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MUSCLE COACTIVATION INDEX IN THE ANKLE JOINT ON DIFFERENT SUPPORT SURFACES

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Abstract

Muscle coactivation represents the phenomenon through which the central nervous system coordinates the activity of the agonist and antagonistic muscle groups. Muscle coactivation is one of the most important components of the motor control system that assures the direction and stability of the movement , influences the learning process and is involved in all the mechanisms for managing postural disturbances. By means of the surface electromyography (BIOPAC MP36), the present research aims to evaluate the muscle coactivation index in the ankle joint. The research included a number of six female subjects, long-jump athletes, aged 14-17. In order to stimulate the occurrence of the muscle contractions, the subjects were subjected to postural deviations, which were obtained by using 4 support surfaces: 1 - ground, 2 - elastic trampoline, 3 - balance disk and 4 – air cushion. The results of the research provide important data on the ability of the central nervous system to coordinate muscle activity, according to the values obtained by the muscle coactivation index, as well as to the support surface used.

Keywords: Ankle, coactivation, electromiography, neuromuscular.

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1. Introduction

Muscle coactivation is the phenomenon by which the central nervous system coordinates the activity of the agonist and antagonistic muscle groups. Muscle coactivation is considered to be a core component of the motor control system, which is mediated by the central nervous system, through the feedback received from the peripheral sensory receptors (FreyLaw & Aavin, 2013). The most studied form of muscle coactivation is the antagonistic one, and in the literature it is also known as co-contraction (Beck, 2015). Some authors consider the muscle co-contraction an active ligament, because for each joint amplitude there is a degree of activation of the agonist and antagonist muscles, which regulates the rate of the muscle contraction and tension in the ligaments (Baratta et al., 1988). An increase in the muscle coactivation index is identified during the development of the motor acts on unstable support surfaces and occurs regardless of age and it is also observed in older persons (Cardinale, Newton, & Noska 2011). Increasing the speed of movement and muscle fatigue does not prevent the occurrence of co-contractions, nevertheless, it influences them by diminishing the coordination between the muscle groups (Kellis & Kellis, 2001), (Agaard et al., 2000).

Because the ankle is the first joint which has contact with the ground, it plays an important role in the postural stability of each athlete. There is an inextricable functional link between the muscle coactivation and postural stability, which represents the ability of the human body to maintain its direction of movement in relation to the dynamic or extrinsic dynamic disturbances. Research shows that the stability of the ankle joint is influenced by the support surface, but also by the existence of the joint disorders such as chronic joint instability or ligament lesions (Linens, Ross, Arnold, Gayle, & Pidoce, 2014), (McKeon & Hertel, 2008).

Any postural deviation produces more co-contraction. For example: the muscle coactivation encountered at the level of the lower limb produces a deviation from the initial movement trajectory with 2 responses:

- the first response occurs in the ankle muscles, which attempts to compensate for all the postural changes, so that the trunk remains straight;
- if the ankle coactivation is not sufficient, the trunk bends forward and the movement is compensated from the coxofemoral joint through the supraspinal mechanism for managing motor disturbances (Konradsen & Ravn, 1990).

A muscle co-contractation increase has also been reported in the neurological disorders, such as multiple sclerosis, stroke or Parkinson's disease (Boudarham et al., 2016) and (Kitatani et al., 2016), while athletes reported changes in the muscle activity pattern depending on the support surface and the type of footwear used (Roca-Dols et al., 2018). Measurements of the muscular coactivation index are made by surface electromyography, and the analysis of the results is different, depending on the calculation method chosen by each researcher (Le, Best, Khan, Mendel, & Marras, 2017). Muscle coactivation is one of the most important components of the motor control system that assures the direction and stability of the movement that influences the learning process and is involved in all the mechanisms for managing postural disturbances.

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2. Problem Statement

Since muscle coactivation is a manifestation of motor control, which has the role of finding the most effective solution to compensate for a postural change in the motor control system, we consider that the subject is topical, its importance being justified by the special attention given by researchers, but also by the important role played by the agonist-antagonist muscle balance in increasing sports performance or in preventing injuries.

3. Research Questions

This research is going to verify the *hypothesis* according to which “a change of the support surface causes changes at the level of the muscle coactivation index”.

4. Purpose of the Study

The purpose of the research is to demonstrate that the shape and the characteristics of the support surface are determinant factors in the activity of the agonist and antagonistic muscle groups. At the same time, we want the results obtained in this research to represent the premises for future experimental research in which to intervene through a proprioceptive exercise programme, whose aim is to improve / decrease the values of the muscle coactivation index.

5. Research Methods

We used for this paper the following research methods: documenting, pedagogical observation, survey, case study, data recording and processing method and graphical method.

5.1. Research subjects

Our research had 6 subjects (Table 01), Junior III and II female athletes, specialized in the high jump and triple jump events. The age of the subjects was between 14 and 17 years and the location of the research was the Athletics Hall in Bacău City. At the time of the evaluation, out of 6 subjects, one athlete had a second degree lesion in the meniscus, while another athlete suffered an injury at the ankle level 3 weeks before the evaluation.

In order to be able to make the recordings, we obtained the written consent of the parents of the six athletes, the research being conducted in accordance with the Helsinki Declaration on Human Subjects Research and with the agreement of the Ethics Committee of “Vasile Alecsandri” University of Bacau.

Table 01. Recognition data for the research subjects

Initials	**Age**	**Height**	**Weight**	**Takeoff Leg**	**High/Triple Jump Results**	
					I	**F**
D.I	17	163	55	LEFT	12.02	12.36
V.T	17	174	58	RIGHT	11.49	11.64
B.B	17	169	58	RIGHT	10.80	10.96
R.S	15	169	56	LEFT	11.46	11.62
M.C	14	173	58	LEFT	1.60	1.63
V.R	14	174	56	RIGHT	1.55	injured

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5.2. Evaluation protocol

Regarding the actual assessment of the subjects, we recorded data related to age, height, weight, takeoff leg and results in the sports events in the test competition on April 23th, 2018, and on June 16th, 2018, which took place at the Athletics Hall in Bacau (Table 01).

The main assessment method was surface electromyography. This was done by means of the electromyograph (Biopac MP36, Biopac System Inc., Santa Barbara, CA). Before starting the evaluation and putting the electrodes, we cleaned the skin, applied a conductive gel, and calibrated the recording unit. The data recording was done via 2 acquisition channels, which were pre-set for electromyography and whose recording frequency was 1000 Hz. The assessed muscles were the tibialis anterior and triceps surae muscles.

In order to position the electrodes at identical anatomical landmarks at the level of the tibialis anterior muscle, they were positioned 3 cm downwards and 1 cm medial to the tibial tuberosity. For the triceps muscle, the electrodes were applied at 4 cm below the popliteal fossa. The neutral electrodes were positioned at the basin's level, on the iliac crests, and the subjects performed the event barefoot.

The evaluation test had the following approach: the subjects stayed for 30 seconds on each support surface, while we recorded the spontaneous muscular activity and the maximum contraction value. The order of the evaluation on the four supporting surfaces was: 1 - ground, 2 - elastic trampoline, 3 - balance disk and 4 - air cushion. The data obtained were recorded, processed using the BIOPAC Student Lab 4.0 software. In order to reduce the measurement errors, we used the "smoothing" function of the software, and in order to highlight only the positive values, we used the "root mean square (RMS)" function. The initial evaluation of the subjects took place on April 23th, 2018, and the final evaluation took place 8 weeks later, on the June 16th, 2018.

5.3. Muscle coactivation index

In order to calculate the values of the muscle coactivation index, we used the maximum contraction value obtained by the agonist muscle and divided it to the maximum contraction value obtained by the antagonist muscle + the muscle contraction value obtained by the agonist muscle. The calculation formula was proposed by (Ervilha, Farina, Arendt-Nielsen, & Graven-Nielsen, 2005). CI = $2* \frac{EMGant}{EMGag+EMGant} * 100$. The authors claim that the accuracy of the calculation formula is 92%, ± 6%. We have not found reference values because they differ from one subject to another, but we have found the specification according to which the results obtained through the calculation formula are considered positive when the percentages obtained have a lower value.

6. Findings

6.1. Research results

First we described the results obtained by the tibialis anterior muscle, then by the triceps surae muscle for each subject. The collected data were grouped and are presented in the table no. 02. Following the subjects' evolution and the analysis of the obtained results, we highlight a series of aspects:

At the ground level, the tibialis anterior muscle of the subject D.I. obtained an initial value of 44% of the muscle coactivation index and a final value of 85%. On the elastic trampoline, the values of the

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muscle coactivation index decreased compared to the results obtained on the ground, our subject having an initial value of 10% and a final value of 30%. On the balance disk, the values of the muscle coactivation index were 9% at the initial assessment and 54% at the final assessment. At the air cushion level, the initial value of 54% of the muscle coactivation index decreased to a final value of 9%.

Regarding the evolution of the triceps surae muscle, it obtained an initial value of 98% of the muscle coactivation index and a final value of 69% at the ground level. The change of the support surface led to a decrease in the initial values of the muscle coactivation index to 37% for the elastic trampoline, 23% for the balance disk and 67% for the air cushion. At the final evaluation, an 18% muscle coactivation index was recorded on the elastic trampoline, 38% was obtained on the balance disk and 39% on the air cushion. The athlete recorded a performance of 12.02m in the first assessment and 12.36m in the second assessment, therefore, an improvement of 0.34m.

For the subject V.T., the values obtained by the muscle coactivation index on the most stable support surface (ground) were 36% at the initial assessment and 27% at the final assessment for the tibialis anterior muscle. On the elastic trampoline, V., recorded a muscular coactivation index of 8% at the initial assessment and 9% at the final assessment. At the level of the balance disk, the initial value of the index was 18% and the final value of 6%. The air cushion led to an initial value of 27% of the muscle coactivation index and a final value of 18%.

By tracking the evolution of the the muscle coactivation index for the triceps surae muscle, we can notice the following: at the ground level, the initial value of the muscle coactivation index was 27% and the final value 47%. At the trampoline level, subject V recorded an initial value of 10% of the muscle coactivation index and a final value of 50%. The values obtained on the balance disk were 13% at the initial evaluation, respectively 15% at the final evaluation. The air cushion recorded a 2% increase from an initial value of 31% to a final value of 33%. The athlete recorded a performance at the first assessment of 11.49m and a second one of 11.64m, therefore, an improvement by 0.15m (Table 02).

Table 02. Muscle coactivation index values obtained by each subject

Assessed Muscle									
D.I	MVC -» TA-TS in (mV)		CI		MVC -» TS-TA in (mV)		CI		
	I	F	I	F	I	F	I	F	
	1.339–0.378	0.719–0.536	44%	85%	0.593–0.570	0.631–0.338	98%	69%	G
	1.501–0.087	0.993–0.182	10%	30%	1.224–0.287	0.660–0.069	37%	18%	Tr
	1.082–0.166	0.526–0.197	9%	54%	1.082–0.166	0.524–0.125	23%	38%	D.bal.
	0.919–0.343	1.702–0.087	54%	9%	0.731-0.370	0.528–0.130	67%	39%	C.a.
V.T	MVC -» TA-TS in (mV)		CI		MVC -» TS-TA in (mV)		CI		
	I	F	I	F	I	F	I	F	
	1.443-0.373	0.768-0.123	36%	27%	1.077-0.158	0.396–0.123	27%	47%	G
	1.564–0.070	1.743–0.084	8%	9%	1.593-0.092	0.856–0.290	10%	50%	Tr
	1.340–0.140	2.200–0.078	18%	6%	1.871-0.140	0.730–0.063	13%	15%	D.bal.
	1.443–0.227	2.121–0.217	27%	18%	2.538-0.478	0.869–0.173	31%	33%	C.a.
B.B	MVC -» TA-TS in (mV)		CI		MVC -» TS-TA in (mV)		CI		
	I	F	I	F	I	F	I	F	
	0.908–0.430	1.057–0.091	60%	15%	0.729-0.371	1.042-0.208	51%	33%	G
	1.119–0.307	1.745–0.469	43%	42%	1.015-0.317	2.024-0.374	57%	31%	Tr
	1.146–0.165	1.039-0.274	25%	27%	1.327-0.365	1.597-0.177	43%	19%	D.bal.
	1.316–0.206	2.016-0.121	27%	11%	1.383-0.019	1.680-0.099	2.5%	11%	C.a.

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M.C	MVC -» TA-TS in (mV)		CI		MVC -» TS-TA in (mV)		CI		
	I	F	I	F	I	F	I	F	
	1.417-0.133	1.027-0.192	17%	31%	1.454-0.126	0.730-0.164	15%	36%	G
	0.862-0.185	2.652-0.320	35%	21%	1.136-0.007	1.065-0.138	1%	22%	Tr
	1.476-0.135	1.726-0.170	16%	17%	1.330-0.108	2.019-0.707	15%	51%	D.bal.
	1.596-0.075	2.704-0.231	8%	15%	2.377-0.048	1.177-0.113	4%	17%	C.a.
R.S	MVC -» TA-TS in (mV)		CI		MVC -» TS-TA in (mV)		CI		
	I	F	I	F	I	F	I	F	
	0.846–0.366	0.735-0.155	60%	34%	0.978-0.171	0.513-0.107	29%	37%	G
	0.865-0.092	0.896-0.063	23%	13%	0.818-0.679	1.052-0.161	90%	26%	Tr
	1.792-0.214	0.853-0.267	21%	47%	0.600-0.206	0.486-0.058	51%	21%	D.bal.
	2.005-0.282	1.033-0.042	24%	7%	1.103-0.425	0.852-0.058	55%	12%	C.a.
V.R	MVC -» TA-TS in (mV)		CI		MVC -» TS-TA in (mV)		CI		
	I	F	I	F	I	F	I	F	
	0.929-0.166	0.892-0.210	30%	38%	0.552-0.041	0.609-0.574	13%	97%	G
	1.177-0.277	1.172-0.028	63%	4%	0.740-0.414	0.557-0.092	71%	28%	Tr
	1.230-0.302	1.309-0.245	39%	31%	0.763-0.370	0.748-0.280	65%	54%	D.bal.
	1.065-0.253	1.270-0.084	38%	12%	0.857-0.029	0.873-0.090	6%	18%	C.a.

Legend: The first value is for the agonist muscle and the second for the antagonist muscle. MVC= maximum of the voluntary contraction, TA= tibialis anterior, TS= triceps surae, CI= coactivation index, G= ground, Tr= trampoline, D.bal. = balance disk, C.a = air cushion.

For subject B.B., the most important changes in the coactivation index were recorded in the evolution of the tibialis anterior muscle. The coactivation index values had a decrease of the initial values directly proportional with the support surface becoming harder (60% - ground, 43% elastic trampoline, 25% balance disk and 27% air cushion). This trend was also maintained at the final assessment, with the athletes recording 15% on the ground, 42% on the elastic trampoline, 27% on the balance disk and 11% on the air cushion.

At the triceps surae muscle level, the values in the initial evaluation showed a muscle coactivation index of 51% on the ground support, 57% on the elastic trampoline, 43% on the balance disk, and a value of 2.5% on the air cushion. In the final evaluation, subject B. recorded a muscle coactivation index of 33% on the ground, 31% on the trampoline, 19% on the balance disk, and 11% on the air cushion. The results obtained by the subject B.B. were very good because both muscle groups obtained better values of the muscle coactivation index on all the support surfaces in the initial assessment and in the final assessment, as well. The athlete recorded a performance at the first evaluation of 10.80 m, and a second one of 10.96 m, thus, an improvement of 0.16 m.

The results obtained by the subject R.S., highlight the perfect evolution of the muscular coactivation index at the initial evaluation of the tibialis anterior muscle. The values obtained for the muscle coactivation index (60%) at the ground level decreased to 23% on the elastic trampoline, 21% on the balance disk and 24% on the air cushion. The positive evolution was also maintained in the final assessment, where we can notice a decrease in the values of the muscular coactivation index, the subject R., recording a value of 34% on the ground, 13% on the elastic trampoline, 47% on the balance disk, respectively 7% on the air cushion.

In the initial evaluation of the coactivation index for the triceps surae muscle, the initial values obtained on the ground had a percentage of 29%, with the change of the support surface (trampoline - 90%,

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balance disk - 51% and air cushion - 55 %), the values show a significant increase. In the final evaluation, the results of the muscle coactivation index had an improvement, the subject R., registering a value of 37% on the ground, 26% on the elastic trampoline, 21% on the balance disk and 55% on the air cushion. The increase in the initial values of the muscular coactivation index for the R.S. subject is justified by the existence of a second degree lesion in the meniscus. The athlete reached a performance of 11.46 m in the first evaluation of 11.62 m, therefore, an improvement of 0.16 m.

Concerning the values obtained by the subject M.C. at the ground level, the muscle coactivation index of the tibialis anterior muscle had an initial value of 17% and a final value of 31%. The change of the support surface led to an increase in the initial values for the elastic trampoline to 35%, while the balance disk values dropped to 16% and those for the air cushion to 8%. At the final evaluation, the coactivation index values on the elastic trampoline were 21%, 7% on the balance disk and 17% on the air cushion.

In the triceps surae muscle, the subject M.C had a perfect evolution. On the ground, the initial value of the muscle coactivation index was 15%. The value obtained by the muscle coactivation index on the elastic trampoline was 1%, 4% on the balance disk and 15% on the air cushion. At the final evaluation, the values obtained had a muscle coactivation index of 36% at the ground level, 22% at the elastic trampoline, 51% on the balance disk and 17% on the air cushion. The athlete recorded a performance at the first assessment of 1.60 m and a second evaluation of 1.63 m, thus, an improvement of 0.34 m.

The analysis of the results obtained by the subject V.R., at the initial evaluation, reveals a poor evolution of the athlete, probably due to the ankle sprain suffered 3 weeks before.

In the initial assessment of the tibialis anterior muscle, the subject had a value of 30% for the muscle coactivation index at the ground level. The change in the support surface increased the muscle coactivation index values up to 63% on the elastic trampoline, 39% on the balance disk and 38% on the air cushion. After 3 weeks, at the final assessment, the values obtained by the subject V. were much better. At the ground level, a muscle coactivation index of 38% was recorded, while on the elastic trampoline it was 4%, on the balance disk 39%, and on the air cushion 12%.

At the triceps surae muscle level, the muscle coactivation index achieved an initial value of 13% at the ground level. The change of the support surface resulted in an increase of 71% in the muscle coactivation index on the elastic trampoline and 65% on the balance disk. At the same time, the values dropped to 6% when assessing it on the air cushion. The final evaluation revealed a change in the muscle coactivation index to 97% on the ground, 28% on the elastic trampoline, 54% on the balance disk and 18% on the air cushion.

6.2. Result interpretation

In the acute phase of an injury, there is an increase in the muscle coactivation index (seen at the injured athletes, R.S. and V.R.). Eight weeks after the initial assessment, we assume that the pain relief due to injuries improved the muscle coactivation index since it has been shown that the related signals sent by the pain receptors can interfere with the corresponding signals sent by the proprioceptors, thus having a negative impact on the entire motor control system (Abd-Efattah, Abdelzeim, & Elshennawy, 2015). A single athlete (MC) recorded higher (ununjustified) values of the muscle coactivation index at the final assessment. The final values of the muscle coactivation index were better when compared to the initial values of the muscle coactivation index. We also note an improvement in the values of the muscle

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coactivation index when the support surface became more unstable. Taking into account that the final evaluation was made one week before the most important competition of the season, it is possible that the improvement of the values of the muscular coactivation index is also justified by the competition period, the moment of the final evaluation being actually the peak of the athletes. The muscle coactivation index may be an effective tool for measuring the quality of the motor acts, because the lower the muscle coactivation index is (i.e., there is an agonist-antagonist muscle balance), the higher the sports performance will be, with a lower risk of injury occurrence.

6.3. Discussions

Starting from Sherrington in (1906 -1897) by justifying and raising the consideration for the mutual inhibition as law, the antagonist muscles have been considered inactive throughout the duration of the agonist muscle contraction for a long time. The remarkable advances made in physiology have demonstrated the existence of the inhibitory neurons, which, by means of the signals received from the neuromuscular spheres, regulate the intensity of the antagonist muscle contraction. The hereby research, having an observational purpose, was to highlight the changes occurring at the level of the muscle coactivation index while changing the support surface. At the same time, we have been trying to find correlations between the changes in the muscle coactivation index and the existence of injuries in the lower limbs. For all the subjects evaluated on the stable support surface, the muscle coactivation index was higher in the tibialis anterior muscle. This suggests the important role of the tibialis anterior muscle statically, which, along with the peroneal and tibialis posterior muscles, provides stability to the ankle joint (Louwerens, van Linge, de Klerk, Mulder, & Snijders, 1995). When the support surface changed, the values obtained were reversed, the triceps muscle becoming dominant. The results highlight the importance of the triceps muscle in dynamics, muscles playing a particularly important role in long jump. The ability of the ankle joint muscles to synchronize the muscle contraction with the ongoing movement is a functional adjustment achieved in training through the muscle coactivation. The same functional modification was found by (Bazzucchi, Riccio, & Felici, 2008) in tennismen, but at the elbow joint level. The changes in the muscle coactivation index were also reported by Linens, Ross, Arnold, Gayle, & Pidoce (2014) in subjects with chronic ankle joint instability, and by Kitatani et al., (2016) in patients with cerebrovascular accident (CVA)/strokes. At the same time, Rossi et al., (2014) reported changes in the muscle coactivation index during exercise or pilates. The ultimate goal of all these exercises is to decrease the values of the muscle coactivation index so that the antagonist resistance is minimal.

In athletes, the changes in the muscle coactivation index were reported by Kellis, Zafeiridis and Amiridis (2011) in the ankle muscles, especially during their contact with the ground. The same authors claim that an increased muscle coactivation may play an important role in the injury occurrences, especially when the running biomechanics is deficient. DeMers, Hicks and Depl (2017), demonstrated that through the feed-forward mechanism (i.e. by the occurrence of the anticipated muscle contraction), the muscle coactivation plays an important role in reducing the risk of ankle joint injuries, especially when the coactivation index values are below 60%.

Regarding the results obtained according to the support surface, the air cushion and the balance disk were the most demanding support surfaces. Authors such as Ridder, Willems, Vanrenterghem and Roosen (2015) or Nepocatych, Ketcham, Vallabhajosula and Balilionis (2018) state that the bosu ball (similar to the air cushion) offers the greatest postural deviations and Harput, Aouylu, Ertan and Ergun, (2013) states that it is not the support surface which determines the amount of muscle contraction, but the type of the exercise practiced.

In injured subjects, modifying the coactivation index is a normal phenomenon, as the onset of pain leads to a change in the muscle contraction pattern (Tam, Santos-Concejero, Coetzee, Noakes, & Tucker, 2017). In these situations, athletes are advised to rest, as a continuation of their sports activity leads to chronic pain and structural reorganization of the motor engramme of the somatosensitive cortex (Borghuis, Hof & Lemmink, 2008).

Since the ankle is the first joint to contact the ground, it plays a particularly important role in balancing the postural deviations coming from the trunk. Taking this into consideration, by optimizing the biomechanics of the lower limb, the muscle coactivation can ensure the optimal operation of the entire motor control system.

7. Conclusion

Based on the analysis and interpretation of the data obtained, we consider that the surface electromyography plays an important role when it is needed to establish the muscle coactivation index at the ankle joint level. Taking into account the values of the muscle coactivation index, we can assert that the hypothesis according to which “a change of the support surface causes changes at the level of the muscle coactivation index” has been confirmed. Knowing this aspect enables the interdisciplinary team to improve the muscle imbalances in the ankle joint, leading to progress in both performance and recovery. There was also an improvement of the sports results following the training process (Table.1).

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