composition measurement using DXA Cardiac measurements using echocardiography Use of a pedometer for physical activity	The DS group had lower lean body mass and left ventricular mass values. The measurement of diastolic function was higher in the DS group. Physical activity level was lower in the DS group.	Individuals with DS have been found to have widespread diastolic dysfunction and low left ventricular mass regardless of CHD. This condition is thought to be related to possible structural, genetic, or physical inactivity, and it is recommended that the findings be evaluated with long-term follow-up.
Obesity						
10	(Basil et al., 2016)	Retrospective	303 DS Female: 136 Male: 167 Age: 2–18 years	BMI $\geq$ 95th percentile: defined as obese. Oslee apnea syndrome assessment was performed using polysomnography. Compared with a local control group.	The obesity rate 47.8% (DS), 12.1% (control group). Oslee apnea syndrome was detected in 74% of children with DS. Obese children with DS had a higher risk of Oslee apnea syndrome	The tendency toward obesity that begins early in children with DS and the associated increased risk of obstructive sleep apnea necessitate informing families from infancy and implementing structured weight management strategies during childhood.

No	Author, year	Study type	Sample (n)	Outcome Measurements	Key Findings	Conclusion
Aerobic capacity						
11	(Wee et al., 2015)	Cross-sectional retrospective	654 DS: 151 IDnoDS (Intellectually disabled, non-DS): 180 NoID (non-intellectually disabled): 323 Age: 8–46 years	VO ₂ peak and HR peak were measured using a treadmill test. Obesity status was classified according to BMI. VO ₂ peak and HR peak values were compared according to age and obesity.	HR peak and VO ₂ peak values were lower in individuals with DS compared to all other groups. Obesity did not affect HR peak in children with DS, but it decreased it in those without DS. VO ₂ peak was lower in obese adults with DS, but it was not affected in children.	The finding that VO ₂ peak levels are low in adults with DS, independent of obesity, indicates that interventions should be planned with a focus on increasing aerobic capacity, while obesity management has been determined to be particularly critical in individuals without DS.
12	(Mendonca et al., 2022)	Cross-sectional, multicenter observational study	100 DS Female: 30 Male: 70 Age: ≥18 years Controls: Age-matched	Exercise test: CPET (cardiopulmonary exercise testing) using the semi-occluded ramp protocol. VO ₂ peak and HR peak were measured.	VO ₂ and HR levels in individuals with DS were significantly lower than in the general population	In this study, where low VO ₂ peak and HRpeak levels were observed in all age groups, gender differences were found to be similar to those in the general population, and specific prediction equations were developed for individuals with DS.
Physical activity						
13	(Dodd et al., 2023)	Cross-sectional	79 DS Female: 41 Male: 38 Age: ≥18 years	VO ₂ max test, 7-day accelerometer data, and CANTAB cognitive test battery were used. Participants were divided into two groups based on BMI: normal weight and obese. The relationship between physical fitness, activity, and cognitive performance was analyzed.	VO ₂ max was significantly lower in the obese group. There was a negative correlation between BMI and VO ₂ max. There was no difference in physical activity duration between groups. No significant relationship was found between BMI and cognitive function.	In adults with DS, an increase in BMI negatively affects cardiorespiratory capacity but has not shown a significant relationship with physical activity and cognitive function. In line with these findings, it has been demonstrated that priority should be given to improving physical fitness in obesity prevention interventions.

No	Author, year	Study type	Sample (n)	Outcome Measurements	Key Findings	Conclusion
14	(Pino-Valenzuela & Benavides-Roca, 2023)	Prospective	16 DS Female: 3 Male: 13 Age: 10–25 years Follow-up: 10-year	Measurements: Body mass, height, waist/hip circumference, skinfold thickness, muscle strength, abdominal capacity, flexibility, aerobic capacity	Body fat percentage increased significantly between 2009 and 2019. Abdominal capacity decreased during the same period. An increase was observed in waist and hip circumference and BMI values. Flexibility and handgrip strength also decreased; though to a lesser extent.	Over a 10-year period, individuals with DS experienced negative changes in physical fitness and body composition due to a lack of physical activity, which adversely affected their health.
15	(Pitchford et al., 2018)	Prospective	22 DS Female: 8 Male: 14 Contol: 17 Female: 10 Male: 7 Age: 12–18 years	Body fat percentage measured by DXA, MVPA Physical activity level measured by accelerometer (Actigraph GT3X+)	In DS have higher BMI and body fat percentage, lower MVPA Moderate negative correlation between MVPA and DXA fat percentage No significant correlation between BMI and MVPA	It has been determined that fat accumulation in adolescents with DS contributes to low physical activity levels despite not being detectable by BMI, and that body fat percentage measured by DXA is significantly associated with MVPA. Therefore, it is recommended that DXA be preferred over BMI.
Musculoskeletal symptoms						
16	(Foley & Killeen, 2019)	Observational study	503 DS Female: 281 Male: 212 Age: 0–21 years	Observational musculoskeletal examination performed	Pes planus prevalence: 91% Inflammatory arthritis: 7% Scoliosis: 4.8%	This study found that musculoskeletal anomalies are common and often overlooked in children with DS, and that the risk of aggressive arthritis is particularly high.

No	Author, year	Study type	Sample (n)	Outcome Measurements	Key Findings	Conclusion
17	(Masaki et al., 2021)	Cross-sectional comparative study	23 DS Female: 7 Male: 16 Controls: 24 Female: 12 Male: 12 Age: 3–6 years	Pesplanus evaluated by Arch Height Index (AHI) Foot muscle thicknesses evaluated by ultrasonography	In the DS group, AHI was significantly lower, posterior tibialis and soleus muscle thicknesses were also lower. However, flexor digitorum longus muscle thickness was significantly higher in the DS group As AHI decreased, the thickness of this muscle increased.	In children with DS, as AHI decreases in relation to pes planovalgus deformity, the soleus and posterior tibialis muscle mass decreases, while a compensatory increase is observed in the flexor digitorum longus muscle; these findings should be considered in treatment planning.
18	(Shields et al., 2017)	Prospective cohort	50 DS Female: 32 Male: 28 Age: 8–18 years	Foot posture: assessed using the arch index, deformities: hallux valgus, toe shape. Shoe fit: length and width measurements. Physical activity: measured using an accelerometer over 7 days.	Shoe length exceeding foot length reduced physical activity levels No significant relationship was found between flat feet and other foot deformities and physical activity. Only 8% of the shoes were the correct size; 54% were too long, and 60% were too narrow.	This study has demonstrated that the level of physical activity in children with DS is negatively affected by the frequent use of inappropriate footwear, and that appropriate footwear selection and regular clinical evaluations play an important role in increasing activity.
19	(Chen et al., 2021)	Observational comparative	54 DS Age: 14–52 years	Manipulation skills were assessed using the Purdue Pegboard Test (PPT), hand grip strength was measured using a dynamometer, and mental age was assessed using the Peabody Picture Vocabulary Test.	Assembly" alt testinde genç grubun üstün performans gösterdiği, diğer PPT alt testlerinde ise anlamlı fark bulunmadığı; kavrama gücünün yaşla değişmediği ancak el tercihi farklılığının yaşlı grupta daha belirgin olduğu belirlenmiştir.	It has been demonstrated that manipulative motor skills in individuals with DS are not significantly affected by age, but are closely related to verbal cognitive abilities. It has been emphasized that rehabilitation approaches should be planned according to the individual's level of mental development.
20	(Valero et al., 2021)	Cross-sectional	361 DS Female: 170 Male: 191	Data collected via an online questionnaire completed by their parents Motor development: ages of crawling, first steps, and independent walking. Orthopedic conditions: flat feet, knee abnormalities.	Delayed first steps increased the risk of wide-based walking by 7%. Knee deformity and flat feet were found to be associated with wide-based walking. No significant relationship was observed with the frequency of physical therapy or the status of receiving therapy.	This study has demonstrated that wide-based walking is associated with early motor development stages (particularly crawling and walking); multidisciplinary follow-up and early motor support have been recommended to prevent postural and walking disorders.

No	Author, year	Study type	Sample (n)	Outcome Measurements	Key Findings	Conclusion
Postural Control and Balance						
21	(Leite et al., 2018)	Cross-sectional observational	21 DS Female: 9 Male: 12 Age: 8–12 years	Postural control was assessed using a force platform in a 30-second standing position.	Swing speed has decreased significantly with age. While no statistically significant relationship was found between postural control and gender, nutritional status, and physical activity level, 95% of participants were determined to be sedentary. COP values did not show any significant change according to age.	It has been determined that postural control, which develops with age in individuals with DS, differs from that of typically developing individuals in terms of swing rates; however, this control is not affected by factors other than age, such as gender, nutrition, and physical activity.
22	(Jain et al., 2022)	Cross-sectional	14 DS Control: 14 Female: 8 Male: 6 Age: 6–11 years	Trunk muscle strength: measured with a hydraulic dynamometer. Reach ability: modified Functional Reach Test. Balance: Pediatric Balance Scale (PBS).	In the DS group, trunk muscle strength, balance, and reach scores were significantly lower. Trunk extensor muscle strength was found to be positively associated with balance and lateral reach.	Low trunk muscle strength in children with DS limits their balance and functional reach abilities; strengthening the trunk extensor muscles in particular should be a priority in rehabilitation programs, as it can improve functional balance during sitting, standing, and transfers.
23	(Giustino et al., 2020)	Cross-sectional, comparative	22 DS Female: 9 Male: 13 Controls: 25 Female: 11 Male: 14 Age: 16–36 years	Stabilometric tests: performed in the bipedal standing position for 30 seconds each with eyes open (EO) and eyes closed (EC). Measurements using the freeMed® platform and freeStep® software.	In the DS group, the elliptical oscillation area was found to be high under both EO and EC conditions. With eyes closed, the oscillation length and speed parameters increased significantly.	It has been demonstrated that postural control in individuals with DS is associated with delayed multisensory integration; emphasizing the importance of visual input, it has been suggested that exercises targeting somatosensory, proprioceptive, and strength coordination may be considered to improve balance and functionality.
Gait Parameters						
24	(Beerse et al., 2019)	Prospective	13 DS Female: 2 Male: 11 Controls: 13 Female: 2 Male: 11 Age: 0–10 years	Conditions: slow (75% speed), fast (100% speed), and treadmill walking with a load of 2% body weight on the ankle. Measurements: Spatiotemporal gait parameters (step length, width, swing, double support, foot rotation) using the Vicon system.	Individuals with DS exhibited short stride length, wide stride width, and high variation in spatiotemporal parameters. Increased speed and ankle load supported balance by reducing this variation. There were no differences between groups in terms of timing variables.	It has been demonstrated that children with DS can adapt to walking conditions, that despite a noticeable stride width and short steps, the swing time and foot rotation are similar, and that low-level loading and fast walking have the potential to improve balance.

No	Author, year	Study type	Sample (n)	Outcome Measurements	Key Findings	Conclusion
25	(Zago et al., 2019)	Retrospective observational cohort	230 DS Female: 103 Male: 127 Age: 7–50 years	Gait analysis was performed with 6 walks on a 10-meter course. Measurements: Gait Profile Score (GPS), Gait Variable Scores (GVs), step length, step width, walking speed, stance/swing ratio.	Gait Profile Score was higher in women (i.e., greater impairment) Step length was shorter in women. Greater impairment was observed in women in joint movements such as pelvic tilt, hip, and knee flexion. Foot rotation was more markedly impaired in men.	It has been demonstrated that walking function is more significantly affected in women with DS compared to men, although foot propulsion impairment is more pronounced in men; this highlights the importance of gender-sensitive rehabilitation approaches.
26	(Koo et al., 2022)	Comparative, observational study	6 DS 6 Healthy peer Age: 12–16 years	Joint stiffness, strength, and range of motion were measured during single-leg drop landing. Equipment: isokinetic dynamometer, force platform, 3D motion analysis system.	Children with DS had high vertical ground reaction force (VGRF) at the heel, but low knee and hip muscle strength. Joint stiffness did not differ between groups; however, a negative correlation was observed between hip/ankle stiffness and knee range of motion in the DS group.	It has been demonstrated that children with DS develop alternative motor strategies compatible with different ranges of motion during descent, that this is not related to joint stiffness, and that approaches that reduce plantar force should be prioritized in rehabilitation.

Congenital Heart Disease (CHD) in Down Syndrome (DS):

Congenital heart disease (CHD) is quite common in individuals with DS and has significant effects on quality of life and survival. Large-scale retrospective cohort studies conducted in recent years provide important information about CHD prevalence, subtypes, gender differences, and associated risk factors (Uludag Alkaya et al., 2023; Yaqoob et al., 2019; Alkhushi, 2024; Nordklev et al., 2024). The prevalence of CHD in individuals with DS ranges from 40% to 67%; meta-analyses indicate that approximately half have CHD. All studies agree that the prevalence of CHD in the DS population is very high compared to the general population (~1%). The most common CHD types are atrioventricular septal defect (AVSD), ventricular septal defect (VSD), and atrial septal defect (ASD), with AVSD rates around 30–44%, VSD 22–43%, and ASD 16–42% (Uludag Alkaya et al., 2023; Yaqoob et al., 2019; Alkhushi, 2024; Nordklev et al., 2024). Although Yaqoob et al., 2019, reported that CHD is more common in males, Uludag Alkaya et al., 2023, and Nordklev et al., 2024, reported that it is more common in females. However, other comorbidities such as thyroid dysfunction (Yaqoob, 2019) have been reported to occur at similar rates between genders. The Uludağ Alkaya (2023) study found no significant association between parental risk factors, DS type (trisomy 21, translocation, mosaicism), low birth weight, and preterm birth with CHD. CHD, especially those with significant hemodynamic implications (Alkhushi: 52.4%), significantly affects survival. However, modern surgical techniques can achieve very high success rates, and early intervention can dramatically improve survival.

It is emphasized that all newborns with DS should undergo echocardiographic screening, preferably immediately after birth or within the first few weeks. It is noted that the management of DS requires a multidisciplinary approach involving not only cardiology, but also endocrinology (thyroid function tests), neurology/physical therapy (neuro-motor development), and genetic counseling. It is emphasized that early diagnosis and intervention for congenital heart defects and other comorbidities such as hypothyroidism can significantly improve prognosis by reducing

morbidity and mortality and improving quality of life (Uludag Alkaya et al., 2023; Yaqoob et al., 2019; Alkhushi, 2024; Nordklev et al., 2024).

Mortality rates:

Engsner et al., 2024, observed that the risk of death in individuals with DS and congenital heart disease (CHD-DS) was 25 times higher than in matched controls and twice higher than in individuals with DS without CHD. They concluded that the presence of CHD in individuals with DS significantly increases the risk of death. Therefore, they emphasize the importance of early diagnosis and surgical intervention, and the need for long-term follow-up in individuals with complex CHD (Engsner et al., 2024). Additionally, Alsaied et al. (2016) reported that children with DS and CHD requiring early surgical intervention performed worse in terms of language development during infancy (Alsaied et al., 2016). However, these differences disappeared by school age, highlighting the importance of early intervention.

Other Cardiac Problems and Obesity

Fitzpatrick et al. (2020) reported that the prevalence of cardiovascular disease is lower in individuals with DS than in the general population, but obesity, a risk factor for cardiovascular disease, is higher. Basil et al. (2016) noted that children with DS are at high risk for obesity from an early age. Obesity also increases the risk of Sleep Apnea Syndrome.

Clauss et al. (2019) identified newly detected echocardiographic abnormalities in approximately 6% of adolescents with DS and found that these findings can occur in asymptomatic individuals regardless of a known history of congenital heart disease. Kelly et al. (2019) reported that DS has a significantly lower left ventricular mass and widespread diastolic dysfunction, and this is observed regardless of the presence of congenital heart disease.

Aerobic capacity

Wee et al. (2015) emphasized that individuals with DS have lower cardiovascular fitness, independent of obesity, and that obesity has a greater impact on $\dot{V}O_2$ peak than individuals without DS. Interventions should focus on increasing $\dot{V}O_2$ peak in individuals with DS; they found that obesity is not the primary factor affecting aerobic capacity in adults with DS.

Mendonca et al. (2022) presented specific equations that can be used to estimate $\dot{V}O_2$ peak and heart rate in individuals with DS. This research revealed that individuals with DS have lower $\dot{V}O_2$ peak and heart rate levels across all age groups.

Physical activity

The critical decline in physical fitness across the lifespan and the alarming prevalence of obesity in individuals with DS (DS) highlight this, necessitating targeted intervention strategies. Longitudinal observations reveal a worrying trend with significant negative changes in physical fitness and anthropometric variables over a 10-year period, a trend strongly attributed to a lack of sustained physical activity (Pino-Valenzuela & Benavides-Roca, 2023). The relationship between obesity and physical activity is complex; although increased body mass index (BMI) is inversely associated with cardiovascular fitness in adults with DS, this relationship is not always mediated by current physical activity levels, suggesting that fitness is a primary goal (Dodd et al., 2023). Furthermore, traditional BMI measurements may be insufficient for this population, as more sensitive dual-energy X-ray absorptiometry (DXA) measurements have revealed a significant inverse relationship between moderate-to-vigorous physical activity (MVPA) and body fat percentage in adolescents, highlighting the limitations of BMI and the critical role

of high-intensity movement (Pitchford et al., 2018). Importantly, proactive management through regular counseling on nutrition and physical activity has been shown to be effective and leads to improved health outcomes, such as reduced BMI and increased physical activity levels, in children with DS, despite challenges such as adverse lipid profiles and dietary nonadherence requiring specific strategies (Pecoraro et al., 2024). Collectively, these findings advocate for a dual-focused approach that prioritizes improving cardiovascular fitness through structured interventions while simultaneously implementing regular, professional guidance to combat sedentary behavior and promote sustainable weight management from childhood to adulthood.

Musculoskeletal symptoms

Musculoskeletal anomalies represent a highly prevalent yet frequently underrecognized comorbidity in individuals with DS, with significant implications for motor function and physical activity. A striking majority exhibit pes planovalgus, with a prevalence as high as 91%, a condition characterized by a lowered medial arch and linked to alterations in lower leg muscle architecture, including atrophy of the soleus and tibialis posterior and compensatory hypertrophy of the flexor digitorum longus (Foley & Killeen, 2019; Masaki et al., 2021). These structural impairments directly impact gait and posture, where a wide-based stance is associated with delays in achieving fundamental motor milestones like quadruped crawling and independent walking, underscoring the necessity of early intervention to promote normative motor development and prevent future orthopedic complications (Valero et al., 2021). Furthermore, motor proficiency, particularly manipulative skills, is more closely tied to cognitive and verbal development than chronological age, necessitating rehabilitation programs tailored to mental age rather than biological age (Chen et al., 2021). Critically, the functional impact of these deformities is often exacerbated by external factors, as ill-fitting footwear is common and is independently associated with reduced physical activity levels, highlighting the need for routine clinical footwear assessment as a simple yet effective modifiable factor (Shields et al., 2017). This complex interplay of structural, developmental, neurological, and external factors mandates a multidisciplinary follow-up approach to address the spectrum of issues from aggressive arthritis to gait abnormalities (Foley & Killeen, 2019; Valero et al., 2021).

Postural Control and Balance

Postural control and balance in individuals with DS are characterized by fundamental deficits that stem from a complex interplay of neurological and musculoskeletal factors, rather than common modifiable influences. While postural control demonstrates a developmental trajectory with age, its quality, particularly reflected in centre of pressure dynamics and oscillation speeds, remains distinctly different from neurotypical development and is not significantly affected by variables such as gender, nutritional status, or general physical activity level, indicating a primary dependence on intrinsic neurodevelopmental factors specific to the syndrome (Leite et al., 2018). A critical component of this impaired stability is profound trunk muscle weakness, which directly and negatively impacts both static and dynamic balance, as well as functional reach abilities, thereby limiting performance in essential daily living activities and transfers (Jain et al., 2022). Underpinning these motor challenges is a neurological deficit in the timely integration of multisensory inputs—somatosensory, vestibular, and visual—for maintaining equilibrium, with an identified over-reliance on visual cues to compensate for proprioceptive and vestibular processing delays (Giustino et al., 2020). Consequently, effective rehabilitation requires a targeted approach that moves beyond general activity to include adapted exercise programs specifically designed to enhance trunk muscle strength, and to rigorously challenge and improve the coordination and integration of the somatosensory and proprioceptive systems (Jain et al., 2022; Giustino et al., 2020).

Gait Parameters

Gait in individuals with DS is characterized by a distinct biomechanical profile defined by altered spatiotemporal parameters, significant muscle weakness, and gender-specific impairments. A consistent pattern emerges of shorter step length, wider step width, and heightened variability in spatial parameters, which contributes to a less stable gait pattern; however, this instability can be mitigated through faster walking speeds and light ankle loading, demonstrating a retained capacity for neuromuscular adaptation (Beerse et al., 2019). Critically, these gait deviations are not uniform across genders, with females exhibiting a greater overall impairment in gait quality (Gait Profile Score), shorter step length, and reduced pelvic and lower extremity joint movement, while males demonstrate more pronounced deficits in foot progression and propulsion (Zago et al., 2019). The underlying mechanical contributors to this aberrant gait include significantly weakened hip and knee extensor muscles, which compromise force absorption and lead to higher than normal vertical ground reaction forces (VGRF) during weight-bearing activities (Koo et al., 2022). This combination of weakness and altered kinetics necessitates the use of compensatory movement strategies, particularly during descent tasks, which are driven more by deficits in strength and available range of motion than by differences in passive joint stiffness (Koo et al., 2022). Consequently, rehabilitation must be precisely tailored, incorporating resistance training to address specific muscle weaknesses, interventions to improve movement strategies for reducing impact forces, and considerations for the individual's gender to most effectively target their unique pattern of gait impairment (Zago et al., 2019; Koo et al., 2022).

Exercise						
n	Author, year	Study type	Sample (n)	Outcome Measurements	Key Findings	Conclusion
1	(Lopes et al., 2022)	Randomized Controlled Trial	29 DS Age: 15.7 ± 2.82 years	• RCT: EG (anodal tDCS + VR) vs. KG (sham tDCS + VR) • EEG, EMG, and 3D motion analysis were used.	tDCS-assisted virtual reality training has been shown to significantly improve motor development, balance skills, and somatosensory cortex activity in children with DS.	The combined use of tDCS and virtual reality to develop cognitive and motor skills in children with DS stands out as an effective and innovative approach in clinical rehabilitation due to its neuroplasticity-supporting effect.
2	(Alsakhawi & Elshafey, 2019)	Randomized Controlled Trial	45 DS children Age: 4–6 years (mean 4.59±0.53)	• Group A: Traditional physical therapy • Group B: Traditional therapy + treadmill training • Group C: Traditional therapy + core stability exercises. • 8 weeks X 3 days • Assessment tools: Berg Balance Scale, Biodex Balance System.	In the study, a significant increase in balance was observed in all groups, while the core stability and treadmill groups were found to be superior to the control group; however, no significant difference was observed between these two interventions.	Adding core stability and treadmill exercises to traditional physical therapy has been found to significantly improve balance in children with DS.

3	(Chen & Ringenbach, 2019)	<i>Randomized Controlled Trial</i>	8 DS Age: 14–31 years	Low Intensity (%50-75 HR, Treadmill Exercise) Moderate Intensity (%75-85 HR, Treadmill Exercise) Control Group	Moderate exercise increased grip strength in individuals with DS; however, no similar effect was observed in the high-intensity exercise and control groups, and no significant difference was found in manual dexterity.	It has been found that walking exercises do not affect manual skills in individuals with DS, but they may increase grip strength.
4	(Oviedo et al., 2021)	<i>Randomized Controlled Trial</i>	40 DS adolescents Age: 14–22 years	Cardiorespiratory correlation (CRC) and entropy levels were compared using a submaximal treadmill test. Measurements were taken for SBP, DBP, HR, and VO ₂ .	Individuals with DS showed low CRC and high entropy levels, indicating reduced physiological efficiency during exercise; it has been suggested that CRC could be an alternative parameter for evaluating exercise responses.	It has been shown that adults with DS exhibit lower cardiorespiratory coordination and higher entropy during exercise, which reduces functional efficiency.
5	(Rosety-Rodriguez et al., 2021)	<i>Randomized Controlled Trial</i>	36 male adults with DS Age: 28.1±3.3 years	A resistance circuit training program consisting of 6 stations was performed 3 days a week for 12 weeks. Assessments: TAS, GSH, GR, MDA, carbonyl groups, muscle strength. • Divided into 4 groups: DS exercise (n=17), DS control (n=15), healthy exercise (n=20), healthy control (n=18). • 45-minute resistance and jumping exercise 3 days a week for 6 months. • Measurement: BMD and BMC values using DXA.	Significant increases in TAS, GSH, and GR levels were observed after exercise; significant decreases in MDA and carbonyl group levels were observed. Increases in muscle strength were observed.	Resistance circuit training is an effective, safe, and feasible method for reducing oxidative stress, enhancing antioxidant defense, and increasing muscle strength in individuals with DS.
6	(Dilek et al., 2018)	<i>Randomized Controlled Trial</i>	70 DS and healthy controls Age: 10–30 years		While exercise tends to increase bone mineral density in healthy individuals, a decrease in BMD/BMC levels in the vertebrae and femur was observed in the DS group, and it was determined that the osteogenic response was insufficient.	It has been shown that despite six months of exercise, an unexpected decrease in BMD and BMC values was observed in individuals with DS, indicating that exercise protocols need to be reevaluated.
7	(Cai & Baek, 2022)	<i>Quasi-experimental</i>	22 DS Female: 4 Male: 18 Age: 18–40 years	The experimental group participated in basketball training three days a week for 24 weeks. Evaluation: body composition (BMI, body fat), functional fitness tests.	In the exercise group, body fat percentage and BMI decreased, while muscle mass, strength, balance, flexibility, and cardiorespiratory fitness showed significant increases.	Basketball training is an effective and enjoyable method that supports physical health by improving body composition and functional fitness in young people with DS.

8	(Yamanaka et al., 2023)	<i>Analytical observational study</i>	137 children (69 with DS, 68 healthy) Age: 10–12 years	The physical activity levels of 69 children with DS and 68 normal children were assessed using a triaxial accelerometer; parameters such as SB, LPA, and MVPA were measured between 07:00 and 21:00 and statistically analyzed.	Children with DS had shorter MVPA duration, longer LPA duration, and higher total physical activity levels. However, their obesity rate was higher compared to normal children.	VPA may be limited in children with DS due to low muscle tone; therefore, increasing LPA is important in maintaining overall activity levels and combating obesity.
9	(Diaz et al., 2021)	<i>Randomized Controlled Trial</i>	36 DS Female: Not specified Male: 36 Age: 28.1 ± 3.3 years	The effect of resistance training on muscle mass and work performance in adult men with DS was evaluated using bioimpedance and biomarkers.	Resistance exercise increased muscle mass and work performance in the DS group; no changes were observed in the control group, and muscle damage markers were unaffected.	Properly planned resistance training is may be beneficial and feasible method for increasing muscle mass and function in individuals with DS without causing muscle damage.
10	(Demir-Er et al., 2025)	<i>Comparative Observational</i>	35 DS, 20 healthy Age: 3–8 years	Gait and balance were assessed in children with DS and typically developing children using the GAITRite system and Bertec platform.	In the DS group, stride length was short, cadence was high, base width was large, and AP/ML oscillations were increased; a significant correlation was observed between walking and balance.	Significant differences were found in gait and balance parameters in children with DS, necessitating individualized and comprehensive rehabilitation approaches.
11	(Reis et al., 2023)	<i>Randomized Controlled Trial</i>	23 (11 DS, 12 Healthy, Age: 27–28 years	Muscle strength and oxidative stress and inflammation markers were compared before and after acute resistance exercise performed with elastic bands.	An increase in oxidative stress was observed in individuals with DS after resistance exercise; muscle strength increased in knee extension and elbow flexion but decreased in handgrip strength; an inverse relationship was found between strength and oxidative and inflammatory markers.	While elastic band exercises are safe for individuals with DS, the oxidative stress response remains limited, and increasing the exercise load may be necessary for optimal adaptation.
12	(Chen et al., 2015)	<i>Randomized Controlled Trial</i>	20 DS Female: 4 Male: 16 Age: 15–30 years	The effect of a 20-minute treadmill walk on executive function components such as choice–response time, attention shifting, and inhibition.	Short-term moderate-intensity walking improved inhibition performance in individuals with DS, but did not produce significant changes in choice–response time and attention shifting parameters.	Moderate exercise has been found to have short-term positive effects on inhibition in individuals with DS; further studies are recommended for long-term effects.

13	(Skiba et al., 2019)	Randomized Controlled Trial	22 adult DS Female: 11 Male: 11 Age: 25–40 years	Nordic Walking was practiced 3 days a week for 10 weeks; walking parameters were evaluated using 3D analysis.	Nordic Walking training has significantly increased step length, walking speed, and joint range of motion in individuals with DS, positively affecting pelvic movements and joint synchronization.	Nordic walking stands out as may be beneficial and feasible intervention that improves locomotor functions in individuals with DS and brings their walking pattern closer to physiological values.
14	(Beqaj et al., 2018)	Randomized Controlled Trial	13 competitive swimmers (8 with DS, 5 without DS) Age: 18–28 years	Functional, motor, and physical performance were evaluated using various measurements.	Fine motor skills and grip strength were found to significantly predict daily living activities in children with DS; grip strength was found to be an important predictor of mobility and responsibility, while 9-HPT was found to be an important predictor of social/cognitive skills.	Fine motor skills and grip strength significantly predict functional performance in individuals with DS; these findings are important in intervention planning.
15	(Nahla M et al., 2022)	Randomized Controlled Trial	30 DS Female: 9 Male: 21 Age: 7–10 years	Participants underwent balance exercises or mechanical vestibular stimulation three days per week for 12 weeks; anterior-posterior, mediolateral, and overall balance indices were measured using Biodex.	Postural balance improved in both groups; however, more pronounced improvement was observed in the mechanical vestibular stimulation group, with decreases of 23.6%, 24.4%, and 26.4% in APSI, MLSI, and OASI values, respectively.	Vestibular stimulation in children with DS develops balance and postural control more effectively than traditional exercises.
16	(Seron et al., 2017)	Randomized Controlled Trial	41 DS Female: 10 Male: 31 Age: 12–20 years	The effects of 12 weeks of aerobic and resistance training on maximum and submaximal cardiorespiratory parameters were examined comparatively.	Aerobic and resistance training increased maximum ventilation in young people with DS, while $\dot{V}O_{2peak}$ remained unchanged; aerobic training increased work capacity while decreasing submaximal heart rate.	Research has shown that aerobic exercise is effective in combating sedentary lifestyles by improving the cardiorespiratory system in young people with DS.
17	(Shields et al., 2010)	Randomized Controlled Trial	70 DS Age: 14–22 years	Participants completed a 10-week resistance training or social activity program under student guidance; work performance, muscle strength, and physical activity were assessed.	Progressive resistance training significantly increased lower extremity muscle strength by 42% in adolescents with DS, while no significant changes were observed in upper extremity strength.	A community-based PRT approach can support long-term health gains by increasing the physical activity and work performance of youth with DS.

18	(Seron et al., 2015)	Randomized Controlled Trial	29 DS Female: 9 Male: 20 Age: 12–20 years (mean 15.7±2.82)	The hemodynamic effects of 12 weeks of aerobic and resistance training were examined comparatively; SBP, DBP, MBP, CO, HR, and PVR.	Twelve weeks of aerobic and resistance training significantly reduced SBP, DBP, and MBP in young people with DS; no changes were observed in other hemodynamic parameters such as HR, CO, SV, and PVR.	Moderate aerobic and resistance exercise in young people with DS contributes to the prevention of cardiovascular disease by lowering blood pressure.
19	(Thein Tun et al., 2025)	Randomized Controlled Trial	30 DS Female: 8 Male: 22 Age: 7–10 years	Participants engaged in a 50-minute exercise program three days a week for six weeks; motor skills, balance, and strength were measured using the TGMD-2, modified stork, and FTSTS tests.	Structured exercise significantly improved basic motor skills, static balance, and lower extremity strength in children with DS and led to improvements in TGMD-2 and other physical measures.	Structured exercise has been shown to promote motor and physical development in children with DS in the short term; further studies are needed to determine long-term effects.
20	(Cline et al., 2025)	Cross-sectional analysis (baseline data from RCT)	42 DS CHD: 21 Non-CHD: 21 Age: 25.4±1.1 years	Physical activity and cardiorespiratory fitness in individuals with DS were analyzed cross-sectionally using 7-day accelerometer and treadmill tests according to the presence of CHD.	Individuals with CHD and DS had lower MVPA levels and higher diastolic blood pressure; cardiorespiratory fitness remained low regardless of CHD status.	Despite the presence of CHD, physical fitness is generally low in individuals with DS, and no difference has been observed in terms of CR fitness; the findings support the need for inclusive exercise programs.
21	(Shields & Taylor, 2010)	Randomized Controlled Trial	23 DS Female: 6 Male: 17 Age: 13–18 years	For 10 weeks, participants underwent resistance training twice a week under student mentorship; muscle strength and functional performance were assessed using 1RM, the stair test, and the Grocery Shelving Task.	Progressive resistance training significantly increased lower extremity muscle strength in adolescents with DS, while showing moderate positive effects on upper extremity strength and functional performance.	Community-based resistance training applied to adolescents with DS has resulted in a significant increase in lower extremity muscle strength with high participation and safe implementation; further studies are recommended for long-term effects.
22	(Mohamed et al., 2021)	Randomized Controlled Trial	36 DS Age: 6–12 years	Children with DS underwent PNF or inspiratory muscle training for 6 weeks; respiratory muscle strength, chest expansion, spirometry parameters, and functional capacity were analyzed using ANOVA.	Both PNF and IMT improved respiratory function in children with DS; PNF training showed a superior effect compared to IMT in terms of muscle strength, chest expansion, and functional capacity.	PNF and inspiratory muscle training increased respiratory muscle strength, chest expansion, and functional capacity in children with DS; the effects were more pronounced with PNF.

23	(Hussein, 2017)	Randomized Controlled Trial	30 DS Female: 6 Male: 24 Age: 10–14 years	The effects of 12 weeks of chest physiotherapy and lower extremity strength training on respiratory function were evaluated using spirometry.	Chest physiotherapy in children with DS significantly increased FVC, PEFR, FEV1, and MVV, while lower extremity strength exercises only improved FVC and PEFR.	It has been shown that lower extremity strengthening exercises in children with DS can improve certain respiratory functions such as FVC and PEFR, but this effect is more limited compared to chest physiotherapy.
24	(Pessoa et al., 2023)	Multicomponent Intervention (pre-post design)	16 DS Female: 7 Male: 9 Age: 11–19 years	The effects of a 12-week multi-component exercise program on muscle strength, cardiorespiratory fitness, agility, flexibility, and body composition were evaluated.	In adolescents with DS, lower and upper extremity strength, cardiorespiratory fitness, agility, and flexibility improved significantly after intervention; no changes were observed in BMI and coordination.	The multi-component program improved physical fitness in adolescents with DS, leading to gains in strength and CRF while having limited effects on coordination and fat mass; family involvement played a critical role.
25	(Anugrah et al., 2023)	Cross-sectional correlational study	30 DS Age: 8–13 years	The relationships between variables were examined using Pearson correlation by assessing the balance, locomotor skills, and core endurance of 30 children with DS.	Strong positive correlations were found between dynamic balance and locomotor skills ($r=0.821$) and core muscle endurance ($r=0.710$) in children with DS.	Children with DS showed a strong positive correlation between dynamic balance and locomotor skills, as well as core muscle endurance; individualized approaches are recommended in exercise planning.

Cardiorespiratory and metabolic responses to exercise

Cardiorespiratory capacity in individuals with DS has been found to be limited due to genetic, neurological and structural factors. In submaximal and maximal exercise tests, it has been reported that cardiorespiratory coordination is low in individuals with DS and that their capacity to reach maximal heart rate is limited (Mendonca et al., 2022; Oviedo et al., 2021). These findings are explained by inadequate autonomic nervous system responses, sinus node dysfunction, and low chronotropic reserve. In contrast, regular aerobic and resistance training has resulted in significant improvement in cardiac and haemodynamic functions (Seron et al., 2015, 2017). These improvements are underpinned by mechanisms including increased contractile capacity of the heart muscle, vasodilation in the peripheral vascular bed, and enhanced oxygen extraction in working muscles. Resistance circuit training has regulated oxidative stress parameters and strengthened antioxidant defence in individuals with DS (Rosety-Rodriguez et al., 2021). Furthermore, it has been reported that the transient oxidative stress arising after exercise is balanced more rapidly in the DS population compared to healthy individuals (Reis et al., 2024). This situation is explained by the exercise rapidly re-establishing redox homeostasis and activating endogenous antioxidant enzymes. In terms of metabolic outputs, it has been observed that DS individuals with a high body mass index have low cardiorespiratory performance (Dodd & Shields, 2005; Pitchford et al., 2018; Wee et al., 2015). These results are associated with obesity increasing the load on the respiratory muscles, limiting ventilation capacity, and increasing cardiac workload. Findings regarding bone metabolism are limited. It has been determined that long-term resistance and jumping protocols do not increase bone mineral density to the expected level in children with DS (Dilek et al., 2018). This result can be explained by the low mineralisation, endocrine differences and growth hormone deficiencies observed in DS. Overall, these findings indicate that exercise increases cardiorespiratory fitness in individuals with DS, provides a protective effect on oxidative stress balance, and improves metabolic

outcomes. These effects can be explained through autonomic nervous system adaptations, cardiac muscle contractility, peripheral circulation regulation, redox balance, and the restructuring of energy metabolism.

When examined from the perspective of respiratory rehabilitation, respiratory functions in individuals with DS may be limited due to hypotonic respiratory muscles, narrow upper airways, and structural differences in the chest wall. Therefore, exercises aimed at respiratory rehabilitation play a critical role in increasing both functional capacity and quality of life. PNF-based respiratory muscle exercises have provided stronger improvements compared to inspiratory muscle training (Mohamed et al., 2021). This superiority is explained by the more effective activation of the diaphragm and intercostal muscles, increased thoracic mobility, and improved alveolar ventilation. Furthermore, the proprioceptive stimuli used in PNF techniques enhance the coordination of respiratory muscles by supporting neuromuscular control. Chest physiotherapy has been found to be superior to lower extremity strength exercises in terms of pulmonary function parameters such as FEV1 and MVV (Hussein, 2017). These findings are explained by the clearance of secretions, maintenance of airway patency, and increased gas exchange surface area at the alveolar level. At the same time, chest physiotherapy increases thoracic expansion, thereby improving ventilation efficiency and oxygen saturation. These results show that respiratory rehabilitation not only increases lung capacity but also has multidimensional effects on exercise tolerance, daily activity capacity, and overall functional independence. In conclusion, PNF-based respiratory exercises and chest physiotherapy are effective strategies for improving respiratory function in individuals with DS. These effects can be explained through mechanisms such as strengthened diaphragmatic activation, increased chest wall mobility, secretion clearance, and improved alveolar ventilation.

Motor and Cognitive Responses to Exercise

Exercise-based interventions provide significant contributions to motor control, postural balance, and cognitive performance in individuals with DS. Core stability and treadmill training have improved postural balance and reduced the risk of falls in children (Alsakhawi & Elshafey, 2019). This development can be explained by the compensation of hypotonia and ligamentous laxity commonly seen in DS, and the strengthening of trunk stability by activating the core muscles. Structured exercise programs have led to significant improvements in fundamental motor skills such as running, jumping, and object control (Thein Tun et al., 2025). These results are associated with the strengthening of proprioceptive sensation, increased coordination capacity of the musculoskeletal system, and support for motor learning processes. Technology-assisted approaches (virtual reality and tDCS) have improved manipulative skills and upper extremity coordination (Lopes et al., 2022). These findings are explained by increased cortical excitability, accelerated sensorimotor integration, and enhanced neuroplasticity. The contribution of aerobic exercise to executive functions is also noteworthy. A single session of moderate-intensity aerobic exercise has been shown to produce short-term improvements in attention and working memory (Chen et al., 2015). These effects can be explained by increased cerebral blood flow, oxygenation, and dopaminergic system activation. The dose-response relationship between exercise intensity and manual motor performance (Chen & Ringenbach, 2019) can be attributed to high intensity triggering greater muscle fiber recruitment and increasing the sensitivity of neural control. When age-related changes are examined, it is seen that manipulative skills decrease with age in individuals with DS, but regular exercise programs slow this decline. (Chen et al., 2021). This finding can be explained by the fact that repetitive motor activities preserve neuroplasticity and slow down age-related neurodegenerative processes. Sports-based activities such as Nordic Walking and swimming have also increased locomotor skills

as well as social interaction and self-confidence (Skiba et al., 2019). These gains are linked to physical activity increasing social participation, strengthening motivation, and reinforcing self-efficacy.

When examining Table 1 for multi-component interventions and lifestyle programs, it is evident that multi-component interventions integrating not only exercise but also nutrition, family support, and behavioral guidance yield the strongest gains in individuals with Down syndrome (DS). Combinations of exercise + nutrition + family support have demonstrated significant improvements in muscle strength, agility, and cardiorespiratory fitness in adolescent individuals with DS (Pessoa et al., 2023). These results are explained by exercise supporting musculoskeletal adaptations, healthy eating maintaining metabolic balance, and family support increasing motivation and continuity. Metabolic and anthropometric outcomes have shown that lifestyle factors are decisive in longitudinal studies. Regular physical activity and healthy eating have improved lipid profile and obesity risk (Pecoraro et al., 2024; Pino-Valenzuela & Benavides-Roca, 2023). These benefits have been associated with improved energy balance, increased insulin sensitivity, and reduced risk of dyslipidemia. The relationship between physical activity levels and obesity is of particular importance in individuals with DS. Low activity levels and poor dietary habits increase cardiometabolic disorders, while regular exercise and healthy lifestyle practices reduce these risks (Basil et al., 2016; Pitchford et al., 2018; Yamanaka et al., 2023). This effect can be explained by the balance between increased energy expenditure and energy intake. The role of family and environmental factors has been critical in the success of multi-component interventions. Family involvement and school-based programs have increased the program adherence of children with DS, while also improving their social interactions (Cline et al., 2025). These findings have been associated with social support systems increasing motivation, strengthening self-efficacy perceptions, and ensuring the sustainability of behavioral change. Consequently, multi-component interventions and lifestyle programs not only provide short-term physical and metabolic gains in individuals with DS; they also increase quality of life, social participation, and independent living skills through lasting behavioral changes. These effects can be explained by the interaction of biological (metabolic regulation, cardiorespiratory adaptation), psychological (self-confidence, motivation), and social (family and environmental support) mechanisms.

Results of Sports-Based Activities and Structured Exercise Protocols

They have been shown to significantly increase both physical capacity and functional independence and social participation in individuals with Down syndrome (DS). Sports-based programs such as Nordic Walking, swimming, and basketball improve walking speed, stride length, and locomotor patterns (Skiba et al., 2019), while also providing significant improvements in body composition and functional fitness (Cai & Baek, 2022). Such cues can be attributed to the stabilization of locomotor patterns within the central nervous system due to rhythmic steps; the availability of ideal resistive forces, as well as adequate proprioceptive stimulation, in the environment; and the utilization of psychosocial stimuli, such as motivational, feelings of membership, or self-confidence, in the case of team sport activities. Structured programs for children have improved fundamental motor skills such as running, jumping, and object control. These improvements are explained by the fact that repetitive movements support motor learning, strengthen proprioceptive sense, and improve neuromuscular coordination. Resistance training implemented under student leadership in adolescents has significantly increased lower extremity muscle strength (Shields et al., 2017; Shields & Taylor, 2010). These effects can be explained by increased motor unit recruitment, strengthened muscle fiber synchronization, and triggered hypertrophic adaptations. Community-based empowerment programs have been shown to improve work performance in young adults. These findings are associated with the transfer of functional strength gains to activities of daily living. The effects of structured

exercises on balance are also noteworthy. Programs focusing on postural stability have improved static and dynamic balance (Giustino et al., 2020). These results are explained by the strengthening of core muscles, more effective use of the vestibular system, and improvement of proprioceptive feedback mechanisms. Age is also an important factor. It has been reported that regular structured programs slow age-related decline in manipulative skills. These findings are associated with the promotion of neuroplasticity by repetitive motor activities and the slowing of age-related degenerative processes. Consequently, structured exercise protocols provide not only motor skill development but also long-term functional independence in individuals with DS. These effects can be explained through mechanisms such as neuroplasticity, musculoskeletal adaptations, motor unit activation, proprioceptive integration, and slowing age-related degenerative processes.

Conclusion

This systematic review of 66 studies demonstrates the multidimensional effects of exercise interventions in individuals with DS. The findings show improvements not only in physical fitness but also in cognitive function, cardiometabolic health, respiratory function, and social participation. Motor and cognitive gains, core stability, treadmill, and structured exercises supported these effects, which were explained by the compensation of hypotonia and ligamentous laxity, the strengthening of proprioceptive sense, and repetitive motor activities that increase neuroplasticity. Technology-assisted programs (VR, tDCS) have led to significant progress in manipulative skills through increased cortical excitability and enhanced sensorimotor integration. Cardiorespiratory and metabolic responses improved with regular aerobic and resistance training; these improvements have been linked to autonomic nervous system adaptation, vasodilation in peripheral circulation, oxygen extraction in muscles, and regulation of redox balance mechanisms. The protective effects of exercise on oxidative stress emerged thanks to the strengthening of the antioxidant defense system. Sports-based programs (basketball, swimming, Nordic walking) not only increased physical capacity but also provided psychosocial gains through motivation, social participation, and self-efficacy mechanisms. Structured exercise protocols have supported functional independence through motor unit recruitment, muscle hypertrophy, and enhanced proprioceptive integration. Respiratory rehabilitation improved respiratory function through PNF-based exercises and chest physiotherapy. These effects can be explained by the mechanisms of effective activation of the diaphragm and intercostal muscles, increased thoracic mobility, secretion clearance, and improved alveolar ventilation. Multicomponent lifestyle programs have yielded lasting gains by combining exercise with nutrition and family support. These results can be explained by the simultaneous contribution of biological (metabolic regulation, cardiorespiratory adaptation), psychological (self-confidence, motivation), and social (family and environmental support) mechanisms. Overall, exercise interventions offer multifaceted benefits in individuals with DS through a biopsychosocial approach. Findings indicate that exercise is not only a clinical treatment but also a comprehensive intervention strategy that supports neurological adaptations, cardiorespiratory health, and social participation.

Limitations: In our review, the sample sizes of the included studies are generally small, and there is marked heterogeneity in terms of study designs, exercise protocols, duration of intervention and the health outcomes assessed. The fact that some studies do not include a control group or employ a quasi-experimental/pre-post design limits the ability to interpret the findings in a causal manner.

Acknowledgement: This research has been supported by the Turkish Scientific and Technological Research Council (TÜBİTAK) under project number 224S903. We would therefore like to express our gratitude to TÜBİTAK for its support.

Clinical Trial Registration: The systematic review protocol was preregistered in PROSPERO (CRD420251046980).

CHD: Congenital Heart Defects/Disease

VSD: Ventricular septal defect, PDA: Patent ductus arteriosus, AVSD: Atrio-ventricular septal defect, ASD: Atrial septal defect

HR: Heart rate

References

- Alkhushi, N. (2024). The detailed profile of congenital heart diseases in 254 children with Down syndrome in Saudi Arabia. *The Cardiothoracic Surgeon*, 32(1), 1. <https://doi.org/10.1186/s43057-023-00121-x>
- Alsaied, T., Marino, B. S., Esbensen, A. J., Anixt, J. S., Epstein, J. N., & Cnota, J. F. (2016). Does Congenital Heart Disease Affect Neurodevelopmental Outcomes in Children with Down Syndrome? *Congenital Heart Disease*, 11(1), 26–33. <https://doi.org/10.1111/chd.12322>
- Alsakhawi, R. S., & Elshafey, M. A. (2019). Effect of Core Stability Exercises and Treadmill Training on Balance in Children with Down Syndrome: Randomized Controlled Trial. *Advances in Therapy*, 36(9), 2364–2373. <https://doi.org/10.1007/s12325-019-01024-2>
- Anugrah, T., Sumaryanti, S., Simatupang, N., Sutapa, P., Ambardini, R. L., & Nugroho, S. (2023). The relationship of dynamic body balance with locomotor ability and endurance of core muscles in children with down syndrome. *Journal of Kinesiology and Exercise Sciences*, 33(102), 1–8. <https://doi.org/10.5604/01.3001.0053.4084>
- Basil, J. S., Santoro, S. L., Martin, L. J., Healy, K. W., Chini, B. A., & Saal, H. M. (2016). Retrospective Study of Obesity in Children with Down Syndrome. *The Journal of Pediatrics*, 173, 143–148. <https://doi.org/10.1016/j.jpeds.2016.02.046>
- Beerse, M., Henderson, G., Liang, H., Ajisafe, T., & Wu, J. (2019). Variability of spatiotemporal gait parameters in children with and without Down syndrome during treadmill walking. *Gait & Posture*, 68, 207–212. <https://doi.org/10.1016/j.gaitpost.2018.11.032>
- Beqaj, S., Tërshnjaku, E. E. T., Qorolli, M., & Zivkovic, V. (2018). Contribution of Physical and Motor Characteristics to Functional Performance in Children and Adolescents with Down Syndrome: A Preliminary Study. *Medical Science Monitor Basic Research*, 24, 159–167. <https://doi.org/10.12659/MSMBR.910448>
- Bush, D. S., & Ivy, D. D. (2022). Pulmonary Hypertension in the Population with Down Syndrome. *Cardiology and Therapy*, 11(1), 33–47. <https://doi.org/10.1007/s40119-021-00251-5>
- Cai, W., & Baek, S. -S. (2022). Effects of 24-week basketball programme on body composition and functional fitness on adults with Down syndrome. *Journal of Intellectual Disability Research*, 66(12), 939–951. <https://doi.org/10.1111/jir.12951>
- Chen, C. C., & Ringenbach, S. D. R. (2019). Dose-Response Association between Exercise Intensity and Manual Motor Performance in Individuals with Down Syndrome: a Preliminary Study. *Journal of Developmental and Physical Disabilities*, 31(3), 299–311. <https://doi.org/10.1007/s10882-018-9640-y>
- Chen, C., Ringenbach, S. D. R., Crews, D., Kulinna, P. H., & Amazeen, E. L. (2015). The association between a single bout of moderate physical activity and executive function in young adults with Down syndrome: a preliminary study. *Journal of Intellectual Disability Research*, 59(7), 589–598. <https://doi.org/10.1111/jir.12163>
- Chen, C.-C. (JJ), Ringenbach, S. D. R., Arnold, N. E., & Nam, K. (2021). Aging Effect on Manipulative Skills in Individuals With Down Syndrome. *Journal of Motor Learning and Development*, 9(2), 172–184. <https://doi.org/10.1123/jmld.2020-0037>
- Clauss, S. B., Gidding, S. S., Cochrane, C. I., Walega, R., Zemel, B. S., Pipan, M. E., Magge, S. N., Kelly, A., & Cohen, M. S. (2019). Prevalence of unsuspected abnormal echocardiograms in adolescents with down syndrome. *American Journal of Medical Genetics Part A*, 179(12), 2420–2424. <https://doi.org/10.1002/ajmg.a.61367>
- Clina, J. G., White, D. A., Sherman, J. R., Danon, J. C., Forsha, D. E., Helsel, B. C., Washburn, R. A., Donnelly, J. E., & Ptomey, L. T. (2025). Daily physical activity and cardiorespiratory fitness in adults with Down syndrome with and without congenital heart disease. *Disability and Health Journal*, 18(3), 101778. <https://doi.org/10.1016/j.dhjo.2025.101778>
- de Graaf, G., Buckley, F., & Skotko, B. G. (2015). Estimates of the live births, natural losses, and elective terminations with Down syndrome in the United States. *American Journal of Medical Genetics Part A*, 167(4), 756–767. <https://doi.org/10.1002/ajmg.a.37001>

- Demir-Er, Ş., Alkan, H., Topuz, S., & Mutlu, A. (2025). Gait and static balance analysis of children with Down syndrome and comparison with typically developing children. *International Journal of Developmental Disabilities*, 1–9. <https://doi.org/10.1080/20473869.2025.2496723>
- Diaz, A. J., Rosety, I., Ordóñez, F. J., Brenes, F., García-Gómez, N., Castejón-Riber, C., Rosety-Rodríguez, M., Bernardi, M., Alveró-Cruz, J. R., & Rosety, M. A. (2021). Effects of Resistance Training in Muscle Mass and Markers of Muscle Damage in Adults with Down Syndrome. *International Journal of Environmental Research and Public Health*, 18(17), 8996. <https://doi.org/10.3390/ijerph18178996>
- Dilek, G., Öztürk, C., Hepgüler, S., Özkinay, F., & Dilek, M. (2018). The Effect of Exercise on Bone Mineral Density in Patients with Down Syndrome. *The Journal of Pediatric Research*, 5(3), 118–123. <https://doi.org/10.4274/jpr.66588>
- Dimopoulos, K., Constantine, A., Clift, P., Condliffe, R., Moledina, S., Jansen, K., Inuzuka, R., Veldtman, G. R., Cua, C. L., Tay, E. L. W., Opatowsky, A. R., Giannakoulas, G., Alonso-Gonzalez, R., Cordina, R., Capone, G., Namuyonga, J., Scott, C. H., D'Alto, M., Gamero, F. J., ... Jansen, K. (2023). Cardiovascular Complications of Down Syndrome: Scoping Review and Expert Consensus. *Circulation*, 147(5), 425–441. <https://doi.org/10.1161/CIRCULATIONAHA.122.059706>
- Dodd, D., Helsel, B., Bodde, A. E., Danon, J. C., Sherman, J. R., Donnelly, J. E., Washburn, R. A., & Ptomey, L. T. (2023). The association of increased body mass index on cardiorespiratory fitness, physical activity, and cognition in adults with down syndrome. *Disability and Health Journal*, 16(4), 101497. <https://doi.org/10.1016/j.dhjo.2023.101497>
- Dodd, K. J., & Shields, N. (2005). A Systematic Review of the Outcomes of Cardiovascular Exercise Programs for People With Down Syndrome. *Archives of Physical Medicine and Rehabilitation*, 86(10), 2051–2058. <https://doi.org/10.1016/j.apmr.2005.06.003>
- Engsner, S., Giang, K. W., Dellborg, M., Fedchenko, M., Eriksson, P., & Mandalenakis, Z. (2024). Impact of Down Syndrome on Survival Among Patients With Congenital Heart Disease. *Journal of the American Heart Association*, 13(2). <https://doi.org/10.1161/JAHA.123.031392>
- Fitzpatrick, V., Rivelli, A., Bria, K., & Chicoine, B. (2020). Heart Disease in Adults With Down Syndrome Between 1996 and 2016. *The Journal of the American Board of Family Medicine*, 33(6), 923–931. <https://doi.org/10.3122/jabfm.2020.06.190425>
- Foley, C., & Killeen, O. G. (2019). Musculoskeletal anomalies in children with Down syndrome: an observational study. *Archives of Disease in Childhood*, 104(5), 482–487. <https://doi.org/10.1136/archdischild-2018-315751>
- Gawel, E., Celebańska, D., & Zwierzchowska, A. (2024). Differentiation of the body build and posture in the population of people with intellectual disabilities and Down Syndrome: a systematic review. *BMC Public Health*, 24(1), 406. <https://doi.org/10.1186/s12889-024-17908-0>
- Giustino, V., Messina, G., Alesi, M., La Mantia, L., Palma, A., & Battaglia, G. (2020). Study of postural control and body balance in subjects with Down syndrome. *Human Movement*, 22(1), 66–71. <https://doi.org/10.5114/hm.2021.98466>
- Hussein, Z. A. (2017). Strength training versus chest physical therapy on pulmonary functions in children with Down syndrome. *Egyptian Journal of Medical Human Genetics*, 18(1), 35–39. <https://doi.org/10.1016/j.ejmhg.2016.02.008>
- Jain, P. D., Nayak, A., & Karnad, S. D. (2022). Relationship between trunk muscle strength, reaching ability and balance in children with Down syndrome – A cross-sectional study. *Brain and Development*, 44(2), 95–104. <https://doi.org/10.1016/j.braindev.2021.09.005>
- Kelly, A., Gidding, S. S., Walega, R., Cochrane, C., Clauss, S., Townsend, R. R., Xanthopoulos, M., Pipan, M. E., Zemel, B. S., Magge, S. N., & Cohen, M. S. (2019). Relationships of Body Composition to Cardiac Structure and Function in Adolescents With Down Syndrome are Different than in Adolescents Without Down Syndrome. *Pediatric Cardiology*, 40(2), 421–430. <https://doi.org/10.1007/s00246-018-2014-5>
- Koo, D., Pathak, P., Moon, J., & Panday, S. B. (2022). Analysis of the relationship between muscular strength and joint stiffness in children with Down syndrome during drop landing. *Technology and Health Care*, 30, 383–390. <https://doi.org/10.3233/THC-THC228035>
- Leite, J. C., Neves, J. C. de J., Vitor, L. G. V., & Fujisawa, D. S. (2018). Evaluation of postural control in children and adolescents with down syndrome aged eight to twelve years old. *Journal of Human Growth and Development*, 28(1), 50. <https://doi.org/10.7322/jhgd.127335>
- Lopes, J. B. P., Miziara, I. M., Kahani, D., Parreira, R. B., de Almeida Carvalho Duarte, N., Lazzari, R. D., Santos, L. V., de Mello Monteiro, C. B., da Silva Cardoso, D. C., de Oliveira Hassel Mendes, J., dos Santos Alves, V. L., Silva, I. O., Oliveira, L. V., Conway, B. A., Galli, M., Cimolin, V., & Oliveira, C. S. (2022). Brain activity and upper limb movement analysis in children with Down syndrome undergoing transcranial direct current stimulation combined with virtual reality training: study protocol for a randomized controlled trial. *Trials*, 23(1), 87. <https://doi.org/10.1186/s13063-022-06014-4>
- Maher, C. G., Sherrington, C., Herbert, R. D., Moseley, A. M., & Elkins, M. (2003). Reliability of the PEDro scale for rating quality of randomized controlled trials. *Physical Therapy*, 83(8), 713–721.

- Masaki, M., Sugawara, K., Iizuka, Y., Uchikawa, Y., Isobe, H., Hattori, F., Mano, K., Saito, K., Sugino, A., Kato, K., & Sakaino, K. (2021). Comparison of the degree of pes planovalgus and muscle mass of the ankle joint and foot muscles between children with Down syndrome and children with typical development. *Journal of Biomechanics*, 122, 110482. <https://doi.org/10.1016/j.jbiomech.2021.110482>
- Mendonça, G. V., Santos, I., Fernhall, B., & Baynard, T. (2022). Predictive equations to estimate peak aerobic capacity and peak heart rate in persons with Down syndrome. *Journal of Applied Physiology*, 132(2), 423–433. <https://doi.org/10.1152/jappphysiol.00421.2021>
- Mohamed, R. A., Mohamed, E. S. H., Habshy, S. M., & Aly, S. M. (2021). Impact of two different pulmonary rehabilitation methods in children with down syndrome. *Journal of Bodywork and Movement Therapies*, 27, 512–521. <https://doi.org/10.1016/j.jbmt.2021.04.009>
- Nahla M, I., Elham El-Sayed, S., Ehab Ragaa, A.-E., & Amr Abd El Ghafar, A. E. hamid. (2022). Mechanical vestibular stimulation versus traditional balance exercises in children with Down syndrome. *African Health Sciences*, 22(1), 377–383. <https://doi.org/10.4314/ahs.v22i1.46>
- Nordklev, C. B., Gjesdal, O., Gunnes, N., Holmstrøm, H., Morken, N., Vangen, S., & Sitras, V. (2024). Down syndrome and associated atrioventricular septal defects in a nationwide Norwegian cohort: Prevalence, time trends, and outcomes. *Acta Obstetrica et Gynecologica Scandinavica*, 103(10), 2024–2030. <https://doi.org/10.1111/aogs.14932>
- Oviedo, G. R., Garcia-Retortillo, S., Carbó-Carreté, M., Guerra-Balic, M., Balagué, N., Javierre, C., & Guàrdia-Olmos, J. (2021). Cardiorespiratory Coordination During Exercise in Adults With Down Syndrome. *Frontiers in Physiology*, 12. <https://doi.org/10.3389/fphys.2021.704062>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*, n71. <https://doi.org/10.1136/bmj.n71>
- Pecoraro, L., Zadra, M., Cavallin, F., Lauriola, S., Piacentini, G., & Pietrobelli, A. (2024). Lipid Profile, Eating Habit, and Physical Activity in Children with Down Syndrome: A Prospective Study. *Diseases*, 12(4), 68. <https://doi.org/10.3390/diseases12040068>
- Pessoa, M. L. F., Bandeira, P. F. R., Silva, E. F. L., Macêdo, D. S., & Martins, C. M. L. (2023). A six-month multicomponent intervention improves Down syndrome adolescents' physical fitness. *Science & Sports*, 38(1), 96–101. <https://doi.org/10.1016/j.scispo.2022.02.005>
- Pino-Valenzuela, M., & Benavides-Roca, L. (2023). Anthropometric and physical condition evaluations in a population with Down Syndrome: a longitudinal study over 10 year. *MHSalud: Revista En Ciencias Del Movimiento Humano y Salud*, 20(2). <https://doi.org/10.15359/mhs.20-2.11>
- Pitchford, E. A., Adkins, C., Hasson, R. E., Hornyak, J. E., & Ulrich, D. A. (2018). Association between Physical Activity and Adiposity in Adolescents with Down Syndrome. *Medicine & Science in Sports & Exercise*, 50(4), 667–674. <https://doi.org/10.1249/MSS.0000000000001502>
- Reis, A. L., Deus, L. A., Passos Neves, R. V., Corrêa, H. de L., Reis, T. L., Aguiar, L. S. de, Honorato, F. S., Barbosa, J. M. da S., Araújo, T. B. de, Palmeira, T. R. C., Simões, H. G., Prestes, J., Sousa, C. V., Ide, B. N., & Rosa, T. dos S. (2023). Exercise-Induced Transient Oxidative Stress Is Mitigated in Down Syndrome: Insights About Redox Balance and Muscle Strength. *Journal of Strength and Conditioning Research*. <https://doi.org/10.1519/JSC.0000000000004664>
- Reis, A. L., Deus, L. A., Passos Neves, R. V., Corrêa, H. de L., Reis, T. L., Aguiar, L. S. de, Honorato, F. S., Barbosa, J. M. da S., Araújo, T. B. de, Palmeira, T. R. C., Simões, H. G., Prestes, J., Sousa, C. V., Ide, B. N., & Rosa, T. dos S. (2024). Exercise-Induced Transient Oxidative Stress Is Mitigated in Down Syndrome: Insights About Redox Balance and Muscle Strength. *Journal of Strength & Conditioning Research*, 38(3), e125–e134. <https://doi.org/10.1519/JSC.0000000000004664>
- Rosety-Rodriguez, M., Bernardi, M., Elsegui, S., Rosety, I., Diaz, A. J., Rosety, M. A., Brenes, F., Oliva-Pascual-Vaca, A., Alvero-Cruz, J. R., & Ordóñez, F. J. (2021). A Short-Term Resistance Training Circuit Improved Antioxidants in Sedentary Adults with Down Syndrome. *Oxidative Medicine and Cellular Longevity*, 2021(1). <https://doi.org/10.1155/2021/8811153>
- Seron, B. B., Goessler, K. F., Modesto, E. L., Almeida, E. W., & Greguol, M. (2015). Blood Pressure and Hemodynamic Adaptations after a Training Program in Young Individuals with Down Syndrome. *Arquivos Brasileiros de Cardiologia*. <https://doi.org/10.5935/abc.20150033>
- Seron, B. B., Modesto, E. L., Stanganelli, L. C. R., Carvalho, E. M. O. de, & Greguol, M. (2017). Effects of aerobic and resistance training on the cardiorespiratory fitness of young people with Down Syndrome. *Brazilian Journal of Kinanthropometry and Human Performance*, 19(4), 385. <https://doi.org/10.5007/1980-0037.2017v19n4p385>

- Shields, N., Lim, P., Wollersheim, D., Nikolopoulos, N., Barrett, J., Evans, A., Taylor, N. F., & Munteanu, S. (2017). Do foot posture, deformity, and footwear fit influence physical activity levels in children with Down syndrome? A prospective cohort study. *Journal of Intellectual & Developmental Disability*, 42(4), 332–338. <https://doi.org/10.3109/13668250.2016.1237623>
- Shields, N., & Taylor, N. F. (2010). A student-led progressive resistance training program increases lower limb muscle strength in adolescents with Down syndrome: a randomised controlled trial. *Journal of Physiotherapy*, 56(3), 187–193. [https://doi.org/10.1016/S1836-9553\(10\)70024-2](https://doi.org/10.1016/S1836-9553(10)70024-2)
- Shields, N., Taylor, N. F., & Fernhall, B. (2010). A study protocol of a randomised controlled trial to investigate if a community based strength training programme improves work task performance in young adults with Down syndrome. *BMC Pediatrics*, 10(1), 17. <https://doi.org/10.1186/1471-2431-10-17>
- Skiba, A., Marchewka, J., Skiba, A., Podsiadlo, S., Sulowska, I., Chwala, W., & Marchewka, A. (2019). Evaluation of the Effectiveness of Nordic Walking Training in Improving the Gait of Persons with Down Syndrome. *BioMed Research International*, 2019, 1–11. <https://doi.org/10.1155/2019/6353292>
- Stang, A. (2010). Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. *European Journal of Epidemiology*, 25(9), 603–605. <https://doi.org/10.1007/s10654-010-9491-z>
- Szczawińska-Popłonyk, A., Popłonyk, N., & Awdi, K. (2024). Down Syndrome in Children: A Primary Immunodeficiency with Immune Dysregulation. *Children*, 11(10), 1251. <https://doi.org/10.3390/children11101251>
- Thein Tun, M., Aye, T., ZarChi Htut, T., Mar Tin, W., & Thuzar Khin, M. (2025). Effect of structured exercise program on fundamental motor skills in children with Down syndrome: A randomized controlled trial. *Journal of Associated Medical Sciences*, 58(2), 48–57. <https://doi.org/10.12982/JAMS.2025.037>
- Uludag Alkaya, D., Ozturk, B., Yuksel Ulker, A., Bozlak, S., Ozturk, E., Dedeoglu, R., Eroglu, A. G., Oztunc, F., & Tuysuz, B. (2023). Congenital Heart Defects and Outcome in a Large Cohort of Down Syndrome: A Single-Center Experience from Turkey. *Turkish Archives of Pediatrics*. <https://doi.org/10.5152/TurkArchPediater.2023.23041>
- Valero, C., Mustacchi, Z., Melo Bezerra, P., Dos Santos Figueiredo, F. W., Merly Martinelli, P., Alves de Siqueira Carvalho, A., & Feder, D. (2021). Foot rotation asymmetry in Down syndrome and the relationship with crawling and walking onset: a cross sectional study. *Journal of Human Growth and Development*, 31(2), 247–256. <https://doi.org/10.36311/jhgd.v31.11279>
- Villamil, V. I., Downing, K. F., Oster, M. E., Andrews, J. G., Galindo, M. K., Patel, J., Klewer, S. E., Nembhard, W. N., & Farr, S. L. (2025). Comorbidities and Healthcare Utilization Among Young Adults With Congenital Heart Defects by Down Syndrome Status—Congenital Heart Survey to Recognize Outcomes, Needs, and wellbeinG, 2016–2019. *Birth Defects Research*, 117(2). <https://doi.org/10.1002/bdr2.2439>
- Wee, S. O., Pitetti, K. H., Gouloupoulou, S., Collier, S. R., Guerra, M., & Baynard, T. (2015). Impact of obesity and Down syndrome on peak heart rate and aerobic capacity in youth and adults. *Research in Developmental Disabilities*, 36, 198–206. <https://doi.org/10.1016/j.ridd.2014.10.002>
- Yamanaka, E., Inayama, T., Okazaki, K., Nakada, T., Kojima, M., Kita, I., & Ohkawara, K. (2023). The Amount of Light to Vigorous Physical Activity (Met's-Hours/Day) in Children with and without Down Syndrome Attending Elementary School in Japan. *International Journal of Environmental Research and Public Health*, 20(2), 1293. <https://doi.org/10.3390/ijerph20021293>
- Yaqoob, M., Manzoor, J., Hyder, S. N., & Sadiq, M. (2019). Congenital heart disease and thyroid dysfunction in Down syndrome reported at Children's Hospital, Lahore, Pakistan. *The Turkish Journal of Pediatrics*, 61(6), 915–924. <https://doi.org/10.24953/turkped.2019.06.013>
- Zago, M., Condoluci, C., Pau, M., & Galli, M. (2019). Sex differences in the gait kinematics of patients with Down syndrome: A preliminary report. *Journal of Rehabilitation Medicine*, 51(2), 144–146. <https://doi.org/10.2340/16501977-2507>

Cite this article as: Kurtoğlu, A., Çar, B., Eken, Ö., Akçay, B., Kurtoğlu, E., Mutlu, E. K., Kılıçarslan, S., Dönmez, E., Taçgın, Z., Türkmen, O. B., Türkmen, M., Koca M. E. (2026). The Effect of Exercise Programmes on Physical and Physiological Health Indicators in Individuals with Down Syndrome: A Systematic Scoping Review. *Central European Journal of Sport Sciences and Medicine*, 2(54), 79–108. <https://doi.org/10.18276/cej.2026.2-07>