Enhancement of muscle’s activity by woven compression bandages

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ABSTRACT – REZUMAT

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Electromyography (EMG) test, the recording of electrical activity in muscle, is a main tool usually used to evaluate the muscle’s activation. This study aims to discuss and analyse the effect of woven compression bandage (WCB) on muscles’ activation. Flexor Carpi (FC), Soleus (SO), and Medial Gastrocnemius (MG) muscles were selected to represent the wrist, ankle, and mid-calf muscles respectively, which were then evaluated by EMG electrical voltage test with and without wearing WCB. The standardized activities used to test the FC muscle were flexion-extension and squeezing a soft roll. While the protocol activities for MG and SO muscles were flexion-extension and walking actions. Wearing WCB significantly decreased the muscle’s activation and was associated with higher median frequency for both SO and MG muscles during the tested activities. The EMG signals were analysed and filtered using MegaWin and MATLAB software. Root mean square (RMS) values confirmed that wearing WCB could improve the performance of FC, SO, and MG muscles and might reduce the muscle’s fatigue during the selected activities.

Keywords: *Electromyography test, woven compression bandages, muscle activation, MegaWin and MATLAB software*

Îmbunătățirea activității musculare prin bandaje de compresie țesute

Testul de electromiografie (EMG), înregistrarea activității electrice în mușchi, este un instrument principal utilizat pentru a evalua activarea mușchiului. Acest studiu își propune să abordeze și să analizeze efectul bandajului de compresie țesut (WCB) asupra activării mușchilor. S-au selectat mușchii Flexor Carpi (FC), Soleus (SO) și Medial Gastrocnemius (MG) pentru a reprezenta mușchii încheieturii, gleznei și, respectiv, cei de la mijlocul gambei, care au fost apoi evaluați prin testul de tensiune electrică EMG cu și fără purtarea WCB. Activitățile standard utilizate pentru a testa mușchiul FC au fost cele de flexie-extensie și compresia unui rulou. Activitățile din protocol pentru mușchii MG și SO au fost cele de flexie-extensie și mers. Purtarea WCB a scăzut semnificativ activarea mușchiului și a fost asociată cu o frecvență mediană mai mare atât pentru mușchii SO, cât și pentru mușchii MG, în timpul activităților testate. Semnalele EMG au fost analizate și filtrate utilizând programele MegaWin și MATLAB. Valorile mediei pătratice (RMS) au confirmat că purtarea WCB ar putea îmbunătăți performanța mușchilor FC, SO și MG și ar putea reduce oboseala mușchiului, în timpul activităților selectate.

Cuvinte-cheie*: test de electromiografie, bandaje de compresie țesute, activare musculară, programe MegaWin și MATLAB*

INTRODUCTION

Compression bandages

Compression bandage (CB) consists of elastic textile that exerts pressure on muscles of any part of the human body, especially hand and lower leg muscles [1–3]. It can be produced as knitted (tubular and socks) or woven compression bandages (CBs) [4, 5]. These medical elastic structures can improve the athletics’ performance and reduce sports injury, which exert compression and pressure on muscles to relieve muscle’s stiffness and fatigue during sports or other activities [6–8]. Most of CBs are practically applied as forms of overlapping multiple layers. It can be applied at 50% spiral overlap to overlay the leg with two layers bandaging technique, CBs applied using 66% overlap achieve three bandage layers while CBs applied with the figure of eight at 50% overlap can overlay the leg with four layers [9, 10]. Compression therapy limits the flow of diseased surface veins and increases the flow through deeper veins and reduces swelling. It can significantly improve the ulcer healing rates and decrease rates of recurrence. Researchers thought that it is either correcting or improving the venous hypertension, due to the improvement of venous pump and lymphatic drainage. It could also improve the blood flow velocity through deep and superficial veins [11, 12]. Eight healthy men were selected to perform 40 min treadmill running trials, one with compression garment (CG) and the others with normal garment (NG). The muscles’ activation were significantly smaller in CG than in NG condition for MG and semitendinosus (ST) at both initial and end stages during stance phase and for Rectus Femoris (RF) at both stages during swing phase. Participants wearing CG had lower muscle activation in MG, ST, and RF muscles, despite there are no additional benefits to the lactate clearance or perceived exertion rate [13].

Normal anatomy and physiology of lower extremity

The venous blood flow of lower extremity consists of 3 components: the superficial, communicating, and deep veins. The superficial venous system is connected to the deep venous system through smaller communicating or perforator veins. The deep veins are categorized as either intramuscular or intermuscular. These three venous systems are equipped with one-way bicuspid valves which open only toward the deep system, allowing blood to flow in a cephalad direction to prevent reflux. Blood is transferred through the leg toward the heart primarily by the pumping action of the leg muscles [14, 15].

Detection and analysis of muscles activation

EMG aims to measure the muscle's activation level and provides estimation for exercise intensity of selected muscles during activity. EMG signal can contribute to enhance the human body muscle's function [16]. It can be defined as the subject, which deals with the detection and evaluation of electrical signals resulting in skeletal muscles. These signals are known as the myoelectric signal which is produced from small electrical currents generated by the exchange of ions across the muscle's membranes and detected with the help of electrodes [17]. Some studies used EMG to evaluate the effect of compression garments (CGs) during sports and other activities. However there is a limited research explored that wearing CGs has positive influence on muscle's activation during running [3]. Most of research related to EMG test was performed on athletics or normal volunteers. Moreover some studies were using only knitted CGs or socks. There is no studies combined using the EMG test while wearing the woven compression bandages (WCBs) on real patients because every patient has clearly different case of bandage application and recovery time. So that the author applied the WCB on 6 healthy men to investigate an accurate comparison using the EMG test. Based on literature review it is essential to propose a research to analyse the effect of WCB on selected muscles of hand and lower leg and discuss the muscles' behaviour of FC, SO and MG muscles while wearing WCB using surface electrodes by e-Motion electromyography wireless tester.

EXPERIMENTAL

Materials

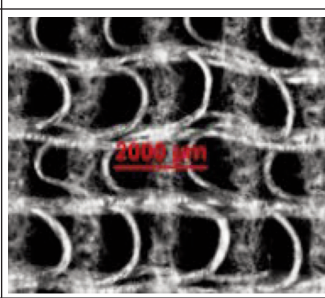
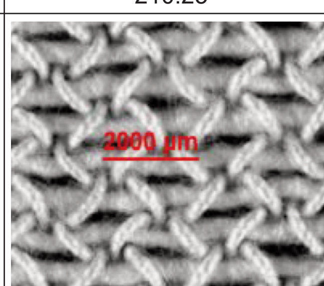
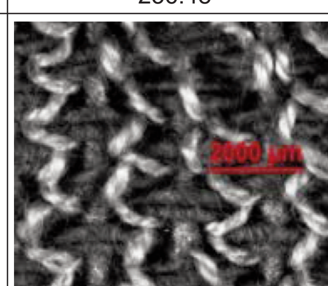
Three types of WCBs namely Viscose/Polyamide (VI-PA), bleached 100% Cotton, and Cotton/Polyamide/Polyurethane (CO-PA-PU) bandages were used for FC, SO and MG muscles EMG tests respectively. Fabric structures of the three WCBs were plain weave. Other parameters such as yarn count, density, and weight per unit area were depending on the final end-use required properties, as shown in table 1. Each structure had different technique to achieve the required stretch. WCBs were produced with optimum stretch using highly twisted warp yarns, or elastomeric filament (Elastane or Lycra) with Cotton or Viscose, or using two or more polymeric yarns having different thermal properties such as VI-PA by shrinkage and heat setting.

Methods

There are two methods of using EMG in measuring muscle activity, needle EMG uses a needle sensor that penetrates the skin and subcutaneous adipose tissue or surface EMG using skin-mounted electrodes. The advantage of needle EMG is that the test administrator does not have to consider the effects of cross-talk between muscles or the superficial fat layer between the muscle and skin which can cause signal impedance. However, this method is invasive to the participant and is not practical during isotonic muscle actions, making surface EMG the most common method of measuring muscle activity. The advantages

Table 1

EXPERIMENTAL WOVEN COMPRESSION BANDAGES' CHARACTERISTICS

Sample	VI-PA bandage	100% Cotton bandage	CO-PA-PU bandage
Warp density (ends/cm)	12	8	11
Weft density (picks/cm)	14	15	18
Warp count	Viscose,16.5 tex Open end (OE)/PA, 7.8 tex	Cotton, 20x2 tex Ply twist 1200 turns/m, ZZ/S, SS/Z	Cotton, 10x2 tex PA, 7.8 tex/PU, 42.5 tex
Weft count	Viscose, 16.5 tex	Cotton, 75 tex, OE	Cotton, 36.9 tex
Fabric weight (g/m^2)	83.34	210.25	236.48
SEM image			

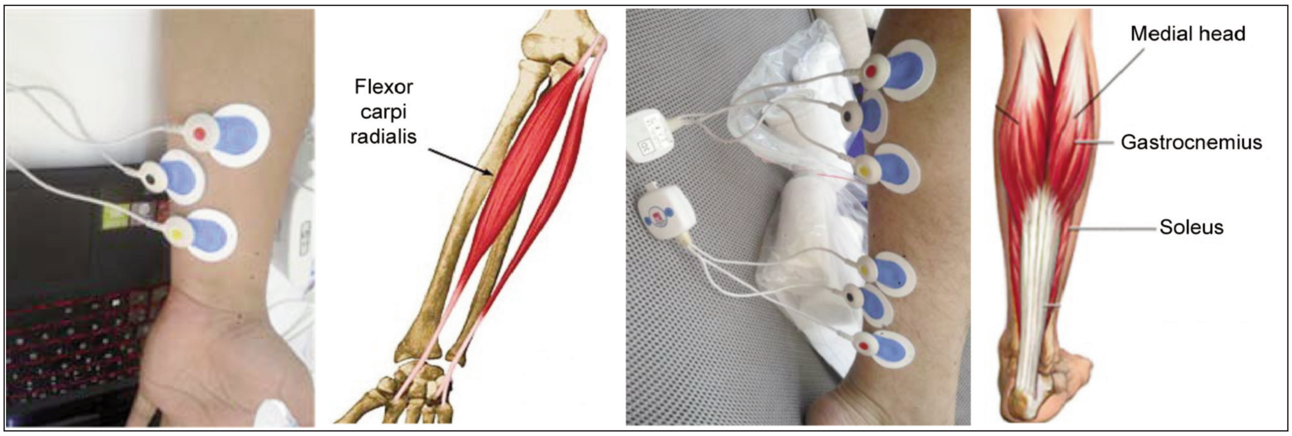


Fig. 1. Electromyography test for FC, SO and MG muscles [22, 23]

of surface EMG are that it is safe, easy, non-invasive, and has the ability to objectively quantify energy of muscle [18].

Viscose/Polyamide bandage was used to test the FC muscle's activation during flexion-extension and squeezing a soft roll action with and without using WCB (figure 1). VI-PA CB was adjusted and standardized to medium compression ranges 22±2 mmHg by 75% bandage extension and 50% overlap. CO-PA-PU and 100% Cotton bandages were used to test MG and SO muscles' voltage while walking and during flexion-extension actions. Both of the 100% cotton and CO-PA-PU bandages were worn on real leg to test and analyse the effect of WCB on bandage pressure using PicoPress at ankle and mid-calf positions during the previously mentioned activities. Bandage pressure of SO muscle was adjusted to 45 ± 3.4 mmHg, by 100% bandage extension and 66% overlap whereas MG muscle was 30 ± 1.9 mmHg, through 100% bandage extension and 50% overlap [1]. All compression and EMG tests were performed on 6 healthy men, age ranges 28–38 years, using e-Motion EMG system at different metronome beats 20, 30, and 40 beats/min (BPM). The average value of the minimum, maximum, and median values of the muscle voltage and RMS values for the 6 men were analysed and listed in tables 2–5. Surface electrodes were mounted on the selected muscles of human skin as shown in figure 1, three trials for each activity were carried out [19].

There are four basic filter types defined by De Luca (2003) including low-pass, high-pass, band-pass, and band-stop. Low-pass filters the frequencies higher than the selected amplitude, while high-pass filters all frequencies below the set amplitude. The band-pass filters all the frequencies below and above the set amplitudes, while band-stop filters all frequencies higher than the low amplitude and frequencies lower than the high set amplitude [20]. A band-pass filter however only allows a selected frequency range often between 25–500 Hz [21]. For evaluation of the muscles activity, RMS values were processed by exporting the filtered signals to MATLAB software using band-pass filtering between 20–500 Hz.

RESULTS AND DISCUSSION

Muscle voltage test for Flexor Carpi

The EMG raw signals of the FC muscle voltage with and without wearing the VI-PA compression bandage during the standardized action (flexion-extension) are illustrated in figure 2. For accurate comparison the

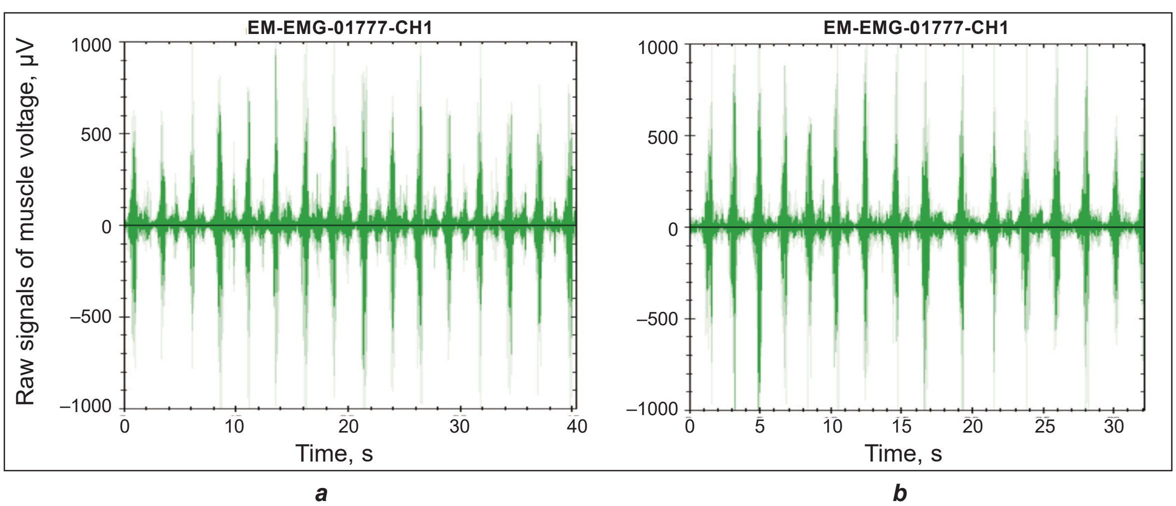


Fig. 2. FC muscle voltage with and without WCB, flexion-extension action, Raw signals:
a – with bandage; *b* – without bandage

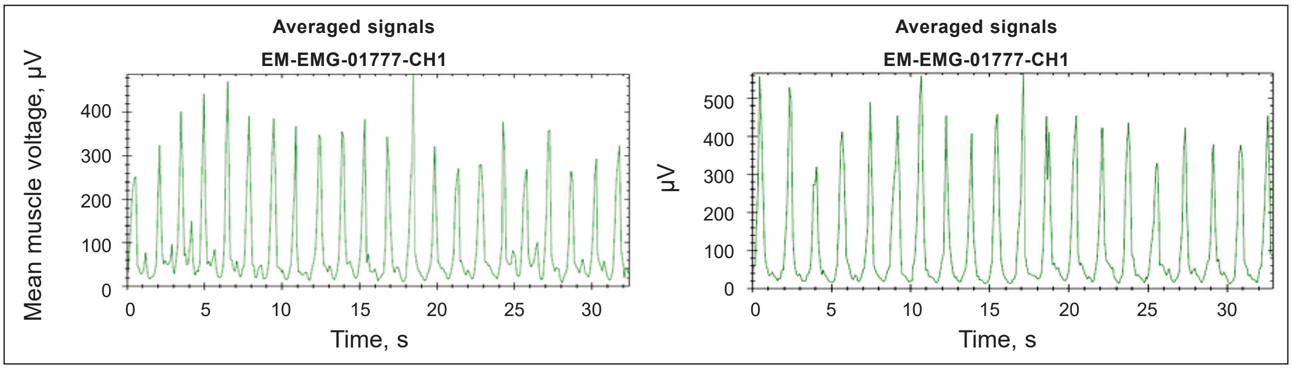


Fig. 3. Average FC muscle voltage with and without WCB, flexion-extension action, 40 BPM

average signals should be used. Figure 3 displays the average FC muscle voltage using the VI-PA CB during flexion-extension action at 40 BPM, average muscle voltage was 85.11 and 93.33 μV respectively, wearing WCB decreases muscle's activity by 8.81%, as illustrated in table 2.

Figure 4 displays the FC muscle's activation using the VI-PA WCB while squeezing a soft roll action, the average EMG voltages were 90.67 and 97.44 μV respectively, so that wearing WCB decreases muscle's activation by 6.96%, as listed in table 2. Obtained results in figures 3 and 4 and statistical

Table 2

EMG AVERAGE VOLTAGE FOR THE FC MUSCLE

Tested action	Metronome beats (BPM)		Mean voltage (μV)			Average 1 (μV)	S.D. (μV)
Flexion-extension action	With bandage	20	74	83	78	78.33	3.68
		30	85	80	87	84.00	2.94
		40	93	88	98	93.00	4.08
		Average (Average 1)				85.11	3.57
	Without bandage	20	81	85	77	81.00	3.27
		30	90	86	78	84.67	4.99
		40	115	106	122	114.33	6.55
		Average (Average 1)				93.33	4.93
Squeezing a soft roll action	With bandage	20	77	72	76	75.00	2.16
		30	81	85	78	81.33	2.87
		40	110	116	121	115.67	4.50
		Average (Average 1)				90.67	3.17
	Without bandage	20	76	79	72	75.67	2.87
		30	93	97	104	98.00	4.55
		40	125	119	112	118.67	5.31
		Average (Average 1)				97.44	4.24

Table 3

EMG MEAN VOLTAGE FOR LEG MUSCLES WEARING CO-PA-PU WCB

Activity	Case	Soleus Muscle		Medial Gastrocnemius	
		μV	S. D.	μV	S. D.
Flexion – extension	with bandage	25.00	2.94	22.33	2.49
	without	32.33	4.92	30.00	3.74
	Reduction (%)	22.68	40.18	25.56	33.33
While walking	with bandage	83.33	4.11	82.00	4.55
	without	126.00	6.98	86.00	5.35
	Reduction (%)	33.86	41.09	4.65	15.09

Table 4

EMG MEAN VOLTAGE FOR LEG MUSCLES WHILE WALKING USING 100% COTTON WCB					
Case	**Beats/min**	**Soleus Muscle**		**Medial Gastrocnemius**	
		µV	**S. D.**	**µV**	**S. D.**
With bandage	20	74.00	2.94	75.33	2.87
	30	88.00	3.74	76.00	4.32
	40	117.33	4.99	103.00	6.98
	Average	93.11	3.97	84.78	4.59
Without bandage	20	96.00	5.35	80.67	3.68
	30	111.33	5.44	94.00	4.55
	40	134.33	7.04	110.33	7.04
	Average	113.89	5.94	94.89	5.09
Reduction (%)		18.24	33.26	10.66	9.82

Table 5

ROOT MEAN SQUARES AND S. D. OF FC ACTIVATION							
Tested action	**Beats/min**		**RMS value**			**Average 1**	**S. D.**
Squeezing a soft roll action	With bandage	20	136.98	139.8	133.7	136.83	2.49
		30	161.78	155	165.9	160.89	4.49
		40	185.7	180.43	173.78	179.97	4.88
		Average (Average 1)				159.23	3.95
	Without bandage	20	135.8	132.1	128.8	132.23	2.86
		30	179.7	189.11	198.4	189.07	7.63
		40	210.9	200.4	189.7	200.33	8.65
		Average (Average 1)				173.88	6.38
Flexion-extension action	With bandage	20	123.68	127.86	131.57	127.70	3.22
		30	132.36	125.68	138.87	132.30	5.38
		40	164.72	155.97	173.74	164.81	7.25
		Average (Average 1)				141.61	5.29
	Without bandage	20	152.45	147.7	143.21	147.79	3.77
		30	164.15	155.44	146.87	155.49	7.05
		40	195.46	184.27	206.67	195.47	9.14
		Average (Average 1)				166.25	6.66

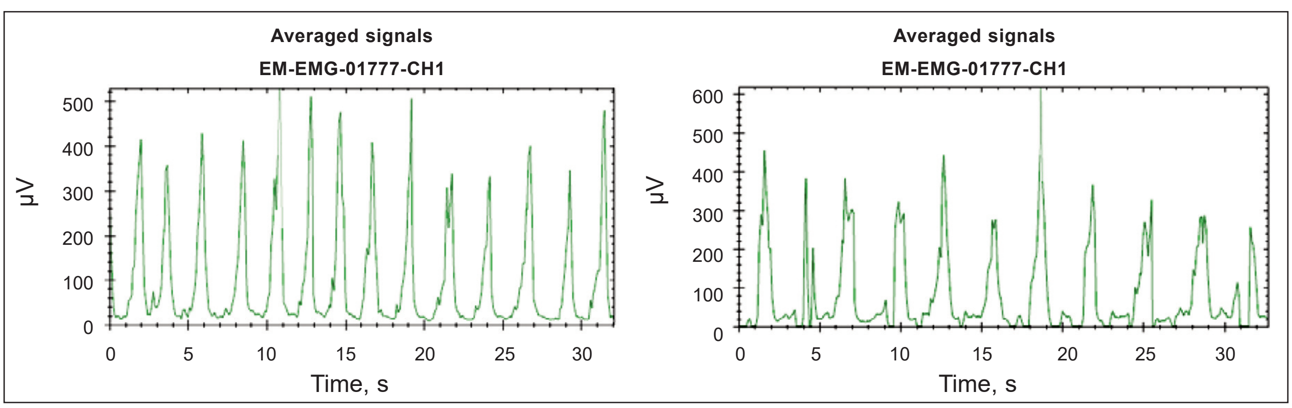


Fig. 4. Mean voltage of FC muscle with and without WCB, squeezing a soft roll action, 30 BPM

Table 6

SUMMARY OF ANALYSIS OF VARIANCE (ANOVA)			
Standardized action	**Dependent variable**	**Sig.* (with or without bandage)**	**Sig.* (Metronome beats)**
Squeezing a soft roll	Mean voltage	0.048	0.000
	RMS values	0.019	0.000
Flexion-extension	Mean voltage	0.045	0.000
	RMS values	0.000	0.000

Note: * Significance at confidence interval 95%.

analysis in table 6 conclude that wearing VI-PA WCB significantly enhances the FC muscle's performance at the protocol activities. It may be summarized as the frequency of flexion and extension actions are similar, hence the WCB causes a reduced muscle oscillation which might improve the muscle's efficiency and performance.

Muscle voltage test for Medial Gastrocnemius

Average EMG signals of the SO and MG muscles were measured using the pre-amplified bipolar surface electrodes [24]. Figures 5 and 6 show MG muscle's voltage with and without using CO-PA-PU bandage for flexion-extension action and wearing 100% Cotton bandage during walking action. As a result, wearing WCB achieves significant decreases in MG muscle's voltage during flexion-extension action by 25.56% and 4.65% when walking action, as listed in table 3. That reduction may be due to the increase in mean muscle's fascicle length and the decrease in mean muscle's thickness and average pennation angle [25]. Recent studies concluded that the muscle's force being exerted for limb's motion and stability may be wasted on muscle's flexion-extension, while CG might prevent muscle vibrations during sports activities which could enhance the athletic performance [16].

Muscle's voltage test for Soleus muscle

Figures 7 and 8 show SO muscle's average signals with and without using the CO-PA-PU and 100% Cotton WCBs during flexion-extension and walking standardized actions respectively at 20, 30, and 40 BPM. Using WCB decreases SO muscle's activation

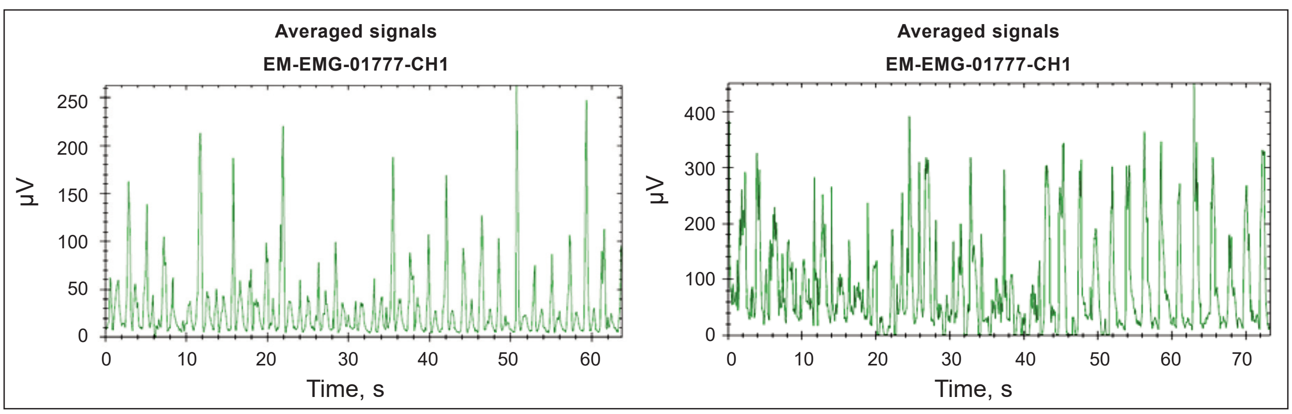


Fig. 5. Medial Gastrocnemius average signals, CO-PA-PU CB, flexion-extension, 30 BPM

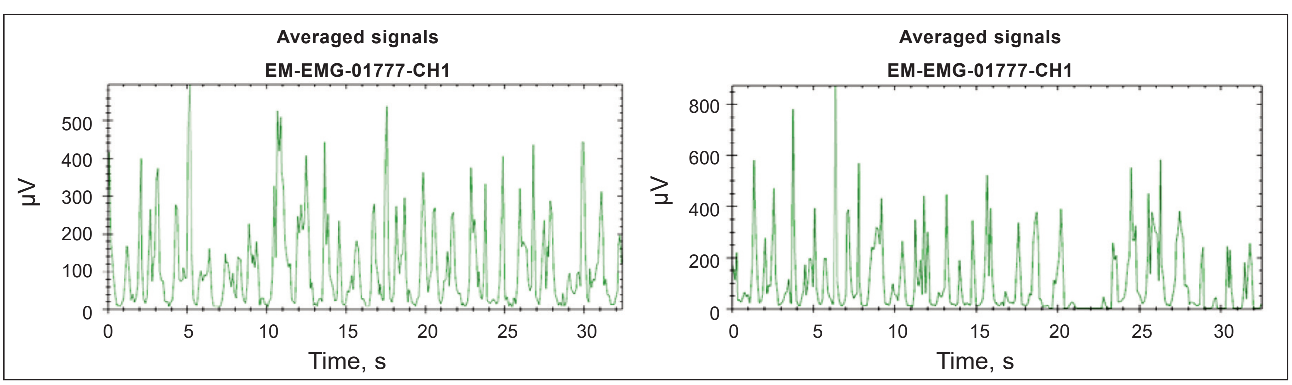


Fig. 6. Medial Gastrocnemius average signals, 100% Cotton CB, walking action, 40 BPM

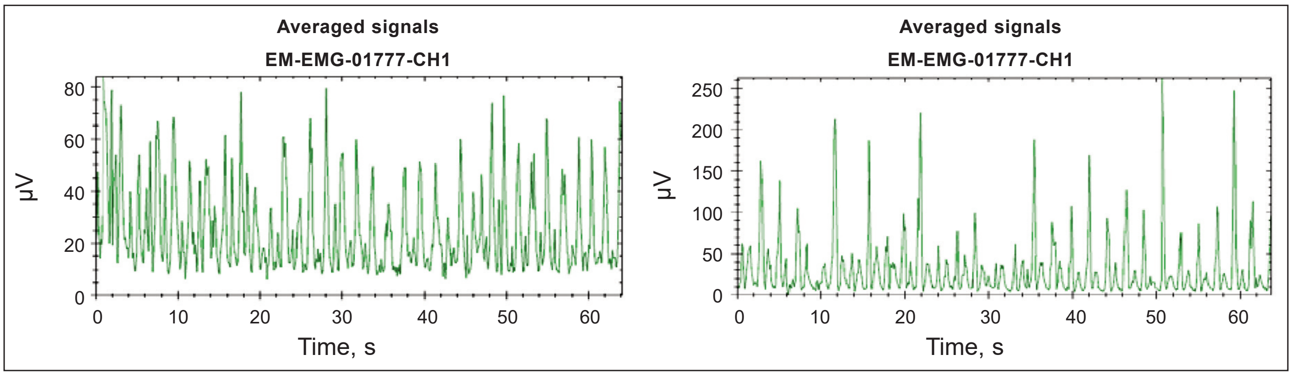


Fig. 7. Mean voltage of Soleus muscle, CO-PA-PU CB, flexion-extension action, 30 BPM

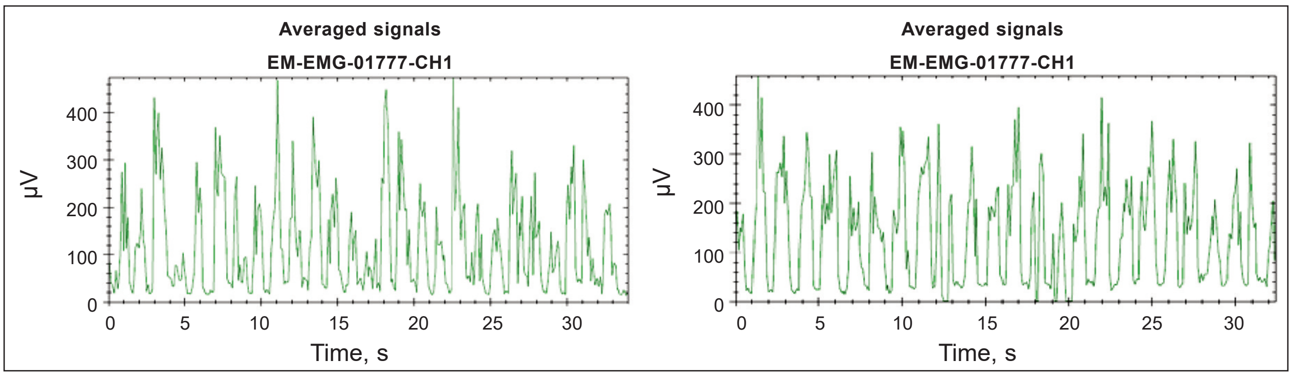


Fig. 8. Mean voltage of Soleus muscle, 100% Cotton CB, walking action, 40 BPM

at flexion-extension action by 22.68% and 33.86% during walking as concluded in table 3.

EMG mean voltage for Flexor Carpi muscle

E-Motion EMG and MegaWin software were used to analyse the relationship between three types of WCBs and muscles activation. The average voltage of FC muscle and standard deviation (S. D.) during flexion-extension and squeezing a soft roll actions are listed in table 2. Average FC muscle's voltages with bandage decreased by a percent 8.81% for flexion-extension action. Meanwhile wearing WCB decreases muscle activation by 6.96% while squeezing a soft roll action. Statistical analysis of the obtained results confirms that both wearing WCB and metronome beats have significant effects at confidence level of 95% on the FC muscle's activation, as illustrated in table 3.

Mean voltage for SO and MG muscles

Mean activation of SO and MG muscles wearing CO-PA-PU and 100% Cotton WCBs during flexion-extension and walking activities at 20, 30, and 40 beats/min are concluded in tables 5 and 6. Using CO-PA-PU bandage during flexion-extension action decreases SO and MG muscles activation by 22.68 and 25.56% respectively (table 3). Moreover using 100% Cotton WCB while walking was associated with a decrease in average SO and MG muscles activation by 18.24 and 10.66% respectively (table 4) while wearing CO-PA-PU WCB decreases SO and MG muscles' activation by 33.86 and 4.65% respectively (table 3).

Analysis and calculation of RMS values

Thanks to MATLAB software that enables to filter the obtained signals and calculate RMS values for all selected muscles, as summarized in tables 7–9. Average RMS and standard deviations of the FC muscle wearing VI-PA WCB are concluded in table 5. Using VI-PA WCB decreases the muscle's activation by 8.43%, as confirmed with low average RMS values, 159.23 compared to 173.88 without WCB, for squeezing a soft roll action. And 141.61 compared to 166.25 without WCB for flexion-extension activity, reduction percent 14.82%. Moreover the S. D. of the average RMS values is lower when wearing the WCBs for all selected activities.
Table 9 illustrates RMS of SO and MG muscles wearing 100% Cotton WCB for walking action. Using WCB reduces the muscle's activation as confirmed by lower average RMS for SO and MG EMG signals. Table 9 concludes RMS values of SO and MG signals using CO-PA-PU WCB. Using WCB reduces the muscle's fatigue (average RMS decreased by 14.36 and 19.86% for SO and MG signals respectively for flexion-extension, meanwhile 22.48 and 5.72% for walking actions). This improvement for muscle's behaviour using WCB might be resulting in little increase of intramuscular pressure in combination

Table 7

RMS OF SO AND MG MUSCLE SIGNALS, WHILE WALKING, 100% COTTON BANDAGE					
Case	**Metronome beats (BPM)**	**Soleus Muscle**		**Medial Gastrocnemius**	
		RMS value	**S. D.**	**RMS value**	**S. D.**
With bandage	20	151.66	4.83	137.68	6.09
	30	145.98	6.79	147.46	6.19
	40	191.58	11.09	183.30	7.23
	Average	178.03	6.75	156.15	6.50
Without bandage	20	165.92	6.98	165.56	5.03
	30	205.65	9.50	181.48	9.21
	40	236.46	8.63	191.11	11.13
	Average	202.68	8.37	166.11	7.34

Table 8

ANOVA FOR TABLES 3 AND 6 (AVERAGE VOLTAGE AND RMS OF SO AND MG MUSCLE SIGNALS)			
Tested muscle	**Dependent Variable**	**Sig.* (with or without bandage)**	**Sig.* (Metronome beats)**
Medial Gastrocnemius	Mean voltage	0.011	0.000
	RMS values	0.000	0.000
Soleus	Mean voltage	0.000	0.000
	RMS values	0.000	0.000

Note: * Significance at confidence interval 95%.

Table 9

RMS OF SO AND MG MUSCLE SIGNALS USING CO-PA-PU WCB					
Activity	**Bandage**	**SO Muscle**		**MG muscle**	
		RMS value	**S. D.**	**RMS value**	**S. D.**
Flexion – extension	with bandage	35.42	3.29	31.56	2.43
	without	41.36	4.83	39.38	3.76
	Reduction %	14.36	31.95	19.86	35.44
While walking	with bandage	144.41	5.06	112.92	5.33
	without	186.28	8.13	119.77	8.98
	Reduction %	22.48	37.78	5.72	40.72

with the suggested reduction of muscle's oscillation [26–28].

Relation between bandage pressure using PicoPress and EMG signals

All bandage pressure testing are measured on the same group of 6 men for Soleus and MG muscles. Figure 9 confirms significant changes of WCB pressure for walking action, which is vibrating as (27–43 mmHg) for Soleus, (18–27 mmHg) for MG muscle when wearing the Cotton CB. While using CO-PA-PU WCB, the oscillations are (20–35 mmHg) for Soleus, (18–25 mmHg) for MG muscle [1, 29]. The main factor which influences these oscillating ranges during walking and flexion-extension activities may be due to the significant changes of muscles voltage, as previously discussed for figures 5–8.

CONCLUSIONS

Both of the EMG muscle's voltage and the PicoPress pressure tests were carried out together on the same group at same conditions. The 100% Cotton CB pressure was oscillating between (27:43 mmHg) for SO and (18:27 mmHg) for MG muscle. This vibration while walking must be taken into consideration before using the WCB for long time to achieve the optimum compression therapy. Using 100% Cotton WCB decreased the muscle activation of SO and MG muscles by 18.24 and 10.66% respectively for walking action. Wearing CO-PA-PU bandage significantly

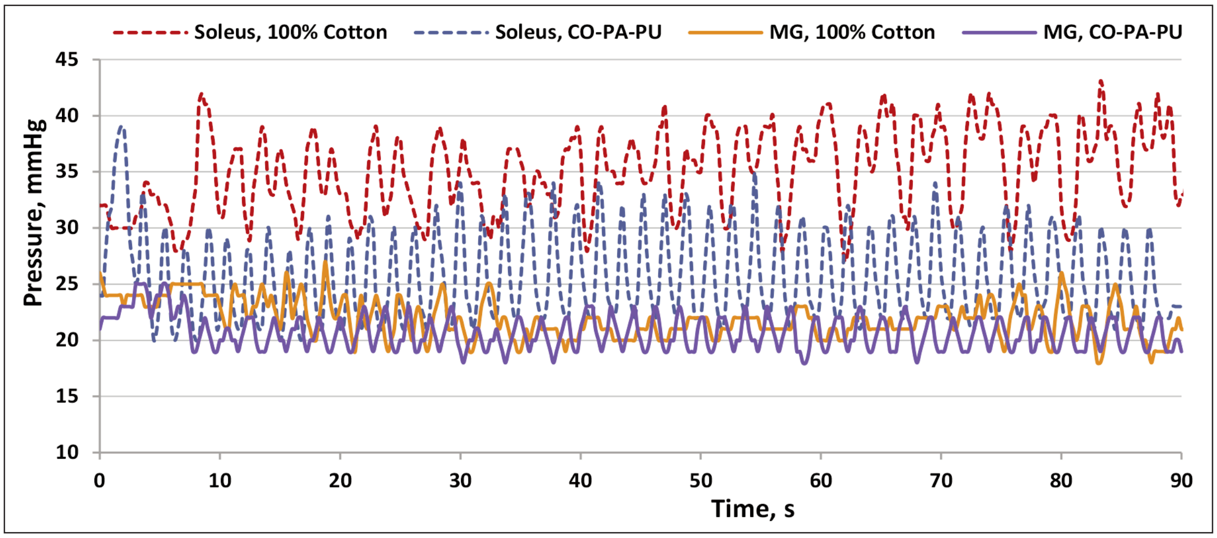


Fig. 9. Bandage pressure while walking action using 100% Cotton and CO-PA-PU WCBs

reduced the muscle's voltage of SO and MG by 22.68 and 25.56% for flexion-extension. Statistical analysis and RMS values ensured that wearing WCB could enhance muscle's behaviour that might improve athletic performance and decrease muscle's activation.

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