applied sciences

MDPI

Article

Evaluation of Symmetrical Exercises in Scoliosis by Using Thermal Scanning

Ana-Maria Vutan [1,2], Erwin-Christian Lovasz [1], Corina-Maria Gruescu [1], Carmen Sticlaru [1], Elena Sîrbu [2,*], Nicolae-Adrian Jurjiu [2], Ion-Silviu Borozan [1] and Călin Vutan [2]

[1] Department of Mechatronics, Faculty of Mechanics, Politehnica University of Timisoara, 300222 Timisoara, Romania; ana.vutan@e-uvt.ro (A.-M.V.); erwin.lovasz@upt.ro (E.-C.L.); corina.gruescu@upt.ro (C.-M.G.); carmen.sticlaru@upt.ro (C.S.); ion.borozan@upt.ro (I.-S.B.)
[2] Department of Physical Therapy and Special Motricity, Physical Education and Sport Faculty, West University of Timisoara, 300223 Timisoara, Romania; nicolae.jurjiu96@e-uvt.ro (N.-A.J.); calin.vutan@e-uvt.ro (C.V.)
* Correspondence: elena.sirbu@e-uvt.ro

Abstract: (1) Background: Scoliosis affects about 3% of the population and the number of children diagnosed with this condition is increasing. Numerous studies have been conducted in recent years to observe the effectiveness of rehabilitation specific exercises for this condition. In the present study we aim to observe if symmetrical exercises activate the back muscles in the same way in the case of children with mild scoliosis and those without postural deviations; (2) Methods: We used the thermal imaging camera, which allows a non-invasive, painless investigation that provides real-time information about muscle activity. The study qualitatively assessed muscle activation during exercises. In this study, 30 children were divided into two groups: 15 children diagnosed with mild scoliosis and 15 children without postural deviations; (3) Results: Acquisition of images after each exercise revealed an imbalance in the functioning of the back muscles in children with scoliosis, with areas of higher temperature after exercise on the convexity side of the scoliotic curve. In the second experiment in which children with scoliosis performed the required exercises under the supervision of a physiotherapist, they showed a symmetrical activation of the back muscles on the right and left side of the back; (4) Conclusions: In children without postural deviations, symmetrical exercises activate the muscles equally on the right and left sides of the back. In the case of children with scoliosis, the symmetrical exercises indicated in the rehabilitation programs should be performed only under the supervision of a physiotherapist to properly activate the back muscles.

Keywords: thermal imaging camera; exercise efficiency assessment; scoliosis

Citation: Vutan, A.-M.; Lovasz, E.-C.; Gruescu, C.-M.; Sticlaru, C.; Sîrbu, E.; Jurjiu, N.-A.; Borozan, I.-S.; Vutan, C. Evaluation of Symmetrical Exercises in Scoliosis by Using Thermal Scanning. *Appl. Sci.* **2022**, *12*, 721. https://doi.org/10.3390/app12020721

Academic Editors: Elena Amaricai and Roxana Ramona Onofrei

Received: 5 December 2021
Accepted: 4 January 2022
Published: 12 January 2022

1. Introduction

According to the International Scientific Society on Scoliosis, Orthopaedic and Rehabilitation Treatment (SOSORT) definition, scoliosis is a heterogeneous group of conditions that cause changes in the shape and position of the spine, thorax and trunk [1]. Thus, scoliosis can occur as the presence of one or more abnormal curvatures of the vertebral column affecting the spinal alignment in all three dimensions. In scoliosis, the primary curvature is associated in the frontal plane with compensatory curves above and below it in the opposite direction. In addition, to the lateral bending of the spine, rotations of vertebrae in the transverse plane are common. Moreover, scoliosis leads to rib cage deformity if the spinal alterations occur in that zone. Ribs on the convex side move away from each other and bulge posteriorly forming a hump, while ribs on the concave side are pushed laterally and anteriorly. In addition, the vertebral bodies undergo structural changes, becoming wedge-shaped and asymmetrical.

Beside clinical examination, a large number of assessment methods have recently been developed in scoliosis. Imaging modalities such as radiography, computed tomography (CT) and magnetic resonance imaging (MRI) are often used in the diagnosis, evaluation, and management of scoliosis. Among these, radiological examination remains the golden method to investigate and assess scoliosis [1]. Unfortunately, all these investigations use radiation and have negative effects on the child's growing body, and therefore new methods were researched.

However, there are other possibilities to investigate and to monitor the evolution of scoliosis, but they are not widely used at the moment: Moiré topography, computerized raster stereography, optical scanning through system ISIS (Integrated Shape Imaging System), thermography, digital ultrasonic mapping (Zebris Medical Gmbh) and three-dimensional mapping through digital image acquisition (InSpeck system) [2,3].

Thermography, one of the more recent techniques, is used to measure the symmetry or asymmetry in distribution of the skin temperature over selected areas of the body. It is increasingly used in medical applications because it is non-invasive, reliable, non-contact, and painless; the human body is not radiated, and it can be applied without restriction to all categories of patients regardless of age, sex or health status. Thermographic technique is based on the property of bodies to emit radiation in the infrared range. Thermal imaging equipment operates on the principle of conversion of infrared radiation in digital image output signal. Currently, thermography is limited to taking static or dynamic images that seek only local variation and/or temperature over time [4–6].

Thermography has proven its effectiveness in many pathologies, namely juvenile idiopathic arthritis [7], diabetes [8], scoliosis [9–11]. In healthy athletes, thermography was used to measure muscle activity in symmetrical or asymmetrical physical training and to predict the best type of effort [12–14].

Recent work by Lubkowska A. et al. [15] on thermography in scoliosis has indicated that the areas of the upper body parts (chest, abdomen, back) are much warmer (by about 4 °C) than the lower parts (thigh, calf) both in healthy children and in scoliosis. They demonstrated that in children with scoliosis, the areas of the body with a significant thermal asymmetry of the surface are the upper back, thighs and calf in the posterior area. Moreover, the size of the thermal asymmetry was significantly correlated with the angle of trunk rotation. Authors concluded that thermography can be used as a complementary tool in screening children with scoliosis.

Starting from the observations presented in the literature, we tried to observe in this study how the back muscles act when the movements are performed symmetrically. To this purpose, we used a thermal camera to record the action of the back muscles in two groups of children, some with scoliosis and others without deviations of the spine. In this way we wanted to evaluate how the muscles of children with scoliosis work and whether for these people it is advisable to perform symmetrical exercises in recovery programs or only exercises specific to scoliosis in the methods already established. Our experiment aimed at the qualitative analysis of muscle contraction and not quantitative. Thus, we did not value the increase of the temperature at the back, but we were interested in how symmetrically the muscles are activated during the exercises and if the presence of a deviation in the frontal plane influences the execution of the exercises. To the best of our knowledge, this is the first study that assess symmetrical exercises in children with scoliosis by using thermal scanning.

2. Materials and Methods

2.1. Participants

The present research was conducted, as an experimental study, between June and August 2021. The study was attended by 30 volunteers, girls and boys, aged between 10 and 18 years. All participants were informed from the beginning about the purpose of the study and how it will be carried out. As minors were involved in the study, the parents/legal guardians signed an agreement regarding their participation in the research.

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the West University of Timisoara (approval number 61504/5 November 2021).

The subjects who entered the study were part of the group of children who approached the Ortokinetica VMC Center for postural evaluation between June and August 2021. Subjects were divided into 2 groups: a control group (only children who did not show postural deviations in the frontal plane) and a study group (only children who were diagnosed with mild scoliosis), each group consisting of 15 participants. The criteria for inclusion in the control group were: subjects aged 10–18 years old, healthy, without posture deviations (the participants were initially assessed to exclude deviations in the frontal plane or asymmetries of the scapular and/or pelvic girdle), that understand indications given by testators and want to participate in the study. The criteria for inclusion in the study group were: subjects aged 10–18 years old, diagnosed with mild scoliosis by a physician and without other associated diseases, no subject had a brace indication and all could understand the indications and collaborate with the evaluators. Initially, a preliminary assessment was performed by the same physiotherapist for all subjects with Adams bending test, noting for every subject the presence or absence of the hump and the rotation of the spine. The scoliometer was used to evaluate the rotation of the spine and the values obtained represented an inclusion criterion in the groups of the study. After this evaluation, the subjects were divided into 2 groups. In the control group were accepted only subjects who did not show signs of back asymmetries or vertebral rotation (0–1° in the evaluation with the scoliometer). In the study group were included only subjects who were diagnosed with scoliosis by the doctor, had a Cobb angle greater than 10° (according to Scoliosis Research Society) and had thoracic and/or lumbar vertebral rotation (3–5° in the evaluation with the scoliometer).

2.2. Measurements with the Thermal Imaging Camera

Four scans with the thermal imaging camera were performed for all subjects. At each scan the subject was positioned standing and the image capture was performed only in the frontal plane from the posterior. The FLIR B200 camera was used in the experiment The acquisitions were made respecting the examination conditions imposed by the European Thermography Association [16]. All assessments were performed by the same person under the same conditions: the temperature inside the room was 23 ± 1 °C and the imagine capture was taken from 1.5 m away from the investigated subject. The main specifications of the camera, acquired by Polytechnic University of Timisoara in 2012, are given in Table 1 [17].

Table 1. Characteristics of the thermographic camera.

Field of View (FOV)/Close Focus Limit	25° × 19°/0.4 m (1.31 ft.)
Detector Type	Focal Plane Array (FPA) microbolometer
IR resolution	200 × 150
Spectral range	7.5 to 13 μm
Digital zoom and pan/focus	1x − 2x continuous/auto and manual focus
Display	Built-in touch-screen LCD display, 3.5 in.
Video lamp	1000 cd
Visible light camera resolution	1280 × 1024 m (1.3 megapixels)
Object temperature range	−20 °C to +120 °C (−4 °F to +248 °F), optional up to +350 °C
Accuracy	±2 °C (±3.6 °F) or ±2% of reading
Measurement modes	5 Spot meters, 5 Box areas, Isotherm, Auto hot/cold spot

Table 1. *Cont.*

Measurement corrections	Reflected ambient temperature and emissivity correction
Digital storage/capacity	Removable SD Memory Card/1000 + JPEGS
Image storage mode & formats	IR/visible light, simultaneous storage of IR/visible images, all standard JPEG

The images were taken in four sequences: before the exercises, one minute after exercises 1, 2 and 3. The height of the camera was adjusted to the patient's height, so that the back of the patient to be captured in the field of view.

Thermal imaging proved to be appropriate for complementary investigation, as it is non-invasive and painless for the patient. The images can be taken anywhere, as the apparatus is small, mobile and light. It is easily handled by the therapist and provides instant results.

The information provided by thermal image are qualitative, but quantification would not bring substantial extra information. The thermal image is unique in regard with its intuitive character. No other imaging procedure provides such an easy-to-read result. The therapist can take images at the beginning of the session and during the exercise program and acquire valuable information regarding the efficiency of the exercise.

2.3. Study Protocol

The protocol was designed as follows: a first acquisition was made after adjusting the body to the ambient temperature in the room where the experiment took place. Each subject had to perform 3 exercises, of 20 repetitions. The 3 exercises chosen for testing are generally recommended by instructors or therapists in order to tone the back muscles. Our aim was to observe what influence have these movements on the back muscles and implicitly, on the body posture of the subjects. After each exercise, a 1-min break was taken, and during this time, a new image of the back was acquired.

The exercises used in the experiment were:

- exercise 1—from the four-legged position, an arching movement of the spine in flexion and extension was performed (the cat and camel exercise) (Figure 1a);
- exercise 2—from the four-legged position the subjects had to raise parallel to the floor their arm to one side simultaneously with the leg on the opposite side, alternatively (Figure 1b);
- exercise 3—from lying on the stomach, the subject had to raise of the floor his/her arm and leg on the opposite side, alternatively (the supermen exercise) (Figure 1c).

The exercises are exemplified in the Figure 1 below.

(**a**) (**b**) (**c**)

Figure 1. (**a**) the cat and camel exercise; (**b**) subject had to raise parallel to the floor their arm to one side simultaneously with the leg on the opposite side, alternatively; (**c**) the supermen exercise.

The exercises performed by the subjects were explained by the same physiotherapist for all of them, at the beginning of the experiment and during their execution no corrections were made, the study participants being allowed to perform the movements at their own pace and depending on how they understood that they should be performed.

3. Results

We observed in the subjects from the control group a symmetrical activation of the muscles within the three analyzed exercises. The back muscles on the right side and on the left side worked in a balanced way, activating symmetrically during the movements. The figures below show three different cases of subjects without scoliosis (Figures 2–4). The images on the left side show the initial thermal image (at the beginning of the experiment) and on the right side the image taken after each exercise (image after exercise 1, image after exercise 2, image after exercise 3).

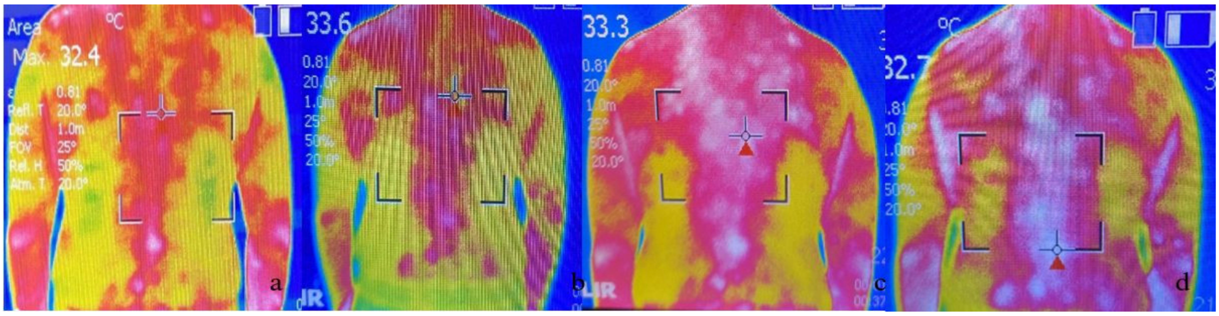

Figure 2. Subject 1 without scoliosis (**a**) image taken at the beginning; (**b**) image taken at the end of exercise 1; (**c**) image taken at the end of exercise 2; (**d**) image taken at the end of exercise 3.

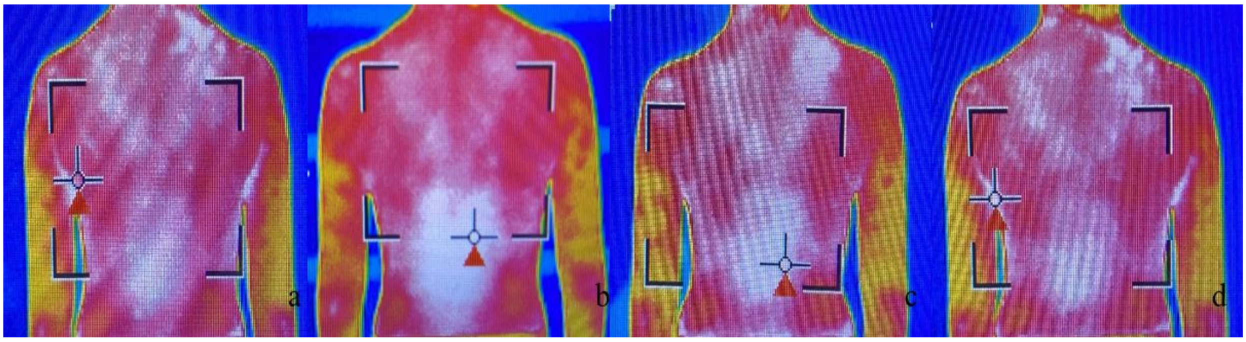

Figure 3. Subject 2 without scoliosis (**a**) image taken at the beginning; (**b**) image taken at the end of exercise 1; (**c**) image taken at the end of exercise 2; (**d**) image taken at the end of exercise 3.

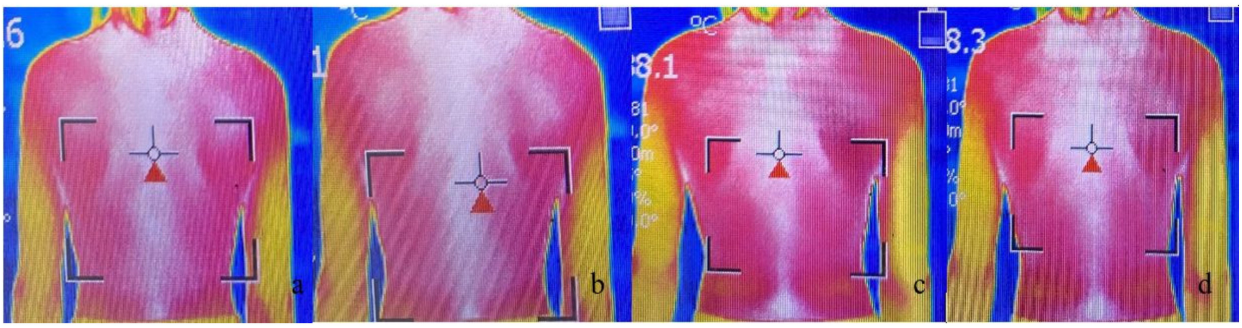

Figure 4. Subject 3 without scoliosis (**a**) image taken at the beginning; (**b**) image taken at the end of exercise 1; (**c**) image taken at the end of exercise 2; (**d**) image taken at the end of exercise 3.

It was found in the case of all subjects in the control group that as the muscles were engaged in performing the exercises, the temperature in the back became easier to differentiate in the muscle groups involved. If at the first image capture, it is much more diffuse, as the movement was performed, muscle activation could be observed more easily.

In the subjects from the study group, the activation of the back muscles was found asymmetrical during the exercises as can be seen in the images below (Figures 5–7).

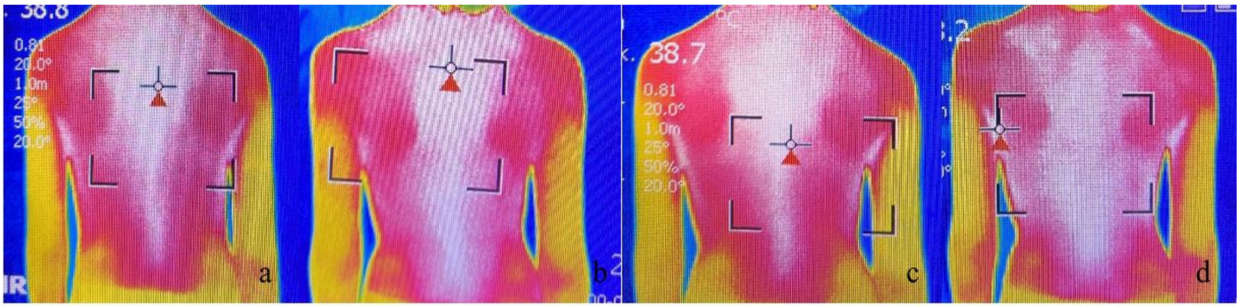

Figure 5. Subject with scoliosis 1 (**a**) image taken at the beginning; (**b**) image taken at the end of exercise 1; (**c**) image taken at the end of exercise 2; (**d**) image taken at the end of exercise 3.

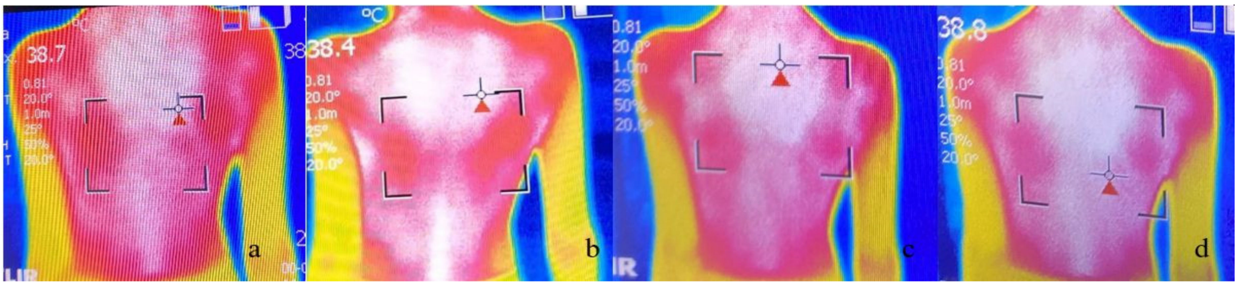

Figure 6. Subject with scoliosis 2 (**a**) image taken at the beginning; (**b**) image taken at the end of exercise 1; (**c**) image taken at the end of exercise 2; (**d**) image taken at the end of exercise 3.

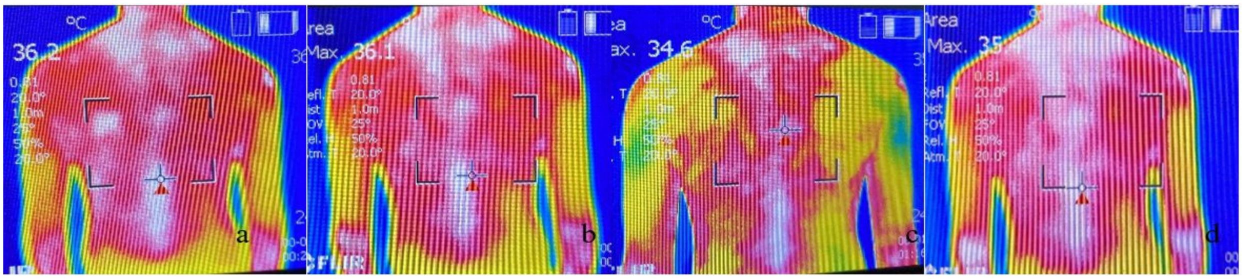

Figure 7. Subject with scoliosis 3 (**a**) image taken at the beginning; (**b**) image taken at the end of exercise 1; (**c**) image taken at the end of exercise 2; (**d**) image taken at the end of exercise 3.

Since the acquired images showed asymmetric muscle activation in subjects with scoliosis, they were also asked to participate in a new evaluation in which the exercises were corrected during the performance by the physiotherapist, by verbal indications on the areas to be tightened or of the position of the back, upper and lower limbs. We present below the initial image purchased in the experiment, the final image from the first experiment and the final image after the second experiment performed on the study group. The images presented in the Figures 8–10 are of the same subjects observed above.

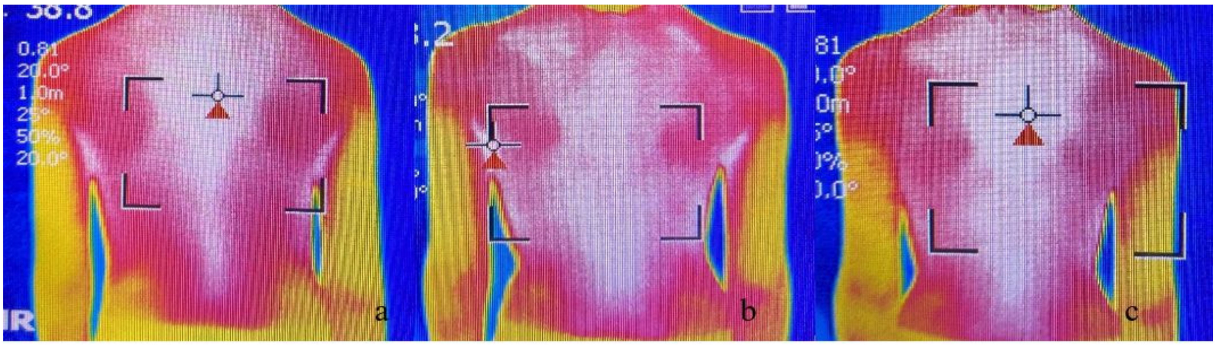

Figure 8. Subject with scoliosis 1 (**a**) image taken at the beginning of the experiment 1; (**b**) image taken at the end of the experiment 1; (**c**) image taken at the end of the experiment 2.

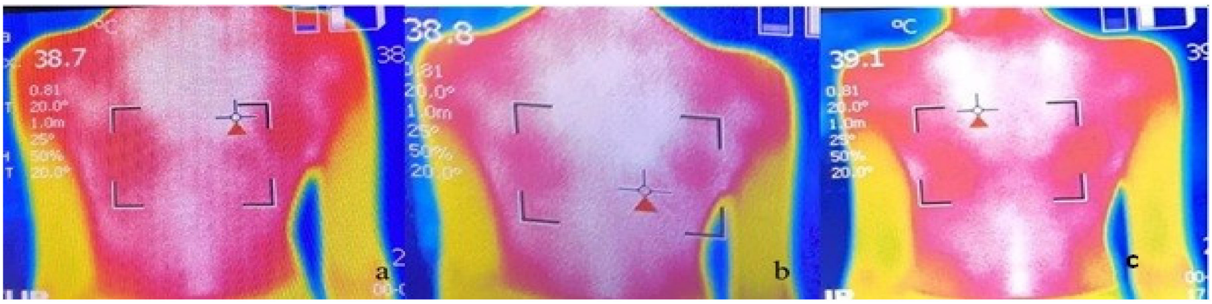

Figure 9. Subject with scoliosis 2 (**a**) image taken at the begining of the experiment 1; (**b**) image taken at the end of the experiment 1; (**c**) image taken at the the end of the experiment 2.

Figure 10. Subject with scoliosis 3 (**a**) image taken at the beginning of the experiment 1; (**b**) image taken at the end of the experiment 1; (**c**) image taken at the end of the experiment 2.

The second experiment highlighted the fact that in the case of patients with mild scoliosis a balanced activation of the back muscles can be obtained, but in their case the precise indications given by the physiotherapist are very important. The minimum imbalance observed at the initial assessment is maintained during the execution of the symmetrical movements unless it is intervened from the outside in order to be aware of the positions or symmetry of the executed movements.

4. Discussion

The efficiency of physical exercises in the case of scoliosis is still being studied by specialists in the field. Orthopedists and physiotherapists have not yet agreed on the influence of exercise on children diagnosed with scoliosis. There are still orthopedists who say that a person with scoliosis should be clinically monitored, and surgery can be performed at the right time. In their conception, physical exercises have only a minor role, in maintaining muscle tone in the back. On the other hand, studies conducted by physiotherapists in collaboration with orthopedic doctors have been able to show that specific physical exercises can stop the evolution or even reduce the amplitude of the Cobb angle in children with scoliosis [18–22].

The way the back muscles work in children with scoliosis has long been studied using an electromyogram. Research has shown increased myoelectric activity on the convex side, near the apex of the curve both at static and dynamic while walking or loading [23–25]. In his study, Farahpour et al. (2014) [26], points out that in people with scoliosis, myoelectric activity is different not only in the back muscles but also in the lower limbs as an adaptive response to movements performed in different planes. They consider that the asymmetry of tone is a consequence of the attempt to stabilize the trunk in dynamic conditions.

In addition, studies on muscle tissue have shown a different distribution of muscle fibers on the convex side and the concave side of the spine. Thus, on the concave side are arranged more type II fibers while on the convex side are predominant type I muscle fibers [27]. Recent studies also show that paraspinal muscles on both the concave and convex sides suffer from atrophy and collagen levels in the tissues are low, similar to degenerative pathologies [28–30].

Muscle activity during scoliosis-specific exercises was monitored by Weiss et al., on patients performing Schroth exercises. They have shown that specific exercises can reduce the difference in activity between the right side and the left side of the back, which demonstrates the importance of physical activity adapted to the condition of each subject [21].

Given the elements observed in studies in the literature, in our research we proposed, as a novelty, to use the thermal imaging camera not only to diagnose scoliosis in children but to observe how the back muscles act during physical activity. Our study analyzed the action of the back muscles during movements performed symmetrically by subjects with scoliosis and by subjects without postural deviations in order to observe if there are differences in the functioning of the back muscles between the two categories of subjects. Three exercises were chosen from the most indicated for mobilizing and toning the back muscles. In the experiment we followed the activation of the back muscles during the dynamic exercises performed from the unloading position of the spine (four-legged position) both in open kinematic chain and in closed kinematic chain using a thermal imaging camera.

Following the activity of the muscles in the control group, it was found that the muscles on either side of the back function harmoniously, balanced, in the three exercises studied. In the case of these subjects, it was observed that exercise 1 mainly activates the muscles in the lumbar area, having less action on the upper back muscles. Exercise 2 mainly involved the muscles in the upper torso, even if it also involves an extension movement of the lower limbs. It should be noted that in the case of subjects with slightly increased areas of temperature in the trapezius muscles (contracture areas), these areas became more active during the exercise (as can be seen in subject 2 without scoliosis presented in Figure 3). The analysis of the images taken after the execution of exercise 3 in the prone position, highlighted an activation of the muscles in the entire back (mainly trapezius and erector spinae).

The analysis of the initial images taken from the subjects in the study group highlighted what was found in other studies in the literature that used the thermal imaging camera [18], namely high temperature areas on the convexity of the scoliotic curve. The acquisition of images after each exercise revealed an imbalance in the functioning of the back muscles. At the thoracic level, the muscles are more active on convexity side during exercises performed with the upper limbs, generally the subjects performing slightly asymmetrical elevations of the upper limbs. Exercise 3 in supine position activates more back muscles than in quadrupeds (four-legged position). In exchange, in the case of subjects with convexity in the lumbar area, it was found that, initially, there is a stronger activation of the muscles on the concave area (we assume due to the eccentric contractions in the concavity and the need to stabilize the pelvic girdle) and only after several repetitions of the exercise there is an increase in temperature in the muscle area of the convex side. This could be observed during the exercises 1 and 3. All these observations were made in the first experiment in which subjects with scoliosis were not corrected by the physiotherapist who participated in the study. In order to evaluate, in more detail, the efficiency of the 3 exercises, we proposed to the subjects diagnosed with scoliosis a second experiment in which they were corrected by the physiotherapist so that the exercises could be performed in symmetrically maintained positions and the movements were conducted correctly and leveled, by the right half body, as well as by the left one. Following this experiment, it was found that muscle activation was much more uniform between the right side and the left side of the body as can be seen in Figures 7–9 which were presented as an example in this study. Following the second experiment, we came to the conclusion that exercises that address the back muscles, performed symmetrically under the supervision of a specialist, can activate the back muscles in a balanced way in the case of children with mild scoliosis. We believe that it is important that these exercises be taught correctly by children with scoliosis under the supervision of specialists and only then, that they be introduced into a program performed at home.

5. Conclusions

- The initial, intermediate and final images allowed the therapist to assess the efficiency of the exercise immediately after its performing and to interact with the patient in the sense of introducing corrections. Thus, this new type of investigation contributes to increasing the efficiency of the exercise program.
- With the study performed on a lot of 30 children-patients, the thermal image provided information on muscles activity during different exercises. Previously, this information could be acquired through electromyography, which supposes an important infrastructure and logistics. The use of the thermographic camera as a method of investigation revealed that the symmetrical exercises performed by children with scoliosis can asymmetrically activate the back muscles if they are not corrected by a physiotherapist. Symmetrical exercises can be recommended in home programs only after the subjects know how to perform them correctly and possibly under the supervision of adults who have been trained in advance.

Author Contributions: Conceptualization, A.-M.V., E.-C.L., C.-M.G., E.S. and C.S.; methodology, A.-M.V., N.-A.J. and C.V.; validation, E.-C.L., C.-M.G., E.S. and C.S.; investigation, A.-M.V., N.-A.J., C.V. and I.-S.B.; writing-original draft preparation, A.-M.V., E.S. and C.-M.G.; supervision, writing-review and editing, A.-M.V., C.-M.G. and E.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of the West University of Timisoara (approval number 61504/5 November 2021).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets either used, analyzed, or both, during the current study are available from the corresponding authors on reasonable requests.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Negrini, S.; Donzelli, S.; Aulisa, A.G.; Czrapowski, D.; Schreiber, S.; de Mauroy, J.C.; Diers, H.; Grivas, T.B.; Knott, P.; Kotwicki, T.; et al. 2016 SOSORT guidelines: Orthopaedic and rehabilitation treatment of idiopathic scoliosis during growth. *Scoliosis* **2018**, *13*, 3. [CrossRef] [PubMed]
2. Berryman, F.; Pynsent, P.; Fairbank, J.; Disney, S. A new system for measuring three-dimensional back shape in scoliosis. *Eur. Spine J.* **2008**, *17*, 663–672. [CrossRef] [PubMed]
3. Kwok, G.; Yip, J.; Yick, K.L.; Cheung, M.-C.; Tse, C.-Y.; Ng, S.-P.; Luximon, A. Postural Screening for Adolescent Idiopathic Scoliosis with Infrared Thermography. *Sci. Rep.* **2017**, *7*, 14431. [CrossRef]

4. Vutan, A.M.; Lovasz, E.C.; Amarandei, M.; Ciupe, V. The methods used for the diagnosis and evaluation of scoliosis. *Timis. Phys. Educ. Rehabil. J.* **2016**, *9*, 36–41. [CrossRef]
5. Gruescu, C.M.; Garaiman, A.; Lovasz, E.C. Modeling of human spinal column and simulation of spinal deformities. *Mechanics* **2015**, *21*, 214–219. [CrossRef]
6. Vutan, A.M.; Gruescu, C.M.; Ciupe, V.; Mărgineanu, D.; Lovasz, E.C. Effectiveness of Physical Exercises in the Treatment of Scoliosis-Mathematical Approach. *New Trends Med. Serv. Robot. Adv. Theory Pract.* **2018**, *65*, 25–34.
7. Lerkvaleekul, B.; Jaovisidha, S.; Sungkarat, W.; Chitrapazt, N.; Fuangfa, P.; Ruangchaijatuporn, T.; Vilaiyuk, S. The comparisons between thermography and ultrasonography with physical examination for wrist joint assessment in juvenile idiopathic arthritis. *Physiol. Meas.* **2017**, *38*, 691. [CrossRef] [PubMed]
8. Etehadtavakol, M.; Ng, E.Y.K.; Kaabouch, N. Automatic segmentation of thermal images of diabetic-at-risk feet using the snakes algorithm. *Infrared Phys. Technol.* **2017**, *86*, 66–76. [CrossRef]
9. Kwok, G.; Yip, J.; Cheung, M.C.; Yick, K.L. Evaluation of myoelectric activity of paraspinal muscles in adolescents with idiopathic scoliosis during habitual standing and sitting. *BioMed Res. Int.* **2015**, *2015*, 958450. [CrossRef] [PubMed]
10. Chwała, W.; Koziana, A.; Kasperczyk, T.; Walaszek, R.; Płaszewski, M. Electromyographic assessment of functional symmetry of paraspinal muscles during static exercises in adolescents with idiopathic scoliosis. *BioMed Res. Int.* **2014**, *2014*, 573276. [CrossRef]
11. Farahpour, N.; Younesian, H.; Bahrpeyma, F. Electromyographic activity of erector spinae and external oblique muscles during trunk lateral bending and axial rotation in patients with adolescent idiopathic scoliosis and healthy subjects. *Clin. Biomech.* **2015**, *30*, 411–417. [CrossRef]
12. Chudecka, M.; Lubkowska, A. Temperature changes of selected body's surfaces of handball players in the course of training estimated by thermovision, and the study of the impact of physiological and morphological factors on the skin temperature. *J. Therm. Biol.* **2010**, *35*, 379–385. [CrossRef]
13. Escamilla-Galindo, V.L.; Estal-Martínez, A.; Adamczyk, J.G.; Brito, C.J.; Arnaiz-Lastras, J.; Sillero-Quintana, M. Skin temperature response to unilateral training measured with infrared thermography. *J. Exerc. Rehabil.* **2017**, *13*, 526–534. [CrossRef] [PubMed]
14. Chudecka, M.; Lubkowska, A.; Leźnicka, K.; Krupecki, K. The use of thermal imaging in the evaluation of the symmetry of muscle activity in various types of exercises (symmetrical and asymmetrical). *J. Hum. Kinet.* **2015**, *49*, 141–147. [CrossRef] [PubMed]
15. Lubkowska, A.; Gajewska, E. Temperature Distribution of Selected Body Surfaces in Scoliosis Based on Static Infrared Thermography. *Int. J. Environ. Res. Public Health* **2020**, *17*, 8913. [CrossRef]
16. Chojnowski, M. Infrared thermal imaging in connective tissue diseases. *Reumatologia* **2017**, *55*, 38–43. [CrossRef]
17. Webography W1. Available online: https://manualzz.com/doc/38468877/flir-b200---flir-systems (accessed on 30 November 2021).
18. Jianu, M. *Pediatric Scoliosis*; Pro Editură şi Tipografie: Bucharest, Romania, 2010; ISBN 978-973-145-245-6.
19. Weiss, H.R. Imbalance of electromyographic activity and physical rehabilitation of patients with idiopathic scoliosis. *Eur. Spine J.* **1993**, *1*, 240–243. [CrossRef]
20. Weiss, H.R. The method of Katharina Schroth-history, principles and current development. *Scoliosis* **2011**, *6*, 17. [CrossRef]
21. Negrini, S.; Fusco, C.; Minozzi, S.; Atanasio, S.; Zaina, F.; Romano, M. Exercises reduce the progression rate of adolescent idiopathic scoliosis: Results of a comprehensive systematic review of the literature. *Disabil. Rehabil.* **2008**, *30*, 772–785. [CrossRef]
22. Romano, M.; Negrini, A.; Parzini, S.; Tavernaro, M.; Zaina, F.; Donzelli, S.; Negrini, S. SEAS (Scientific Exercises Approach to Scoliosis): A modern and effective evidence based approach to physiotherapic specific scoliosis exercises. *Scoliosis* **2015**, *10*, 3. [CrossRef]
23. Negrini, S.; Donzelli, S.; Negrini, A.; Parzini, S.; Romano, M.; Zaina, F. Specific exercises reduce the need for bracing in adolescents with idiopathic scoliosis: A practical clinical trial. *Ann. Phys. Rehabil. Med.* **2019**, *62*, 69–76. [CrossRef] [PubMed]
24. Zetterberg, C.; Björk, R.; Örtengren, R.; Andersson, G.B. Electromyography of the paravertebral muscles in idiopathic scoliosis: Measurements of amplitude and spectral changes under load. *Acta Orthop. Scand.* **1984**, *55*, 304–309. [CrossRef] [PubMed]
25. Reuber, M.; Schultz, A.; McNeill, T.; Spencer, D. Trunk muscle myoelectric activities in idiopathic scoliosis. *Spine* **1983**, *8*, 447–456. [CrossRef]
26. Farahpour, N.; Ghasemi, S.; Allard, P.; Saba, M.S. Electromyographic responses of erector spinae and lower limb's muscles to dynamic postural perturbations in patients with adolescent idiopathic scoliosis. *J. Electromyogr. Kinesiol.* **2014**, *24*, 645–651. [CrossRef] [PubMed]
27. Schneider, E.G.; Niethard, F.U.; Schiele, H. Evoked potentials in children with adolescent idiopathic scoliosis. In Proceedings of the ESDS Meeting, Amsterdam, The Netherlands, 17–22 September 1989; pp. 17–22.
28. Zetterberg, C.; Aniansson, A.M.; Grimby, G. Morphology of the paravertebral muscles in adolescent idiopathic scoliosis. *Spine* **1983**, *8*, 457–462. [CrossRef] [PubMed]
29. Paz, A.C.; Brandao, I.; Silveira, E.B.; Gomes, C.R. Morphological and Morphometric Analysis of Paraspinal and Intercostal Musculature on Adolescent Idiopathic Scoliosis. *J. Spine* **2015**, *4*, 1000206.
30. Shahidi, B.; Yoo, A.; Farnsworth, C.; Newton, P.O.; Ward, S.R. Paraspinal muscle morphology and composition in adolescent idiopathic scoliosis: A histological analysis. *JOR Spine* **2021**, *4*, e1169. [CrossRef]