Original Article :

Gender Differences, Body Mass Index (BMI), and their Impact on Balance and Muscle Strength in School-Aged Children

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Received on May 25, 2025, accepted for Publication on Dec 23, 2025, dx.doi.org/10.5455/mjhs.2026.03.002

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Abstract

Background and Aims:
Balance is essential for daily activities and is influenced by various factors, including gender, body mass index (BMI), and weight status. This study investigates the relationships between gender, BMI, static and dynamic balance, and evaluates the impact of weight status on muscle strength in school-aged children.

Methods:
A cross-sectional study was conducted in primary schools in Al-Majmaah province, Riyadh, Saudi Arabia, involving 86 girls and 80 boys aged 7 to 9 years. Static balance was assessed using the Single-Leg Stance (SLS) test, dynamic balance using the Timed Up and Go (TUG) test, and muscle strength using a handheld dynamometer for quadriceps and hamstring muscles.

Result:
TBoys demonstrated significantly better dynamic balance performance on the TUG test compared to girls ($p < 0.001$), indicating faster movement control and coordination. In contrast, static balance, measured by the SLS test showed no significant gender difference ($p = 0.13$), suggesting comparable postural stability between boys and girls. Boys demonstrated greater quadriceps and hamstring strength compared to girls ($p < 0.001$). Weak to moderate positive correlations were identified between BMI and muscle strength in both genders.

Conclusion:
The findings highlight notable gender differences in dynamic balance and muscle strength, while static balance remains comparable between genders. The positive correlation between BMI and muscle strength underscores the importance of maintaining a healthy weight for optimal physical development in children.

Keywords:
Gender; BMI; Obesity; Balance; Muscle Strength; Children

Introduction:

In recent decades, the rise of physical inactivity and sedentary behaviors has become a pressing global health issue. Children today spend significantly more time engaged in sedentary activities such as playing video games, using smart devices, and performing light-intensity tasks. This shift has profound health implications, leading to increased risks of cardiovascular diseases, diabetes, and other health concerns[1].

The surge in sedentary lifestyles correlates with a worrying increase in global obesity rates, fueled by rapid lifestyle changes [2,3]. In Saudi Arabia, alarming obesity rates have been reported: 28.7% among individuals aged 15 and older and 32% among school-age children [4]. Childhood obesity carries severe health risks, including heightened susceptibility to chronic diseases and diminished quality of life[5].

Balance, defined as the ability to maintain the body's center of gravity over its base of support, is crucial for physical health[6]. This ability relies on the integration of sensory information from proprioceptive, vestibular, and visual systems, and is significantly influenced by factors such as obesity, age, and gender [7,8,9]. Muscle strength is another vital component of physical health, especially in children, as it is essential for performing daily activities, supporting growth, and preventing injuries[10].

Recent studies indicate a complex interplay between BMI, gender, and physical capabilities in children[11,12]. Boys and girls may exhibit different balance and muscle strength patterns due to varying physical development and activity levels [13]. Higher BMI is associated with poorer balance and reduced muscle strength, affecting children's overall physical development and health[14–16].

The objective of this study is to explore how gender and BMI influence static and dynamic balance, as well as muscle strength in school-aged children, providing insights for targeted interventions that promote healthier lifestyles among this population.

Materials And Methods:

Study Design, Setting, and Participants:

A cross-sectional study was conducted in primary schools located in Al-Majmaah Province, Riyadh Region, Saudi Arabia. Before initiating data collection, an a priori power analysis was conducted using G*Power 3.1 to determine the minimum sample size required for adequate statistical power. Based on a two-tailed test with an effect size of 0.5, a significance level of $\alpha = 0.05$, and a desired power $(1 - \beta) = 0.80$, the analysis indicated that a minimum of 128 participants was required. To account for potential dropouts and ensure balanced gender representation, a total of 166 children (86 girls and 80 boys) were

recruited.

Participants were selected through a multistage cluster sampling approach from several primary schools in Al-Majmaah Province, Riyadh Region, Saudi Arabia. Schools were chosen based on accessibility, administrative approval, and willingness to participate. Within each school, children aged 7 to 9 years who met the inclusion criteria were invited to participate.

The inclusion criteria were healthy school-aged children within the specified age range, regular school attendance, and absence of any acute or chronic illness. The exclusion criteria included children with neurological, vestibular, or musculoskeletal disorders, recent lower limb injuries, or any conditions that could affect balance or muscle strength. Written informed consent was obtained from the parents or legal guardians of all participants prior to testing, and the study protocol adhered to the ethical principles of the Declaration of Helsinki and was approved by the Majmaah University Research Ethics Committee (MUREC-Feb.11/COM-2024/6-1)

Outcome Measures:

Static Balance Assessment:

Static balance was assessed using the Single-Leg Stance (SLS) test to evaluate postural stability, with timing for maintaining balance recorded for both eyes open and closed conditions. The SLS has excellent reliability in children, with reported Intraclass Correlation Coefficient (ICC) values typically ranging from 0.84 to 0.97 [17].

Dynamic Balance Assessment:

The Timed Up and Go (TUG) test measured the time taken for participants to rise from a chair, walk 3 meters, turn around, return to the chair, and sit back down. The TUG test has high validity and reliability for measuring dynamic balance for various populations, including those with and without disabilities, with reliability scores often ranging from 0.80 to 0.99 [18].

Muscle Strength Assessment:

Muscle strength of the quadriceps and hamstrings was measured using a handheld dynamometer (MicroFET Series, Hoggan Health Industries, West Jordan, Utah, USA), providing precise readings during muscle contraction. The MicroFET dynamometer has demonstrated excellent validity and reliability for lower limb strength measurement in children, with ICC values typically ranging from 0.90 to 0.98 [19].

Study Procedure:

Informed consent was obtained from the parents of all participants through the respective school principals. Before testing, each participant's age, gender, height, weight, and BMI were recorded. All assessments were conducted individually

in a quiet, well-ventilated room within the school premises to ensure comfort and minimize distractions. Participants were instructed clearly, and each test was demonstrated before the actual trial. A five-minute warm-up consisting of light stretching and walking was performed prior to testing.

Static Balance Assessment (SLS Test):

Static balance was assessed using the SLS test. Participants stood barefoot on their dominant leg, identified as the leg used to kick a ball, while placing both hands on the hips. The non-dominant leg was flexed at approximately 90° at the knee, ensuring it did not touch the standing leg. They were instructed to maintain balance while looking at a fixed visual target placed at eye level two meters away. They performed the test twice, once with eyes open and once with eyes closed.

Timing began when the non-dominant foot left the ground and stopped if the participant moved the standing foot, removed their hands from the hips, or touched the raised leg to the ground. Each participant performed three trials, with 30-second rest intervals, and the best performance (longest duration) was recorded for analysis.

Dynamic Balance Assessment (TUG Test):

After a one-minute rest, dynamic balance was evaluated using the TUG test. Each participant began seated in a standard chair (seat height approximately 40 cm) with their back against the chair and feet flat on the floor. Upon the examiner's signal, the participant stood up, walked 3 meters, turned around a cone, returned to the chair, and sat back down. Timing began as soon as the back left the chair and stopped when it touched the chair again.

Each participant completed two practice trials followed by two measured trials, and the average time (in seconds) was used for statistical analysis. The TUG test has been reported to have high reliability and validity in assessing dynamic balance in children, with ICC values between 0.80 and 0.99.

Muscle Strength Assessment:

Muscle strength of the quadriceps and hamstrings was assessed using a handheld dynamometer. Participants were seated on a sturdy chair with their hips and knees flexed at 90°. For quadriceps testing, the dynamometer was placed just above the ankle on the anterior aspect of the lower leg, and participants were instructed to extend the knee with maximum effort for 3-5 seconds. For hamstring testing, the device was positioned on the posterior aspect of the lower leg, and participants were instructed to flex the knee maximally against resistance.

Each test was performed three times per limb with 30 seconds of rest between trials, and the highest value (in pounds) was used for analysis.

Statistical Analysis:

An unpaired t-test was conducted to compare participant characteristics, TUG test results, SLS test results, and muscle strength between genders. Pearson correlation coefficients were calculated to explore the relationships between BMI, balance, and muscle strength, with a significance level set at $p < 0.05$. All analyses were performed using SPSS version 25.

Results:

Participant Characteristics:

Eighty-six school-aged girls and eighty boys participated in the study. There were no significant differences between the groups in terms of age, weight, height, or BMI ($p > 0.05$) (Table 1).

Table 1: Basic characteristics of participants.

	Girls (N = 86)	Boys (N = 80)	MD	t- value	p-value
	Mean ± SD	Mean ± SD			
Age (years)	7.91 ± 0.92	7.86 ± 0.69	0.05	0.35	0.72
Weight (kg)	26.73 ± 7.21	26.22 ± 6.83	0.51	0.47	0.64
Height (cm)	124.81 ± 7.83	122.88 ± 7.22	1.93	1.65	0.10
BMI (kg/m²)	16.95 ± 3.14	17.15 ± 3.09	-0.2	-0.41	0.68

SD, standard deviation; MD, mean difference; p-value, level of significance

Comparison Between Gender by TUG Test and SLS Test:

TUG Test:

The mean ± SD of the TUG test for girls was 8.40 ± 1.44 seconds, while for boys it was 7.28 ± 1.04 seconds, with a mean difference of 1.12 seconds. Boys performed significantly better on the TUG test compared to girls ($p < 0.001$) (Table 2).

For the SLS test, the mean ± SD for girls was 37.42 ± 24.14 seconds, while for boys it was 43.56 ± 27.77 seconds, with a mean difference of -6.12 seconds. There was no significant difference in SLS test performance between girls and boys ($p = 0.13$) (Table 2).

Table 2: Mean TUG test and SLS test of girls and boys.

TUG (sec)	Girls	Boys	MD	95% CI		t- value	p value
	Mean ± SD	Mean ± SD		Lower limit	Upper limit		
	8.40 ± 1.44	**7.28 ± 1.04**	**1.12**	**0.73**	**1.50**	**5.69**	**0.001***
SLS (sec)	**37.42 ± 24.14**	**43.56 ± 27.77**	**-6.12**	**-14.08**	**1.84**	**-1.52**	**0.13**

SD, standard deviation; MD, mean difference; CI, confidence interval; p-value, probability value.

Correlations Between Gender by Quadriceps and Hamstring Strength:

Quadriceps Strength:

The mean ± SD of right quadriceps strength for girls was 17.38 ± 3.64 lb, while for boys it was 20.88 ± 4.83 lb, with a mean difference of -3.5 lb. Boys exhibited significantly greater right quadriceps strength compared to girls ($p < 0.001$) (Table 3). For the left quadriceps, the mean ± SD for girls was 18.54 ± 4.26 lb, while for boys it was 20.47 ± 4.63 lb, with a mean difference of -1.93 lb. Boys also had significantly greater left quadriceps strength compared to girls ($p < 0.006$) (Table 3).

Hamstring Strength:

The mean ± SD of right hamstring strength for girls was 16.52 ± 4.39 lb, while for boys it was 18.61 ± 3.82 lb, with a mean difference of -2.09 lb. Boys demonstrated significantly greater right hamstring strength compared to girls ($p < 0.001$) (Table 3). Similarly, the mean ± SD of left hamstring strength for girls was 16.42 ± 4.26 lb, while for boys it was 18.05 ± 3.52 lb, with a mean difference of -1.63 lb. Boys also exhibited significantly greater left hamstring strength compared to girls ($p < 0.008$) (Table 3).

Table 3: Mean quadriceps and hamstring strength of girls and boys.

Strength (lb)	Girls	Boys	MD	95% CI		t- value	p value
	Mean ± SD	Mean ± SD		Lower limit	Upper limit		
Right quadriceps	17.38 ± 3.64	20.88 ± 4.83	-3.5	-4.81	-2.20	-5.30	0.001*
Left quadriceps	18.54 ± 4.26	20.47 ± 4.63	-1.93	-3.29	-0.57	-2.80	0.006*
Right hamstring	16.52 ± 4.39	18.61 ± 3.82	-2.09	-3.35	-0.82	-3.26	0.001*
Left hamstring	16.42 ± 4.26	18.05 ± 3.52	-1.63	-2.83	-0.43	-2.68	0.008*

SD, standard deviation; MD, mean difference; CI, confidence interval; p-value, probability value.

Correlation Between BMI, TUG Test, SLS Test, Quadriceps and Hamstring Strength in Girls:

The correlation between BMI and the TUG test was weak, positive, and non-significant ($r = 0.127$, $p = 0.24$) (Table 4). Similarly, BMI showed a weak, positive, and non-significant correlation with the SLS test ($r = 0.011$, $p = 0.92$) (Table 4). The correlation between BMI and quadriceps strength was weak, positive, and significant for both the right quadriceps ($r = 0.235$, $p = 0.03$) and the left quadriceps ($r = 0.255$, $p = 0.01$) (Table 4). Additionally, BMI demonstrated a moderate, positive, and significant correlation with hamstring strength in both the right hamstring (r =

0.395, p = 0.001) and the left hamstring (r = 0.41, p = 0.001) (Table 4).

Correlation Between BMI, TUG Test, SLS Test, Quadriceps and Hamstring Strength in Boys:

Table 4: Correlation between BMI, TUG test, SLS test, quadriceps, and hamstring strength in girls and boys.

		Girls		Boys	
		r value	p value	r value	p value
BMI (kg/m²)	TUG test (sec)	0.127	0.24	-0.013	0.91
	SLS test (sec)	0.011	0.92	-0.161	0.15
	Right quadriceps strength (lb)	0.235	0.03	0.091	0.42
	Left quadriceps strength (lb)	0.255	0.01	0.060	0.60
	Right hamstring strength (lb)	0.395	0.001	0.395	0.001*
	Left hamstring strength (lb)	0.41	0.001	0.404	0.001*

Single-Leg Stancer value: Pearson correlation coefficient; p-value, probability value.

The correlation between BMI and the TUG test was a weak, negative, and non-significant (r = -0.013, p = 0.91) (Table 5). Similarly, BMI had a weak, negative, and non-significant correlation with the SLS test (r = -0.161, p = 0.15) (Table 5). The correlation between BMI and quadriceps strength was weak and positive, though non-significant, for both the right quadriceps (r = 0.091, p = 0.42) and the left quadriceps (r = 0.060, p = 0.60) (Table 5). However, BMI showed a moderate, positive, and significant correlation with hamstring strength in both the right hamstring (r = 0.395, p = 0.001) and the left hamstring (r = 0.404, p = 0.001) (Table 4).

Discussion:

This study investigated the relationship between gender, BMI, dynamic and static balance, and muscle strength in school-aged children. The significant gender differences in dynamic balance, as measured by the TUG test, showed boys outperforming girls. This aligns with previous research by Li et al. (2022) [20] and Butz et al. (2015) [21], who found similar patterns. However, no significant gender differences were observed in static balance, despite boys having a slightly longer mean duration than girls. This nuanced understanding highlights the importance of considering different types of balance when designing interventions.

The significant gender differences in muscle strength, with boys exhibiting greater strength in both the quadriceps and hamstrings, align with Holm et al. (2008)[22]. This study provides additional evidence that boys' higher lean body mass and engagement in physical activities contribute to their superior muscle strength[23,24,25]. These

findings underscore the need for tailored physical activity programs that consider gender-specific strengths and weaknesses to optimize children's physical development.

The weak positive correlation between BMI and dynamic balance for girls contrasts with previous findings by Alhusaini et al. (2020) [26] and Barros et al. (2022) [27], who reported significant negative impacts. This discrepancy could be due to differences in sample characteristics or assessment methods. The lack of significant correlation between BMI and static balance aligns with D'Hondt et al. (2011)[16], suggesting that static balance might be less affected by BMI than dynamic balance. The results indicated that the center of pressure (COP) area in obese children was significantly larger than normal weight children. This suggests that obese children have a reduced ability to maintain proper postural balance [28].

Interestingly, the positive correlations between BMI and muscle strength, particularly for the hamstrings, suggest that higher BMI is associated with greater absolute muscle strength. This finding supports Hasan et al. (2016) [29] and Tomlinson et al. (2016) [13], indicating that interventions for overweight and obese children should focus not only on weight reduction but also on enhancing muscle strength and coordination to improve overall physical health.

Previous studies reported factors that contribute to impairments in static and dynamic balance among boys and girls aged 7 to 9 years with higher BMI. Children with higher BMI often engage in lower levels of physical activity, leading to weaker muscles and poorer neuromuscular coordination, further impairing balance [30]. Higher BMI may alter the distribution of body mass, shifting the center of mass higher and away from the base of support. This shift makes it more challenging to maintain balance during both static and dynamic activities [31].

The study's findings have several practical implications. They highlight the importance of incorporating balance and strength training into physical education curricula, particularly for girls, who may benefit from targeted interventions to improve dynamic balance. Additionally, strategies to engage children in diverse physical activities that promote both balance and muscle strength should be prioritized to counteract the negative effects of high BMI.

Limitations:

Despite its contributions, this study has several limitations. The cross-sectional design limits the ability to infer causality between BMI, gender differences, and balance or muscle strength. Future longitudinal studies are necessary to establish cause-and-effect relationships and to track changes over time.

The sample size, limited to primary schools in Al-Majmaah Province, may not be representative of all school-aged children in Saudi Arabia. To enhance generalizability, future research should include larger and more diverse samples from different regions and socio-economic backgrounds.

The focus on children aged 7 to 9 may not capture the full spectrum of developmental changes in balance and muscle strength. Including a broader age range could provide more comprehensive insights into how these parameters evolve with age.

The exclusion of children with musculoskeletal or neurological disorders may limit the applicability of the findings to the general population. Including such participants in future studies could help understand the impact of these conditions on balance and muscle strength.

Finally, the reliance on specific tests (SLS, TUG, and handheld dynamometer) might not fully capture all aspects of balance and muscle strength. Future research should incorporate a variety of assessment methods to provide a more holistic understanding of these parameters.

Future research should conduct longitudinal studies to track the long-term effects of early balance and muscle strength training on children's physical development. Additionally, exploring the impact of different types of exercises and interventions on improving these parameters could inform the development of more effective physical activity programs.

By addressing these limitations and building on the current findings, future studies can further elucidate the complex relationships between BMI, gender, balance, and muscle strength, ultimately contributing to better health outcomes for children.

Conclusions:

We conclude that there are notable gender differences in children's physical performance. Boys excel in agility, as demonstrated by the significant difference in the TUG test, while both genders show similar performance in balance, as indicated by the SLS test results. However, boys exhibit greater muscle strength in the quadriceps and hamstrings compared to girls. Moreover, BMI shows a positive correlation with muscle strength, indicating that higher BMI is associated with greater muscle strength.

Author Contributions:

Conceptualization, A.A.; methodology A.A..; formal analysis, A.A..; investigation, A.A., R.A., H.A..; resources, A.A..; data curation, A.A., R.A., H.A.; writing—original draft preparation, A.A., R.A., H.A.; writing—review and editing, A.A., R.A., H.A.; visualization, A.A.; supervision, A.A.; project administration, A.A.; All

authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement:

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Majmaah University under ethics project # MUREC-Feb.11/COM-2024/6-1.

Acknowledgments:

We would like to extend our deepest and most sincere thanks to the participants, their parents, and the school principals at Majmaah Province for their invaluable support in facilitating and streamlining the sample collection process for this study.

Conflict of interest:

The authors declare no conflicts of interest.

Funding:

This research received no external funding.

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