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EMG activation of abdominal muscles in the crunch exercise performed with different external loads

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ABSTRACT

Objective: The aim of this study was to describe by means of surface electromyography the activation of the rectus abdominis, obliquus externus and rectus femoris muscles during the "crunch" abdominal exercise performed with loads.

Methods: Thirteen subjects performed crunch exercises with loads representing 80, 60, 40 and 20% of the 1-RM (100%) in a random order with the subjects drawing lots, and with a 5 min rest between sets. Surface bipolar EMG electrodes were used. The root mean square of the EMG was calculated for the first repetition of each load. Differences between conditions were tested using a one way ANOVA for repeated measures. Post-hoc Bonferroni tests was used to detect significant differences between specific loads ($p < 0.05$).

Results: An average of the percentage values of all studied abdominal muscles was used as a representative value of abdominal synergy (Ab Syn). In general it can be concluded that the abdominal muscles were significantly more recruited in the 100% load condition. Abdominal activation significantly differed between the various loads; however, in general adjacent loads (20 vs. 40% – 1-RM) did not differ.

Conclusions: These results suggest that for young, healthy and physically active adults when the objective is progression in the training process of abdominal force, the option ought to be for changes of load superior to 20% of the 1-RM.

1. Introduction

Scientific and technological advances have enlarged our areas of knowledge in many disciplines, making possible significant improvements in diverse aspects related to the life of the human being. Abdominal exercises have been included in the daily routine of fitness centers and programs of physical preparation. Thus, there are a growing variety of movements elaborated to strengthen abdominal musculature, including the utilization of weights. But, why are weights needed to strengthen the abdominal muscles?

It has been verified that for the skeletal muscles in general, the addition of weights with adequate repetitions has proven to be efficient for reaching hypertrophy (MacDougall Sale, Moroz, Elder, Sutton, & Howald, 1979; Staron, Malicki, Leonardi, Falkel, & Hagerman, 1990; Tesch & Karlsson, 1985; Thorstensson, Karlsson, Viitasalo, Luhtanen, & Komi, 1976). In a recent study Stevens et al. (2008) investigated the effect of increasing resistance during flexion and extension movement, on trunk muscles activity.

Various authors have presented results of EMG activation of the abdominal musculature during flexing movements of the trunk (Bankoff & Furlani, 1986; Flint & Gudgell, 1965; Floyd & Silver, 1950; Moraes, Bankoff, Pellegrinotti, Moreira, & Galdi, 1995; Moraes, Bankoff, Almeida, Simoes, Rodrigues, & Okano, 2003; Pezarat-Correia, Nobre, & Cabri, 2002; Sheffield & Major, 1962; Sternlicht, Rugg, Bernstein, & Armstrong, 2005; Walters & Partridge, 1957). A recent study by Bressel, Willardson, Thompson, and Fontana (2008) assessed the effect of verbal instruction, surface stability, and load intensity on trunk muscle activity during the free weight squat exercise.

According to Axler and McGill (1997) several exercises are required to train all the abdominal muscles, and these exercises are best designed for an individual and depend on a number of variables such as fitness level, training goals, history of previous spinal injury and any other factors specific to the individual.

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With the intention of also comparing the EMG activity of the superior and inferior regions of the Rectus abdominus muscle, Axler and McGill (1997) and Willett, Hyde, Uhrlaub, Wendel, and Karst (2001) did not find significant differences between the exercises of flexing the spinal column and those elevating the legs in suspension (flexing the hip). However, Brooks and Brooks, 2001 verified greater activity of the superior portion of the rectus abdominus muscle in flexing exercises of the spinal column. Axler and McGill (1997) affirmed that the efficiency of abdominal exercises differs among individuals as a function of the related work to force of compression of the vertebral column.

The studies of Guimarães, Vaz, Campos, and Marantes (1991) and Moraes et al. (1995) verified that the fixation of the feet and the utilization of the inclined bench, do not interfere in the EMG pattern of the abdominal muscles since the greatest difficulty encountered in the execution of these movements is related to the flexing activity of the hip.

Muscular architecture, defined by the length, type and crest of muscular fibers, also seems to be a determinant in the definition of muscular function, as well as in the possible force and speed being produced by the muscle after the initial stimulus.

The Rectus abdominus (RA) muscle is made up of parallel fibers, crossed by three tendinous intersections (Rasch & Burke, 1977). According to Haggmark and Thorstensson (1979) it consists of 55% of type I fibers, 22% of type IIa fibers and 23% of type IIb fibers. Johnson et al. (1973) indicated that its composition is 46.1% of type I fibers and 53.9% of type II fibers, while according to Sakkas et al. (2003) its composition is 52% of type I fibers, 43% of type II fibers and 5% of type IIb fibers.

The obliquus externus (OE) muscle consists of a bundle of parallel fibers that diagonally and laterally extend upward from their origin (Rasch & Burke, 1977). In its constitution it presents 24% of type I fibers, 52% of type IIa and 23% of type IIb (Marquez & Finol, 1990), while Haggmark and Thorstensson (1979) reported it to be made up of 58% type I fibers, 21% of type IIa and 21% of type IIb.

The rectus femoris (RF) muscle has a rectilinear trajectory composed of muscular fibers that obliquely cross from one superior tendon to another tendon if the inferior plane (Rasch & Burke, 1977). Goss (1988) described it as a muscle with superficial fibers ordered in a two-winged way and with the deep fibers going directly to the deep aponeurosis. It is classified as a bi-articulated muscle that actuates in articulations of the hip and the knee (Rasch & Burke, 1977). According to Jennekens, Tomlinson, and Walton (1971) type II fibers predominate in its constitution. According to Johnson et al. (1973) it is comprised of 38.1% type I fibers and 61.9% type II fibers.

Thus, the morphological nature of these muscles and the mechanical order they present offer a variety of activation possibilities, above all in exercises with weights. The purpose of the present study is to describe by means of surface electromyography the activation of the RA, OE and RF muscles during the "crunch" abdominal exercise performed with weights (loads).

2. Materials and methods

2.1. Participants

The participants in the study were 13 (eight male and five female) sports science students (mean age = 19.76 ± 1.53) with no history of injury.

2.2. Procedure

The individuals were told about the purpose of the study, as well as the procedures they would be submitted to, and then signed an agreement consenting to participate in the project. The study was approved by the Research Ethics Committee of the State University of Campinas (Unicamp) in accordance with document number 099/2005. Measurements of weight (kg) and height (cm) were initially done wearing a bathing suit, and the weight of the trunk was estimated by the method proposed by Zatsiorsky and Seluyanov (1983).

Registry of the electromyographical signal of the muscles assessed was achieved utilizing "Neuroline – Medicotest" surface electrodes in bipolar configuration with a distance of 2 cm between the centers of the surfaces of detection. In the supra-umbilical portion (RAUR – Rectus Abdominis upper right and RAUL – Rectus Abdominis upper left) of the RA muscle the electrodes were placed 3 cm from the sagittal plane and 5 cm above the umbilicus (Fig. 1). In the infra-umbilical portion (RALR – Rectus Abdominis lower right and RALL – Rectus Abdominis lower left) of the RA the electrodes were placed 3 cm from the sagittal plane and 5 cm below the umbilicus. In the OE (OER – Obliquus Externus right and OEL – Obliquus Externus left) muscle the electrodes were placed 8 cm above the iliac crest and 14 cm from the umbilical scar. In the RF muscle the electrode was placed at a point

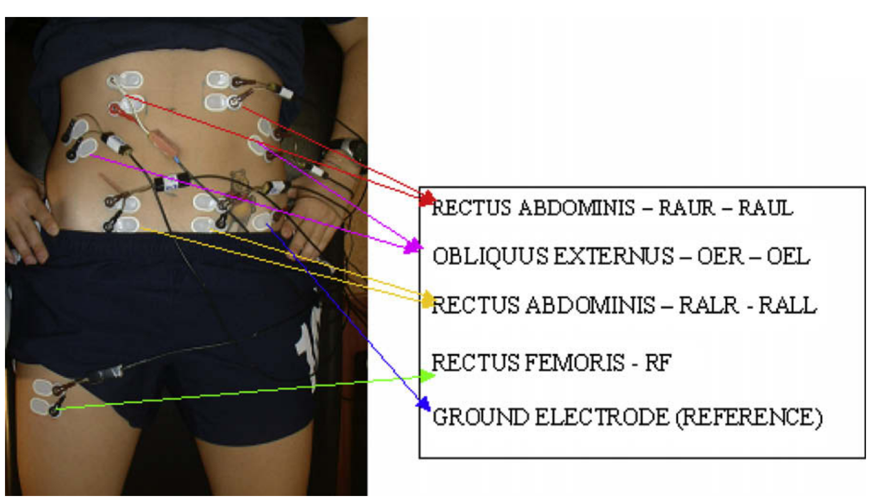

Fig. 1. Locations of electrodes in the RA and OE (right and left sides) muscles and the RF (right side). (RAUR – Rectus Abdominis upper right, RAUL – Rectus Abdominis upper left; RALR – Rectus Abdominis lower right, RALL – Rectus Abdominis lower left; OER – Obliquus Externus right, OEL – Obliquus Externus left; RF – Rectus Femoris).

midway between the anterior superior iliac spine and the superior part on the patella. An EMG signal from the left and right sides of the muscles was obtained. The ground electrode (reference) was placed over the anterior superior iliac spine. Alcohol and a razor were used for cleaning the places. In order to minimize possible interferences, all the parameters approved by ISEK (1999) were obeyed.

For collecting the data, the MP100 – BIOPAC System was used. The myoelectric signals were amplified (band pass filter of 10–500 Hz, CMRR – Commom Mode Rejection Rate >80 dB) and digitized by means of a 16-bits A/D converter with a sample rate of 1024 Hz. One of the channels was used for the trigger signal in order to synchronize with the video camera. The data were processed and analyzed by means of the AcqKnowledge 3.7.1 software. The EMG signals were full wave rectified and the root mean square (RMS) of the signal was determined for the first repetition of each load.

In this study, the "crunch" abdominal exercise was used; it consists of flexing the spinal column approximately 30 degrees from the lying down position with knees flexed and feet fixed (by a person) in place (Fig. 2). The volunteers were properly familiarized with the execution of the movements, through repetitions and previous information.

The time for executing each repetition was 4 s (2 s for each of the concentric and eccentric phases) with this being delimited by a "Wittner – Taktell Piccolo" metronome. Repetitions of the movement were filmed with a "Sony" digital video camera at a speed of 50 frames per second; this made it possible to assess the amplitude of movement and speed of each repetition. The images were captured and analyzed by the version 8.10.4.0 Pinnacle Studio and the Apas System software's, respectively.

Participants completed the maximum load test – 1-RM (Baechle & Earle, 2000). The test of 1-RM was accomplished through the initial estimate of load. After, a repetition was accomplished with the largest load supported by the volunteer, during the time established for the test (4 s – concentric and eccentric). After establishing the 1-RM, repetitions were performed with loads equivalent to 80, 60, 40 and 20% of the 1-RM in a randomly pre-established order. The movements were executed until the volunteer was unable to maintain the established pattern for the exercise. The EMG signal was obtained in the five conditions in which the exercise was assessed (1-RM, 80, 60, 40 and 20%). The interval of recuperation between conditions was 5 min, enough time for complete neuromuscular and metabolic recuperation (Kellis, 1999; Matuszak, Fry, Weiss, Ireland, & Mcknight, 2003; Seger & Thorstensson, 1994, 2000). Different loads utilized in the experiment were obtained with a 9 kg bar and respective disks (1.25, 2.5, 5, 10 and 20 kg) placed at its extremities. The bar was positioned and held in place by the arms to avoid displacement (Fig. 2) on the sternum bone (manubriosternal joint) at the upper part of the trunk in the direction of the line of the shoulders. The height of the bar was maintained at a constant by a volunteer positioned on a stretcher (Fig. 2).

Fig. 2. Example of movement utilizing a weight equivalent to 40% of the maximum weight (1-RM).

Table 1
Values (mean ± SD) of the anthropometric characteristics, of the maximum load test (1-RM), and of the number of repetitions referring to the abdominal exercise in loads relative to 20, 40, 60 and 80% of the 1-RM.

	Mean	SD
Weight total	65,28	9,38
Weight of the trunk	31,15	3,19
Height total	169,64	9,29
Maximum load test	79,00	20,33
Repetitions with 100%	1	–
Number of repetitions with 80%	14	±2,5
Number of repetitions with 60%	22	±5,0
Number of repetitions with 40%	26	±3,8
Number of repetitions with 20%	30	±2,8

2.3. Data analysis

Differences between conditions were tested by the application of ANOVA for repeated measurements. Post-hoc Bonferroni test was used to detect significant differences between specific loads. A level of significance of $p < 0.05$ was used.

3. Results

Table 1 presents the values (mean ± SD) for anthropometric characteristics of participants, for the maximum load test (1-RM), and for the number of repetitions referring to the abdominal exercise in loads relative to 20, 40, 60 and 80% of the 1-RM. When the test outlines were written there was no intention to make comparisons, this may be done in a further test.

Table 2 presents the average values (mean ± SD) of the normalized RMS for the first repetition of each percentage of 1-RM of the different muscles monitored. It also presents the abdominal synergy value (Ab Syn) corresponding to the average of all the monitored muscles or muscular portions of the antero-lateral wall of the abdomen as a value representative of the intensity of activation of the abdominal musculature. Table 3 presents the significant differences ($p < 0.05$) existing in the value of the Ab Syn between the different loads.

The results of this study show a significant ($p < 0.05$) reduction in the intensity of EMG activation by the set of abdominal muscles monitored with the diminution of the dislocated load. This reduction was verified between the loads of 100 and 80% (RALR, RALL,

Table 2
Normalized values (mean ± SD) of the RMS of the EMG signal for the first repetition of each percentage of the 1-RM load.

	100%	80%	60%	40%	20%
RAUR	100 ± 0	81 ± 19	77 ± 17[a]	68 ± 17[a]	52 ± 16[abc]
RALR	100 ± 0	81 ± 9[a]	79 ± 15[a]	64 ± 17[abc]	49 ± 10[abc]
OER	100 ± 0	62 ± 16[a]	64 ± 21[a]	47 ± 14[a]	43 ± 16[abc]
RAUL	100 ± 0	91 ± 20	72 ± 12[a]	63 ± 16[ab]	49 ± 21[abc]
RALL	100 ± 0	80 ± 12[a]	74 ± 13[a]	60 ± 14[ab]	50 ± 14[abc]
OEL	100 ± 0	65 ± 20[a]	59 ± 19[a]	42 ± 17[ab]	41 ± 17[abc]
Ab Syn	100 ± 0	77 ± 13[a]	70 ± 10[a]	58 ± 12[ab]	47 ± 13[abc]
RFR	100 ± 0	68 ± 39	73 ± 36	36 ± 21[a]	45 ± 29[a]

[a] ≠of 100%.
[b] ≠of 80%.
[c] ≠of 60%.

Table 3
Comparison between the Ab Syn and different loads.

	100%	80%	60%	40%	20%
100%		*	*	*	*
80%	*			*	*
60%	*				*
40%	*	*			
20%	*	*	*		

*Significant differences ($p < 0.05$).

OER, OEL and Ab Sin), 80 and 40% (RALR, RAUL, RALL, OEL and Ab Syn), and 60 and 20% (RAUR, RALR, OER, RAUL, RALL, OEL and Ab Syn). With the exception of the comparison between the loads of 100 and 80% of the 1-RM, changing the load to the percentage immediately below or above was not sufficiently sensitive to promote significant alterations in the intensity of activation/activity of the Ab Syn found during the first trial.

According to the values expressed in Tables 2 and 3, and demonstrated in Fig. 3, it can be verified that during the "crunch" abdominal exercise the average intensity of EMG activation of the set of abdominal muscles (in this study denominated synergy of the abdominal muscles) presented a significant statistical difference between the 100% load (1-RM) and the other loads analyzed (20, 40, 60 and 80% of the 1-RM).

Use of the normalized values referring to the test of 1-RM, verified greater EMG activity in the RA muscle (superior and inferior) of both sides in all the loads, which reflect the intense participation of this muscle during the execution of the "crunch" in the experimental conditions used in this study (Table 2). For the RF muscle there was significant difference between the loads of 20 and 40% in relation to 100% – 1-RM.

Fig. 4 shows a representative EMG signal register of the RA muscle (upper umbilical – right) in loads of 100, 80, 60, 40 and 20%).

4. Discussion and conclusions

The purpose of this study was to describe by means of surface electromyography the activation of the RA, OE and RF muscles during the typical "crunch" abdominal exercise performed with and without weights. An average of the percentage values of all studied abdominal muscles as a representative value of abdominal synergy (Ab Syn) was used.

Analysis of the rectified EMG signals of the muscles monitored clearly demonstrates the greater EMG activity during the concentric phase of the movement, with the highest muscular activation registered in the second half of this phase. Relative to the concentric phase, the progressive increase of EMG activity observed at the end of this phase appears to be an interesting find. The reduction of the perpendicular distance between the point of load application (barbell) to the hip occurred progressively throughout this phase; this clearly implies a reduction in the torque of resistance. In principle, this fact should reduce the demand at the muscular level. However, the greater superimposition of the contractible protein filaments of the muscle that occurs progressively during the concentric phase seems to have significantly harmed the production of force in opposition to resistance, resulting in a recruitment of more motor units in the final half of this phase. Such circumstances seem to have been responsible for the increment of the EMG signal during this period of time.

These results support those of previous studies in which it was demonstrated that the RA muscle participates more during flexing movements of the spinal column performed with the subjects lying down, independent of having or not having their feet fixed; it was also observed that the intensity of the myoelectric signals increases in the medium phase of the exercise, that is, close to 45 degrees, and diminishes during the final flexing of the spinal column (Sheffield & Major, 1962; Walters & Partridge, 1957).

Bankoff and Furlani (1986) and Flint (1965) stated that abdominal muscles present more intense activation in the flexing movement of the spinal column performed while lying down, mainly between 30, 45 and 60 degrees independently of the position of the feet. In a study done with children, Moraes et al. (1995) verified that the RA and OE muscles present more accentuated activation close to this amplitude of movement between 45 and 60 degrees of flexing the spinal column.

In a recent study by Bressel et al. (2008) the goal was to enhance EMG activity of the abdominal muscles during a multi-joint squat exercise then verbal instructions may be more effective than increasing load intensity or lifting on an unstable surface. However,

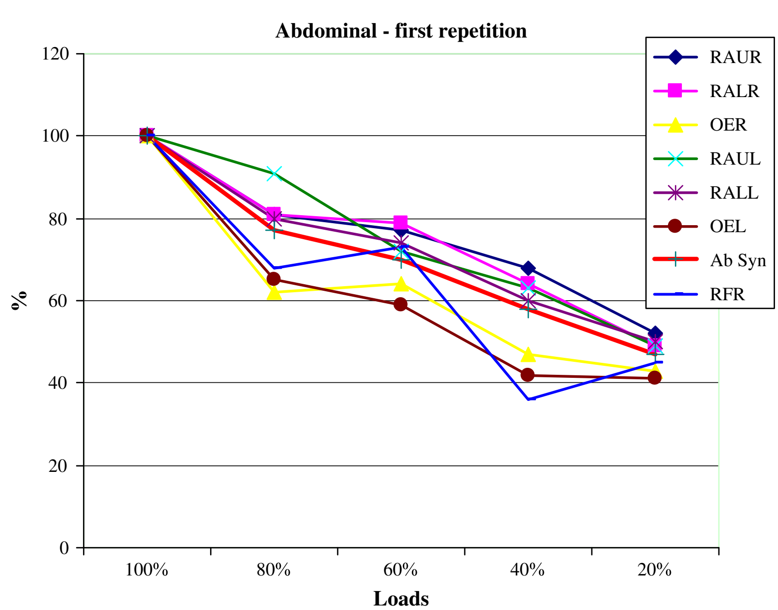

Fig. 3. Participation of the RA, OE and RF muscles while executing the "Crunch" exercise with different loads. Ab Syn refers to the overall work of the abdominal muscles.

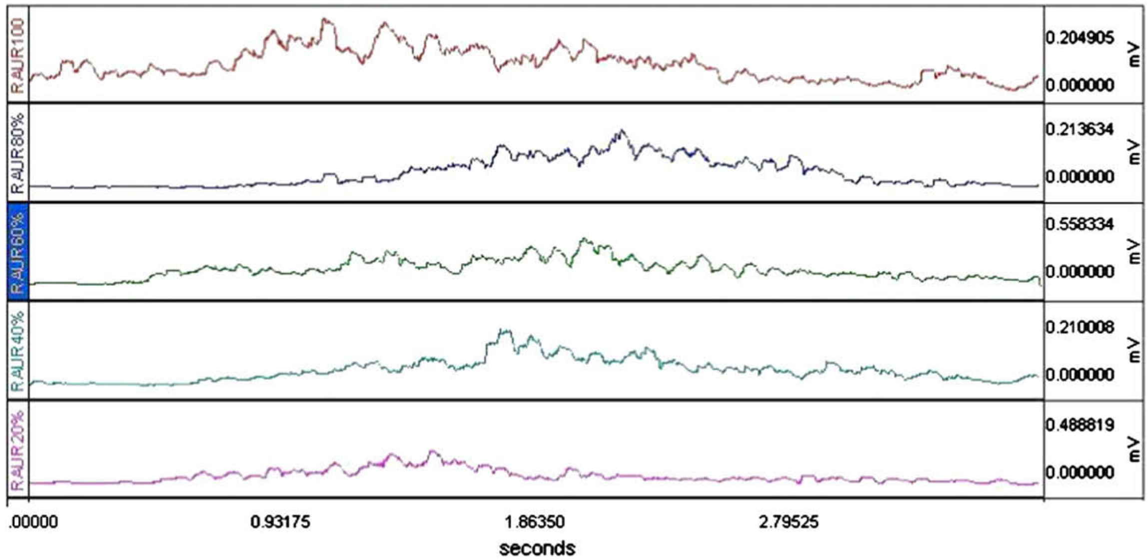

Fig. 4. Representative EMG signal register of the RA muscle (upper umbilical - right) in loads of 100%, 80%, 60%, 40%, 20%.

in light of other research, conscious co-activation of the trunk muscles during the squat exercise may lead to spinal instability and hazardous compression forces in the lumbar spine.

Among the muscles and muscular portions monitored, the RF was the muscle that presented less variability in EMG activity when the weight was progressively being increased, which is explained by the reduced amplitude of movement utilized in this experiment, even if this increase comes from the greater need for stability of the pelvis. The EMG activity presented by this muscle could be related to the sustentation of the inferior members and the consequent stabilization of the pelvis because of the fixation of the feet with the knees flexed at 90 degrees. It should be pointed out that, with loads equivalent to 60 and 80% of the 1-RM, the muscular work seemed to be more intense than in the other loadings.

According to Moraes et al. (2003), the utilization of loads in abdominal exercises accentuates the work of the RF muscle. Nevertheless, it should be pointed out that in this study the flexing of the trunk was more accentuated (60 degrees), which implies that the results differ from those of the present study where amplitude of movement of only 30 degrees was utilized, thus indicating that the value of 100% of muscle RF does not correspond to the maximum activation of the muscle but only to the maximum of activation of the muscle during the accomplishment of the exercise crunch, where RF muscle has a reduced action.

For Guimarães et al. (1991), it is probably the Rectus Femoris (RF) muscle that assumes the function of supporting the loads since the addition of weights. The position of the feet and knees does not interfere with the EMG intensity of the supra- and infra-umbilical regions of the RA muscle during exercises that flex the trunk. The difficulty verified in exercises performed on the inclined bench was probably due in large part to the intense activity of the flexors of the hip and nothing to do with the abdominal muscles. In the Study of Parfrey, Docherty, Workman, and Behm (2008) the foot fixation resulted in significantly lower activation levels of all abdominal sites and higher levels for the rectus femoris (RF) muscle.

In the study of Stevens et al. (2008) it was demonstrated that activity of the abdominal muscles increased during movements flexing the trunk with increasing resistance from 30, 50 and 70% of the mean maximal torque. However, the experiment was accomplished with the use of different equipment, as was used in this study and was accomplished with the exercise abdominal "crunch".

It was been verified that for the skeletal muscles in general, the addition of weights with adequate repetitions has proven to be efficient for reaching hypertrophy. To verify the adaptation of loads in the accomplishment of abdominal exercises it is necessary to give continuity in the research elaborating and applying a training program, which will be available after the publication of the data in this study.

The hypertrophy of the abdominal muscles has an important part in the maintenance and or modification of the posture and in the prevention of lesions on the lumbar column. The exercises that seek to invigorate the muscle, above all, those of the abdominal musculature should concentrate on the routine of the training programs independent of the age group. The invigoration of the abdominal muscles seems to be more determined by the amount of repetition than to the load applied, taking into account the architecture of the muscles (type, length and arrangement of the muscular fibers). However, a confrontation exists with other studies which presume to show that moderate repetitive loads build resistance, but it does not show here, while the most effective modality for building force is high load and low repetition.

5. Conclusion

Considering abdominal synergy as a representative measurement of the abdominal musculature, it can be determined that, with the exception of the 100% load of maximum repetition, no significant differences in intensity of abdominal activation were verified between each load and the load immediately above or below. These results suggest that for young adults, healthy and physically active similar to those studied in the sample, that when the objective is progression in the training process of abdominal force, the option ought to be for alterations of load superior to 20% of maximum repetition.

Conflict of Interest Statement

None.

Acknowledgement

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