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Distinct effects of trampoline-based stretch-shortening cycle exercises on muscle strength and postural control in children with Down syndrome: a randomized controlled study

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Abstract. – OBJECTIVE: The aim of the study was to investigate the effect of a 3-month, trampoline-based stretch-shortening cycle (SSC) exercises on muscle strength and postural control in children with Down's syndrome (DS).

PATIENTS AND METHODS: Thirty-two children with DS aged between 7-9 years were enrolled and randomly assigned into the control group (n = 16); received standard physical therapy (sPT) or SSC group (n = 16); received sPT in addition to a 15-minute, trampoline-based SSC training program twice per week for 12 successive weeks. Lower limb muscle strength and postural stability [anterior/posterior stability index (A/P-SI), medial/lateral stability index (M/L-SI)], and overall stability index (O-SI) were assessed pre- and post-treatment.

RESULTS: Strength of hip extensor (*p*=0.034) and adductor (*p*=0.015), knee extensor (*p*=0.028) and flexor (*p*=0.01), and ankle dorsi (*p*=0.033) and plantar flexor (*p*=0.007) muscles increased significantly in the SSC group when compared with the control group. Also, the A/P-SI (*p*=0.019), M/L-SI (*p*=0.002), and O-SI (*p*=0.021) decreased significantly in the SSC group when compared with the control group, suggesting better postural control.

CONCLUSIONS: Twelve weeks of trampoline-based SSC exercises are likely effective for enhancing muscle strength and postural control in children with DS and should consequently be included in the rehabilitation programs for these children.

Key Words:
Trisomy 21, Physical rehabilitation, Plyometric exercises, Muscle power, Postural stability.

Introduction

Down syndrome (DS) is the most common and readily identifiable genetic disorder among children[1], it accounts for 91% of all genetic disorders and occurs in about 1 in 1,000 live births every year[2]. DS is related to a chromosomal anomaly caused by the existence of a whole or

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part of an extra 21st chromosome[3]. Children with DS usually encounter problems with the motor function as a result of decreased muscle tone, ligamentous laxity, decreased muscle strength, and endurance[4]. Muscle weakness is prevalent amongst children with DS in comparison with healthy counterparts, especially the lower limb musculature, which is more significant to general physical health and execution of daily activities[5]. Moreover, children with DS experience decreased balance capacity on account of the brain stem and cerebellar hypoplasia leading to disruption of motor function and postural control of these children relative to typical peers[6]. DS children have difficulty preserving their body posture which is frequently combined with an abnormality in gait pattern and increased number of falls[7].

Presently, a variety of physical therapy techniques are being used to improve lower limb muscle strength and postural control in children with DS including, but not limited to, progressive resistance training[5,8], hippotherapy[9], aquatic therapy[10], and isokinetic strength training[11]. Stretch-shortening (SSC) exercises-also referred to as plyometric exercises, are a traditional form of resistance training that involves three-phase muscle contraction during dynamic movements (like jumping and hopping), where the muscle moves rapidly through the eccentric, isometric, and concentric phases[12]. The SSC exercises have effectively been used to enhance muscle strength, muscle coordinative responses, and response-capacity to balance threats in children with neurodevelopmental disorders[13,14]. SSC exercises using the trampoline are of interest to researchers in the field of pediatric physical rehabilitation, especially as the trampoline-based exercises are enjoyable activities that promote fun and maintain children's interest to participate and continue with involvement in physical activities for longer duration[15,16]. This form of SSC exercise incorporates proprioceptive, vestibular, and visual inputs[17,18], which are of great importance for motor functions in children with DS. Besides, SSC exercises on a trampoline provide the benefits of aerobic exercises without adding stresses on lower limbs, as with vigorous exercises. Vertical shocks induced by jumping or jogging on the elastic floor, spread gently through bones and spine, thus reducing risks of minor nerve damage or heels and ankles micro-traumas[19].

The trampoline-based SSC exercises have been used for children with different physical and intellectual disabilities. Abd El-Aziz reported meaningful improvement in the motor control of the knee joint in a sample of children with cerebral palsy received a 3-months, a minitrampoline-based SSC exercise program besides traditional physical therapy[20]. Also, Lourenço et al[21] stated that trampoline exercises over 32 weeks contributed considerably to an improvement in strength and motor proficiency in children diagnosed with autism spectrum disorders. Further, Giagazoglou et al[17] demonstrated that trampoline training is an effective intervention for improving balance and motor function in children with intellectual disorders.

To our knowledge, there is only a single study that examined the effectiveness of a trampoline-based SSC on muscle strength and balance control in children with DS[22]. Identifying potential implications of the trampoline-based SSC exercises on these variables in children with DS should be of immense interest for physical therapists as it is considered a form of playing and fun activities which encourage the children to continue in engaging in exercises more than traditional exercises, and it could be essential to plan and design effective exercise programs premised on children's unique capacities and interest. This study, therefore, was designed to investigate the effect of a 3-month, trampoline-based SSC exercises on muscle strength and postural control in children with DS.

Patients and Methods

Study Design

This was a randomized clinical trial undertaken at the College of Applied Medical Sciences' outpatient clinic at Prince Sattam Bin Abdulaziz University (PSAU) in Saudi Arabia between December 2018 and August 2019. PSAU's Physical Therapy Research Ethics Committee approved the study (Protocol No: 0018/0086). All experimental procedures were in line with the legal principles of the 1975 Helsinki Declaration. The outlines of the research methodology were thoroughly demonstrated for the participants and their families before registration. Legal guardians signed a written informed consent form once they approved children's participation in the study. An independent researcher who did not know the treatment assignment measured lower limb muscle strength and postural control on two occasions (pre- and post-treatment). The following identifier has been assigned to the study on ClinicalTrials.gov: NCT04966403.

Participants

Thirty-two children with DS from both sexes were enrolled in this study. They were recruited from three local schools placing children with DS altogether in special classes not in ordinary classes. They were included on the following basis: age between 7 and 9 years, the capability of understanding and following basic commands, independent standing, and walking, and not suffering from atlantoaxial joint instability. Children with un-corrected cardiac anomalies, vision or hearing loss, pulmonary disorders, neurological signs as epilepsy, and children who had a history of musculoskeletal surgery in the lower extremities through the past year were excluded.

A pre-study calculation of the required sample size was done through the G-Power software, version 3.1.9.7 (Neu-Isenburg, Germany). The analysis was based on estimates of mean difference (the mean of three measurements of the maximum isometric muscle strength has been estimated) and standard deviation for knee extensor strength, which were collected from a preliminary study. Using a two-sided two-sample equal-variance *t*-test with a significance level of 0.05, a total sample size of 28 children with DS (i.e., group sample sizes of 14 children) was needed to achieve an actual power of 91.3% to reject the null hypothesis of equal means when the population mean-difference of knee extensor strength is $\mu1 - \mu2 = 55.2 - 64.6 = -9.4$ newtons, with a common standard deviation of 7.2 newtons. Assuming the dropout rate to be ~15%, the sample size was inflated to 32 children (16 for each group).

Children were assigned into two treatment groups with a 1:1 allocation ratio. Participants were numbered from 1 to 32 consecutively. An independent researcher who was not a part of this study performed a single sequence of random assignment of these numbers (i.e., simple randomization) through a web-based randomizer[23], to create two equal-sized sets as follows: Set #1 [Control group (n = 16); received standard physical therapy] and set #2 [SSC group (n = 16); received standard physical therapy along with a minitrampoline-based SSC training program].

Outcome Measures

Muscle Strength

A calibrated hand-held dynamometer (Micro FET2, Hoggan Health Technologies Inc., UT, USA) was used for measuring maximum isometric voluntary muscle strength (MIMS) of hip extensors and abductors, knee flexors and extensors, and ankle dorsi and plantar flexors. The intra-rater reliability of the hand-held dynamometer was tested before the collection of baseline data – details are given below in the results. A pre-test session was devoted to demonstrating and familiarizing children with the measurement procedure. Three trials were performed by each child for each muscle group (5 seconds each, with rest intervals of at least 30 seconds between trials, and 5 minutes between groups). During measurement, the assessor encouraged children verbally to exert as maximal effort as possible. The mean MIMS of the three trials (in newtons) was estimated and used for the analysis. The child position and dynamometer placement are shown in Table I. For this study, data from the dominant side (the right side for all participants) was employed for the statistical analysis.

Postural Control

Postural stability indices were assessed through the Balance Biodex System (Biodex Medical Systems, Shirley, NY, USA), which has previously been reported as a reliable test[24]. The system consists of a dynamic balance platform that allows simultaneous movements around the anterior-posterior and medial-lateral axes, adjustable support handles, and an all-in-one flat computer panel. The system was calibrated before each measurement according to the manufacturer's manual. During the measurement, each child was instructed to stand with a two-leg stance in a comfortable upright position on the platform and try to achieve a centered position while grasping the handrails and to keep the cursor centered on the screen grid. Once centering is achieved on the unstable foot platform and the cursor is in the center of the display target, the child was instructed to maintain position and the platform was stabilized. Afterward, the platform has been released to become unstable, and then the child was instructed to focus on the feedback screen directly in front of him and try to maintain the cursor in the middle of the screen while hands at the body side. The test duration was 30 sec. Three attempts were dedicated for each child and the average values of the anterior/posterior stability index (A/P-SI), medial/lateral stability index (M/L-SI), and overall stability index (O-SI) were documented[14].

Table I. Standardized testing position and dynamometer placement positions for assessing lower limb muscle strength.

Muscle group	Testing position	Dynamometer position – resistance direction
Hip extensors	Prone standing: trunk supported on the testing-table, the standing limb in a stable and comfortable standing, while the tested limb position was full knee extension and 45° hip flexion	The posterior aspect of the thigh, 10 cm above the knee joint, in line with the middle of the knee joint – resist hip extension
Hip abductors	Supine: hip and knee of the untested limb positioned against the wall for stabilization. The tested limb fully extended with 10° hip abduction	The mid-lateral aspect of the knee joint, in line with the knee joint – resist hip abduction
Knee extensors	Sitting on plinth: hips and knees flexed to 90°, hands resting on the lap.	The anterior aspect of the leg in line with the middle of the ankle joint, just superior to the lateral malleolus of the ankle – resist the knee extension movement
Knee flexors	Sitting on plinth: hips and knees flexed to 90°, hands resting on the lap.	The posterior aspect of the leg, in line with the middle of ankle joint, just superior to lateral malleolus of the ankle – resist the knee flexion movement
Ankle dorsiflexors	Supine: hip and knee flexed to 90° on a height-adjustable table, ankle in neutral.	The dorsum of the foot in line with the s cond metatarsal of the foot – resist the e dorsiflexion movement
Ankle plantar flexors	Supine: hip and knee flexed to 90° on a height-adjustable table, ankle in neutral.	The plantar surface of the foot in line with the second metatarsal of the foot – resist the plantar flexion movement

Intervention

Standard Physical Therapy

Participants in the control and SSC groups received the standard physical therapy (sPT) program, which was conducted according to the needs of each participant and was generally concerned with building strength, enhancing developmental skills, boosting balance, coordination, and postural control, improving physical fitness, and minimizing the development of the compensatory movement patterns that children with DS are likely to develop. The program comprised of progressive resistance training (performed using weights, two sets of 10 repetitions were given for each muscle group, resistance increased by ½ Kg as children were able to complete without undue stresses); core strengthening exercises, balance exercises (stand on a balance board, one-leg stance, heal-to-toes stance, walking on balance board, walking on a balance beam, walking on a line, and walking on the inclined surface); flexibility exercises (if required); coordination exercises; and aerobic exercises on a treadmill or a stationary bicycle according to children preferences. The training was conducted for 45 minutes/session, twice/week for 12 successive weeks by two pediatric physical therapists. Therapy was conducted in a 1:1 child-to-therapist ratio.

Trampoline-Based SSC Exercises

In addition to the sPT, the SSC group received 15-minute SSC exercise sessions, twice weekly, with a total of 24 sessions over 12 successive weeks. The program was adopted from previous reports on the trampoline-based exercise for children with DS or other developmental disorders[21,22]. The participants performed SSC exercises at least 10-15 minutes after the physical therapy sessions. The SSC exercise program was conducted in compliance with guidelines of the National Strength and Conditioning Association guidelines[25] and safety rules of the American Academy of Pediatrics ("American Academy of Pediatrics. Committee on injury and poison prevention and committee on sports medicine and fitness. Trampolines at home, school and recreational center," 1999)[26]. The program consisted of nine exercises performed on a round trampoline, 4.3 meters in diameter (JumpKing, Inc., Portland, OR) – details are shown in Table II. The proper execution of each exercise was explained to participants in a pre-practice session. Instructions were repeated until participants understood what was anticipated. Exercise load was raised gradually in two training paradigms: the first one prioritizing the horizontal exercises and the second focusing on the vertical exercises. Training progression was achieved by increasing repetitions of exercises in three blocks, each continued for one month.

Statistical Analysis

The Intraclass Correlation Coefficient (ICC) and Coefficient of variation (CoV) were used to determine the test re-test reliability of muscle strength measurement (a single rater, one-week precision test). The Shapiro-Wilk test was used to assess data normality. The two-way repeated-measures ANOVA test [two treatment factors (Control and SSC) and two measurement occasions (pre/post) in the two factors] was used to compare the mean differences of dependent variables between groups across the time from the pre- to post-treatment (i.e., treatment x time interaction). In the event of significant treatment x time interaction, the paired-sample *t*-test was used to calculate the pre-to-post changes within each group. Partial eta-squared (η^2p) and Cohen's *d* were used to calculate the effect size for the significant ANOVA and *t*-test, respectively. The significance level accepted for this analysis was $p<0.05$. Statistical analyses were done using the SPSS software for windows, version 24 (SPSS Inc., IBM Armonk, NY, USA).

Table II. Trampoline-based SSC exercise program.

Exercise	Description	1st block Sets/Reps	2nd block Sets/Reps	3rd block Sets/Reps
Trampoline-based SSC (horizontal exercises)				
Bounding	Start off like skipping, then push off with one leg, add a high knee with the opposing leg, and jump as high and forward as possible.	1×5 (RT), 1×5 (LT)	1×10 (RT), 1×10 (LT)	1×15 (RT), 1×15 (LT)
Forward jumping	Stand with feet together, swing arm forward, and jump with both feet as far as possible.	1×5	1×10	1×15
Side leaping	Stand on one leg with slight bend at the knee and other leg raised off the ground. Then, jump laterally and land on the opposite foot.	1×5 (RT), 1×5 (LT)	1×10 (RT), 1×10 (LT)	1×15 (RT), 1×15 (LT)
Forward hopping – one leg	Stand with feet at hip width, left up one foot behind, then hop forward on the other.	1×5 (RT), 1×5 (LT)	1×10 (RT), 1×10 (LT)	1×15 (RT), 1×15 (LT)
Side-to-side jump	Stand with both feet at shoulder width, bend both knees, push off the trampoline forcefully, and jump to the RT side and repeat with the LT side.	1×5 (RT), 1×5 (LT)	1×10 (RT), 1×10 (LT)	1×15 (RT), 1×15 (LT)
Trampoline-based SSC (vertical exercises)				
Symmetrical stride jumping	Stride stand, jump up, and alternately advance feet forward between jumps.	1×5	1×10	1×15
Squat jumping	Stand with feet together, hinge at the knee and lower down such that thighs are parallel to the floor, press feet down to explode off the trampoline, and jump as high as possible.	1×5	1×10	1×15
Knee tuck-jumping	Stand with feet shoulder-width apart, get down in a ¼ squat, Jump up by push the trampoline down forcefully, and bring knees to chest during jumps	1×5	1×10	1×15
Lunge jumping	Stand with your feet hip-width apart, take a big step forward, lower down the body until knees bent to 90o, push explosively off the trampoline, and switch leg position while airborne to land on one knee with the opposite leg forward	1×5	2×5	3×5

Notes: The number of sets/repetitions that participants started with have been determined in a pilot study. – No pauses were permitted between repetition. A 1-2-minute rest interval were dedicated between sets. – Participants were encouraged constantly to exert as maximal efforts as possible during exercise.

Results

Participants' Flow and Baseline Characteristics

The participants' flow throughout the study is illustrated in Figure 1. Forty-eight children were screened, among them, 32 children were eligible, and were randomized to the study groups. However, one child was lost from the control group for unknown reasons. Therefore, a total of 31 children completed the study and their data were analyzed. The baseline demographic characteristics are demonstrated in Table III. The control and SSC groups were homogenous concerning age, weight, height, BMI, and IQ level (all *p*-values > 0.05).

Reliability of Measurements

There were excellent agreements between duplicate measurements of muscle strength. The ICC (95 CI) and CoV were [0.98 (0.94-0.99) and 2.29%] for hip extensor, [0.97 (0.92-0.99) and 3.93%] for hip abductor, [0.96 (0.96-0.98) and 3.62%] for knee extensors, [0.96 (0.85-0.98) and 4.10%] for knee flexor, [0.95 (0.84-0.99) and 5 %] for ankle dorsiflexor, and [0.97 (0.90-0.99) and 3.58%] for ankle plantar flexors.

Muscle Strength

Table IV shows the lower extremity muscle strength for the study groups. There were significant treatment x time interactions in the strength of hip extensors ($p = 0.034$), hip abductors ($p = 0.015$), knee extensors ($p = 0.028$), knee flexors ($p = 0.01$), ankle dorsiflexors ($p = 0.033$), and ankle plantar flexors ($p = 0.007$), with a moderate effect size for all strength variables ($0.25 > \eta^2 p > 0.09$). There was a greater improvement in muscle strength scores for the SSC group from the pre- to post-treatment as compared to the control group. The paired sample analysis showed significant large changes in

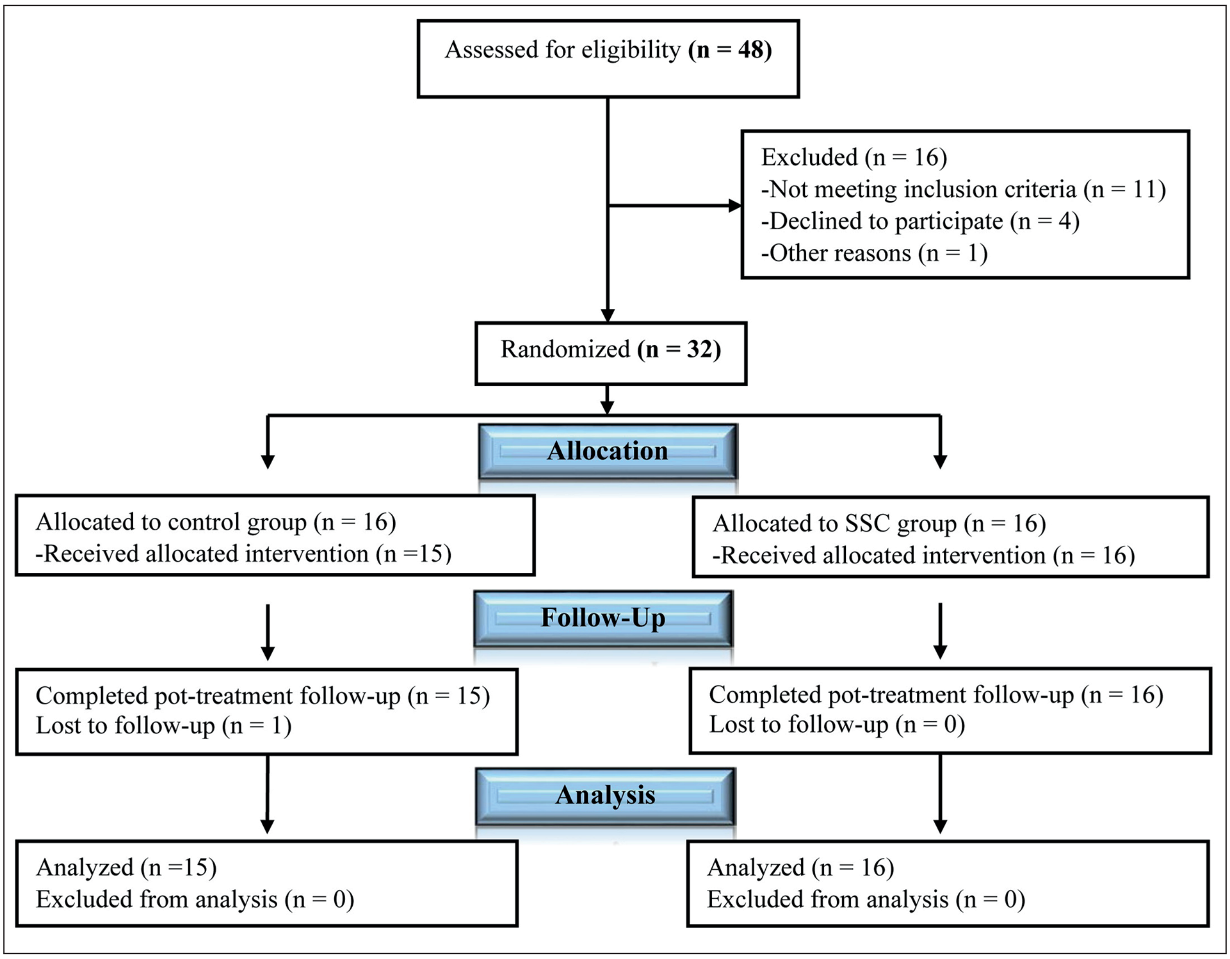

Figure 1. Participants' flow through the study.

Table III. Baseline demographic characteristics of children with Down's syndrome in the control and SSC groups.

	Control group (n = 15)	SSC group (n = 16)	*p*-value
Age, year	8.60 ± 0.98	9.19 ± 0.75	0.07†
Gender (boys/girls), n (%)	11 (73.3)/4 (26.7)	9 (56.3)/7 (43.7)	0.46‡
Weight, Kg	34.60 ± 3.27	34.81 ± 2.37	0.84†
Height, m	1.27 ± 0.05	1.26 ± 0.04	0.33†
BMI, Kg/m^2	21.45 ± 1.32	22.03 ± 1.28	0.12†
IQ level, %	56.13 ± 4.10	58.19 ± 3.56	0.15†

Continuous data expressed as mean ± SD and categorical data shown as frequency (%), BMI: body mass index, IQ: Intelligence quotient – measured by Wechsler Intelligence Scale for Children-IV by a clinical psychologist †Independent *t*-test, ‡Fishers' exact test.

all strength variables within the SSC group ($p < 0.05$, $d > 0.8$) and non-significant changes within the control group ($p > 0.05$).

Postural Control Indices

Table V displays the postural control indices for the study groups. There were significant treatment x time interactions in A/P-SI ($p = 0.019$), M/L-SI ($p = 0.002$), and O-SI ($p = 0.021$), with a moderate effect size for the A/P-SI and O-SI ($0.25 > \eta^2p > 0.09$) and a large effect size for the M/L-SI ($\eta^2p > 0.25$). There was a greater improvement in postural stability indices for the SSC group from the pre- to post-treatment than

Table IV. Lower extremity muscle strength (in Newton) for the control and SSC groups.

Variables	Control group (n = 15)	SSC group (n = 16)	Treatment x Time interaction		
			$F_{(1,30)}$	*p*-value	η^2p
Hip extensors					
Pre	52.88 ± 7.23	56.14 ± 8.10	4.92	0.034*	0.15
Post	53.97 ± 6.68	60.59 ± 9.86			
p-value	0.23	0.003*			
Cohen's d (95% CI)	–	0.90 (0.37-1.44)			
Hip Abductors					
Pre	47.13 ± 7.52	49.98 ± 8.75	6.74	0.015*	0.19
Post	48.28 ± 7.29	54.57 ± 7.54			
p-value	0.17	0.002*			
Cohen's d (95% CI)	–	0.96 (0.42-1.49)			
Knee Extensors					
Pre	57.61 ± 9.39	60.96 ± 8.86	5.37	0.028*	0.16
Post	59.63 ± 7.83	68.03 ± 8.71			
p-value	0.11	0.001*			
Cohen's d (95% CI)	–	0.99 (0.46-1.52)			
Knee flexors					
Pre	55.44 ± 7.81	57.54 ± 10.36	7.35	0.01*	0.20
Post	57.14 ± 8.30	64.57 ± 7.80			
p-value	0.16	0.0004*			
Cohen's d (95% CI)	–	1.13 (0.59-1.66)			
Ankle dorsiflexors					
Pre	51.96 ± 9.20	53.34 ± 5.82	4.99	0.033*	0.15
Post	52.76 ± 7.93	58.06 ± 7.66			
p-value	0.29	0.008*			
Cohen's d (95% CI)	–	0.76 (0.23-1.30)			
Ankle plantar flexors					
Pre	58.90 ± 12.44	57.42 ± 10.58	8.40	0.007*	0.23
Post	59.77 ± 9.98	64.43 ± 9.87			
p-value	0.42	0.001*			
Cohen's d (95% CI)	–	1.02 (0.49-1.55)			

Data are presented as mean ± SD, η^2p: effect size for significant ANOVA test, Cohen's d: effect size for significant *t*-test *significant at $p < 0.05$.

Table V. Postural control indices (*in degrees*) for the control and SSC groups.

Variables	Control group (n = 15)	SSC group (n = 16)	Treatment x Time interaction		
			$F_{(1,30)}$	*p*-value	η^2p
A/P-SI					
Pre	3.11 ± 0.54	2.87 ± 0.51	8.23	0.019*	0.18
Post	2.83 ± 0.36	2.10 ± 0.66			
p-value	0.014*	0.0004*			
Cohen's d (95% CI)	0.72 (0.17-1.26)	1.13 (0.60-1.66)			
M/L-SI					
Pre	2.97 ± 0.40	3.08 ± 0.45	11.92	0.002*	0.26
Post	2.87 ± 0.38	2.48 ± 0.56			
p-value	0.025*	0.001*			
Cohen's d (95% CI)	0.65 (0.10-1.18)	1.10 (0.56-1.62)			
O-SI					
Pre	3.18 ± 0.39	3.10 ± 0.42	5.99	0.021*	0.17
Post	2.92 ± 0.43	2.46 ± 0.33			
p-value	0.016*	0.0001*			
Cohen's d (95% CI)	0.70 (0.16-1.24)	1.33 (0.80-1.87)			

Data are presented as mean ± SD, η^2p: effect size for significant ANOVA test, Cohen's d: effect size for significant *t*-test, *significant at $p < 0.05$. A/P-SI: anteroposterior stability index, M/L-SI: mediolateral stability index, O-SI: overall stability index.

the control group. The paired sample analysis revealed significant medium improvements in all indices for the control groups ($p < 0.05$, $0.8 > d > 0.5$) and significant large improvements for the SSC group ($p < 0.05$, $d > 0.8$).

Discussion

Motor function in children with DS is characterized by decreased muscle tone, muscle weakness, and joint hyper-extensibility, all of which may have a detrimental effect on the postural control efficiency[4,5]. Further training schemes need to analyze how their physical capacities can be enhanced. In this respect, we investigated the effect of a 12-week, trampoline-based SSC exercise program on muscle strength and postural control in children with DS. The main findings of our study were that SSC exercise (15 minutes/session; twice weekly) in association with the sPT program was more efficient in increasing lower limb muscle strength and enhancing postural control than the sPT program alone in children with DS. Although several studies evaluated the effect of trampoline-based SSC exercises in children with other developmental disabilities and reported favorable effects[17,18,20,21], the impacts of this therapeutic approach on children with DS remains very interesting to physiotherapist. This may, therefore, highlight the significance of the results demonstrated herein, which expand the evidence on the effectiveness of trampoline-based SSC exercises in children with developmental disabilities.

The trampoline-based SSC exercises increased the MIMS of lower limb muscles and reduced A/P-SI, M/L-SA, and O-SI, suggesting that trampoline-based SSC exercises may a helpful intervention to improve muscle strength and postural control in children with DS. There are several possible explanations for these results. Primarily, the nature of SSC exercises, which include quick and repeated transformations between muscle stretching and contraction[12]. This countermovement action may have led to enhanced motor unit recruitment as a consequence of activation of the stretch reflex and contributed greater muscle force/power through the recovery of stored elastic energy during jumping and hopping movements[27]. Besides, SSC exercises offer a broad array of balancing challenges, where the body's center-of-gravity shifts horizontally and vertically, thereby creating a neural adaptation that improves postural stability[28]. Further to this, the SSC exercises can increase the proprioceptive feedback to the central nervous system by eliciting an involuntary stretch reflex, which may have eventually led to an increase in kinesthetic perception, and consequently improved postural stability[29]. Another possible explanation for our results is that performing SSC exercises on a trampoline may have induced changes in the complex sensory-motor stimulation of children's effort to adapt to the unstable surface of the trampoline and preserve balance. The jumping and hopping activities on the trampoline allow constant integration of the visual, kinesthetic, and vestibular inputs. Due to its vertical body motions on the trampoline, the vestibular sensory system, that reacts to changes in head positions, body movement and gravity pull, is enhanced during rebounds[30]. Also, the trampoline training permits children to engage actively in varied, enjoyable, and therapeutic movement activities. From this perspective, it can be claimed that the favorable improvement in motor function may be linked to the positive change of temper and interest toward exercise[30].

Although the role of trampoline exercises has been appreciated in children with different health conditions, evidence on the trampoline-based SSC on limb muscle strength and postural control in children with DS remains scarce. Only one study by Apoloni et al[22] evaluated the effectiveness of a 10-minute exercise program consisting of jumping activities on a trampoline, applied three times/week for three months in a sample of 12 children with DS. Their results showed a significant reduction in the center-of-pressure excursion in the anteroposterior and mediolateral directions, suggesting an improvement in the postural control. Despite the paucity of evidence on the effect of the trampoline-based SSC exercises in children with DS, there are previous studies that indicated the positive effect of this training model on these measures in some other cases. Giagazoglou et al[17] investigated the effect of trampoline-based SSC exercises on motor performance and balance ability in 18 children with intellectual disability and he concluded that there was a significant improvement in motor activities and balance in these children after 12 weeks of training. Lourenço et al[21] examined the effect of trampoline-based SSC exercises in children with autism spectrum disorder and reported significant improvements in lower limb muscle strength and motor proficiency. Abd-Elmonem and Elhady[31] assessed the effectiveness of trampoline-based SSC exercises on balance in children with diplegic cerebral palsy and demonstrated a meaningful improvement in the children's capacity to control posture when subjected to dynamic restraints. Elnaggar et al[13,32] explored the impacts of two- and three-month ground-based SSC exercises in children with unilateral cerebral palsy and demonstrated remarkable improvements in several aspects of motor function including strength, walking performance, co-activation pattern, and balance capabilities. Despite the methodological variations in terms of study population and training medium, the findings from children with DS shown in the present study may support the evidence from the afore-mentioned observations from children with other developmental motor disabilities.

The generalizability of our results is subject to certain limitations, e.g., the lack of previous information on the role of trampoline-based SSC exercises in children with DS. Considerably, more work will need to be done to confirm the results shown in the present study. It is also unfortunate that this study did appraise the long-term effects. Further works are therefore required to plan for frequent measurements at three-, six- and 12-month post-treatment to provide insights on the long-term effects of the trampoline-based SSC exercises. This study analyzed the effect of trampoline-based SSC exercises besides sPT *vs.* sPT program alone, where the entire session time was different. Thus, future studies are needed to compare the trampoline-based SSC exercises and sPT program with matching both groups for the training volume. The study didn't assess activity level after the program, so further studies are needed to investigate the effect of SSC exercises on activity level in children with Down syndrome. Despite the favorable effect of trampoline-based SSC, it is not currently possible to determine if the children's interest in this type of exercise affected their performance compared to the control group. Therefore, future studies need to consider measuring children's preferences of exercises to address this concern.

Conclusions

Based on the results of the current study, it can be concluded that SSC exercises can be an effective therapeutic addition to the sPT program of children with DS for improving lower limb muscle strength and enhancing postural control. While children with DS often need interventions that are enjoyable and interesting to stay physically active, therefore the trampoline-based SSC should be integrated into rehabilitation programs of DS children.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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Conception and design: Alshimaa R Azab, Waleed S Mahmoud, Abbas E Elsayed, Sahar M HAssan, Enas N Morgan , FatmaAlzahraa H Kamel. Analysis and interpretation of data: Alshimaa R Azab, Maged A Basha, Ragab K. Elnaggar. Drafting the article: Alshimaa R Azab, Waleed S Mahmoud, Sahar M Hassan, Enas N. Morgan. Supervision: Alshimaa R Azab, Maged A Basha, Ragab K. Elnaggar. Validation and final approval of the version of the article to be published: Alshimaa R Azab, Waleed S Mahmoud, Maged A Basha, Sahar M Hassan, Enas N. Morgan, Abbas E. Elsayed, FatmaAlzahraa H Kamel, Ragab K. Elnaggar.

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Data Availability Statement

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

References

1) Rahmani P, Shahrokhi H, Daneshmandi H. Evaluation of spinal abnormalities associated with flexibility and body mass index in girls with Down syndrome. J Rehabil Sci 2012; 8: 754-762
2) Weijerman ME, deWinter JP. Clinical practice. Eur J Pediatr 2010; 169: 1445-1452.
3) Gardiner KJ. Molecular basis of pharmacotherapies for cognition in Down syndrome. Trends Pharmacol Sci 2010; 31: 66-73.
4) Cowley PM, Ploutz-Snyder LL, Baynard T, Heffernan KS, Jae SY, Hsu S, Fernhall B. The effect of progressive resistance training on leg strength, aerobic capacity and functional tasks of daily living in persons with Down syndrome. Disabil Rehabil 2011; 33: 2229-2236.
5) Gupta S, Rao BK, Kumaran S. Effect of strength and balance training in children with Down's syndrome: a randomized controlled trial. Clin Rehabil 2011; 25: 425-432.
6) Ghaeeni S, Bahari Z, Khazaei AA. Effect of core stability training on static balance of the children with Down Syndrome. Physical Treatments-Specific Physical Therapy Journal 2015; 5: 49-54.
7) Aly SM, Abonour AA. Effect of core stability exercise on postural stability in children with Down syndrome. Int J Med Health Res 2018; 5: 213-222.
8) Shields N, Taylor NF. A student-led progressive resistance training program increases lower limb muscle strength in adolescents with Down syndrome: a randomised controlled trial. J Physiother 2010; 56: 187-193.
9) Champagne D, Dugas C. Improving gross motor function and postural control with hippotherapy in children with Down syndrome. Physiother Theory Pract 2010; 26: 564-571.
10) Hamed SA, Osama SA, Azab AR. Effect of aquatic program therapy on dynamic balance in Down's syndrome children. J Med Sci Clin Res 2016; 4: 9938-9942.
11) Eid MA, Aly SM, Huneif MA,Ismail DK. Effect of isokinetic training on muscle strength and postural balance in children with Down's syndrome. Int J Rehabil Res 2017; 40: 127-133.
12) Davies G, Riemann BL, Manske R. Current concepts of plyometric exercise. Int J Sports Phys Ther 2015; 10: 760-786.
13) Elnaggar RK. Effects of plyometric exercises on muscle-activation strategies and response-capacity to balance threats in children with hemiplegic cerebral palsy. Physiother Theory Pract 2020; 1-9. doi: 10.1080/09593985.2020.1833389. Online ahead of print.
14) Elnaggar RK, Elbanna MF, Mahmoud WS, Alqahtani BA. Plyometric exercises: subsequent changes of weight-bearing symmetry, muscle strength and walking performance in children with unilateral cerebral palsy. J Musculoskelet Neuronal Interact 2019; 19: 507-515.
15) Aalizadeh B, Mohammadzadeh H, Khazani A, Dadras, A. Effect of a trampoline exercise on the anthropometric measures and motor performance of adolescent students. Int J Prev Med 2016; 7: 91.
16) Germain AM, Blackmore AM, Gibson N, Newell B, Williams SA. Effects of adaptive bungee trampolining for children with cerebral palsy: a single-subject study. Pediatr Phys Ther 2019; 31: 165-174.
17) Giagazoglou P, Kokaridas D, Sidiropoulou M, Patsiaouras A, Karra C, Neofotistou K. Effects of a trampoline exercise intervention on motor performance and balance ability of children with intellectual disabilities. Res Dev Disabil 2013; 34: 2701-2707.
18) Giagazoglou P, Sidiropoulou M, Mitsiou M, Arabatzi F, Kellis E. Can balance trampoline training promote motor coordination and balance per-

formance in children with developmental coordination disorder?. Res Dev Disabil 2015; 36: 13-19.

19) Carter AE. Rebound Exercise: The Ultimate Exercise for the New Millennium (1st ed.). Library of Congress Contro: Indiana University Bloomington. 2014.

20) Abd El-Aziz AA. Balance training versus rebounding exercises program on motor control of knee joint in spastic diplegic cerebral palsied children. Int J Curr Res Acad Rev 2014; 2: 79-88.

21) Lourenço C, Esteves D, Corredeira R, Seabra A. The effect of a trampoline-based training program on the muscle strength of the inferior limbs and motor proficiency in children with autism spectrum disorders. J Phys Educ Sport 2015; 15: 592.

22) Apoloni BF, Lima FEB, Vieira JLL. Effectiveness of an intervention program with trampoline exercises in postural control of children with Down Syndrome. Rev Bras Educ Fís Esporte 2013; 27: 217-223.

23) Urbaniak G, Plous S. Research Randomizer (Version 4.0). Retrieved from https://www.randomizer.org/. 2013

24) Schmitz R, Arnold B. Intertester and intratester reliability of a dynamic balance protocol using the Biodex Stability System. J Sport Rehabil 1998; 7: 95-101.

25) Faigenbaum AD, Kraemer WJ, Blimkie CJ, Jeffreys I, Micheli LJ, Nitka M, Rowland TW. Youth resistance training: updated position statement paper from the national strength and conditioning association. J Strength Cond Res 2009; 23: S60-S79.

26) American Academy of Pediatrics. Committee on injury and poison prevention and committee on sports medicine and fitness. Trampolines at home, school and recreational center. Pediatrics 1999; 103: 1053-1056.

27) Cormie P, McGuigan MR, Newton RU. Developing maximal neuromuscular power. Sports Med 2011; 41: 17-38.

28) Chaouachi A, Othman AB, Hammami R, Drinkwater EJ, Behm DG. The combination of plyometric and balance training improves sprint and shuttle run performances more often than plyometric-only training with children. J Strength Cond Res 2014; 28: 401-412.

29) Hogan N. Adaptive control of mechanical impedance by coactivation of antagonist muscles. IEEE Trans Automat Contr 1984; 29: 681-690.

30) Arabatzi F. Adaptations in movement performance after plyometric training on mini-trampoline in children. J Sports Med Phys Fitness 2016; 58: 66-72.

31) Abd-Elmonem AM, Elhady HSA. Effect of rebound exercises on balance in children with spastic diplegia. Int J Ther Rehabil 2018; 25: 467-474.

32) Elnaggar RK, Elbanna MF. Evaluation of independent versus integrated effects of reciprocal electrical stimulation and botulinum toxin-A on dynamic limits of postural stability and ankle kinematics in spastic diplegia: a single-blinded randomized trial. Eur J Phys Rehabil Med 2019; 55: 241-249.