Technical Device for Prevention of Spinal Column Disorders. Pilot EMG Study for Estimation of Back Muscle Activity

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Abstract: *One possible cause of abnormal spinal column curvatures in adolescents is standing in "bad posture" for a long time. If this bad habit can be corrected on time, by creating a dynamic stereotype for correct body position maintenance, further health problems can be avoided. To present a technical device for prevention of scoliotic deformations signaling when the angles of inclination forward or sideward are bigger than preliminary set ones. To elaborate an experimental protocol based on analysis of EMG activity (EMGs) of spine muscles for verification of its effect. Study design: Devising of the device and of software for EMGs processing. Pilot experiments were conducted recording EMGs of eight spinal muscles for estimation of the device efficiency. Different mathematical procedures were proposed and programmed for data processing and illustration. Two device prototypes (with sound and vibration signal) are developed and experimentally used. EMG data from 20 motor tasks (half of them with carrying the device) are processed. The device can be used as a simple tool for biofeedback-type pupil teaching of dynamic stereotype for right posture maintenance. The developed software for EMGs processing can be used for tracing the effect of using the device.*

Keywords: *Prevention, Spine muscle, EMGs, Scoliosis, Technical device.*

Introduction

Many authors state that the cause of spinal column deformities in adolescents is idiopathic, which means unknown [29]. Some of the possible causes reported are genetic predisposition, vestibulobasilar or central nervous system injuries, growth pattern asymmetries [3]. It appears that most likely adolescent idiopathic scoliosis is a result of multiple factors including genetic and environmental influences [26]. Independently of the nature of originate of initial abnormal spine curvature it causes nonsymmetrical loading of vertebrae (postural imbalance) and nonsymmetrical muscle activities [18, 34]. Some of the spine muscles are shortened, with greater tension; some of them are elongated with decreased force capabilities. This imbalance influences reaction forces in-between the vertebrae and further damages their anatomical structure [26, 33]. This closed vicious circle could be broken by a proper natural or artificial stimulation of the weak muscles. Contradictory results, however, are reported concerning surface electrical stimulation [5]. Some authors conclude that this method is not an alternative of bracing. Reasons for not very successful treatment of weak spinal muscles with electrical stimulation can be: the proper places for electrodes; duration and type of electrical impulses; compulsory way of muscle training. Alternatives are prevention before the occurrence of irreversible changes and non-compulsory self training of the appropriate muscles.

Presently it is the common opinion that the physical activity of children and adolescents is insufficient. The prevalence of overweight and obesity among them is increasing; they spend much time at the computers or watching TV in very bad position [17, 35]. Alongside with other prevention measures like sport activities, swimming, appropriate school and home environment, etc., it is very advisable to teach children, to maintain right posture as long as possible. Creating dynamic stereotype, by means of a biofeedback device, will ensure unostentatious training of the necessary muscles and their symmetrical loading. Dworkin [13, 14] stressed on the disadvantages of conventional brace therapy and proposed one of the pioneer devices which signalize for incorrect spine position. This posture-training device is based on measurement of spine lengths, i.e. it controls scoliotic curve [38]. There are not many really used and available similar devices maybe because usually the designer intentions are to make them complex, aiming to gather big amount of information, even stored on computer for further processing [10, 25, 39]. The main peculiarity of such technical devices for creating good dynamical stereotype is that they are of biofeedback type [21]. Their basic elements are switches (sensors) which measure undesired deviation of the spine angles (or lengths) from normal ones and signalizing elements, warning by light, sound, melody, vibration, etc., for bad body posture. The commercially available "SpiderMed" (Med Patent Ltd., Poland), can be used for posture correction only in the *sagital* plane, i.e. in cases of lordosis and kyphosis. Its use in the presence of scoliotic deformations is *contra-indicated*. Spine Tuner®Belt and Sensor biofeedback training device (http://www.supports4u.com/back/posture/kyphosis.htm) also helps to correct habitually poor posture. It is recommended only for people with thoracic *kyphosis*, head-forward, and rounded-shoulder posture. The device "Posture Belt" (http://www.exercise-ball-exercises.com/exercises-for-posture.html) uses coil springs for detecting bad position, while more modern technologies use microfilaments in the back and shoulder area of a shirt. "Virtual Corset" is an inclinometer, alarming when a preset limit of a body angle is reached (http://www.microstrain.com/virtualcorset.aspx). Other, more traditional approaches for correcting body posture also exist, based on using belts and corsets [37]. They have different disadvantages: steaming, additional stretching of the muscles, muscle atrophy, etc.

One of the suitable and commonly used noninvasive methods for estimation of the spine muscle activity is registration and processing of electromyographic signals (EMGs). Clinical electromyography is often used for pre-operative and postoperative assessment of neuromuscular activation and muscle coordination, for investigation of reasons for back pain, for diagnosis of different muscle dysfunctions, even in scoliosis deformations [2, 15, 16, 27, 41]. The problems with direct estimation of muscle forces from EMGs as well as for intra-individual comparison are well known [23, 32]. Moreover, one extra problem exists for some spinal muscles – the interference of the ECGs (electro-cardiographic-signals) [11, 12, 40]. Independently of these problems, many authors state that suitable processed surface EMGs of spine muscles can be used as preoperative noninvasive tool or as a tool for estimation of usefulness of different ways of treatment of scoliotic patients [4-8, 28].

The aims of the present study are: to present one simple feedback type technical device for prevention of spinal column disorders (scoliosis); to elaborate a protocol based on analysis of EMG activity of spine muscles for verification of the effect of the device; to test different techniques for EMGs processing and graphical presentation for estimation of working capabilities of the spine muscles which can be suitable for diagnostic purposes.

Methods

The technical device

The device is of "feed-back" type and it is aimed at *prevention* of spinal curvatures and creation of a dynamic stereotype for right posture maintenance (Fig. 1). It signalizes with sound or with vibration signal when the spine is over inclined forward or sideward. The developed custom-made prototype is supplied with three roll-ball tilt sensors from pendulum type. It is with small sizes and weight of 50 g, inexpensive and simple to use. The sensors switch on when some of the angles of inclination forward or sideward is bigger than a preliminary set one. These angles can be individually adjusted by fine tuning of the slope of the sensors. A time delay of 5 s for start of signaling is provided so that normal usual movements to be performed without disturbance. The device is fixed on the back by elastic belts with adjustable lengths (Fig. 1). Two batteries (AAA, 1.5 V) are mounted in the plastic box where a circuit board is placed. The device can be placed inconspicuously under the clothes.

Fig. 1 Prototype of the technical device for prevention from spinal curvatures. Sound or vibration signal warms when trunk inclination forward or sideward is bigger than preliminary set angles by means of the position of build inside the plastic box 3 roll-ball tilt sensors from pendulum type.

The experimental procedure

In this study, only data from a pilot experiment are presented aiming to develop appropriate protocol and procedure (including appropriate processing and visualization of EMG data) for estimation of the usefulness of the device, monitoring and long term follow up. The volunteer was 12-year-old girl with thoracolumbar scoliosis I-II degree, which uses the technical device with vibration signal. She and her parents gave informed written consent (including publication of photographs) prior to testing. All procedures are not in conflict with the Ethical Principles for Medical Research Involving Human Subjects as stated in the Declaration of Helsinki. The research has been approved by the institutional ethics committee. All investigations were followed the ethical and humane principles of research. Medical check up was performed and a questionnaire was filled. The girl and their parents were informed about the purposes of using the device and of the experiments. The sensors (i.e. the angle limits after which the warning signal is switched on) were adjusted by a physical therapist and the girl was taught to use the device. The experiments were performed after several minutes training.

EMGs from 8 spine muscles (Fig. 2) during different motor tasks were stored and processed. The EMGs were recorded by means of Telemyo 2400T G2 8-channel electromyography and kinematics measuring telemetric system (Noraxon USA, Inc.) using surface circle electrodes “Skintact-premier” F-301 with 9 mm diameter (Fig. 2a). The reference electrode for the whole system was placed at the upper left part of the m. trapezius. Bipolar EMGs were obtained by means of pair of electrodes placed at 3 cm center to center distance on the cleaned with alcohol and dried skin surface of the subject. The electrode locations were symmetrical on the both sides of the upper and lower part of m. trapezius, on m. latissimus dorsi and on the thoracolumbar fascia overlapping the lumbar part of m. erector spinae.

The following abbreviations for the muscles are used in Fig. 2b: (1) TUL – m.trapezius upper left; (2) TUR – m.trapezius upper right; (3) TLL – m.trapezius lower left; (4) TLR – m.trapezius lower right; (5) LDL – m.latisimus dorsi left; (6) LDR – m.latisimus dorsi right; (7) ESLL – m.erector spinae lumbar left; (8) ESLR – m.erector spinae lumbar right.

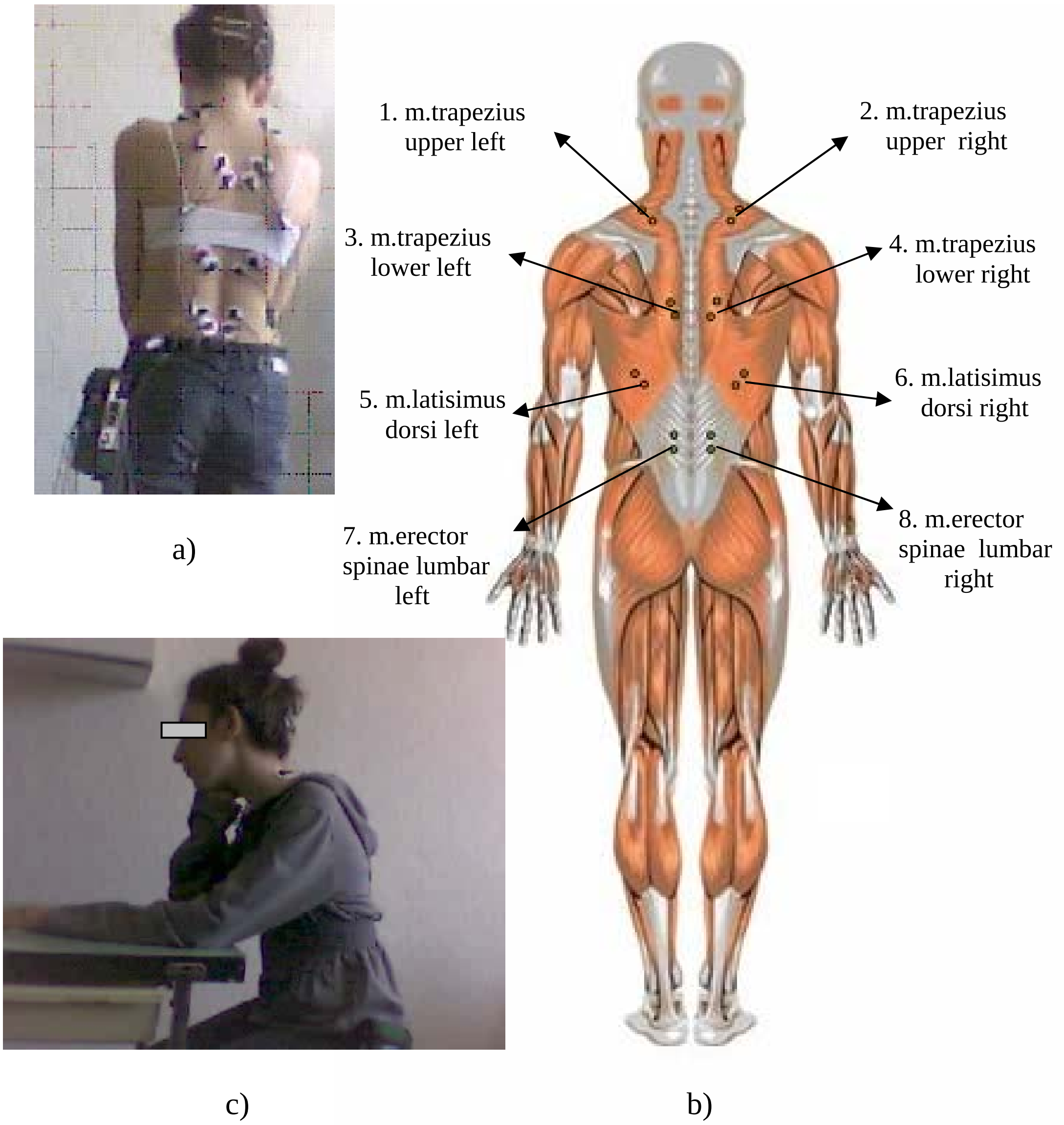


Fig. 2 (a) position of the electrodes on the subject; (b) the eight muscle parts beneath them; (c) body position during the 9-th motor task – Right hand support (see Table 1).

The frequency of the EMG recording was 1500 Hz and the maximal recording time was set at 60 s. Gains for each channel throughout the experimental series were constants. The data were stored on-line on a hard disc with MyoResearch XP data and video acquisition system (version 1.07.05) and processed further off-line. A PC camera monitored and stored the behavior of the subject during the experimental session. 20 motor tasks with duration of 1 minute were performed, 10 of them were without the device and next 10 were with the device. The experimental series are described in Table 1. When the device is used, it is in position "**test**", i.e. the time delay for signalling is zero. There is also a position "**on**" for which the time delay is 5 s.

Table 1. Descriptions of the experimental series

№	**Acronym**	**Motor task**	**Device**
1	Upright normal	upright normal posture with hanging arms	-
2	Upright corrected	upright corrected posture by thrusting forward chest and head	-
3	Sitting normal	sitting on a chair (the chair is with adjusted height) with bended chest and knees at about 90º with arms hanging down	-
4	Sitting corrected	sitting on the chair in corrected posture by thrusting forward chest and head, with flexed chest and knees at about 90º and with arms hanging down	-
5	Right bending	from position 3 several times maximal bending to the right and return;	-
6	Left bending	from position 3, several times maximal bending to the left and return	-
7	Forward bending	from position 3 several times maximal bending forward and return	-
8	Two hands support	sitting on the chair with supporting head on two hands on a table	-
9	Right hand support	sitting on the chair with supporting head on the right hand on the table	-
10	Left hand support	sitting on the chair with supporting head on the left hand on the table	-
11	Upright normal + device	upright normal posture with hanging arms	+
12	Upright corrected + device	upright corrected posture by thrusting forward chest and head	+
13	Sitting normal + device	sitting on a chair (the chair is with adjusted height) with bended chest and knees at about 90º with arms hanging down	+
14	Sitting corrected + device	sitting on the chair in corrected posture by thrusting forward chest and head, with flexed chest and knees at about 90º and with arms hanging down	+
15	Right bending + device	from position 13 several times maximal bending to the right and return	+
16	Left bending + device	from position 13, several times maximal bending to the left and return	+
17	Forward bending + device	from position 13 several times maximal bending forward and return	+
18	Two hands support + device	sitting on the chair with supporting head on two hands on a table	+
19	Right hand support + device	sitting on the chair with supporting head on the right hand on the table	+
20	Left hand support + device	sitting on the chair with supporting head on the left hand on the table	+

The duration of each motor task is one minute. There are breaks of 2 minutes in-between the tasks. After the first 10 tasks, the technical device was placed and fixed without changing the position of the electrodes. The same 10 tasks as the first ten ones were then performed. The tasks number 1, 2, 3, 4, 8, 9, 10, 11, 12, 13, 14, 18, 19 and 20 are near without movement (static tasks). For dynamic tasks the difference is that for the movements without (–) device (tasks number 5, 6 and 7) the rhythm is given by an instructor and for the movements with (+) device (tasks number 15, 16 and 17) – from the vibration signal of the technical devices when the angles of bending exceed the preset by position of the sensors values.

Processing of the EMG signals

The stored EMGs in text format were processed by custom made program written in MATLAB in accordance with procedure recommended in the literature [22]. First two digital high-pass Butterworth filters were applied for removing cardiac artifacts [9, 19, 30] (Fig. 3a). The first one is standard MATLAB function (Butterworth filter, order 4, cutoff frequency of 30 Hz). The second one is specially designed 4 order high-pass filter with cut-off frequency of 60 Hz which is applied only in the record segments where big peaks from QRS complex are still observed [20]. After that, rectification and low-pass filtration (Butterworth filter, order 2, cutoff 60 Hz) was performed (Fig. 3b). Then the EMGs were averaged for each 100 ms (Fig. 3c and 3d).

The next step is processing and visualization of the data in order to facilitate the comparison between individual motor tasks and between different muscles. To achieve this, normalization was done with respect to the assumed as reference first experiment (*Upright normal*). A 30s time interval within this 1 minute record was visually chosen (Fig. 3c). An average value for each EMG channel was found, i.e. coefficients $k_i = (\sum EMG_i(j))/Num$ were calculated, where j is the number of the sample, i = 1, 2, … , 8 is the number of the channel and *Num* is the number of data (samples are taken only in the chosen 30 s interval). Then all experimental data are normalized dividing the EMGs to the respective coefficient of the corresponding channel. After normalization, for all remaining static tasks, i.e. for the experiments 2, 3, 4, 8, 9, 10, 11, 12, 13, 14, 18, 19 and 20, a 30 s time interval for each experiment was visually chosen for further processing. These parts of the records were chosen to be with fewer artifacts. For each dynamic task, i.e. for the experiments 5, 6, 7, 15, 16 and 17, the best 5 successive trials were visually chosen (Fig. 3d) based on the start and the end of the activity of the muscle erector spinae.

Results

Comparing the activity of all 8 muscles during the static experiments for chosen 30 s intervals (not shown by figures) several main conclusions can be made. Asking the subject to correct the posture, the activity of the upper parts of m.trapezius increases, while the activity of the m.erector spinae and m.latissimus dorsi slightly decreases. In sitting position the last two muscles are more active than in erect posture. The effect of wearing the technical device is more visible for all parts of m.trapezius – their activity increase probably because of a psycho effect, since the weight of the device is very small. This increase is most evident during experiments 18, 19 and 20 because the subject is expecting the appearance of the auditory signal if, supporting the head on the hands, this position can slightly violate some of the critical values of the angles preset by the three sensors. Lower activity of all muscles was observed for experiment number 8 (*Two hands support*).

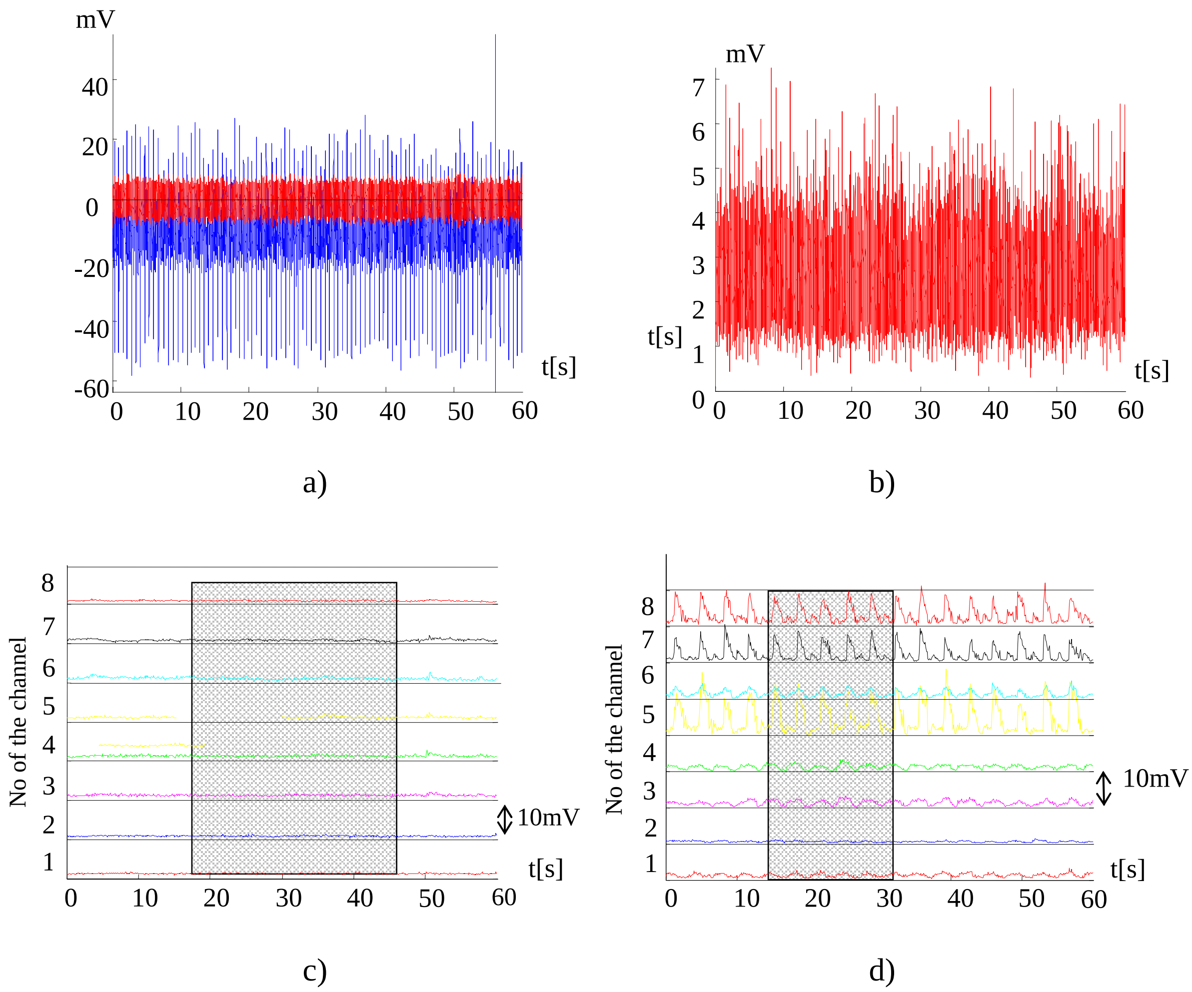
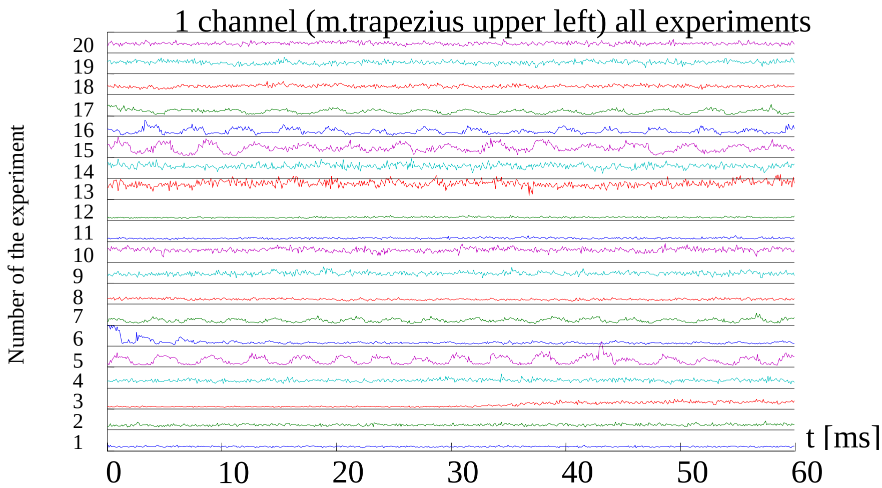


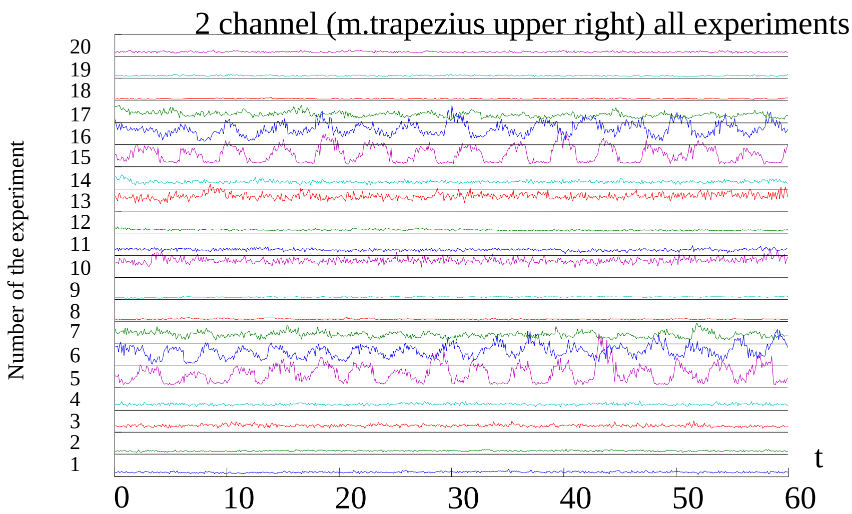
Fig. 3 Successive steps for processing of EMG data: (a) results from high-pass filtration – blue is the original data from channel 1 (m.trapezius, upper left part) during the first experiment (without device, right normal posture) and red is the filtered signal; (b) the same data as in Fig. 3a after rectification and low-pass filtration; (c) EMG signals from the eight channels (see Fig. 2b for the correspondence between channels and the muscles), for the same experiment, after the first two steps of processing and then integration of the signals each 100 ms. The most noiseless 30 s interval is visually chosen (see the filled rectangle) for further purposes; (d) EMG signals from the eight channels for the experiment 7 (without device, sitting on chair, forward bending) after filtration, rectification and integration. 5 successive forward bendings are visually chosen for further processing (see the filled rectangle). The beginning and the end of the movement is considered in the local minima of the EMGs of the muscle erector spinae.

Comparing the chosen 5 bendings, the following conclusions can be made: during right bending the muscles TLR and ESLR do not show good rhythmic activity, during left bending the muscles TUL and TLL do not participate visibly enough. During forward bending the muscles TUL, TUR, TLL and TLR act synchronously with simultaneous peaks. The same refers to the muscles LDL, LDR, ESLL and ESLR and their simultaneous peaks are shifted in time in comparison to the previous group. The effect of wearing the device is a more rhythmic and distinct motion performance.

To investigate presence of an asymmetry, the activity of left and right parts of the muscles was compared for all experiments (Fig. 4). It is visible that the muscle TUR is more active than TUL during experiments 5, 6, 15 and 16. During experiments 7 and 17, however, the activity of the muscle TUR is not so rhythmic and distinct as this one of TUL. Nevertheless, no essential asymmetry was observed for these two muscles. Similar conclusions are made for other muscles. For 5 and 15 experiments the muscle TLL is more active than the muscle TLR, the opposite is observed for experiments 6, 7, 16 and 17. For dynamic experiments 5, 7, 15 and 17 the left part of m.latisimus dorsi is more active than the right part. Left part of m.erector spinae is more active for experiments 6, 15 and 16.



a)



b)

Fig. 4 Comparison of the activity of the left and the right upper trapezius for all 20 experiments. The EMG signals are filtered, rectified, averaged and normalized as follows: for each channel a mean value is obtained for the first experiment for the time period from 20 to 50 ms (see Fig. 3c). Then data for each experiment of each channel is divided to respective channel' mean value. The distance between each two black horizontal lines is 5.

This visual inspection of the processed EMGs is subjective and shows more evidences for dynamic experiments. That is why other data representations are proposed. For static tasks the sum of the activity of all muscles during the chosen 30 s intervals logically divided to a factor of 30 are calculated and illustrated by bars (Fig. 5).

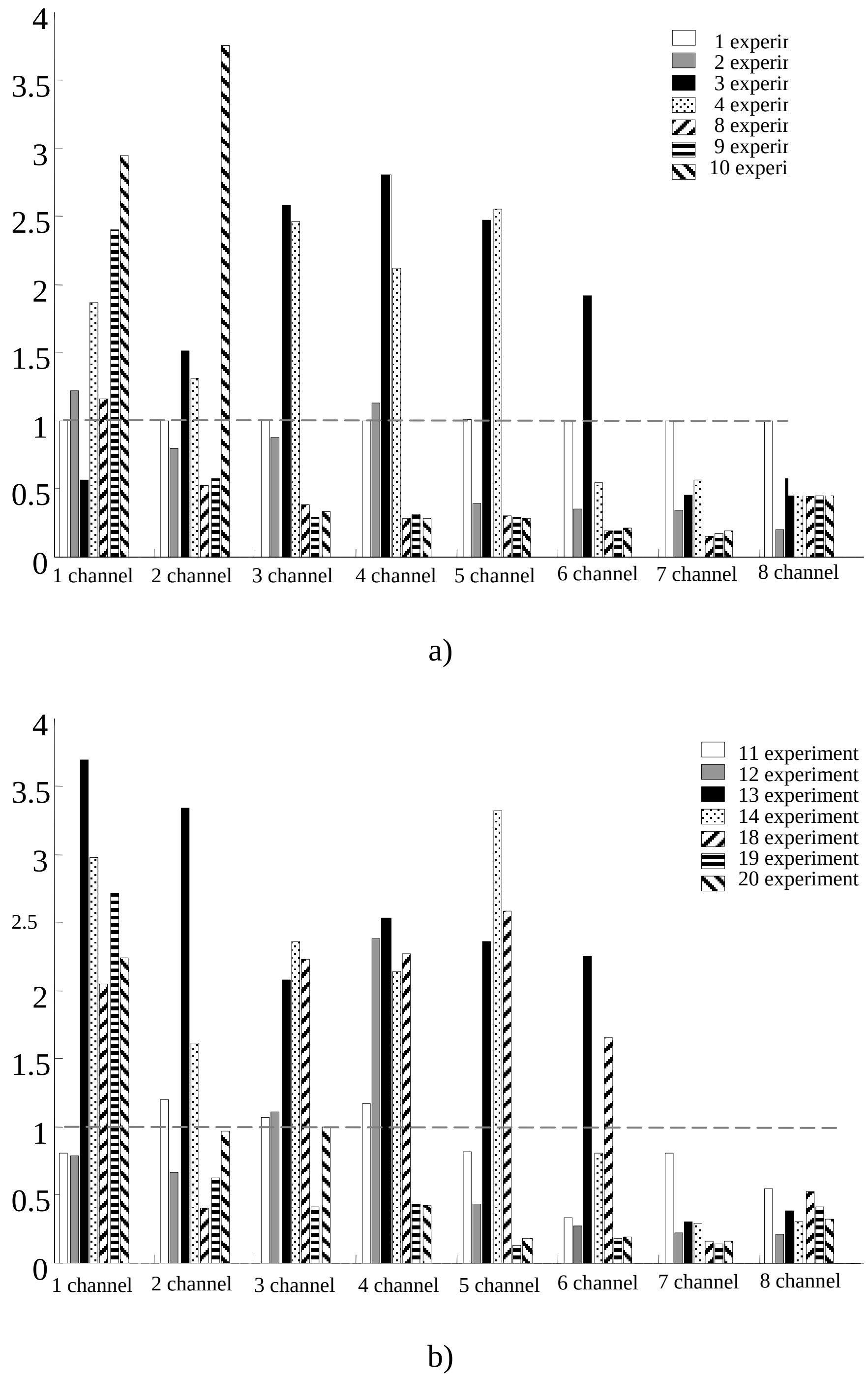


Fig. 5 Overall mean activity of all muscles (respective channels) during static tasks (a) without the device and (b) with the device. The dashed grey horizontal line is the mean activity of the muscles during the first experiment, which is taken as unit during the normalization.

Comparing Fig. 5a to Fig. 5b the effect of using the device is better visible and evident. Comparing bars for TUL versus TUR, TLL versus TLR, LDL versus LDR, ESLL versus ESLR, an asymmetry between left and right parts of the respective muscle can be perceived. The data for the first experiment are taken as units (Fig. 5a white bars) and all other data are expressed by these units. It is visible, for example, that the activity of m.trapezius upper left and right parts increases during experiments 13 and 14; muscles TLL, TLR, LDL and LDR show greater activity when the device is used by the subject during experiment 18; the muscles ESLL and ESLR have comparatively lower activity if the subject wears the device. The same data are presented in Fig. 6 in a different, clearer for non-specialists way. The asymmetry in m.latisimus dorsi is visible during experiments 4 and 14, the requirement to correct the posture results in chest unloading (experiments 2 and 12 – see m.erector spinae).

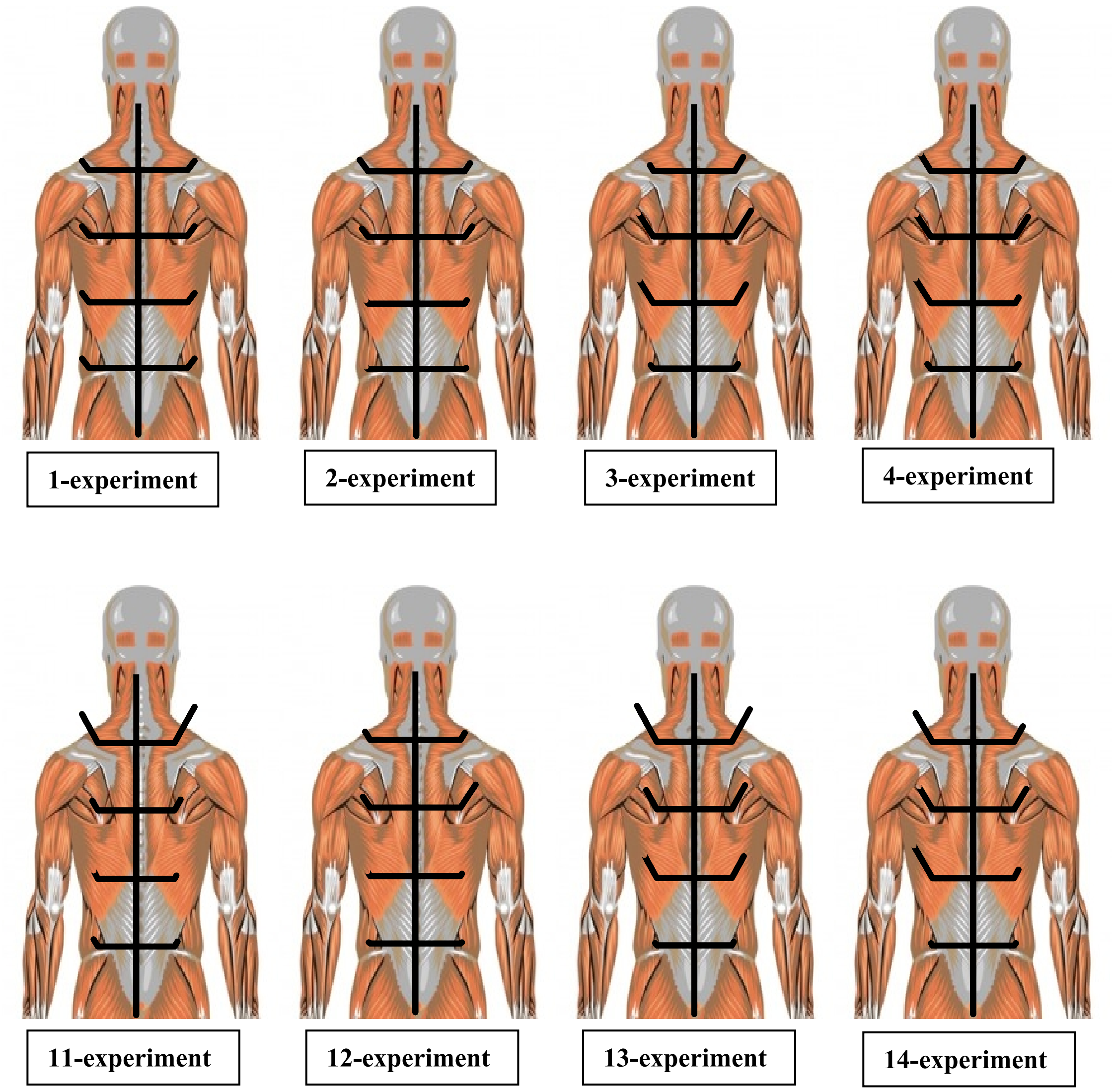


Fig. 6 Graphical form of representation of the results of some experiments.
The magnitudes of the inclined under 45° segments are proportional to the mean value of the normalized EMG activities of the respective muscles (see Fig. 2b).
These activities for the first experiment are taken as units; hence the magnitudes of the segments on the first figure are unities.

Similar presentation of the data for the dynamic tasks is shown in Fig. 7. The difference here is that the sum of the activity of each channel is divided by the duration (in seconds) of the chosen five successive bendings (Fig. 3d), which durations are different for experiments 5, 6, 7, 15, 16 and 17. It can be seen that the TUR is always more active then TUL during these motions. During forward bending, left parts of mm. lower trapezius, latissimus dorsi and erector spinae are more active.

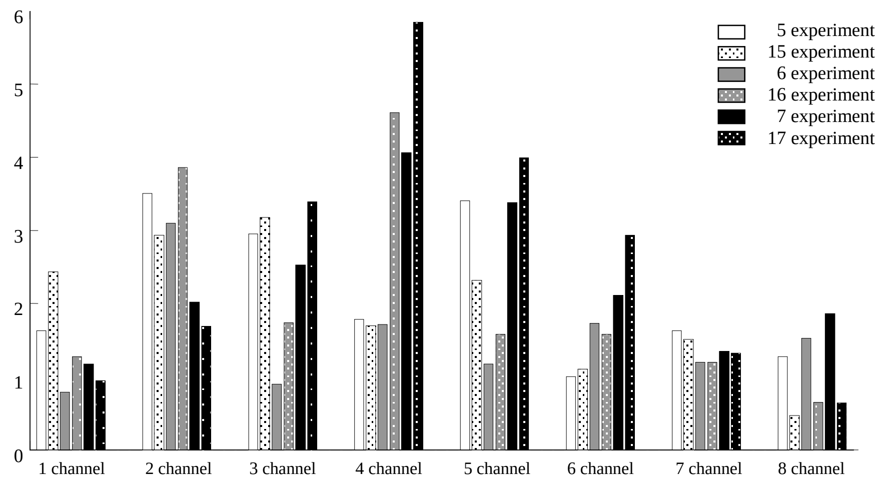


Fig. 7 Activity of all muscles (channels) for 5 times successive bendings to the right (5 and 15 experiments), to the left (6 and 16 experiments) and forward (7 and 17 experiments). The data are normalized and divided to the time duration of the chosen 5 trials (see Fig. 3d).

Discussion and conclusions

We share the hypothesis that one of the causes of scoliotic spine deformation is biomechanical, i.e. long time maintenance of bad posture [31, 36]. Therefore, prevention is possible. This paper is a pilot investigation concerning the use of a prototype technical device of feedback type for creating dynamic stereotype for right posture maintenance. Its main purpose is prevention and it can be used for stopping the progression of scoliosis in its initial stage. As a test the device was given for using of 7 volunteers (8-9 years old girls, one without spine problems but with bad posture habits and the others with different small degrees of scoliosis). The first verbal reports from children are positive. They share the opinion that even when the device is not in use they instinctively endeavor to maintain right posture. The disadvantage reported is the difficult correction of the angle limits if this is necessary. Sometimes the signal does not stop immediately after posture correction since the sensors are ball and roll type and they are sensitive to vibration.

The performed pilot experiments meant to establish an experimental procedure and way of processing and visualization of the EMGs in order to track out the results of device wearing and possibly to help in diagnosis and proper rehabilitation of scoliosis. The way of presenting the data shown in Figs. 5 and 6 can help specialists in physical therapy to obtain a more quantitative and comprehensive conception for the spine curvatures. The main discussion point in the proposed scheme of data processing is the way of normalization. The chosen as reference first experiment may contain itself abnormal muscle functions and this can compromises the next conclusions. Regardless of the way of normalization, since the data of each channel are divided by the same coefficient, comparison of activity of a muscle during different tasks can be made trustworthy. Only the comparison between different muscles can be affected by the normalization procedure. In many scientific investigations normalization of the EMGs is performed according to the maximal isometric force of the muscle [1, 24]. This approach is suitable if the aim is to calculate individual muscle *forces*. Our purpose is to compare the *activity* of the back muscles (not forces) during different motor tasks. Moreover, it is not evident which exercise will ensure maximal isometric forces of the investigated muscles. If some of the muscles are influenced by a deformation and become weak, its maximal force will be less than normal and this will also influence the normalization coefficient. The reference posture (*Upright normal*), can be used, with some speculation perhaps, for initial estimation of the spine muscle activity – see Fig. 8. Since all channels have the same settings, the electrodes are immovable and symmetrically placed, the average values of the signal of each channel, i.e. the coefficients k_i, can be used for a global initial estimation of the muscles capability. If the right part of a spine muscle is more active, i.e. the respective coefficient is bigger; this muscle is more contractile and pulls the vertebra to the right (muscles 6 and 8 in Fig. 8). Otherwise, this pulling direction will be to the left (muscles 1 and 3). If the activity of the left and right part of a muscle is approximate equal there will be no pathological asymmetry in spine loading. The so-obtained dashed line in Fig. 8 could be used for initial estimation of a possibly existing spine abnormal curvature.

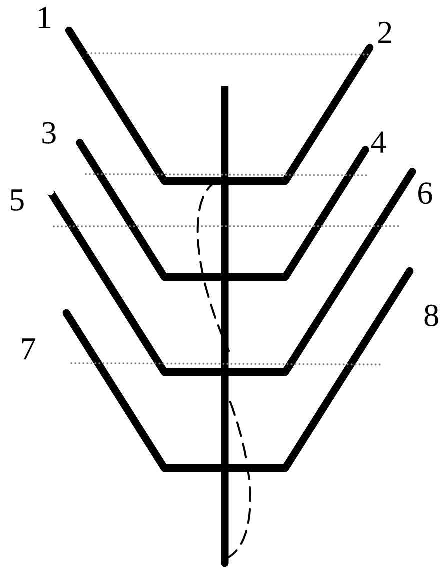


Fig. 8 Graphical presentation of the mean values of the EMG signals of the 8 muscles for the first experiments. The inclined segments are proportional to the respective calculated coefficients: k_1 = 2.2342, k_2 = 1.9854, k_3 = 1.9854, k_4 = 1.8777, k_5 = 2.6722, k_6 = 2.9809, k_7 = 2.2974 and k_8 = 2.9201. The thin dashed grey horizontal lines mark the difference in the activity of the left and the right part of the respective muscle. The broken S-type curve shows a hypothetical twist of the spinal column (different from the normal vertical position) due to muscle asymmetrical activities. The twist is on the side of the bigger muscle activity.

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