J Musculoskelet Neuronal Interact 2024; 24(3):267-275

Journal of Musculoskeletal and Neuronal Interactions JMNI

Original Article

Impact of Rounded Back Posture on Motor Unit Potentials and Fascicle Length of Shoulder Retractors in Children

Mostafa S. Ali[1,2], Ahmed S. Awad[1]

[1]Department of physical therapy for pediatrics, faculty of physical therapy, Cairo University, Egypt;
[2]Department of Physical Therapy, Faculty of Applied Medical Sciences, Al-Zaytoonah University of Jordan, Amman, Jordan

Abstract

Objective: There is little proof to determine the features of the muscles' motor unit potentials (MUPs) in children with poor posture. Current evaluation could be of value for future studies as a reference. The purpose was to detect the impact of rounded back posture on the characteristics of the MUPs and fascicle length of the shoulder retractors in children. **Methods**: Participants in this study were 60 children (boys and girls), their ages were from 7 to 10 years old. Children were allocated into healthy children group (A) and rounded back posture group (B). MUPs and fascicle length of middle trapezius were assessed by electromyography and ultrasonography respectively. **Results**: When compared to the normal group, the rounded back group's right and left middle trapezius MUPs count and amplitude significantly increased. As regards to the middle trapezius MUPs duration between the two groups, there was no significant difference. Also, the rounded back posture group exhibited significantly lower fascicle length in middle trapezius of both sides than the normal group. **Conclusion**: Forward shoulder posture is accompanied by atypical middle trapezius MUPs characteristics and also lowered fascicle length. Thus, children with forward-leaning posture could increase the likelihood of developing any of the many shoulder disorders.

Keywords: Fascicle Length, Middle Trapezius, Motor Unit Potentials, Rounded Back, Ultrasonography

Introduction

Human behaviour is thought to produce posture, highlighting the fact that daily behaviours have characteristics that can influence incorrect posture. Accordingly, individual's posture conveys information about their activity level, overall health, and perhaps even their pertinent personality[1]. Although human body posture changes continuously throughout life, the largest challenges are most noticeable during the dynamic growth stage because these changes occur rapidly and steadily. In reaction to these changes, the human body goes through a variety of compensatory mechanisms to reestablish equilibrium, and these mechanisms frequently result in the development of postural abnormalities[2].

The development of a child's posture could be influenced by multiple intrinsic and extrinsic factors. Intrinsic factors include age, height, sex, heredity and physiological alterations during human growth and development. Extrinsic factors include emotional influences, incorrect postural habits, lack of appropriate teaching equipment with ergonomic essentials, and heavy bags. Furthermore, activities like playing on smart phones, videogames and watching television help acquire inappropriate postures[3].

When children start school, their spontaneous movement activities start to decline. Long periods of sitting, at home or at school, poorly designed school furniture, stress, and most importantly not getting enough movement overall all have a negative impact on the musculoskeletal system[4]. Important considerations for school bags include weight, quality, and fit (i.e., shoulder strap size adjustment, strap asymmetry, and how to put on and take off the backpack). Unfortunately, numerous reports indicate that students are carrying heavier loads than is advised[5].

The authors have no conflict of interest.

Corresponding author: Mostafa S. Ali, Associate Professor of Physical Therapy for Pediatrics, Faculty of Physical Therapy, Cairo University, Egypt. Associate Professor at Department of Physical Therapy, Faculty of Applied Medical Sciences, Al-Zaytoonah University of Jordan, Amman, Jordan. Ahmed El- Zayate street, Giza, Egypt
E-mail: drmostafamalak@cu.edu.eg

Edited by: G. Lyritis
Accepted 5 June 2024

Physical education and sports activities provide the most effective means of preventing and correcting the various forms of postural abnormalities that exist, especially in young children. If structural abnormalities in the tissues are not caused by postural deficiencies, they can usually be addressed if they are identified early. Often planned physical education programs might help achieve this[3].

Round back posture is characterized by an increased thoracic curve, protracted scapulae (rounded shoulders), and usually associated with forward head. Potential muscle impairment occurs as a consequence of this sustained position[6]. The forward shoulder position has been associated with head, shoulder, and neck pain. There is association between forward shoulder posture and the consequent muscle imbalances and upper quarter musculoskeletal symptoms. The corresponding body parts of tight muscles are prone to being pulled, which might result in abnormal postures. The antagonistic muscles may deteriorate and allow for postural abnormalities in the absence of balanced support[7].

Abnormal scapulohumeral rhythm, impingement of rotator cuff tendons, acromioclavicular joint degeneration, bicipital tendinitis, and painful trigger areas is usually associated with forward shoulder. Additionally, compression of the neurovascular bundle in the thoracic outlet region may, in part, be due to forward shoulder posture[8].

When a motor unit (MU) or population of MUs is activated or deactivated, the forces generated by its or their muscular fibres are added or subtracted, respectively. This process is known as motor unit recruitment or derecruitment. The recruitment strategies for motor units differ based on the intrinsic characteristics of individual motor neuron pools within a muscle[9].

Clinical quantitative electromyography, or QEMG, aims to enhance clinical decisions about the diagnosis, treatment, or management of neuromuscular disorders by using the information included in an EMG signal to characterise the muscle from which it was recorded[9].

Fascicle length was defined as the separation between the intersections of the deep aponeurosis with the fascicle and the superficial aponeurosis with fascicle[10]. Several human muscles include fascicles that are slanted and connected to the muscular aponeurosis rather than running straight from origin to insertion[11]. The length of a fiber or fascicle, which is proportional to the muscle's maximum excursion and contraction velocity, reveals the number of sarcomeres in series[12]. The numbers of muscle thickness and pennation angle can be utilized for determining fiber length (fiber length = muscle thickness/ sin pennation angle)[13].

Because the muscle architectural parameters often change markedly with contraction, recent attempts have been made to use changes in fascicle length measured by US to detect or measure muscle activity[14]. There is a perfect distance between sarcomeres where the tension in the muscle fiber is highest and the force of contraction is greatest. The tension and power of contraction will be reduced if sarcomeres are located either closer together or further apart than this ideal length[15].

After extensive literature review and analysis, it was found that there is previous studies that investigate the relation between rounded back posture and MUPs but there is lack of information regarding the electromyographic variations in children as general and more specifically, there is no previous studies concerned with the effect of rounded shoulders on muscle architecture especially fascicle length in children as regards to the electromyographic activity of shoulder retractors so, in order to improve the standards of the physical therapy evaluation as there is insufficient proof to determine the properties of the muscle motor unit potentials and the fascicle length in children with poor posture. Also, this study could be of value for future studies as a reference. The aim of this study was to detect how children's rounded back posture affects the properties of their shoulder retractors' motor unit potentials and fascicle length of middle trapezius.

Materials and Methods

The study design is a cross-sectional study.

Participants

The period of this study's execution was from January to June 2023. In order for their children to take part in the study and be evaluated, parents had to complete an informed consent form. Two groups of sixty children were selected from primary schools and evaluated at Cairo University's faculty of physical therapy outpatient clinic. Children in group (A) were healthy children, whereas group (B) were rounded back posture. The inclusion criteria were a) Ages varied from seven to ten years, b) normal developed children, c) They were able to follow the instructions, d) The weight and height of each child was measured and recorded, all the children were within the same range. The exclusion criteria were a) Current or past musculoskeletal issues or operations, whether acquired or congenital, b) Taking medications, c) Athletic children, d) Any history or current cardiopulmonary conditions, e) Present or history of neurogenic disorders e.g. convulsions, epilepsy, f) Suffering from sensitivity of the skin, g) Current or history of participation in any other physical therapy interventions.

Procedures

1. Body mass index (BMI)

Weight Status children body height was measured by using a portable stadiometer with an accuracy of 0.1 cm. and their body weight was determined using a digital scale with an accuracy of 0.1 kg. The child's BMI was computed using these values by dividing body weight by squared height (kg/m^2)[16].

2. Plumb line

By free hanging of a rope with a weight at its end as a reference standard, the plumb line represents the pathway of the line of gravity. This method uses the linear deviation distance between body parts and the plumb line and is graded as minimal, moderate and severe. This method has a high intra-rater reliability and moderate inter-rater reliability[17]. Children stood barefoot topless or wearing cut tops for shoulder visualization. Circular adhesive dots were applied to the child's right acromion process of the shoulder to measure their posture. From the sagittal view, each child stood in front of a posture grid which was placed behind the plumb line by 1.9 meters. A smartphone camera mounted on a tripod was used to take portrait-format pictures of the standing toddler from a distance of three meters. To guarantee that the subject's right side was aligned perpendicular to the camera and to standardize subject placement, floor markers were positioned 1.1 meters in front of the posture grid. After ten steps walking on the spot, children were to stand comfortably in their "normal, loose, or habitual" posture, with their hands at their sides, their knees straight, their gaze forward, and their weight evenly distributed on both feet. They were instructed not to stand straight or in their "best posture" in order to record their usual or habitual standing position." After that, a picture of the child was taken and classified as follows: Group A denotes the instance in which the robe passed through the child's shoulder joint, and Group B denotes the instance in which it travelled behind the child's shoulder joint.

Electromyography device (EMG)

Non-invasive electrodes record surface EMG signals, while invasive electrodes record intramuscular EMG signals. These days, the best method for determining the duration or strength of superficial muscular activation is to use surface-detected signals. In the domains of engineering and medicine, the electrophysiological signals obtained by electromyography (EMG) are considered to be the most valuable. The main technique for comprehending the actions of the human body in both healthy and diseased states is to capture EMG signals[18]. Components are Neuro EMG apparatus from Neurosoft, Surface disposable electrodes, Ground electrode, Cables and Foot Switch. EMG technique is a valid and reliable for measuring MUPs in children by using surface electrodes[19].

Any distracting factors should be eliminated from the examination room. Clear explanation of the procedure was given to the child or caregiver. The child was instructed to remove their clothing, sit comfortably in a chair, and keep their head in the middle position. Over the contralateral shoulder, an earth electrode was positioned. To lower skin impedance, alcohol was applied to the skin prior to applying surface electrodes. A pair of surface recording electrodes were positioned on the middle trapezius, 0.5 cm apart, directly medial to the right scapular spine's medial edge. The EMG device (Neuro-MEP-Micro) was switched on and Neuro-MEP.net Software was opened on the laptop. Create New Exam", the child's name, gender, age, weight and height items were filled. The right middle trapezius muscle was selected first then "Set up". The "Motor Unit Potential (MUP)" item was selected. "Spontaneous activity" item was selected. During the recording of the unplanned action, the child was cautioned to remain totally still. Afterwards, the children underwent the extension Maximum Voluntary Isometric Contraction Test (MVIC). They were sat with their arms at 30° abductions, their elbows fully extended, and their thumbs facing the body[20]. Using the foot Switch, the MUPs was recorded while applying resistance to the child's arm. During testing, verbal reinforcement was offered to the subjects, and they were watched closely to make sure they didn't do any scapula or trunk compensatory movements. To ensure that the maximal contraction was achieved, each contraction was carried out for five seconds. The test was administered three times, with a minimum of 20 seconds of break in between each repetition. This was repeated for the left middle trapezius muscle. The results were saved and the report was printed.

Ultrasonography

By using ultrasonography device (type GE Logiq P6) to measure the muscle fascicle length of the middle trapezius muscle. The LOGIQ P6 PRO is a high end, highly mobile and easy to use, performance multipurpose color Doppler imaging system, designed for Obstetrics, Gynecology, Cardiology, Musculoskeletal, Vascular, Urological, Small Parts, Superficial, Pediatric, Neonatal, Trancranial, Abdominal and other applications. It is a valid and reliable tool to measure muscle architectures including fascicle length[21].

The child was first seated with their head in the middle. The transducer was positioned halfway perpendicular to the long axis of the top fibres of the middle trapezius muscle, halfway between the spinous process of C7 and the lateral third of the clavicle. The researcher, seated next child, provided support and adjusted their posture as needed. Following the ultrasound image capture, the researcher assessed the length of the fascicle by calculating the distance between the points where the fascicle and the deep and superficial aponeuroses connect. Every parameter (in every image) was measured three times, and the average was computed, noted, and saved to an Excel document[22].

Statistical analysis

The statistical analysis and Data management were conducted by SPSS version 28 (IBM, Armonk, New York, United States). The normality of quantitative data was assessed using the Shapiro-Wilk test and direct data visualization tools. According to normalcy, quantitative data were summarized as means and standard deviations, or as medians and ranges. Utilizing percentages and numbers, the categorical data was summarized. The quantitative data between the research groups were compared using either the Mann-Whitney U test or the independent t-test, based on whether the quantitative variables were regularly distributed or not. Categorical data were compared using the Chi-

Table 1. Demographics of the studied groups.

		Normal group (n = 30)	Rounded back (n = 30)	P-value
Age (years)	Mean ±SD	8.5 ±0.9	8.9 ±0.7	0.089
Sex				
Males	n (%)	12 (40)	16 (53.3)	0.301
Females	n (%)	18 (60)	14 (46.7)	
Weight	Mean ±SD	27.23 ±8.05	26.9 ±3.51	0.837
Height	Mean ±SD	128.1 ±8.66	128.84 ±6.79	0.714
BMI	Mean ±SD	17.33 ±2.64	16.42 ±1.14	0.092

BMI: Body mass index.

Table 2. Motor unit parameters for right and left middle trapezius in the studied groups.

		Normal group (n = 30)	Rounded back (n = 30)	P-value
Right middle trapezius				
M.U count	Median (range)	6 (2 - 7)	6 (3 - 10)	**0.019***
M.U duration	Mean ±SD	12.33 ±2.15	12.27 ±2.6	0.916
M.U amplitude	Mean ±SD	304 ±44	347 ±50	**<0.001***
Left middle trapezius				
M.U count	Median (range)	5 (2 - 9)	5 (3 - 9)	0.518
M.U duration	Mean ±SD	11.19 ±1.48	12.72 ±2.05	**0.002***
M.U amplitude	Mean ±SD	286 ±52	349 ±46	**<0.001***

**Significant P-value; MU: Motor unit.*

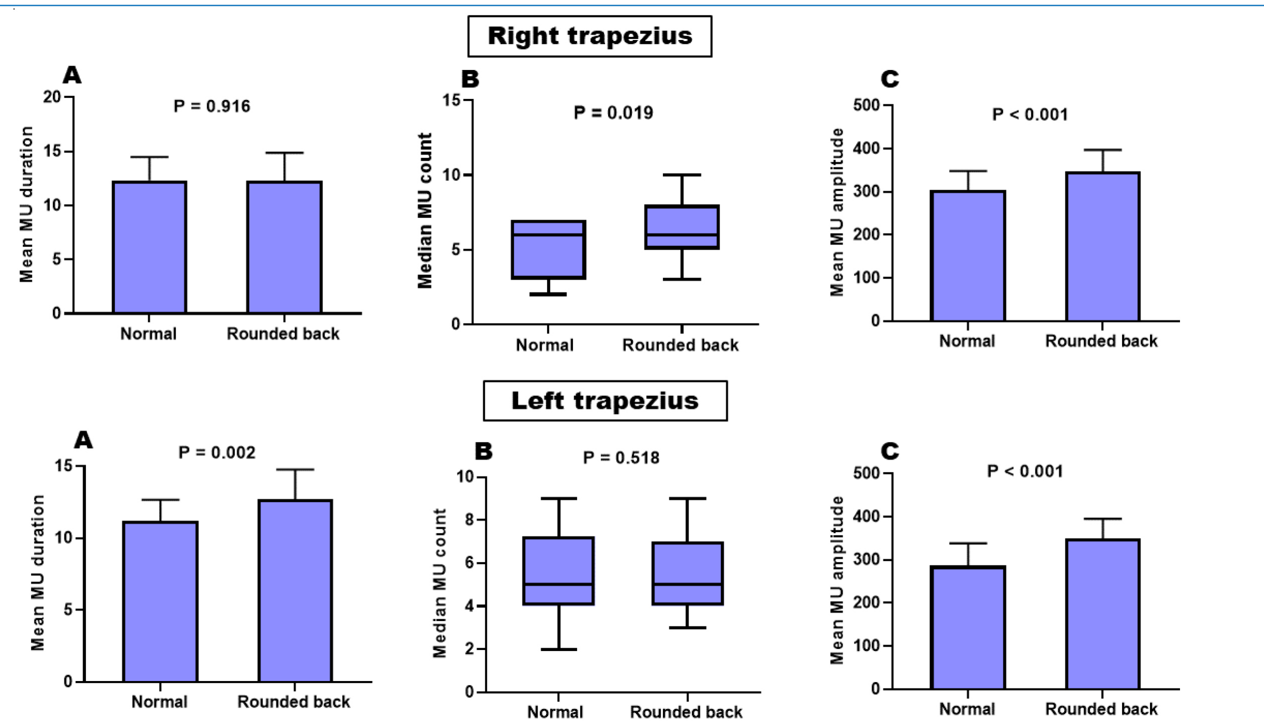

Figure 1. Motor unit parameters for right and left middle trapezius in the studied groups: a) motor unit duration; b) motor unit count; c) motor unit amplitude.

Table 3. Fascicle length of right and left middle trapezius of the studied groups.

Fascicle length		Normal group (n = 30)	Rounded back (n = 30)	P-value
Right trapezius	Mean ±SD	1.7 ±0.1	1.5 ±0.1	**<0.001***
Left trapezius	Mean ±SD	1.6 ±0.1	1.4 ±0.1	**<0.001***
*Significant P-value.				

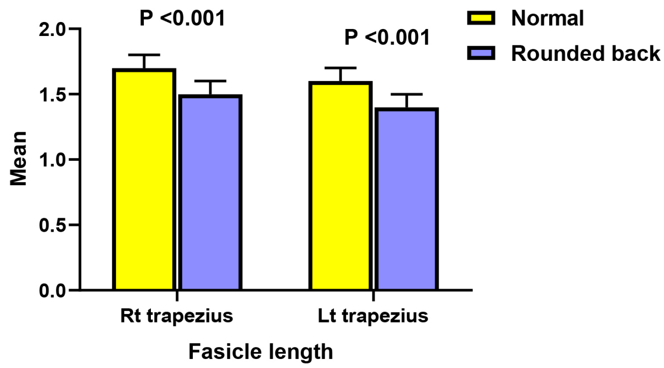

Figure 2. Fascicle length of right and left middle trapezius of the studied groups.

square test. Multivariate linear regression analysis assessed rounded back as a predictor of motor unit parameters and fascicle length. 95% confidence intervals for the regression coefficients were calculated. Every statistical test used two sides. P values considered significant if they were less than 0.05.

Results

Demographics

Table 1 illustrates that there were no significant differences between the studied groups regarding age (P = 0.089), gender (P = 0.301), weight (P = 0.837), height (P = 0.714), and body mass index (P = 0.092).

Motor unit parameters

For the right middle trapezius, the rounded back group demonstrated significantly higher motor unit count (range = 3–10 vs. 2–7, P = 0.019) and motor unit amplitude (347 ±50 vs. 304±44, P < 0.001) than the normal groups. Regarding motor unit duration, no significant difference was reported (P = 0.916) (Table 2, Figure 1).

For left middle trapezius, the rounded back group demonstrated significantly higher motor unit duration (12.72±2.05 vs. 11.19±1.48, P = 0.002) and motor unit amplitude (349±46 vs. 286±52, P < 0.001) than the normal group. Regarding motor unit count, no significant difference was reported (P = 0.518) (Table 2, Figure 1).

Fascicle length

The rounded back group exhibited significantly lower fascicle length in the right middle trapezius (1.5±0.1 vs. 1.7±0.1, P < 0.001) and left middle trapezius (1.4±0.1 vs. 1.6±0.1, P < 0.001) than the normal group (Table 3, Figure 2).

Prediction of motor unit parameters & fascicle length

Multivariate linear regression analysis assessed rounded back as a predictor of motor unit parameters and fascicle length, controlling for age, gender, and BMI. It revealed that for the right middle trapezius, rounded back was associated with 1.133 units increase in the motor unit count (B = 1.133, 95% CI = 0.225 – 2.042, P = 0.015) and 39.884 units increase in the motor unit amplitude (B = 39.884, 95% CI = 14.203 – 65.565, P = 0.004). For the left middle trapezius, rounded back was associated with 1.765 units increase in motor unit duration (B = 1.765, 95% CI = 0.772 – 2.757, P = 0.001) and 60.302 units increase in motor unit amplitude (B = 60.302, 95% CI = 33.044 – 87.561, P < 0.001) (Table 4).

Table 4. Multivariate linear regression analysis to predict motor unit parameters and fascicle length.

Outcome	B (95% CI)**	P-value
Right middle trapezius		
M.U count	1.133 (0.225 - 2.042)	**0.015***
M.U duration	-0.093 (-1.391 - 1.205)	0.886
M.U amplitude	39.884 (14.203 - 65.565)	**0.003***
Left middle trapezius		
M.U count	-0.052 (-1.092 - 0.988)	0.92
M.U duration	1.765 (0.772 - 2.757)	**0.001***
M.U amplitude	60.302 (33.044 - 87.561)	**<0.001***
Fascicle length		
Right middle trapezius	-0.291 (-0.347 - -0.234)	**<0.001***
Left middle trapezius	-0.243 (-0.308 - -0.177)	**<0.001***

**Significant P-value; **Adjusted for age, gender, and BMI; B: Regression coefficient; 95% CI: 95% confidence interval; MU: Motor unit.*

For fascicle length, rounded back was associated with 0.291 units decrease in the fascicle length of the right middle trapezius (B = -0.291, 95% CI = -0.347 - -0.234, P < 0.001) and 0.243 units decrease in the fascicle length of left trapezius (B = -0.243, 95% CI = =0.308 - -0.177, P < 0.001) (Table 4).

Discussion

This study was carried out to clear the impact of rounded back posture on motor unit potentials and fascicle length of shoulder retractors in children. The study's findings suggested that when compared to normal group, the rounded back group's right and left middle trapezius MUPs count and amplitude significantly increased. As regards to the middle trapezius MUPs duration, there was no significant difference between the two groups. Also, the rounded back posture group exhibited significantly lower fascicle length in both middle trapeziuses than normal group.

The results of this study is reinforced by AL QAZZAZ et al. (2020), who stated that the middle trapezius MUPs count can fluctuate in response to forward-shouldered posture. Therefore, it may be inferred that having a forward-leaning posture may increase the likelihood of developing one of the several shoulder disorders[23].

Also, our results came in agreement with Yoo, (2013) who performed a study to compare the activity of the shoulder muscles during shoulder abduction in a group with a forward shoulder posture and a group without any symptoms. When comparing the forward shoulder posture group to the asymptomatic group, the middle trapezius and clavicle region of the pectoralis major showed significantly higher activities. Therefore, according to our research result the children having a forward-leaning posture may increase the chance of developing any of the many shoulder problems[24].

However, none of the previous studies cleared the relation between motor unit potentials and fascicle length of shoulder retractors in rounded back children. Therefore, due to the lack of studies in this field, it is necessary to conduct this our research, which will aid in objective muscular evaluation in these children.

The current study showed that the rounded back posture group exhibited significantly lower fascicle length in both middle trapeziuses than normal group. This result was positively correlated with Delicce and Makaryus (2022) who suggested that the initial length of the muscle fibers and the force produced by contraction serve as the foundation for the Frank-Starling relationship. The length of the sarcomeres and the tension of the muscle fibers have a predictable connection. There is a perfect distance between sarcomeres where the tension in the muscle fiber is highest and the force of contraction is greatest. The tension and power of contraction will be reduced if sarcomeres are located either closer together or further apart than this ideal length[20].

Children with rounded back associated with reduced fascicle length of middle trapezius as a result of our research which were reinforced by Noelle et al. (2010) who showed that an intermediate stage that influences how force and muscle fiber excursion are converted into joint motions is the muscular architecture. When estimating muscle actions from joint observations, it is crucial to comprehend this level of detail[25]. Also, it has been demonstrated that both intrinsic and architectural factors, such as fiber composition and muscle fiber length, affect a muscle's functional properties (such as maximal tension and shortening velocity)[26,27].

In some earlier studies, the architecture of human muscles was discovered in cadaver specimens and connected with functional traits[28-32], But there is a dearth of information on human muscles in real humans. The reduced fascicle length of the middle trapezius in this study is consistent with the findings of Fukunaga et al. (1997), who discovered that joint angles affect the differences in fascicle lengths and pennation angles between the muscle in an isometrically contracted and relaxed state, at least at the submaximal contraction level. They described how passively changing the knee position from 110° to full extension resulted in an average fascicle length change from 133 to 97 mm. The longer series elastic component would have been absorbed, leading to a larger shortening[33].

The results of current study concluded that children with rounded back had reduced fascicle length which supported by previous studies that were stated that because there is less fascicle shortening during contraction, there is less activation, which causes fascicles to lengthen[34], Furthermore, the insertion sites on the superficial and deep aponeuroses are pulled closer together as fascicles shorten, increasing the pennation angle[35], This, as the section "Limitations" explains, was not measured in this study. Reduced activation would lead to reduced pulling of fascicle insertions together, which would reduce pennation change and the pennation angle overall[35,36].

The constant higher level of contraction of the middle trapezius muscle in rounded back posture causes decreasing its range-of-relaxation so this muscle rarely become extended to its full length, that leading to reduction of the fascicle length of this muscle. In addition, the chronic rounded back posture makes the middle trapezius tighter with time, further reducing the fascicle length even more. So, the rounded back posture includes higher levels of motor unit potentials and lowered levels of muscle fascicle length.

Finally, according to results of this study, children with rounded back are at high risks to develop a lot of physical abnormalities especially musculoskeletal and spinal limitations which came with Latalski et al. (2013) who stated that Although postural abnormalities are becoming more common, they are also becoming a greater issue among school-age children and teenagers. Inadequate measures and prophylactic negligence can result in motor and physical limitation, back pain, or the formation of serious spine abnormalities. It is imperative to identify and address the risk factors that may contribute to the development of the condition at an early age. This enables the development and implementation of specific educational plans aimed at parents and schools, as well as the establishment of suitable settings for children's psychomotor development[37].

Study limitations

The present study has some limitations, including: 1) As a muscle architecture, only fascicle length was measured in this study, but other parameters as pennation angle need to be measured to detect the relation between these architecture parameters during muscle contraction. 2) This study was limited to evaluation of middle part of trapezius muscle, whereas upper and lower trapezius need to be evaluated in rounded back posture.

Conclusion

It was concluded that forward shoulder posture alters the muscles activity and morphology represented by upper trapezius MUPs characteristics and also its fascicle length. These alterations could affect children's postures in advance. Therefore, children's forward-shoulder posture may be a risk factor for different posture problems in children, so this need frequent orientation of optimal posture characteristics for children which is a responsibility of physical educators in schools and also parents in homes to prevent future postural problems. Future recommendations include measuring motor unit potentials and fascicle length of shoulder retractors in CP children and adolescents in various age groups.

Ethics approval

The study was approved by the Cairo University faculty of physical therapy's Ethical committee (No: P.T.REC/012/004088).

Consent to participate

Written informed consent to participate in this study was obtained from the parents or legal representatives of all participating children.

Acknowledgments

Sincere gratitude and appreciation are extended to both the parents and children who participated in this study.

Authors' contributions

MSM conceived and designed the study and conducted the research. ASA provided research materials, and collected and organized the data. The article's initial and final drafts were written by ASA and MSM, who also handled logistics and conducted data analysis and interpretation. The final draft has been critically reviewed and approved by all authors, who also bear responsibility for its content and similarity index.

References

1. Ningthoujam R. Postural deformities in lower extremities among school children. International Journal of Physical Education, Health & Sports Sciences 2014;3(1): 78-84.
2. Latalski M, Bylina J, Fatyga M, Repko M, Filipovic M, Jarosz M, Borowicz K, Matuszewski Ł and Trzpis T. Risk factors of postural defects in children at school age. Annals of Agricultural and Environmental Medicine 2013;20(3):583–587.
3. Cosma G, Ilinca I, Rusu L, Nanu C. and Burileanu A. Physical exercise and its role in a correct postural alignment. Discobolul – Physical Education, Sport and Kinetotherapy Journal 2015;11(39):58-64.
4. Kratenová J, Zejglicová K, Malý M, Filipová V. Prevalence and Risk Factors of Poor Posture in School Children in the Czech Republic. Journal of School Health 2007;77(3):131-137.
5. Kistner F, Fiebert I, Roach K and Moore J. Postural compensations and subjective complaints due to backpack loads and wear time in school children. Pediatric Physical Therapy 2013;25(1):15–24.

6. Kisner C, and Colby L. Therapeutic exercise: foundations and techniques, 5th ed. Philadelphia: F. A. Davis Company, 2007.
7. Peterson D, Blankenship K, Robb J. Walker M, Bryan J, Stetts D, Mincey L and Simmons G. Investigation of the Validity and Reliability of Four Objective Techniques for Measuring Forward Shoulder Posture. Journal of Orthopaedic & Sports Physical Therapy 1997;25(1): 34-42.
8. Peterson D, Blankenship K, Robb J, Walker M, Bryan J, Stetts D, Mincey L and Simmons G. Investigation of the Validity and Reliability of Four Objective Techniques for Measuring Forward Shoulder Posture. Journal of Orthopaedic & Sports Physical Therapy 1997;25(1): 34-42.
9. Adel T and Stashuk D. Clinical Quantitative Electromyography. In: H. Turker, ed., Electrodiagnosis in New Frontiers of Clinical Research 2013.
10. Kubo K, Ikebukuro T and Yata H. Mechanical properties of muscles and tendon structures in middle-aged and young men. Scientific Reports 2022;12(1):1702.
11. Blazevich AI. Effects of Physical Training and Detraining, Immobilisation, Growth and Aging on Human Fascicle Geometry Journal of Sports Medicine 2006; 36(12):1003-1017.
12. Moreau N G, Teefey SA, Damiano D L. *In vivo* muscle architecture and size of the rectus femoris and vastus lateralis in children and adolescents with cerebral palsy. Journal of Developmental Medicine and Child Neurology 2009;51(10):800-806.
13. Legerlotz K, Smith H K, Hinge W A. Variation and reliability of ultrasonographic quantification of the architecture of the medial gastrocnemius muscle in young Children-Journal of Clinical Physiological Function Imaging 2010;30(3):198-205.
14. Critchley D. Instructing pelvic floor contraction facilitates transversus abdominis thickness increase during the low-abdominal hollowing. Journal of Physiotherapy Research International 2002;7(2):65-75.
15. Delicce AV, Makaryus AN. Physiology, Frank Starling Law. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023
16. D'Hondt E, Deforche B, Gentier I, Verstuyf J, Vaeyens R, Bourdeaudhuij I and Lenoir M. A longitudinal study of gross motor coordination and weight status in children. Obesity 2014;22(6):1505-1511.
17. Wilmarth M and Hilliard T. Measuring head posture via the craniovertebral angle. Orthopedic Physical Therapy Practice 2002;14(1):13-5.
18. Chowdhury R, Reaz M, Ali M, Bakar A, Chellappan K and Chang T. Surface Electromyography Signal Processing and Classification Techniques. Sensors 2013; 13(9): 12431-12466.
19. Thomas H, Edward A. C, David A. G, Lara A. G. The reliability of surface EMG derived motor unit variables. Journal of Electromyography and Kinesiology 2020; 52:102419.
20. Ginn K, Halaki M and Cathers, I. Revision of the Shoulder Normalization tests is required to include rhomboid major and teres major. Journal of Orthopaedic Research 2011;29(12):1846-1849.
21. Susanna B, Cliona O'S, Maria S. Thickness of the middle trapezius muscle measured by rehabilitative ultrasound imaging: Description of the technique and reliability study. Clinical Physiology and Functional Imaging 2010; 30(6):426-431.
22. Ema R, Wakahara T, Mogi Y, Miyamoto N, Komatsu T, Kanehisa H, and Kawakami Y. *In vivo* measurement of human rectus femoris architecture by ultrasonography: validity and applicability. Clinical physiology and functional imaging 2013;33(4):267-273.
23. AL qazzaz AM, Olama KA, Abdul rahman RS: Recording of Motor Unit Potentials Count of Middle Trapezius in Children with Rounded Back. Medical journal of Cairo University 2020;88(2):865-868.
24. Yoo W. Comparison of Shoulder Muscles Activation for Shoulder Abduction between Forward Shoulder Posture and Asymptomatic Persons. Journal of Physical Therapy Science 2013;25(7):815-816.
25. Noelle G M, Kit N, Sharlene A, Teefey L D. Muscle Architecture Predicts Maximum Strength and Is Related to Activity Levels in Cerebral Palsy, Physical Therapy 2010;90(11):1619-1630.
26. Burkholder T J, Fingado B, Baron S, and Lieber R L. Relationship between muscle fiber types and sizes and muscle architectural properties in the mouse hind limb, Journal of Morphology 1994;221(2):177–190.
27. Sacks R D, and Roy R R. Architecture of the hind limb muscles of cats: functional significance, Journal of Morphology 1982;173(2):185– 195.
28. An K N, Fui F C, Morrey B F, Linscheid R L, and Chao E Y. Muscles across the elbow joint: a biomechanical analysis. Journal of Biomechanics 1981;14(10):659–669.
29. Brand R A, Pedersen D R, and Friedrich J A. The sensitivity of muscle force predictions to changes in physiologic cross-sectional area. Journal of Biomechanics 1986;19(8):589-596.
30. Edgerton V R, Apor P, and Roy R R. Specific tension of human elbow flexor muscles. Acta Physiologica Hungarica 1990;75(3):205-216.
31. Huijing P A. Architecture of the human gastrocnemius muscle and some functional consequences. Acta Scientiae Anatomica 1985;123(2):101-107.
32. Wickiewicz T L, Roy R R, Powell P L, Perrine J J and Edgerton V R. Muscle architecture and force-velocity relationships in humans. Journal of Applied Physiology 1984;57(2):435-443.
33. Fukunaga T, Ichinose Y, Ito M, Kawakami Y, Fukashiro S. Determination of fascicle length and pennation in a contracting human muscle *in vivo*- Journal of Applied Physiology 1997;82(1):354-358.
34. Avela J, Finni T, Liikavainio T, Niemelä E. Neural and mechanical response of the triceps surae muscle group after 1 h of repeated fast passive stretches. Journal of

Applied Physiology: Respiratory, Environmental and Exercise Physiology 2004;96(6):2325-2332.

35. Narici MV, Hoppeler H, Kayser B, Landoni L, Claassen H, Gavardi C, Conti M, Cerretelli P. Human quadriceps cross-sectional area, torque and neural activation during 6 months strength training, Acta Physiologica Scandinavica 1996;157(2):175-186.
36. Manal K, Dustyn P. R, Thomas S. B. Can pennation angles be predicted from EMGs for the primary ankle plantar and dorsiflexors during isometric contractions? Journal of Biomechanics 2008;41(11):2492-2497.
37. Latalski M, Bylina J, Fatyga M, Repko M, Filipovic M, Jarosz M, Borowicz K, Matuszewski Ł and Trzpis T. Risk factors of postural defects in children at school age. Annals of Agricultural and Environmental Medicine 2013;20(3):583-587.