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Article

Assessment of the Effectiveness of Vibration Therapy and Passive Rest on the Recovery of Muscular Strength and Plasma Lactate Levels in the Upper Limbs after Intense Anaerobic Exercise in Elite Boxers and Kickboxers

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Abstract: Background/Objectives: High-intensity anaerobic physical training frequently results in muscle damage among boxers and kickboxers, which can impede performance and recovery. Vibrational therapy (VT) and passive rest (PR) have been employed as methods to enhance muscular recovery and performance. This study evaluates the effectiveness of these two recovery methods on upper limb muscle strength and lactate levels in plasma after high-intensity exertion. **Methods:** Eighteen elite boxers and kickboxers, aged 19-32 years, underwent tests employing VT and PR as recovery methods in a controlled, crossover study. Muscle performance was assessed via isokinetic dynamometry, and lactate levels were measured pre-exercise, post-exercise, and post-recovery. The study adhered to the Declaration of Helsinki guidelines and was approved by the relevant bioethics committee. **Results:** The results showed that VT led to a faster recruitment of muscle fibers and improved muscle endurance as indicated by decreased fatigue work indices compared to PR. However, no significant differences were observed in peak torque or lactate levels between the two recovery methods. The VT group exhibited quicker recovery times in torque generation and better performance in fatigue resistance. **Conclusions:** VT appears to provide superior muscular recovery compared to PR following intense anaerobic effort, particularly in terms of muscle strength endurance and activation speed. These findings support the potential of VT in sports recovery protocols, although similar lactate response suggests that metabolic recovery rates are not significantly affected.

Keywords: vibration therapy; passive rest; muscle recovery; lactate levels; isokinetic dynamometry

1. Introduction

Physical training in boxers and kickboxers often results in muscle damage causing soreness and swelling, which leads to post-traumatic scarring and consequently reduces their performance and muscle strength. This condition is frequently a result of inadequate rest and biological regeneration necessary for proper muscle preparation for the next training session [1]. When recovery from the damage caused by physical activity is insufficient, the risk of injury increases, and difficulties arise in performing subsequent physical tasks [2], creating a barrier to continued physical engagement [3].

Achieving post-exercise muscle relaxation, associated with the removal of harmful by-products of energy metabolism and the restoration of motor potential, is a highly desirable and essential element of post-exercise recovery.

Currently, various methods are used in high-level sports to regenerate tired and damaged muscles during exercise. Properly selected biological regeneration shortens the individual phases and

accelerates the restitution process, allowing for greater exercise capacity due to the hypercompensation phase of the body's motor potential.

Vibrations, as a factor inducing strong mechanical stimuli in the neuromuscular system, skeletal tissues, and muscles, have been studied in medicine [3]. It is now known that whole body vibration (WBV) is used in sports training to increase muscle strength, as demonstrated by research from various scientists [4–6]. Authors [7–11] have also shown in their publications that vibrations are effective in alleviating muscle pain caused by physical exertion. Unfortunately, current studies provide limited information on how the reduction of muscle pain, especially from short-term intense physical exertion, correlates with the recovery and potential hypercompensation of muscle strength. The use of vibrations as an innovative post-exercise recovery method is becoming an important topic that is gaining increasing popularity [12].

Few authors who have applied vibration therapy after physical exercise report positive effects on muscle recovery [13], although these studies did not involve high-level athletes. On the other hand, there is information suggesting that using vibrations within 24 hours post-exercise may be detrimental to muscle strength loss and biological regeneration during this period. During vibration therapy, small muscle contractions occur, involving muscle lengthening and shortening. It is possible that the additional work required by the muscles during WBV may have prolonged the damage to the muscles, consequently increasing the loss of muscle strength [14]. This theory is supported by studies suggesting that increased muscle contractions lead to decreased muscle strength [15]. Other authors report that WBV does not aid muscle recovery post-exercise, as muscle damage changes the effectiveness of WBV as a recovery tool. They suggest that the excitation-contraction coupling is impaired after muscle damage, reducing calcium release, leading to an inability to activate force-generating muscle fiber structures. It has also been suggested that muscle injury from physical exertion reduces the sensitivity to stretch reflex and muscle stiffness, decreasing the mechanisms that enhance muscle strength [16].

The aim of this experiment was to assess and compare the impact of an original vibration therapy and passive rest on the compensation of upper limb muscle strength and plasma lactate levels after intense anaerobic exercise.

2. Materials and Methods

The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Bioethics Committee at the Regional Medical Chamber (No. 287/KBL/OIL/2020).

Participants

Participants in the study, aged 19–32, comprised an 18-member group of boxers and kickboxers, each holding at least a master class and a minimum of 8 years of training experience. The sample size was calculated using G*Power. All recruited athletes were free from upper limb injuries sustained within 6 months prior to the study date and had fully healed from any other injuries that could affect the results. The participants were in the active training phase during the preparatory period. Each participant had up-to-date medical examinations. Before the experiment began, the participants were informed about the study's purpose and procedure, their right to withdraw at any time, and each signed an individual consent form to participate.

Exclusion criteria included injuries in the past 6 months that could significantly affect upper limb functionality, lack of current medical exams, or lack of consent to participate in the study.

The 18 participants engaged in the study twice, serving as both the experimental and control groups, with group assignment determined by the type of biological regeneration applied (vibration therapy – experimental group, passive rest – control group). Fourteen athletes completed all the required trials. The characteristics of the study group are presented in Table 1.

Table 1. Somatic characteristics of the participants.

	Aver.	Min	Max	SD
BM [kg]	76.0	52	90	9.67
BH [cm]	178.3	165	189	7.77
BMI [mkg ⁻²]	23.9	18	28	2.66
Age [years]	23.0	19	32	5.81
Fat [%]	10.4	5	21	3.73
TBW [%]	62.9	56	67	3.04

Study Procedure

The study was conducted in the morning and divided into several stages.

Stage I

Initially, body height was measured to an accuracy of 0.01 m, body weight (accuracy of 0.01 kg), and body fat percentage using a Tanita scale. The resting plasma lactate level was then determined.

Stage II

Following preliminary measurements, a 15-minute individual standard warm-up for boxers and kickboxers was performed. Subsequently, the individual maximum punching strength was measured based on three punches with each upper limb with maximum force, with short breaks to adjust position. Accelerometric sensors attached to a boxing trainer and the participant’s boxing gloves were used for the measurement. The best result for each limb served as the baseline for determining the minimum punching force level for each upper limb in the main experiment.

Stage III

Next, the maximum strength capabilities were measured under isokinetic contraction conditions for the flexors and extensors of the elbow joints of both upper limbs at an angular velocity of $\omega=300^{\circ}\text{s}^{-1}$, using the Biodex v.4 according to protocol [17]. These measurements were used to calculate the muscle force moment generation indices for the elbow joint antagonists of both upper limbs.

Stage IV

This stage involved a muscle exertion phase designed to induce muscle fatigue. Boxers and kickboxers performed auxotonic exercises over three rounds, involving alternating 180 straight punches in each round using a boxing trainer over 120 seconds, at a pace set by a metronome, at no less than 80% of the maximum punching force individually determined for each upper limb. Efforts were monitored in real-time via an accelerometer application. Each round was separated by a 1-minute passive rest. Immediately after the physical exertion phase, maximum strength capabilities under isokinetic contraction conditions for the flexors and extensors of the elbow joints of both upper limbs were remeasured.

Stage V

For muscle biological regeneration, a post-exercise vibration massage of the upper limb muscles was conducted for 15 minutes, applying low-amplitude vibration stimuli with frequencies fluctuating between 20 to 50 Hz. These changes followed the algorithm of the LBV (Local Body Vibration) program, which defined the frequencies, amplitudes, and durations of stimuli and breaks. Seven LBV interventions were applied at level I intensity for 1 minute with 30-second breaks, separated by two 2-minute LBV interventions with increasing intensity from level I to II with a 30-second break. The experiment utilized a vibration therapy device designed by Vitberg, dedicated to vibrational impact on upper limb muscles. A vibrating mat with a vibrating module, covering the flexors and extensors of both elbow joints without repositioning during the procedure, was used. The device produced vibrations in the 20 to 50 Hz frequency range with an amplitude <0.5 mm. Participants underwent vibration therapy lying on their backs, in a relaxed position for the upper limb joints (shoulder joint at 0° , elbow joint at 0° , wrist joint in a relaxed slight palmar flexion).

Vibration was directed locally to the shoulder flexors and elbow extensors of both upper limbs. Immediately after vibration therapy, isokinetic tests from stage III were repeated.

After a 10-day break, an identical experiment concluded with a 15-minute passive post-exercise rest in a relaxed supine position, similar to the vibration therapy (passive recreation - PR). During both study phases, all participants were tested using the same measurement tools by the same personnel and identical procedures.

Plasma lactate levels were measured three times in each study: after warm-up, immediately post-exercise, and after vibration or passive rest. Fourteen participants completed all the experiments.

After recording and processing the data, a total of 44 biomechanical and physiological variables for four muscle groups (flexors and extensors of the elbow joint) were analyzed. The strength capabilities analysis included variables: PEAK TORQUE (PTQ), PEAK TQ/BW (PTQ/BW), TIME TO PEAK TORQUE (T_PTQ), WORK/BODYWEIGHT (WRK_BW), TOTAL WORK (TOT_WRK), WORK FATIGUE (WRK_FAT), AVG. POWER (AVG_POW), ACCELERATION TIME (T_ACC), DECELERATION TIME (T_DEC), AVG PEAK TQ (AVG_PTQ), AGON/ANTAG RATIO (AGN_ANT_RAT). Lactate levels (LA) were also measured in both groups at three study stages.

Relative values of the Rel. SBFT index [18] were used to compare loads in the exertion test.

Statistical Analysis Methods

Statistical analysis of the collected data was conducted using Statistica 13.3 (Tibeco). Basic descriptive statistics were calculated: mean, standard deviation, minimum, and maximum. After assessing the normality of variable distributions with the Shapiro-Wilk test and homogeneity of variances with the Levene test, repeated measures analysis of variance was performed to identify significant contrasts between studies (between-group analysis) using Tukey's post-hoc testing. A p-value of <0.05 was considered statistically significant.

3. Results

Peak Torque Dynamics (PTQ)

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

3.1. Peak torque dynamics (PTQ)

The application of vibration therapy (VT) resulted in improved dynamics of peak torque generation. The VT group achieved peak torque faster than the passive rest (PR) group, indicating quicker recovery of muscle contraction ability (Table 2, Figure 1). The mean time to reach peak torque (T_PTQ) was significantly shorter in the VT group, suggesting better muscle performance and faster response to training stimuli.

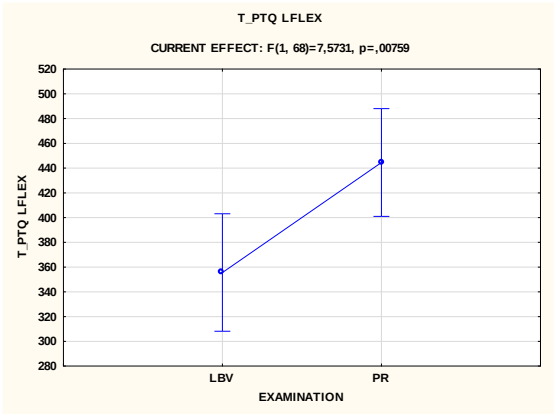


Figure 1. Time to reach peak PTQ in the LBV and PR groups.

3.2. Acceleration and reaction time

The acceleration time (T_ACC), measuring the speed at which muscles reach a set velocity, was significantly shorter in the VT group. This reflects a faster response and potentially more efficient recruitment of muscle fibers following vibration therapy, which could be crucial in sports requiring rapid muscle reactions (Table 2, Figure 2).

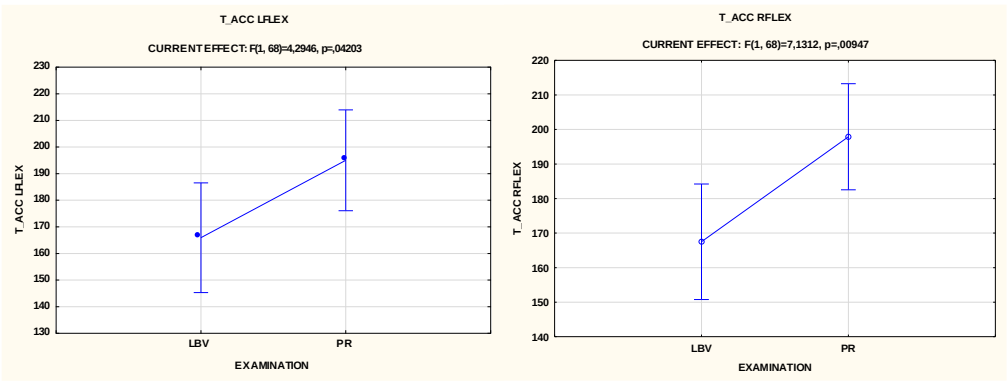


Figure 2. Acceleration time T_ACC in the LBV and PR groups.

3.3. Muscle work and fatigue

Muscle fatigue indices (WRK_FAT) indicated that the VT group experienced a lower rate of fatigue compared to the PR group. This suggests that VT contributes to better muscle endurance and maintains performance over time, mitigating the effects of fatigue during recovery phases (Table 2, Figure 3).

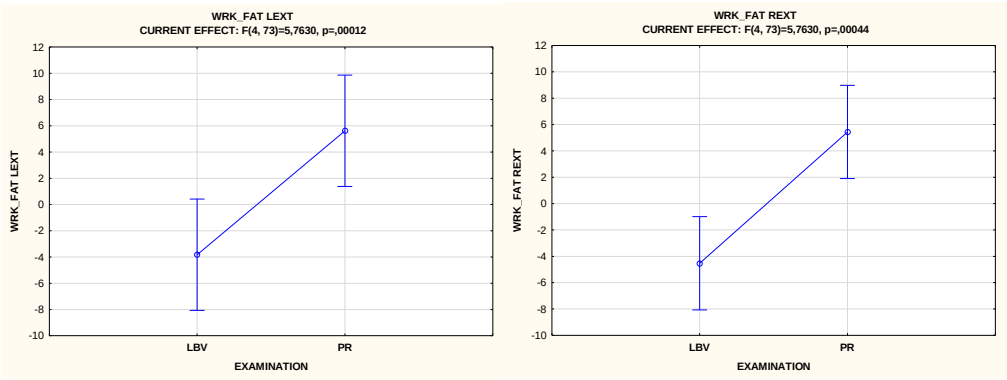


Figure 3. Work fatigue WRK_FAT in the LBV and PR groups.

3.4. Muscle strength balance

The agonist-to-antagonist ratio (AGN_ANT_RAT) was more favorable in the VT group. The improved ratio suggests a more symmetrical recovery of muscle groups, potentially reducing injury risk by maintaining better joint stability and muscle health (Table 2, Figure 4).

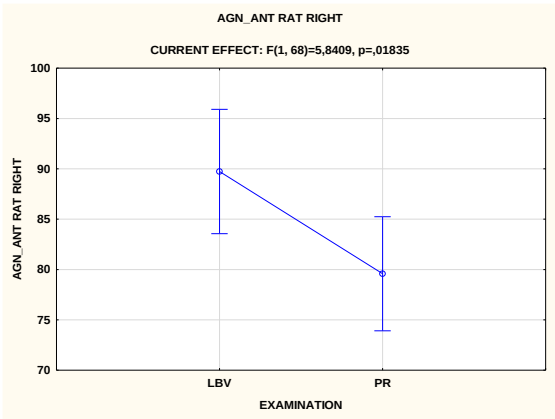


Figure 4. AGN_ANT_RAT ratio in the LBV and PR groups.

3.5. Total muscle work

Despite the observed benefits in other variables, the total work (TOT_WRK) performed by the muscles during the tests was slightly higher in the PR group. This may indicate that although VT improves certain aspects of muscle function, it does not necessarily translate into increased total work performed during the recovery phase (Figure 5).

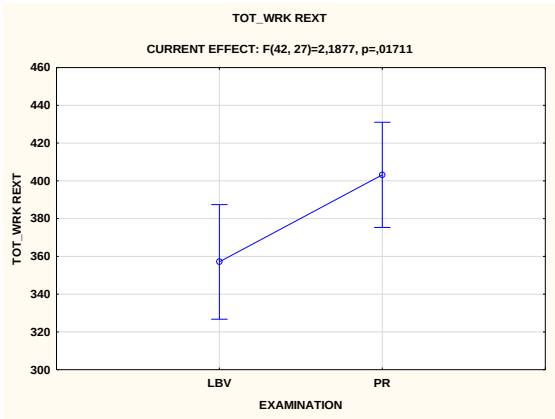


Figure 5. Total work TOT_WRK in the LBV and PR groups.

3.6. Physiological responses – Lactate levels

Lactate levels were measured to assess the metabolic response to both recovery methods. Although initial lactate levels post-exercise were comparable between groups, the VT group showed a more significant reduction in lactate levels after recovery, suggesting more efficient removal of metabolic by-products (Table 2, Figure 6).

Table 2. Descriptive statistics of the analyzed variables.

Variables	Average		P	Min		Max		SD	
	LBV	PR		LBV	PR	LBV	PR	LBV	PR
PTQ REXT [Nm]	56	58		32	34	85	79	11.1	11.0
PTQ LEXT [Nm]	58	60		29	30	88	88	14.9	14.7
PTQ RFLEX [Nm]	47	45		31	29	70	73	9.0	10.0
PTQ LFLEX [Nm]	45	46		28	30	64	69	9.0	10.1
PTQ_BW REXT [%]	74	77		50	59	95	96	9.9	9.4
PTQ_BW LEXT [%]	76	79		53	51	100	109	13.2	13.8
PTQ_BW RFLEX [%]	63	61		43	39	105	90	12.3	12.4

PTQ_BW LFLEX [%]	59	61		41	38	86	91	10.4	11.6
T_PTQ REXT [ms]	331	363		10	10	440	460	106.1	91.6
T_PTQ LEXT [ms]	353	347		10	160	790	440	116.8	66.1
T_PTQ RFLEX [ms]	347	405		60	190	610	660	137.3	126.0
T_PTQ LFLEX [ms]	364	444	0.00759	50	60	650	760	139.0	133.3
WRK_BW REXT [J]	88	96		61	66	118	127	14.0	16.5
WRK_BW LEXT [J]	90	96		62	59	122	130	17.5	17.9
WRK_BW RFLEX [J]	85	89		60	37	119	135	18.4	23.2
WRK_BW LFLEX [J]	87	89		57	41	117	170	18.9	24.7
TOT_VRK REXT [J]	360	402	0.01711	214	194	535	578	78.4	92.0
TOT_WRK LEXT [J]	372	401		205	234	621	637	107.6	103.7
TOT_WRK RFLEX [J]	364	381		197	144	553	615	100.5	115.0
TOT_WRK LFLEX [J]	374	377		199	168	598	596	107.0	112.5
AVG_POW REXT [W]	103	110		63	62	145	154	20.7	21.7
AVG_POW LEXT [W]	104	111		54	68	151	165	26.4	25.4
AVG_POW RFLEX [W]	103	99		58	34	152	157	24.8	29.6
AVG_POW LFLEX [W]	103	100		53	47	157	156	27.0	28.4
AVG_PTQ REXT [Nm]	51	54		29	31	80	76	11.6	11.2
AVG_PTQ LEXT [Nm]	52	55		27	28	84	84	14.9	14.3
AVG_PTQ RFLEX [Nm]	44	43		29	26	65	70	8.5	9.5
AVG_PTQ LFLEX [Nm]	42	43		25	28	63	64	9.2	9.3
T_ACC REXT [ms]	110	116		10	80	160	170	25.8	21.0
T_ACC LEXT [ms]	126	112		80	80	660	150	91.2	17.5
T_ACC RFLEX [ms]	172	197	0.00947	120	120	250	360	36.4	56.5
T_ACC LFLEX [ms]	173	195	0.04203	120	120	330	570	40.4	72.8
T_DEC REXT [ms]	238	233		140	180	430	350	62.7	37.8
T_DEC LEXT [ms]	246	232		180	180	460	370	59.0	41.8
T_DEC RFLEX [ms]	156	158		90	90	260	240	42.1	36.6
T_DECC LFLEX [ms]	160	169		100	90	290	260	39.6	39.3
AGN_ANT RAT RIGHT [%]	86	80	0.01835	57	56	136	117	17.2	17.9
AGN_ANT RAT LEFT [%]	80	80		57	49	137	117	17.6	15.1
LBV_WRK_FAT REXT [J/J]	- 4.5	5.4	0.0044	-31.2	- 34.2	26.0	32.4	11	11
LBV_WRK_FAT LEXT [J/J]	- 3.8	5.6	0.0012	-37.8	- 7.4	42.2	13.8	16	6
LBV_WRK_FAT RFLEX [J/J]	1.8	4.8		-26.8	- 13.9	20.8	24.2	10	7
LBV_WRK_FAT LFLEX [J/J]	5.3	5.1		-16.4	- 12.9	13.0	18.3	7	8
LA [mmol]	5.2	5.3		0.5	0.5	14.8	12.5	4.5	4.2
Rel. SBFT Index [bmp/Nkg ⁻¹]	2.42	2.42		2.02	1.99	3.66	3.49	0.44	0.42

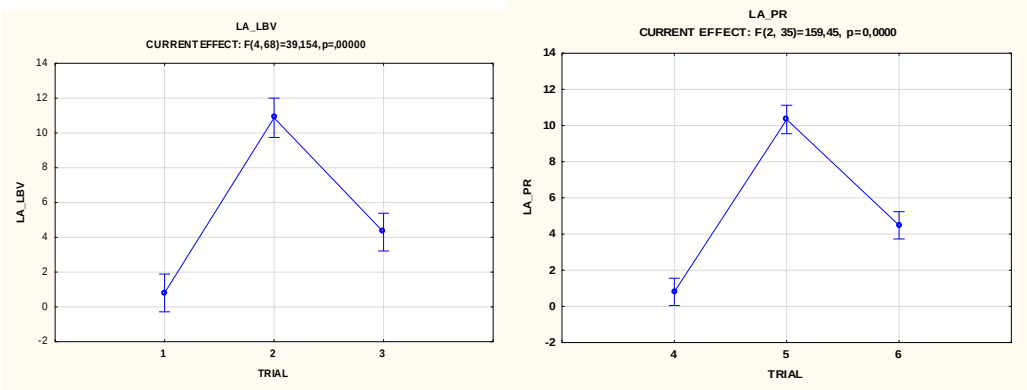


Figure 6. Lactate level measurements in blood plasma.

The results of lactate level measurements in the blood indicated similar, statistically insignificant average values obtained in both studies, in the LBV and PR groups. However, the serum lactate level differed significantly between individual trials in both studies at the level of $p < 0.001$. The lowest values in both groups were obtained in the initial measurement before exercise. Subsequently, the values increased significantly to above 10 mmol, then returned to minimally above 4 mmol after biological regeneration.

4. Discussion

The results of the studies conducted by Chapman, Barnes, Dabbs, and Chwała & Pogwizd indicate discrepancies in the presented views, allowing the conclusion that the authors did not always achieve improvements in the measured parameters after applying vibration therapy following exercise or during breaks between exercise sets [13-16]. This may be due to the fact that each study used different vibration frequencies and amplitudes. The studies also varied in terms of the duration and location of the vibration application, which undoubtedly could have significantly impacted the final effects of the therapy. However, recent studies have shown positive observations regarding the use of vibration as a superior form of intervention over passive rest in biological regeneration [11].

Whole-body vibration (WBV) treatments are an innovative form of intervention in the training process, and to date, only a few studies have examined the effect of combining different frequencies and amplitudes of vibration. As indicated by research [19], beneficial effects can be achieved by smoothly changing the frequency and amplitude of vibration applied during a WBV program. Similar methodologies have been used only in separate treatment cycles, comparing the effects of different frequencies and amplitudes on the achieved results. In most studies, authors utilized a strictly defined vibration stimulus (frequency, amplitude, acceleration) and examined its effect on measured variables.

Therefore, it seems reasonable to apply a vibration stimulus with variable frequency, amplitude, and duration, which will more effectively impact all types of muscle fibers and sensory receptors.

An essential condition for comparing the effects of varied interventions on the speed and effectiveness of biological regeneration is ensuring that the muscles of the study participants are fatigued to the same extent, in this case, during intense anaerobic exercise. When comparing loads in the exercise test, it should be noted that the relative values of the Rel. SBFT index [18] did not differ significantly between the LBV and PR groups. This indicates a similar level of fatigue in the flexor and extensor muscles of the elbow joints in both groups.

The use of dedicated vibrating mats allowed for localized vibration intervention in a comfortable resting position for the muscles controlling the upper limb joints, which could be significant for the relaxation and regeneration of muscles fatigued by exercise and its superiority over passive rest.

This is confirmed by the significantly shorter time to achieve peak torque (PTQ) for elbow flexor muscles in the LBV group compared to the PR group ($p < 0.01$) (Figure 1). TIME TO PEAK TORQUE - a measure of the time from the start of a muscular contraction to the point of highest torque development (Peak TQ). This value is an indicator of the muscle's functional ability to produce torque quickly. This variable illustrates the neuromuscular readiness to rapidly develop torque [20] and achieve maximum contraction [21]. A short T_PTQ time indicates a high level of proprioception in the joint area being studied.

A similar interpretation applies to the variable acceleration time (T_ACC), measured from the start of the movement to the moment of reaching the set speed during isokinetic contraction. The T_ACC variable for both the right and left limb flexors was significantly shorter in the LBV group compared to the PR group by 25 ms (RFLEX), $p < 0.01$ and 22 ms (LFLEX), $p < 0.05$ (Figure 2). Lower acceleration time values may indicate better recruitment ability of muscle fibers in the studied skeletal muscles and may be associated with shorter time needed to generate torque [21-23].

In our studies, besides faster recruitment of motor units in the muscle group after vibration intervention (LBV) compared to passive rest (PR), more favorable indices of strength endurance and muscle resistance to fatigue were also noted. The work fatigue (WRK_FAT) index, calculated as the ratio of the work performed by the muscles in the first 30% range of motion of all contractions to the

work performed during the last 30% range of motion in the entire trial, characterizes the state of muscle fatigue in subsequent repetitions of the isokinetic test. The index value for elbow extensor muscles was significantly higher in the PR group compared to the LBV group - the significance level for contrasts for the right limb $p < 0.001$ and for the left limb $p < 0.05$. Higher WRK_FAT values in the PR group indicate that the work performed in the first 30% of the contraction was significantly higher than in the last 30% range of motion, indicating faster muscle fatigue during this test. In the LBV group, the index values were negative, indicating greater strength endurance of muscles after recovery using vibration interventions compared to passive rest.

As Gillet et al. argue, the risk of injury may be related to the strength balance of antagonistic muscle groups that provide joint stability [24]. The variable AGN_ANT_RAT (agonist/antagonist ratio), calculated as the ratio of peak PTQ values (maximum torque of agonist muscles divided by the peak torque of antagonist muscles in the joint), is used by researchers to assess muscle balance. This index is important for evaluating muscle function [25,26]. Researchers indicate that the value of this index depends on age, sex, and training level [27]. Comparing the results of our studies regarding this index in the LBV and PR groups, it should be noted that a significantly higher AGN_ANT_RAT index was recorded in the LBV group for the right upper limb, which for all subjects was the dominant limb ($p < 0.05$). The corresponding index for the left upper limb did not show significant differences.

Another variable that showed significant contrasts between the LBV and PR groups was the total work (TOT_WRK) performed by the muscles during all movements in the isokinetic test. The total work value recorded in the PR group for the right elbow extensor was significantly higher by approximately 42 W compared to the analogous variable in the LBV group ($p < 0.05$). As shown above, the elbow extensor muscles performed most of the work in the first 30% of isokinetic contractions, which proved decisive for higher TOT_WRK values. The left elbow extensors also performed more work on average by about 28 W, but the differences were not statistically significant ($p < 0.05$).

Other variables, including the maximum torque levels (PRQ) and their relative values (PRQ_BW), despite some differences between the mean values in both groups, did not show significant contrasts at $p < 0.05$. In summary, it can be concluded that the type of post-exercise muscle recovery used did not significantly affect strength capabilities, but significantly differentiated the speed of motor unit recruitment and strength endurance in the group with proprietary vibration intervention compared to passive rest.

5. Conclusions

The use of post-exercise vibration intervention with variable amplitude and frequency had a more favorable effect on the biological regeneration of elbow joint muscles in the LBV group compared to PR.

The vibration intervention applied after intense anaerobic exercise positively affected the time, acceleration of recruitment, and strength endurance of motor units.

No significant differences were noted in the level of maximum and relative torque between the two groups.

Lactate levels (LA) in both studies were similar at various time points of the experiments, but significantly differed between trials in both groups. After anaerobic exercise, LA significantly increased from baseline values and then significantly decreased following biological regeneration.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Bioethics Committee at the at the Regional Medical Chamber (No. 287/KBL/OIL/2020).

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

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

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

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