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ORIGINAL ARTICLE

Investigation of surface electromyography amplitude values during stair climbing task in children with Duchenne muscular dystrophy

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Abstract

Objective The aims of this study were (a) to examine the surface electromyography (sEMG) amplitude values of the lower limb muscles during stair climbing both between different functional levels of Duchenne muscular dystrophy (DMD), in comparison with healthy children, and (b) to investigate the relationships between sEMG amplitudes and physical performance.

Methods sEMG amplitudes of the lower limbs of twenty-one children with DMD between levels I and III according to the Brooke Lower Extremity Functional Classification Scale and eleven healthy peers were evaluated by using sEMG during stair climbing task. Physical performance was evaluated by 6-min walk test and ascending 4-step timed performance test.

Results The lower limb sEMG amplitude values of children with DMD were statistically higher than healthy children ($p < 0.001$). sEMG amplitudes of the right ($p = 0.01$) and left ($p = 0.003$) biceps femoris, the right ($p < 0.001$) and left ($p = 0.001$) gastrocnemius medialis, and the right vastus lateralis ($p = 0.02$) muscles were higher in children with levels 2–3 than those in level 1. Moderate-to-strong relations were found between the gastrocnemius medialis and biceps femoris sEMG amplitudes and physical performance assessments ($p < 0.05$).

Conclusion Increased sEMG amplitude values in the lower limbs during stair climbing task are thought to be caused by the effort to compensate for progressive muscle weakness and are associated with lower physical performance in children with DMD. Further, sEMG amplitude values are determined to increase as the functional level deteriorates.

Clinical trial registration number and URL NCT04287582 (https://clinicaltrials.gov/ct2/show/NCT04287582?term=merve+bora&draw=2&rank=1).

Keywords Duchenne muscular dystrophy · Electromyography · Physical performance · Stair climbing

Introduction

Duchenne muscular dystrophy (DMD) is the most common type of neuromuscular disease in childhood [1]. Due to the lack of a cell membrane protein called dystrophin, which

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plays an important role in ensuring membrane stability in DMD, progressive damage occurs in all skeletal muscles and over time in the cardiac muscle and diaphragm [2]. As a result of progressive muscle weakness caused by muscle degeneration, children with DMD experience difficulty in performing various daily life tasks such as walking, standing up from a chair, and climbing up and down the stairs, as they have been using different compensatory movement mechanisms since the early stages of the disease [3, 4].

Climbing up the stairs is a complex and frequently used task in daily life that requires the activity of more muscles than walking. A successful stair climbing task requires many components to act together such as muscle strength, postural control, sensory processing, and integration [5]. In children with DMD, walking in the ankle equinus position, decreased joint range of motion, muscle shortness, and various degrees of loss of postural control make the task difficult and have a negative effect on performance [6]. This limits independence during the task as it cannot be performed as in healthy children [7].

Evaluations performed during functional tasks are important to predict and prevent possible functional losses. In neuromuscular diseases, evaluation is generally made based on the timed performance or the level of difficulty experienced during performance such as ascending/descending 4 steps and functional scales rather than the analysis of the movement during the task [8, 9]. However, performance-based evaluations are insufficient to explain the compensation mechanisms during the tasks. Therefore, an additional biomechanical analysis of joint positions, muscle moments, and force distribution has been used to better understand the joint position and active muscles during compensated movement. Objective assessment methods such as surface electromyography (sEMG) and 3D motion analyses are widely used for this purpose [10–12]. Studies involving the analysis of different tasks with the use of these methods in neuromuscular diseases have been included in the literature, albeit to a limited number [13–16]. In studies of adult neuromuscular diseases, it has been observed that sEMG amplitude values were higher than in healthy individuals, when examined in tasks such as walking and standing from sitting [15, 17].

It is noteworthy that the limited number of biomechanical studies performed in DMD have mostly been performed on walking and trunk and upper extremity-related tasks [13, 16]. In a study by Ropars et al. [16] which presented electromyography (EMG) measurement results during walking task in children with DMD, it was reported that sEMG amplitude values increased compared to those of healthy individuals in order to compensate for muscle weakness in relation to disease progression. In addition, significantly increased co-activation in both proximal and distal muscles has been shown to be a compensatory strategy to improve stability in gait [16]. Another EMG study of children with DMD revealed increased sEMG amplitude values compared to those of healthy individuals during functional tasks involving the upper extremity. In the same study, it was reported that surface EMG could be a suitable method to distinguish between normal and compensatory movements [13].

The objectives of this study were (a) to examine sEMG amplitude values of certain lower limb muscles during one of the fundamental daily living tasks—stair climbing—using sEMG both between different functional levels of DMD and in comparison with healthy children and (b) to investigate the relationships between sEMG amplitudes and performance.

Methods

This study was conducted on children with Duchenne muscular dystrophy who presented at the Pediatric Neuromuscular Diseases Unit of Hacettepe University, Physical Therapy and Rehabilitation Faculty, and a healthy control peer group. This is a cross-sectional observational study carried out from April 2019 to March 2020. Ethical approval was obtained from Hacettepe University, Non-Interventional Clinical Research Ethics Committee (decision No.: GO 19/323). Informed consent forms were signed by children and their parents included in the study.

Participants

The study included 21 children with DMD (study group), aged 5–12 years, who were at levels 1–3 according to the Brooke Lower Extremity Functional Classification (BLEFC) [18]. Of the total 21 children, 11 were classified as level 1 (52.4%) who could climb stairs without support (walks and climbs 4-step stair without holding the handrails) and 10 as levels 2–3 (7 children (33.3%) in level 2 and 3 children (14.3%) in level 3) who could climb stairs with support (walks and climbs 4-step stair in less than 12 s holding the handrails—climbs the stairs in more than 12 s holding the handrails). A control group was formed of 11 healthy children matched to the study group with similar body mass index (BMI) and age.

Children with DMD were excluded from the study if they had any history of lower extremity injuries and/or surgery, had started steroid treatment within the last 6 months, or had any systemic disease other than DMD. In healthy children, any abnormality that could prevent climbing stairs was determined as the exclusion criterion.

In the post hoc power analysis performed using the G* power version 3.1 (power analysis software) based on the hypothesis that the relevant sEMG amplitude values of children with DMD would be different from those of healthy children, the power of the study was determined as 99%

with 21 DMD and 11 healthy children considering 5% type 1 error and 95% confidence interval.

Assessments

After the demographic, physical characteristics (BMI and age), and genetic characteristics were recorded, the following assessments were performed.

sEMG measurements

Eight-channel wireless 99.9% Ag surface bar electrodes with 10-mm fixed interelectrode distance and a portable data collection system were used to acquire measurements of the bilateral vastus lateralis, biceps femoris, tibialis anterior, and gastrocnemius medialis muscles. EMG data were captured at 1926 Hz with the bandwidth of 20–450 Hz and a CMRR of < 80 dB. The preparation phase consisted of shaving the hair on the skin where the electrodes were to be placed and cleaning with 70% isopropyl alcohol to minimize skin impedance. The electrodes were fixed with double-sided strong adhesive tape to the skin surface. For the vastus lateralis, the electrodes were placed corresponding to 2/3 of the line between the spina iliaca anterior superior and the lateral edge of the patella. For the biceps femoris, the electrodes were placed corresponding to the midpoint of the line between the tuber ischium and the lateral condyle of the tibia. For the tibialis anterior, the electrodes were placed on 1/3 of the line between the head of the fibula and the medial malleolus. For the gastrocnemius medialis, the electrodes were placed in the most bulging point of the muscle. Electrode placements according to the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) criteria was shown in Fig. 1 [19].

Standardized maximum voluntary isometric contraction (MVIC) measurement To measure the MVIC, the children were first placed in MVIC positions where the muscles to be measured showed the most activation. For the vastus lateralis, resistance was applied over the ankle in a sitting position with the legs hanging from the bed and the knees flexed at 90°. For the biceps femoris, resistance was given over the ankle with the knee flexed at 45° in the prone position. For the tibialis anterior, the resistance was applied from the dorsal of the foot in the supine position with the heels not in contact with the bed. For the gastrocnemius medialis, the resistance was performed from the plantar side of the foot in the prone position with the ankles not in contact with the bed [20]. The children were asked to maintain the positions stated above against manual resistance by using hand dynamometer (JTech, The Commander™ Muscle Tester Dynomometer) and were verbally encouraged to produce maximum effort, resulting in a maximum isometric

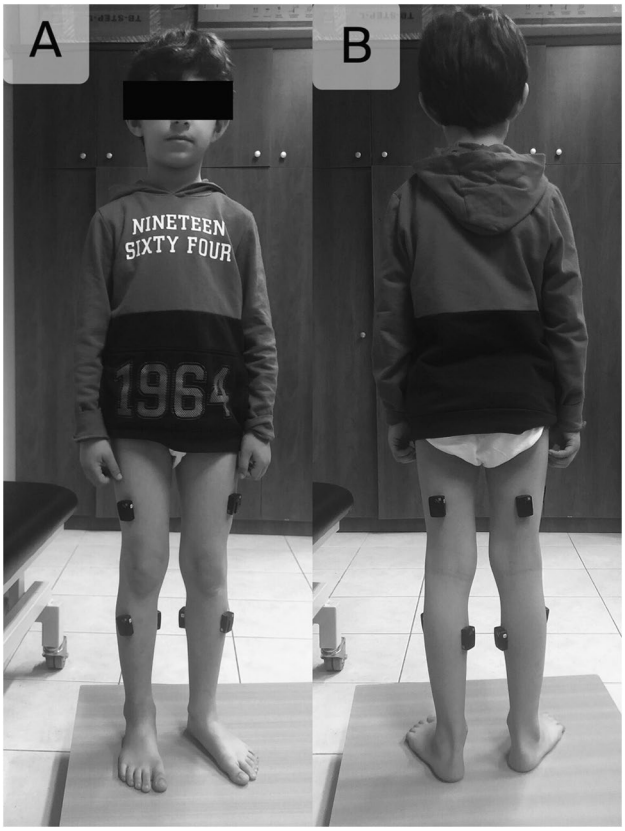

Fig. 1 Electrode placement according to SENIAM guidelines (Hermens et al., 2000). **A** Electrode placement for the vastus lateralis and tibialis anterior muscles. **B** Electrode placement for biceps femoris and gastrocnemius medialis muscles

contraction for 6 s in each position. During the MVIC measurement, the knee flexor and extensor and ankle dorsi- and plantar flexor muscle strengths were recorded as Newton. The MVIC value of each muscle was measured with three repetitions, and a 1-min resting period was given between each repetition. The maximum values of the three repetitions were recorded, and then after a 10-min rest period, the 4-step stair climbing task was started.

Stair climbing task The children were asked to climb a 4-step stair using alternate legs. The "start" command was given while the child was standing on the ground, and the recording was stopped at the end of the task. An accelerometer was also used to determine the start and end of the stair climbing task. The children were asked to climb the stairs as fast as they could (Fig. 2). The task was performed with a 1-min rest period between the 3 attempts. The raw EMG signal of evaluated dominant side lower limb muscles obtained on a child with DMD was shown in Fig. 3.

Normalized sEMG amplitude In the normalization process, the maximum EMG signals during the stair climbing task

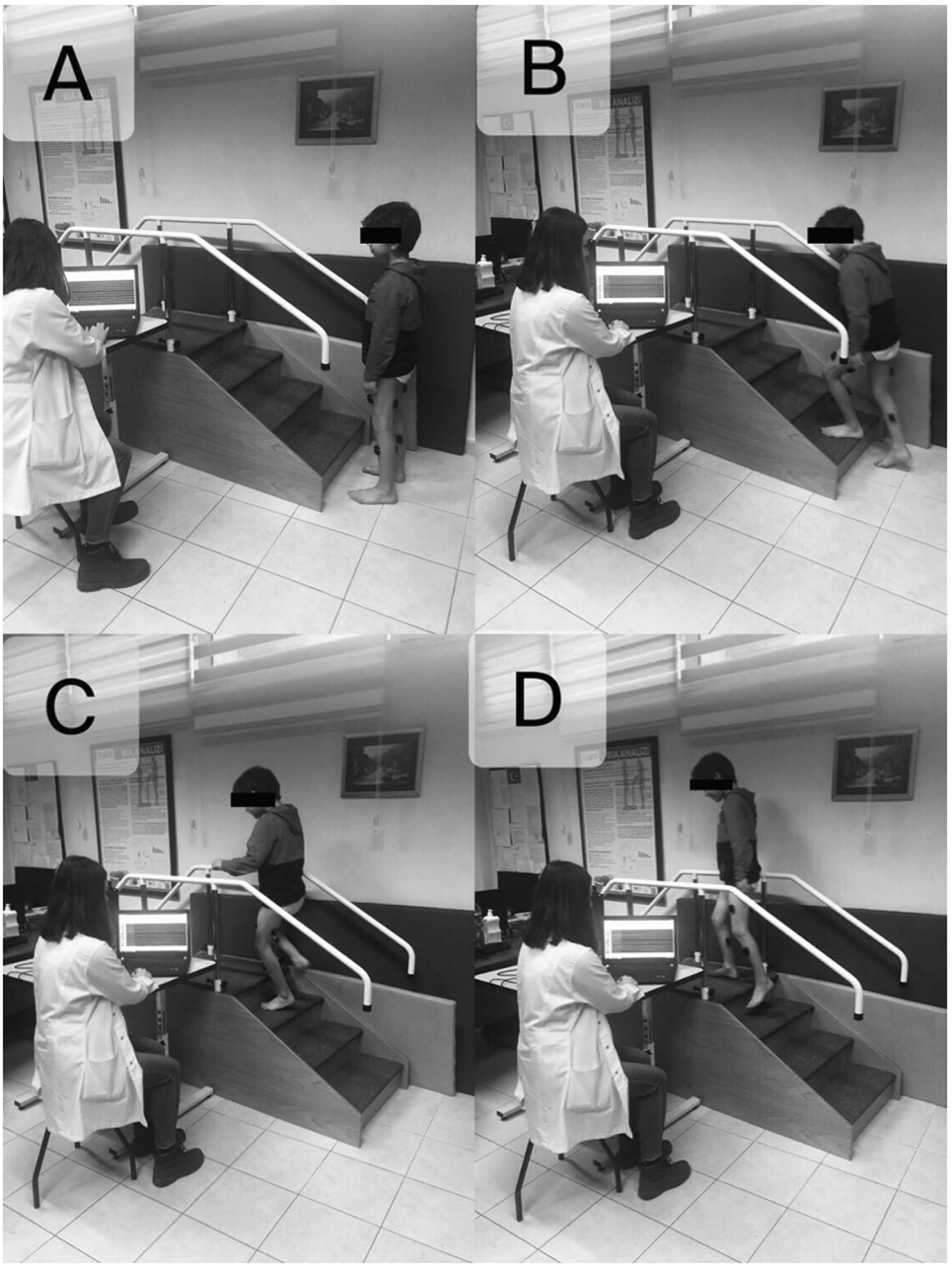

Fig. 2 sEMG amplitude measurement during stair climbing task. **A**–**D** The phases of stair climbing

were divided by the maximum value of 3 MVIC measurements for each muscle of interest. The sEMG amplitude is expressed as a percentage of MVIC (%).

Electromyographic data processing Delsys EMGworks Analysis software (Delsys Inc. Natick, Massachusetts, USA) was used to analyze the electromyographic signals. All signals were passed through a 4th degree Butterworth filter in the 20–450 Hz band to minimize the artifact effect and were then smoothed using a root-mean-square (RMS) with 100 ms window length and 50 ms window overlap.

Musculoskeletal system assessments

The range of motion (ROM) assessments for hip flexion–extension, knee flexion–extension, and ankle dorsi–plantar flexion in the lower extremity was performed passively with a hand goniometer in the study group. A thin pillow was placed under the knee to relax the gastrocnemius muscle in order to evaluate the range of motion of the ankle. Movement limitations were recorded in degrees (°) [21].

In addition to the above sEMG amplitude and muscle strength measurements during MVIC, muscle strength

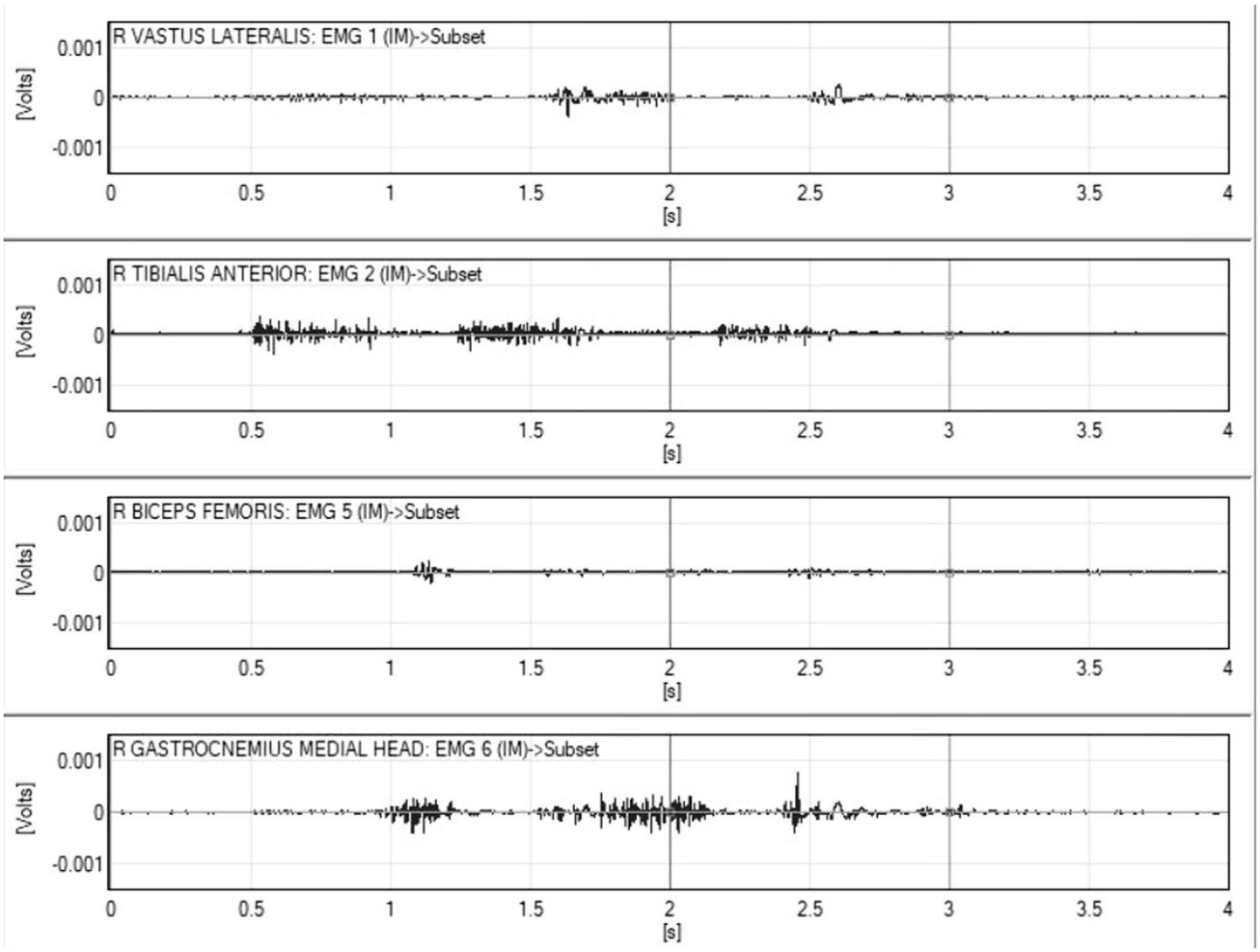

Fig. 3 The raw EMG signal of dominant lower limb muscles obtained on a child with DMD

assessment was applied to the hip flexors and extensors by following the same protocol. For this, the children were assessed in supine position with the hip and knee at 90° flexion, and hand dynamometer was placed at proximal to knee and popliteal fossa, consecutively [22]. Muscle strength measurements were repeated 3 times both in the right and left lower extremities in the study and control groups, and the mean of the 3 measurements was recorded as Newton (N).

Physical performance assessments

The 6-min walk test (6MWT) and ascending 4-step timed performance tests were used for both groups. The 6MWT, which is valid and reliable for children with DMD and recommended for use as a primary outcome measure for clinical trials, measures the maximum distance that individuals can walk within 6 min [23]. The children were asked to walk in a 25-m corridor for 6 min. During the test, the children were encouraged periodically by the physiotherapist. The distance walked in 6 min was recorded in meters [24]. In the ascending 4-step timed performance test, the time spent to climb a standard four-step stair was recorded with a stopwatch in seconds. During the evaluation, while the children were performing the task, there was no interference with their speed, but verbal encouragement was provided.

Statistical analysis

Data obtained in the study were analyzed statistically using IBM SPSS 23.0 (Statistical Program for Social Sciences, version 23). The conformity of the data to normal distribution was determined using histograms and skewness and kurtosis. With the exception of demographic characteristics, the data related to normalized sEMG amplitudes, musculoskeletal system assessments, and physical performance assessments did not fit the normal distribution. The results related to demographic characteristics were presented as mean and standard deviation values ($X \pm SD$). In descriptive analyses, the results were shown as median and interquartile

range (IQR 25–75%) values for quantitative variables and as number (n) and percentage (%) for qualitative variables. Independent sample t test was used to compare demographic characteristics within group (level 1 vs. levels 2–3 children with DMD) and between groups (DMD vs. healthy children). The Mann–Whitney U test was used to compare variables related to sEMG values, performance, and musculoskeletal system assessments between different functional levels of DMD and between the healthy children and children with DMD. Spearman's correlation coefficient (rho) was used to determine the strength of the correlations between 4-step timed performance test, 6-min walk test, joint limitation, and muscle strength with sEMG amplitudes. According to the Spearman's correlation coefficient (r), the level of the relationship was accepted as follows: $r > 0.90$ very strong, $r = 0.70$–0.90 strong, 0.40–0.70 moderate, $r = 0.20$–0.40 weak, and $r < 0.20$ very weak/negligible correlation. The level of statistical significance was accepted as $p < 0.05$ in the analyses [25, 26].

Results

Twenty-five children with DMD were determined to meet the inclusion criteria in the beginning of the study. Four children were excluded from the study because of poor cooperation. The study was completed with 21 children with DMD and 11 healthy subjects. The mean age and the body mass index (BMI) of the study group were 7.81 ± 0.78 years and 16.69 ± 1.87 kg/m^2 for level 1 and 9.60 ± 1.28 years and 17.50 ± 2.27 kg/m^2 for levels 2–3. The body mass index (BMI) and age of control group were 16.80 ± 1.80 kg/m^2 and 8.81 ± 1.64 years, respectively. Statistically significant differences were determined between the level 1 and level 2–3 groups in terms of age ($p = 0.003$) and BMI ($p = 0.041$). No difference was found between the healthy children and children with DMD (levels 1–3) in terms of age ($p = 0.873$) and BMI ($p = 0.874$). According to the results of genetic testing, 14 children had deletions, 4 had duplications, 2 had nonsense mutation, and one child had a frameshift mutation.

sEMG measurements

It was determined that all the sEMG amplitude values of children with DMD were higher than those of the healthy children ($p < 0.05$) (Table 1).

In the study group, amplitude values of the right vastus lateralis, right and left biceps femoris, and gastrocnemius medialis muscles were higher in children with levels 2–3 than in level 1 ($p < 0.05$) (Table 2).

Musculoskeletal system assessments

The range of motion assessment results showed a statistically significant difference between children in level 1 and levels 2–3, in favor of level 1 where the median values of dorsiflexion limitation degrees were 17.50 (15.50–19.25) and 22.50 (20.75–28.50) in the right ankle ($p = 0.001$) and 19.00 (17.75–19.25) and 22.50 (18.75–25.50) in the left ankle ($p = 0.024$), respectively.

Of the children with DMD, those at level 1 had higher strength values than those at levels 2–3 with a median of 23.00 (19.03–24.16) and 17.31 (9.86–20.22) N in the right hip extensor, 16.13 (13.83–21.83) and 8.41 (4.63–14.69) N in the right knee extensor, and 15.50 (13.00–20.50) and 8.66 (5.26–11.66) N in the left knee extensor muscle, respectively. The comparisons of muscle strength between the groups are shown in Table 3.

Table 1 Comparison of sEMG amplitude values during stair climbing task between study and control groups ($n = 32$)

Muscles (%MVIC)		Study group ($n = 21$)		Control group ($n = 11$)		z	p
		Median	Percentiles (IQR) (25–75th)	Median	Percentiles (IQR) (25–75th)		
Vastus lateralis	**Right**	31.50	(23.90–34.75)	11.30	(8.60–14.80)	−4.464	**< 0.001**
	Left	28.40	(24.50–35.95)	10.30	(9.10–11.70)	−4.583	**< 0.001**
Biceps femoris	**Right**	32.00	(26.35–42.85)	10.30	(9.60–12.10)	−4.543	**< 0.001**
	Left	32.90	(24.25–38.80)	8.40	(7.40–14.70)	−4.583	**< 0.001**
Tibialis anterior	**Right**	25.80	(21.95–30.40)	11.50	(10.50–13.60)	−4.424	**< 0.001**
	Left	25.00	(23.25–28.45)	13.10	(10.60–15.30)	−4.466	**< 0.001**
Gastrocnemius medialis	**Right**	37.20	(26.10–50.55)	13.40	(12.00–18.30)	−4.644	**< 0.001**
	Left	30.40	(21.55–41.95)	12.70	(11.60–16.90)	−4.107	**< 0.001**

$p < 0.05$, Mann–Whitney U Test. *MVIC*, maximum voluntary isometric contraction; *IQR*, interquartile range

Table 2 Comparison of sEMG amplitude values during stair climbing task in DMD children with different functional levels ($n=21$)

Muscles (%MVIC)		DMD level 1 ($n=11$)		DMD level 2–3 ($n=10$)		z	p
		Median	Percentiles (IQR) (25–75th)	Median	Percentiles (IQR) (25–75th)		
Vastus lateralis	**Right**	27.30	(21.00–33.00)	33.80	(30.32–37.25)	−2.183	**0.02**
	Left	26.50	(24.50–31.20)	29.80	(24.12–40.52)	−0.740	0.46
Biceps femoris	**Right**	26.90	(25.30–34.50)	40.35	(29.02–61.55)	−2.394	**0.01**
	Left	26.20	(22.70–31.30)	38.80	(33.95–57.77)	−2.958	**0.003**
Tibialis anterior	**Right**	24.30	(19.20–30.00)	26.95	(24.17–30.85)	−0.916	0.36
	Left	24.50	(23.00–25.00)	28.00	(23.40–32.00)	−1.340	0.18
Gastrocnemius medialis	**Right**	26.10	(24.20–35.70)	50.55	(43.82–64.40)	−3.663	**< 0.001**
	Left	23.50	(16.50–27.90)	41.95	(34.17–54.10)	−3.310	**0.001**

$p<0.05$, Mann–Whitney U test. *MVIC*, maximum voluntary isometric contraction; *IQR*, interquartile range

Table 3 Comparison of muscle strength values between study and control groups ($n=32$)

Muscle strength (N)		Study group ($n=21$)		Control group ($n=11$)		z	p
		Median	Percentiles (IQR) (25–75th)	Median	Percentiles (IQR) (25–75th)		
Hip flexors (N)	**Right**	14.16	(10.93–16.19)	20.00	(16.00–22.33)	−3.316	**0.001**
	Left	12.86	(11.35–16.16)	18.00	(16.00–20.50)	−3.394	**0.001**
Hip extensors (N)	**Right**	19.80	(13.88–23.09)	24.00	(19.00–33.16)	−2.163	**0.03**
	Left	20.23	(14.64–22.84)	27.00	(18.00–36.00)	−2.125	**0.03**
Knee flexors (N)	**Right**	14.76	(12.44–16.33)	24.00	(21.00–26.00)	−3.949	**< 0.001**
	Left	13.50	(11.86–16.49)	22.00	(19.73–24.33)	−4.028	**< 0.001**
Knee extensors (N)	**Right**	13.83	(8.41–18.08)	32.50	(30.50–42.00)	−4.227	**< 0.001**
	Left	12.83	(8.66–16.06)	38.50	(31.36–49.83)	−4.265	**< 0.001**
Ankle dorsiflexors (N)	**Right**	14.63	(11.03–16.38)	25.63	(21.50–33.33)	−4.069	**< 0.001**
	Left	14.16	(11.41–16.20)	27.33	(23.00–30.66)	−4.326	**< 0.001**
Ankle plantar flexors (N)	**Right**	26.93	(25.41–29.48)	32.00	(26.00–33.50)	−1.746	0.08
	Left	23.16	(22.55–27.58)	32.00	(24.00–36.66)	−2.540	**0.01**

$p<0.05$, Mann–Whitney U test. *N*, Newton; *IQR*, interquartile range

Physical performance assessments

The median values of the 6MWT distance and ascending 4-step stair climbing in the study and control groups were 390.00 and 598.00 m and 3.80 and 2.12 s, respectively. A statistically significant difference was determined in favor of the control group in all the performance tests ($p<0.001$).

Relationships between sEMG measurements and performance tests

There was a positive, strong correlation between the duration of ascending 4-step stair climbing and right gastrocnemius medialis sEMG amplitudes ($r=0.758$, $p<0.001$) and positive moderate correlations between the duration of ascending 4-step stair climbing and left gastrocnemius medialis ($r=0.584$, $p=0.005$) and left biceps femoris sEMG amplitudes ($r=0.564$, $p=0.008$). Negative, moderate correlations were determined between the 6MWT distance and right gastrocnemius medialis ($r=-0.569$, $p=0.008$), left gastrocnemius medialis (r = -0.519, p = 0.016), and left biceps femoris sEMG amplitudes ($r=-0.636$, $p=0.002$).

Relationships between sEMG measurements and musculoskeletal system assessments

There was a positive strong correlation between the right dorsiflexion limitation and the right gastrocnemius medialis sEMG amplitude values in children with DMD ($r=0.711$, $p<0.001$).

A negative moderate correlation was found between the left biceps femoris sEMG amplitude and left knee flexor ($r=-0.561$, $p=0.008$) and left knee extensor ($r=-0.618$, $p=0.003$) muscle strength in children with DMD.

Discussion

In this study, which aimed to investigate the sEMG amplitudes of children with DMD at different functional levels, and to compare the sEMG amplitude values of children with DMD and healthy control subjects during a stair climbing task, it was determined that children with DMD had approximately 3 times higher sEMG amplitude values over a longer duration when performing the stair climbing task compared to the healthy controls. Of the muscles evaluated, the gastrocnemius medialis and biceps femoris sEMG amplitude values were found to have moderate-to-strong relationships with stair climbing and gait performance. It was also determined that as the functional levels deteriorated, the sEMG amplitudes increased in children with DMD. To the best of our knowledge, this is the only study in the literature to have examined the sEMG amplitudes of the related lower limb muscles during a stair climbing task, with comparisons made between different functional levels of a DMD population and between children with DMD and a healthy control group.

In previous EMG studies, in which sEMG amplitudes have been examined during various tasks in individuals with neuromuscular diseases, higher sEMG amplitudes were determined compared to healthy controls similar to the current study. In a study of Sutcu et al., all lower extremity sEMG amplitudes investigated in relation to the sit-to-stand task were higher in adult patients with muscle diseases than in healthy individuals [17]. Furthermore, the extra effort of the patients to compensate for progressive loss of muscle strength was claimed to be the primarily factor responsible for the increase in sEMG amplitudes [17]. In another study of adults with Charcot–Marie–Tooth (CMT) disease, the biceps femoris, rectus femoris, gastrocnemius medialis, and tibialis anterior muscles were found to have developed adaptive motor strategies resulting in increased sEMG amplitudes during stair climbing task compared to a healthy control group [14]. In a study of Esposito et al., the vastus lateralis and tibialis anterior muscles in individuals with myotonic dystrophy type 1 were analyzed with EMG, and it was shown that the prolonged EMG values during a fatiguing exercise compared to healthy individuals may be a guide in explaining exercise intolerance in these patients [27]. Electromechanical delays during contraction and relaxation were evaluated with EMG, and it was thought that EMG could be a reliable tool in determining neuromuscular dysfunction in another study with adult myotonic dystrophy type 1 patients [28]. The few studies in literature which have analyzed EMG values of muscles in children with DMD have generally focused on gait task [16, 29–31].

Consistent with the findings of the current study, Ropars et al. reported that the sEMG amplitudes in the lower extremity muscle groups during walking in children with DMD were different from those of healthy individuals, and increased sEMG amplitudes of the rectus femoris, medial hamstring, and tibialis anterior muscles were reported in the stance phase [16]. Although the stair climbing task examined in the current study is similar to walking in that it requires the function of similar joints and muscles during movement and is rhythmic, it is a more complex and challenging task in terms of biomechanics because it requires more muscle activity, range of motion, and muscle moment in the lower extremity than walking [32]. Therefore, considering the compensation mechanisms seen during walking in children with DMD, it is not surprising that, in order to compensate for muscle weakness, sEMG amplitudes are higher when climbing stairs, as in walking, compared to healthy children. Similar to all the above-mentioned studies, the increased sEMG amplitudes obtained in the current study were thought to be due to the need for more firing of the remaining intact motor units to be able to compensate for the loss of muscle strength and perform the same task.

This study demonstrated that as the functional level worsens, the sEMG amplitudes increase in relation to the progression of the disease. This result supports the relationship between increased sEMG amplitudes in muscles during walking and the functional status in children with DMD [16]. Moreover, children with DMD gain weight due to decreased energy expenditure as a result of reduced mobility and physical inactivity as the functional level progresses [33]. In the current study, children with DMD at a worse functional level were seen to have a higher BMI, so it can be considered that BMI values may also affect the increase in sEMG amplitudes. The results of the current study showed that sEMG amplitude values of the gastrocnemius medialis, an antigravity muscle, were found to be higher in the group with worse functional level, but no difference was observed between different functional levels in respect of the sEMG amplitudes of the tibialis anterior. The tendency of the ankle to flex to the plantar, which is seen in children with DMD, is a natural consequence of the dystrophic posture as a requirement of the weakness of the dorsiflexor muscles and the compensation mechanism for standing [34]. The importance of plantar flexor muscle strength in maintaining ambulatory abilities in children with DMD has also been reported [35]. Sivaraman et al. stated that the ankle dorsiflexor and plantar flexor muscles play a crucial role during stair climbing, and it is more difficult for children with DMD to perform this task, especially in the foot equine position, with reduced muscle strength and range of motion [36]. As the functional level deteriorates, the increased limitation in the ankle triggers the transition to plantar flexion. The current study results showed a strong positive relationship between dorsiflexion limitation and sEMG amplitude values of the

gastrocnemius medialis in children with DMD, suggesting that the tendency to plantar flexion of the ankle affects sEMG amplitude as a compensation mechanism. However, with the progressive loss of strength over time in plantar flexors that are overloaded during tasks such as walking and climbing stairs, these muscles have to show more activation compared to dorsiflexors, which are already weaker from the beginning of the disease. In other words, as the functional level deteriorates, it is thought that sEMG amplitude of plantar flexor muscles increase as the loss of strength in this muscle during task becomes more pronounced. In addition, moderate-to-strong relationships between the sEMG amplitude values of the gastrocnemius medialis and the 6-min walking distance and 4-step stair climbing duration also support the knowledge that plantar flexors are important muscles affecting physical performance during tasks such as walking and climbing stairs [35].

The performance of children with DMD is known to decrease in daily life tasks due to the loss of muscle strength [37]. In this study, the time taken to climb the stairs was approximately double, the walking distance decreased by approximately 200 m, and the muscle strength was significantly decreased in children with DMD compared to the healthy peer control group. The results also showed moderate-to-strong relationships between physical performance tests and sEMG amplitude values of the gastrocnemius medialis and biceps femoris. In addition, negative, moderate relationships were found between sEMG amplitude of the biceps femoris and knee flexor and extensor muscle strength. Decreased muscle strength is thought to increase sEMG amplitudes, and especially, the increase in sEMG amplitudes of biceps femoris is due to the effort to compensate for weakness in the quadriceps. Based on the results, it can be interpreted that antagonist muscles exert more effort to be able to compensate for the weakness of the dorsiflexor and quadriceps muscles, which are known to affect performance [37], during task in DMD.

The lack of a technological infrastructure to evaluate task by a 3D motion analysis system was one of the limitations of this study. Another limitation was that the effect of different physical characteristics of the children (such as weight, height), which might affect the quality of movement in this disease, could not be examined on EMG analysis. In addition, the inclusion of 3 children with a functional level of 3 according to the BLEFC may be considered as another limitation of the study.

Conclusion

In conclusion, the results have demonstrated that the increased sEMG amplitudes in the lower extremity muscles measured during stair climbing task in children with DMD are caused by the effort to compensate for progressive muscle weakness and that these compensations increase as the functional level deteriorates. Especially, the relationship between performance and the gastrocnemius medialis and biceps femoris sEMG amplitude values also demonstrates how difficult it is for these muscles to compensate for their weak antagonists. In order to increase physical performance and continue to perform daily life tasks, functional training from the early stages of the disease is necessary to keep compensation to a minimum, to provide agonist–antagonist muscle balance, and to delay functional losses as much as possible in DMD. However, there is a need for studies including more patients whose metabolic profiles are determined by objective measurement techniques, and in which advanced motion analysis methods with tasks divided into phases, and relevant kinetic and kinematic analyses are used to be able to make a greater contribution to the rehabilitation process of these patients.

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Author contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Merve Bora, Öznur Yilmaz, Ayşe Karaduman, Semra Topuz, İpek Alemdaroğlu-Gürbüz, Numan Bulut, and Ali Yalçin. The first draft of the manuscript was written by Merve Bora and İpek Alemdaroğlu-Gürbüz, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability Any data and material associated with this article will be made available by reasonable request to the corresponding author.

Code availability Not applicable.

Declarations

Ethics approval This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the ethics committee of Hacettepe University (Date: 03.04.19/No.: GO 19/323).

Consent to participate Informed consent to participate was obtained by children and their parents included in the study.

Consent for publication Informed consent to publish was obtained by children and their parents included in the study.

Conflict of interest The authors declare no competing interests.

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