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Research Article

Neuromuscular and Muscular-Skeletal Modulations as the Antiaging Strategy of Physical Adaptation in non-communicable Diseases

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Abstract

Introduction: The current scientific medical concept considers ageing as a disease, thus medical and bioregenerative antiaging strategies can significantly delay the development of age-related diseases. Of them, arterial hypertension, as well as other dysfunctions of the cardiovascular system, are the leading risk factors for premature death. Together with conventional preventive protocols of hypertension, bioregenerative technologies can eliminate such risks seriously. Regular physical exercises, such as walking, climbing stairs, or gardening, could be stressful for individuals with hypertension and metabolic disorders. To improve their condition, repair the heart tissue and attenuate endothelial dysfunction, new bioregenerative technologies are implemented. These methods include but are not limited to cellular therapy, mitochondrial medicine, nanomized peptides, exosomes, cell membrane harmonization, etc. Also, physical activity modification could have an important impact on cardiovascular health.

Materials and Methods: This study targeted eighty-eight male and seventy-one female individuals, a total of 159, diagnosed with arterial hypertension (systolic BP ≥ 130 mmHg and/or diastolic BP ≥ 80 mmHg). The unique physical exercise protocol aimed at neuro-muscular and muscular-skeletal activation was elaborated. Each exercise utilized concentric, eccentric, and isometric muscle contractions to improve strength, stability, and posture in a seated position, while also regulating blood circulation through muscle function, supporting blood pressure and heart rate. The data analysis involved using paired t-tests to compare pre- and post-exercise measurements of systolic BP, diastolic BP, and heart rate.

Results: Males had slightly lower systolic BP and diastolic BP, with a more consistent range, while females exhibited higher maximum systolic BP and more variability. Heart rates were similar between genders. Results: Comparing the pre- and post-procedure parameters, males had significant reductions in systolic BP (11 mmHg on average by 11-12 minutes, $p < 0.05$). Females also had significant reductions (13 mmHg on average by 11-12 minutes, $p < 0.05$). Patients showed significant decreases in systolic and diastolic BP, confirming that neuromuscular activation exercises help regulate BP during physical activity. Also, neuromuscular and musculoskeletal exercises caused short-term fluctuations in heart rate, but they did not lead to sustained changes.

Conclusions: This study supports the hypothesis that neuromuscular and musculoskeletal activation exercises reduce systolic BP during light to moderate physical activities. Also, this study partially supports the hypothesis that heart rate is not stabilized during light to moderate activities. Thus, neuromuscular and muscular-skeletal modulations, as an important part of lifestyle modification, are effective components of the bioregenerative approach for cardiovascular-compromised patients. Lifestyle modification (physical concentric, eccentric, and isometric muscle contractions) combined with other regenerative techniques like mitochondrial therapy, peptides and exosomes could help to achieve better clinical and morphological improvements. Further studies on these combinations are necessary.

Keywords: Bioregenerative medicine, Cardiovascular health, Hypertension, Mitochondrial therapy, Physical activity

Introduction

Aging as a holistic biological process affects almost all systems and organs of the body. According to the concepts of medicine of the late 20th - early 21st century, the aging process is considered as a disease, since its occurrence and rate of development are determined by genetic factors, environmental influences and lifestyle. In addition, medical and bioregenerative strategies can significantly delay the development of aging. Thus, antiaging is one of the promising trends in medicine aimed at preventing disorders and restoring the functions of all organs and systems of the body [1-3].

Arterial hypertension and dysfunction of the cardiovascular system as a whole are the leading components of the risk factors for premature and sudden death. Uncontrolled hypertension causes secondary morphological and functional changes in kidneys, lungs, coronary and brain arteries. It also can cause the life-threatening conditions such as acute myocardial infarction, stroke, etc. The protocols for the prevention and treatment of hypertension developed by the European Society of Cardiology and the American Heart Association allow for drug-based control of target blood pressure [4-42].

In contrast, the bioregenerative approach is aimed to the prevention of the development of hypertension. In most situations, this strategy does not require taking medications. It involves lifestyle modification (quitting smoking, salt intake limitation, getting enough rest at night, high-quality sleep, calculating the amount of calories consumed in food in accordance with daily physical activity) [4,27,33,43,44,46]. In general, study of the influence of the above factors (separately and in combination) on blood pressure can serve as an assessment of their effectiveness as an anti-aging strategy.

The human body, when healthy, can typically manage routine physical tasks with ease. Simple activities such as walking, climbing stairs, or carrying groceries generally do not cause significant stress to the body's physiological systems [46]. During these tasks, heart rate and blood pressure remain within normal, healthy ranges, indicating that the body efficiently manages these demands without overexertion [2,33].

However, individuals with non-communicable diseases (NCDs) such as hypertension, diabetes, and cardiovascular diseases often face disruptions in their body's ability to regulate these processes, leading to imbalances in blood circulation, heart rate, and blood Such disturbances make it difficult to perform even the simplest physical activities, which can significantly affect the individual's quality of life [3,32,47-77].

Neuromuscular and musculoskeletal activation exercises, including concentric, eccentric, and isometric exercises, could be a potential solution to help individuals with NCDs regain control over their heart rate and blood pressure while promoting physical adaptation to everyday physical exertion. Lack of stability in cardiovascular function impedes their ability to engage in regular exercise routines, which in turn limits their physical adaptation and hinders their overall recovery process. Neuromuscular and musculoskeletal activation exercises, which focus on enhancing neuromuscular control and cardiovascular stability, have been proposed as a potential intervention to help regulate these physiological responses, thereby improving physical adaptation and enabling individuals with NCDs to safely participate in physical activities [5,26,30].

European Wellness Biomedical Group implemented the bioregenerative technology of the prevention and treatment of non-communicable diseases, e.g., arterial hypertension. As a first-line strategy, lifestyle modification is recommended to all patients. Physical activity, cell membranes rejuvenation (phospholipid therapy by Alfa PlaqX oral and intravenous interventions), replacement of the damaged mitochondria (mitochondrial organelles peptides), organ-specific nanomized organo peptides, and anti-inflammatory plant-based bioactive molecules are essential part of the primary antiaging program. For muscle tissue and cardiovascular system repair, European Wellness clinics professionals use widely natural bioingredients including but not limited to peptides, cell extracts, tissue- and organ-specific ingredients manufactured with specific pathogen free technologies, which are recognized worldwide as a golden standard of the safety in bioregenerative medicine.

NCDs are responsible for a significant reduction in physical independence and quality of life [77-79]. This study explores how neuromuscular and musculoskeletal activation exercises can be utilized to stabilize heart rate, regulate blood pressure, and enhance the recovery and adaptation process for individuals living with NCDs. This study is aimed to determine whether neuromuscular and musculoskeletal activation exercises can improve physical adaptation, blood pressure control, and heart rate stabilization during light to moderate physical activities in individuals with NCDs.

Materials and Methods

This study adopts a quantitative research design utilizing a pre-test/post-test methodology to assess the effects of neuromuscular activation exercises (NMAEs) on cardiovascular stability, physical adaptation, and recovery in individuals with NCDs. The pre-test/post-test approach allows for tracking changes in blood pressure, heart rate, muscle endurance, strength, and recovery over time, providing a comprehensive understanding of how specific exercise parameters impact these outcomes [76].

The study targeted eighty-eight male and seventy-one female individuals, totally 159, diagnosed with hypertension, a condition linked to an increased risk of cardiovascular disease and metabolic disorders [26,47]. Both male and female participants are included in the study.

Inclusion Criteria

i. Adults aged 18 and older diagnosed with hypertension according to *Whelton, et al.* (2018) criteria: systolic blood pressure ≥ 130 mmHg and/or diastolic blood pressure ≥ 80 mmHg.

ii. Individuals with both primary (essential) and secondary hypertension are eligible. This approach ensures a more representative sample that reflects the varying underlying causes of hypertension, as well as its association with cardiovascular events like heart disease and stroke [32].

Exclusion Criteria

i. Pregnant or breastfeeding individuals.

ii. Those with severe psychiatric conditions, advanced diseases (e.g., cancer, organ failure), or currently participating in conflicting clinical trials [32].

iii. Individuals with musculoskeletal or neurological disorders that could interfere with exercise performance or recovery.

These exclusion criteria ensure that the participants were physically capable of engaging with the exercise protocol, reducing confounding variables and focusing on those who can fully participate in the study.

Phase 1 Intervention: Pre-Data Collection and Procedure

Participants were seated and given a detailed briefing on the study's objectives, procedures, eligibility criteria, and potential risks, followed by an opportunity for questions and informed consent. After a 10-minute rest period for cardiovascular stabilization, baseline blood pressure was measured [1,60]. After that, anthropometric data were recorded, and body composition was assessed using bioelectrical impedance analysis (BIA). Finally, participants performed a practice session of the prescribed exercise routine, consisting of four exercises, to assess their ability to safely execute the exercises without musculoskeletal injury, with guidance provided as necessary.

To ensure accurate baseline cardiovascular measurements, participants must refrain from consuming food or stimulant-containing beverages (e.g., caffeine, energy drinks) for at least two hours prior to data collection. This precaution is based on research showing that substances like caffeine can temporarily elevate heart rate and blood pressure, which could distort baseline readings [31,75]."Participants who do not comply were excluded to prevent confounding effects, ensuring that the data accurately represents their baseline cardiovascular state.

The Modified Rating of Perceived Exertion (RPE) scale was used to monitor exercise intensity, a well-validated tool for assessing subjective exertion [9]. Participants were educated on how to assess their exertion during exercise, aiming for an RPE score between 2 and 4, corresponding to light-to-moderate intensity levels. This intensity range promotes neuromuscular and musculoskeletal activation while minimizing the risk of fatigue and injury [14,40].

Exercise intensity was closely monitored by the practitioner, who provided real-time feedback through two-way communication, along with observing the participant's breathing rate, facial expressions, and movement quality, ensuring they remain within the prescribed intensity zone.

If participant exceeded a RPE of 4 or exhibit signs of overexertion (e.g., labored breathing, distressed facial expressions, or unstable movement patterns), the exercise was immediately stopped to safeguard the participant's health and well-being.

A 10-minute rest period preceded the blood pressure measurement to ensure cardiovascular stabilization, as supported by existing literature for accurate baseline readings [1,60]. Blood pressure was measured using an automated cuff system, which ensures consistent and reliable readings, minimizing inter-observer variability [36]

After blood pressure measurement, anthropometric data (height) was recorded using a height scale. Body composition (weight, fat-free mass, skeletal muscle mass, body fat percentage, lean mass) was assessed using bioelectrical impedance analysis (BIA), adhering to standardized protocols to ensure consistency and accuracy [74].

Participants performed all four exercises in the prescribed routine, with their ability to safely complete each exercise assessed. Particular attention was paid to cardiovascular and musculoskeletal health [16,73]. If any exercise causes overexertion or reduces the range of motion by 60% (i.e., incomplete muscle contraction), the exercise was removed from the study to minimize risk [11].

Phase 2 Intervention: Neuromuscular Activation Exercise

The exercise routine estimated 12 minutes of total 4 exercise with the aims to enhance muscle endurance, strength, and recovery. Every exercise involved concentric, eccentric and Isometric contractions are particularly effective for neuromuscular adaptation as they engage both slow-twitch (Type I) and fast-twitch (Type II) muscle fibers [28,56]. This approach was focused on optimizing muscle engagement, which contributes to improved overall physical health and neuromuscular efficiency [28,72].

Participants performed 2 sets of 8 repetitions for each exercise, with each repetition involving an 8-second isometric hold. Research has demonstrated that holding each contraction for 8 seconds is effective for targeting fast-twitch muscle fibers, which are essential for strength and power development [20,39]. This duration is optimal for enhancing muscle performance and promoting muscular adaptations [28].

Exercise intensity was maintained within an RPE range of 2-4, representing a light-to-moderate intensity level. This intensity ensured sufficient neuromuscular activation while preventing excessive fatigue, which could interfere with recovery and long-term adaptation [38,8]. This intensity level is effective for neuromuscular activation and promoting endurance without compromising recovery [38].

Rest intervals between sets were 60-90 seconds to allow for optimal recovery of motor units, ensuring that each set was performed at an effective intensity [15]. Importantly, there were no rest between exercises; participants completed each set of four exercises consecutively. This approach helps maintain intensity and promotes muscle endurance and recovery [8].

Phase 3 Intervention: Exercise Routine

The exercise routines in this study focused on strengthening and stabilizing muscles through various seated movements that target specific muscle groups. (Routine 1) featured movements such as the Seated Alternate Knee Tuck & Ankle Flexion, engaging the core, hip flexors, and abdominals through controlled knee lifts and ankle flexion, with isometric holds for core stability [29,34]. (Routine 2), the Seated Chest Fly & Handgrip, emphasized the forearm flexors, trapezius, rhomboids, and latissimus dorsi, focusing on grip strength and shoulder stability with movements like handgrip squeezing and outward arm openings [12,25]. (Routine 3), the Seated Alternate Leg Extension & Ankle Flexion, strengthened the quadriceps and tibialis anterior, while also working the core and hip flexors during knee extensions and ankle flexion holds [66]. Lastly, (Routine 4), the Seated 180 Front Raise targeted the deltoids, trapezius, and core muscles to enhance shoulder stability and upper body posture, incorporating controlled upward arm movements and core engagement [25,34]. Each movement utilized concentric, eccentric, and isometric muscle contractions to improve strength, stability, and posture in a seated position, while also regulating blood circulation through muscle function, supporting blood pressure and heart rate [41,53].

Routine 1: Seated alternate knee tuck & ankle flexion.

Movement 1: starting position with both arms on top of shoulders.

Movement description: Sit in a chair with your feet flat on the ground. Keep your back straight and your chest lifted. Place both arms across your chest or rest your hands on top of your shoulders to help stabilize the upper body.

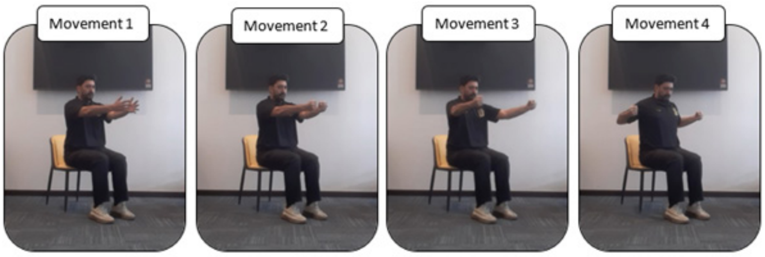
Muscle contraction: concentric: none; eccentric: none; isometric: engage the core muscles, especially the abdominals and obliques, as well as the shoulders, to maintain a stable posture [49].

Movement 2: knee lift, ankle flexion, and knee tuck.

Movement description: Slowly lift one knee towards your chest while simultaneously flexing your ankle (pointing toes upward). Bring the knee toward your chest and tuck it as close as possible to your abdominal region. Hold this position for 8 seconds to fully engage the muscles. Afterward, return the leg to the starting position and repeat with the other leg to complete one repetition.

Muscle contraction: concentric: the hip flexors (iliopsoas, rectus femoris), quadriceps, and abdominal muscles (rectus abdominis) contract concentrically as the knee is lifted and tucked toward the chest; eccentric: as you lower the knee, the hip flexors, quadriceps, and abdominals lengthen eccentrically to control the movement; isometric: the abdominal muscles (especially the rectus abdominis and obliques) engage isometrically to stabilize the trunk and prevent backward leaning [44,51,52,67].

Repeat this movement alternately for both legs. Right and left knee tucks together count as one full repetition.



Routine 2: Seated chest fly & handgrip.

Movement 1: Starting Position and Handgrip Open

Movement description: begin in a seated, upright position. Position your hands open with palms facing each other, keeping the arms at shoulder height or slightly in front of the body.

Muscle contraction: concentric: none; eccentric: none; isometric: light isometric contraction in the forearm flexors to maintain the open hand position. The latissimus dorsi stabilizes the torso and prevents excessive rounding of the back [70].

Movement 2: Starting Position and Squeezing Handgrip (50-80%)

Movement description: squeeze the handgrip with 50-80% of your maximum strength based on individual capabilities and comfort.

Muscle contraction: concentric: The forearm flexors (e.g., Flexor Digitorum Superficialis) concentrically contract to initiate the squeeze; eccentric: none; isometric: the forearm flexors engage to maintain the grip. The trapezius, rhomboids, and latissimus dorsi stabilize posture and prevent slouching [55].

Movement 3: Open Your Hands to Shoulder Width

Movement description: gradually open the arms outward to shoulder-width while maintaining the handgrip.

Muscle contraction: concentric: the pectoralis major and deltoids concentrically contract to move the arms outward. The latissimus dorsi stabilizes the shoulder girdle; eccentric: none; isometric: forearm flexors continue to engage to maintain the grip, while the trapezius, rhomboids, and latissimus dorsi stabilize the shoulder blades [65].

Movement 4: Pull Arms Back and Outward, Hold for 8 Seconds

Movement description: pull the elbows backward and outward until the thumbs align with the chest. Hold this position for 8 seconds while maintaining the handgrip.

Muscle contraction: concentric: the pectoralis major, deltoids, and latissimus dorsi concentrically contract to pull the arms backward and outward. The rhomboids and trapezius stabilize the shoulder blades; eccentric: the pectoralis major, deltoids, and latissimus dorsi eccentrically contract to maintain the position, preventing the arms from swinging forward; isometric: the pectoralis major, forearm flexors, latissimus dorsi, trapezius, and rhomboids engage isometrically to hold the position for 8 seconds [62].

Routine 3: Seated alternate leg extension & ankle flexion.

Movement 1: starting position with both arms on top of shoulders.

Movement description: sit in a chair with your feet flat on the ground, back straight, and chest lifted. Place both arms across your chest or on top of your shoulders to stabilize the upper body.

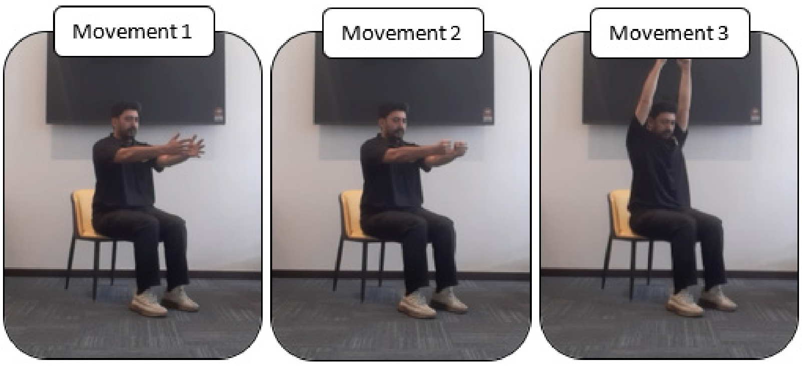
Muscle contraction: concentric: none; eccentric: none; isometric: the core (especially the abdominals and obliques) and shoulders engage isometrically to stabilize the body and maintain an upright posture [49].

Movement 2: Swing Knee Forward (knee extension) and Ankle Flexion with 8-Second Hold

Movement description: extend one leg straight out in front of you (knee extension), ensuring both thighs are parallel and at the same height. Simultaneously, flex the ankle by pulling the toes upward toward your shin. Hold the extended position for 8 seconds, maintaining the leg straight and the ankle flexed. Return the leg slowly to the starting position. Repeat with the other leg to complete one full repetition.

Muscle contraction: concentric: the quadriceps contract concentrically to extend the knee, and the tibialis anterior contracts concentrically to flex the ankle [49,78]; eccentric: as you lower the leg, the quadriceps and tibialis anterior lengthen eccentrically to control the return movement [7]; isometric: the core muscles (especially the abdominals and obliques) engage isometrically to maintain an upright posture. The hip flexors work isometrically to support the extended leg during the hold [49].

Repeat the movement alternately for both legs. Right and left knee extensions together count as one full repetition.



Routine 4: Seated 180 front raise.

Movement 1: starting position and handgrip open.

Movement description: Begin seated, with your hands open and palms facing each other, arms at shoulder height or slightly in front of the body.

Muscle contraction: concentric: none; eccentric: none; isometric: light isometric contraction in the forearm flexors to maintain the open hand position. The latissimus dorsi stabilizes the torso, and the erector spinae and rhomboids engage to help maintain an upright posture [50,65].

Movement 2: Starting Position and Squeezing Handgrip (50-80%)

Movement description: Squeeze the handgrip with 50-80% of your maximum strength based on comfort.

Muscle contraction: concentric: the forearm flexors contract concentrically to initiate the squeeze; eccentric: none; isometric: forearm flexors engage to maintain the grip. The trapezius, rhomboids, latissimus dorsi, and erector spinae stabilize posture to prevent slouching and maintain an upright position [55,61].

Movement 3: Swing Both Arms Upward, Elbows Locked Straight

Movement description: swing both arms upward, elbows locked straight, performing a 180-degree motion until the arms are fully extended and parallel to the ears. Focus on controlled movement, avoiding momentum, while ensuring the arms remain straight throughout.

Muscle contraction: concentric: deltoids (especially anterior and middle fibers) contract to lift the arms upward. The trapezius and serratus anterior assist in stabilizing the shoulder blades; eccentric: none; isometric: core muscles (rectus abdominis, obliques, erector spinae) maintain an upright posture, preventing leaning or torso swaying. Latissimus dorsi, rhomboids, and trapezius stabilize the shoulder girdle during the arm movement [58, 70].

Phase 4 Intervention: Post-Data Collection & Procedure - Post-Exercise Recovery Monitoring

After participants completed their exercise routine, they remained seated to undergo post-exercise monitoring. Blood pressure (BP) and heart rate (HR) were recorded at five distinct recovery phases, with measurements taken at intervals starting at 3 minutes post-exercise and then every 2 minutes thereafter. BP measurements were initiated at the beginning of each recovery phase. This procedure was designed specifically for individuals performing exercise at a Modified Rating of Perceived Exertion (RPE) of 4 or lower, reflecting light-to-moderate exercise intensity. At this intensity, the physical strain remained relatively low, leading to a less intense recovery response compared to higher-intensity exercises [23].

Recovery Phases

Phase 1: Immediate recovery (3-4 minutes post-exercise). Immediately following the exercise, BP and HR remained being elevated as the cardiovascular system worked to clear metabolic by-products such as lactate and carbon dioxide, which were produced even during light-to-moderate intensity exercise. The body began to gradually return to a more normalized state, with a gradual decline in BP and HR. These responses were observed as the system adapted to the recovery phase [24,57].

Phase 2: Early recovery (5-6 minutes post-exercise). During this phase, BP and HR began to decrease as parasympathetic nervous system activity increased. The low-to-moderate exercise intensity (RPE 4 and below) resulted in quicker parasympathetic activation, aiding in a more rapid decline in both BP and HR. This phase marked the transition from the heightened stress of physical exertion to a more relaxed state, signaling the beginning of the recovery process [45,57].

Phase 3: Mid-recovery (7-8 minutes post-exercise). At this stage, BP and HR were generally approach baseline levels. The moderate intensity of the exercise ensured a quicker recovery compared to higher-intensity exercises. With moderate metabolic demands, the cardiovascular system efficiently returned to its resting state, reflecting a smooth transition back to homeostasis [24,57].

Phase 4: Late recovery (9-10 minutes post-exercise). By this point, BP and HR may remained slightly elevated but were significantly lower than during the immediate post-exercise phase. The body was still adjusting, and these minor elevations reflected the final cardiovascular adjustments. Despite these slight increases, substantial reductions in BP and HR had already occurred, signaling the body is nearing full recovery [45,57].

Phase 5: Near-Full Recovery (11-12 minutes post-exercise). In the final phase, BP and HR returned to baseline levels, indicating the body has fully recovered. The lower intensity of the exercise (RPE 4 and below) facilitated a faster recovery process compared to more intense activities. By this phase, the cardiovascular system has successfully restored homeostasis, and physiological markers returned to pre-exercise levels, signaling the completion of [13,45,57].

These stages were designed to help researchers and practitioners observe the gradual physiological responses that occur during recovery after low-to-moderate intensity exercise. Understanding these stages is crucial for designing effective recovery strategies and interventions.

Data Analysis

The proposed data analysis involved using paired t-tests to compare pre- and post-exercise measurements of key physiological variables such as systolic blood pressure, diastolic blood pressure, and heart rate [48]. The analysis calculated the mean baseline value (paired t test) of difference and percentage change between pre and post intervention measurements using the formula:

Percentage Change = (Post Value − Pre Value) / Pre Value × 100

Ref: [63]

A negative percentage indicated a decrease, while a positive percentage indicates an increase. Statistical significance was evaluated using a two-tailed p-value, with values less than 0.05 considered statistically significant [17,48]. The paired t-test is an appropriate choice for comparing measurements from the same group before and after an intervention, assuming that the data are normally distributed [48]. The results provided insights into the physiological effects of the exercise intervention, contributing to understanding how it influences cardiovascular health [69].

Results

As it is shown in (Tables 1,2), males tended to have higher body weight, fat-free mass, skeletal muscle mass, and lower body fat percentage compared to females, reflecting typical gender differences in body composition. Males were also taller on average.

Table 1: Male Descriptive Statistic: Anthropometry and Body Composition (N=88).

	Age (yrs. old)	Standing height (cm)	Body weight (kg)	Fat free mass (kg)	Skeletal muscle mass (kg)	Percentage body fat (%)
Highest	78	196	113.1	73.5	43.5	53.2
Average	55	167.2	76.3	54.1	29.8	28.5
Lowest	17	144	51.1	33.9	18.1	3

Standard Deviation (SD)	11.8	8.7	12.9	8.2	4.9	7.5

Table 2: Female Descriptive Statistic: Anthropometry and Body Composition (N=71).

	Age (yrs. old)	Standing height (cm)	Body weight (kg)	Fat free mass (kg)	Skeletal muscle mass (kg)	Percentage body fat (%)
Highest	85	173	138	61.5	34.3	55.4
Average	55	155.5	67	41.1	22.1	37.5
Lowest	21	142	38.2	25	12.4	10.5
Standard Deviation (SD)	11.26	6.52	16.06	6.52	3.92	7.59

In terms of blood pressure (Tables 3,4), males had slightly lower systolic and diastolic pressures on average, with a more consistent range, while females exhibited higher maximum systolic pressures and more variability. Heart rates were similar between genders, but males had slightly lower average heart rates. Overall, both genders showed significant variability in blood pressure and heart rate, but males tended to have more stable body composition and blood pressure measures, while females exhibit higher extremes in systolic blood pressure and heart rate variability.

Table 3: Male Descriptive Statistic: Blood Pressure Monitoring.

Time Frame	Pre			Post 3 - 4 Minutes			Post 5 - 6 Minutes			Post 7 – 8 Minutes			Post 9 - 10 Minutes			Post 11 - 12 Minutes		
	SYS	DIA	HR	SYS	DIA	HR	SYS	DIA	HR	SYS	DIA	HR	SYS	DIA	HR	SYS	DIA	HR
Highest	168	109	102	167	109	114	168	108	105	157	108	107	161	100	108	153	104	102
Average	138	85	74	135	83	77	132	82	76	129	82	76	128	81	75	127	80	75
Lowest	101	62	43	100	57	46	102	62	45	104	57	47	108	59	47	104	57	48
Standard Deviation (SD)	12.1	8.8	12	12.8	8.4	12	12.8	8.4	10.8	11	8.3	10.9	11.3	8.2	10.9	11.4	8.1	10.2

Note: Systolic - SYS (mmHg), Diastolic - DIA (mmHg), Heart Rate (bpm) (N=88).

Table 4: Female Descriptive Statistic: Blood Pressure Monitoring.

Time Frame	Pre			Post 3 - 4 Minutes			Post 5 - 6 Minutes			Post 7 – 8 Minutes			Post 9 - 10 Minutes			Post 11 - 12 Minutes		
	SYS	DIA	HR	SYS	DIA	HR	SYS	SYS	DIA	HR	SYS	DIA	HR	DIA	SYS	DIA	HR	SYS
Highest	196	124	97	184	125	107	180	119	105	184	114	109	184	111	106	178	113	103
Average	140	83	73	133	80	75	130	80	74	128	79	74	127	78	73	127	78	73
Lowest	112	69	56	108	63	58	109	64	59	107	62	56	106	63	55	102	64	55
Standard Deviation (SD)	14	8.7	9	15.2	9.7	71.5	13.9	9	8.9	13.5	8.7	9.3	13.5	8.4	9.5	12.9	7.6	8.7

Note: Systolic - SYS (mmHg), Diastolic - DIA (mmHg), Heart Rate (bpm) (N=71).

The comparison between Pre and Post values (Tables 5-10) was used to assess changes over time or after an intervention. The difference between the two values indicates whether there was a reduction (negative value) or increase (positive value). The percentage difference expressed this change as a percentage, helping to understand the magnitude of the change relative to the initial value. The t-statistic (t-Stat) measured how much the means of the Pre and Post groups differ, with higher values suggesting a more significant difference. The P-value or P(T<=t) SYS (Two-tail) indicated the probability that the observed difference is due to random chance, and values less than 0.05 typically suggested that the difference was statistically significant, meaning it was unlikely to have occurred by chance. These measures together allowed for a thorough understanding of the data and its statistical significance.

Table 5: Male: Systolic Blood Pressure (SYS).

Time Interval	Pre Average SYS (mmHg)	Post Average SYS (mmHg)	Average Difference (Post - Pre)	% Average Difference	t Stat SYS	P(T<=t) SYS (Two-tail)
Pre BP	138	-	-	-	-	-
Post 3-4 min	138	135	-3	-2	2.74	*0.0074*
Post 5-6 min	138	132	-6	-4	5.9	*6.82E-08*
Post 7-8 min	138	129	-9	-7	8.3	*1.21E-12*
Post 9-10 min	138	128	-10	-7	9.49	*4.37E-15*
Post 11-12 min	138	127	-11	-8	11.23	*1.31E-18*

Table 6: Male: Diastolic Blood Pressure (DIA).

Time Interval	Pre Average DIA (mmHg)	Post Average DIA (mmHg)	Average Difference (Post - Pre)	% Average Difference	t Stat DIA	P(T<=t) DIA (Two-tail)
Pre BP	85	-	-	-	-	-
Post 3-4 min	85	83	-2	-2	3.35	*0.001*
Post 5-6 min	85	82	-3	-4	5.96	*5.23E-08*
Post 7-8 min	85	82	-3	-4	6.47	*5.61E-09*
Post 9-10 min	85	81	-4	-5	7.44	*6.59E-11*
Post 11-12 min	85	80	-5	-6	8.11	*2.90E-12*

Table 7: Male: Heart Rate (HR).

Time Interval	Pre Average HR (bpm)	Post Average HR (bpm)	Average Difference (Post - Pre)	% Average Difference	t Stat HR	P(T<=t) HR (Two-tail)
Pre BP	74	-	-	-	-	-
Post 3-4 min	74	77	3	4	-5.68	*1.78E-07*
Post 5-6 min	74	76	2	3	-5.68	*1.78E-07*
Post 7-8 min	74	76	2	3	-3.54	*0.001*
Post 9-10 min	74	75	1	1	-2.52	*0.014*
Post 11-12 min	74	75	1	1	-2.62	*0.011*

Table 8: Female: Systolic Blood Pressure (SYS).

Time Interval	Pre Average SYS (mmHg)	Post Average SYS (mmHg)	Average Difference (Post - Pre)	% Average Difference	t Stat SYS	P(T<=t) SYS (Two-tail)
Pre BP	140	-	-	-	-	-
Post 3-4 min	140	133	-7	-5	6.19	*0.0000*
Post 5-6 min	140	130	-10	-7	9.02	*2.39E-13*
Post 7-8 min	140	128	-12	-9	10.82	*1.35E-16*
Post 9-10 min	140	127	-13	-9	10.87	*1.11E-16*
Post 11-12 min	140	127	-13	-10	11.85	*2.19E-18*

Table 9: Female: Diastolic Blood Pressure (DIA).

Time Interval	Pre Average DIA (mmHg)	Post Average DIA (mmHg)	Average Difference (Post - Pre)	% Average Difference	t Stat DIA	P(T<=t) DIA (Two-tail)
Pre BP	83	-	-	-	-	-
Post 3-4 min	83	80	-3	-3	3.68	*0.0005*

Post 5-6 min	83	80	-3	-4	4.86	*7.02E-06*
Post 7-8 min	83	79	-4	-5	5.31	*1.25E-06*
Post 9-10 min	83	78	-5	-5	5.94	*1.00E-07*
Post 11-12 min	83	78	-5	-6	6.99	*1.31E-09*

Table 10: Female: Heart Rate (HR).

Time Interval	Pre Average HR (bpm)	Post Average HR (bpm)	Average Difference (Post - Pre)	% Average Difference	t Stat HR	P(T<=t) HR (Two-tail)
Pre BP	73	-	-	-	-	-
Post 3-4 min	73	75	2	3	-2.65	*9.94E-03*
Post 5-6 min	73	74	1	2	-1.78	*7.89E-02*
Post 7-8 min	73	74	1	1	-0.72	0.4741
Post 9-10 min	73	73	0	1	-0.34	0.736
Post 11-12 min	73	73	0	1	-0.48	0.6305

The comparison between Pre and Post values (Tables 5-10) was used to assess changes over time or after an intervention. The difference between the two values indicates whether there was a reduction (negative value) or increase (positive value). The percentage difference expressed this change as a percentage, helping to understand the magnitude of the change relative to the initial value. The t-statistic (t-Stat) measured how much the means of the Pre and Post groups differ, with higher values suggesting a more significant difference. The P-value or P(T<=t) SYS (Two-tail) indicated the probability that the observed difference is due to random chance, and values less than 0.05 typically suggested that the difference was statistically significant, meaning it was unlikely to have occurred by chance. These measures together allowed for a thorough understanding of the data and its statistical significance.

(Table 5 and Table 8) demonstrate that males had significant reductions in systolic blood pressure (11 mmHg on average by 11-12 minutes, $p < 0.05$). Females also had significant reductions (13 mmHg on average by 11-12 minutes, $p < 0.05$).Both males and females showed significant decreases in systolic blood pressure, supporting hypothesis that neuromuscular and musculoskeletal activation exercises reduce systolic blood pressure during light to moderate physical activities. The reduction was consistent and statistically significant across all time intervals.

(Table 6 and Table 9) show that males had a consistent decrease in diastolic blood pressure, averaging a 5 mmHg reduction ($p < 0.05$). In females, similarly, a 5mmHg reduction was observed ($p < 0.05$). Both males and females experienced statistically significant reductions in diastolic blood pressure, confirming that neuromuscular activation exercises helped regulate diastolic pressure during physical activity. This supports hypothesis, which states that these exercises reduce diastolic blood pressure.

(Table 7 and Table 10) demonstrate that males had an initial increase in heart rate post-exercise (up to 2 bpm increase at 3-4 minutes) but it returned to baseline by 9-12 minutes. In females, a significant initial increase in heart rate (up to 2 bpm at 3-4 minutes), but no sustained changes were observed after the initial post-exercise period (no significant changes at 9-12 minutes). Thus, males experienced a temporary increase in heart rate, with a return to baseline levels, suggesting that while neuromuscular activation exercises may cause short-term fluctuations in heart rate, they did not lead to sustained changes. This result suggests partial support for hypothesis that heart rate is not stabilized during light to moderate activities. Females showed a notable increase in heart rate immediately after exercise, but no significant heart rate changes were seen thereafter. This suggests that heart rate stabilization was not achieved, further supporting hypothesis that neuromuscular activation exercises may not effectively stabilize heart rate.

Collecting data together, males generally had higher body weight, fat-free mass, skeletal muscle mass, and lower body fat percentage than females, with greater height on average. In terms of blood pressure, males had slightly lower and more stable systolic and diastolic values, while females showed higher maximum systolic pressures and more variability. Heart rates were similar, but males tended to have slightly lower average heart rates. Overall, males exhibited more stable body composition and blood pressure, while females showed higher extremes in systolic blood pressure and heart rate variability.

In paired T-Test: Blood Pressure (Systolic, Diastolic & Blood Pressure), significant reductions of systolic blood pressure were seen in both males (11 mmHg) and females (13 mmHg) at all post-exercise intervals ($p < 0.05$). Both males and females showed a steady reduction (5 mmHg) in diastolic blood pressure with statistical significance ($p < 0.05$). Males showed temporary increases in heart rate, while females had a higher initial increase in heart rate, but neither group showed sustained significant changes in heart rate.

Discussion

Neuromuscular activation exercise protocols represent a clinically significant intervention strategy for individuals diagnosed with non-communicable diseases, functioning as a complementary therapeutic modality within comprehensive cardiovascular management frameworks and physiological recovery paradigms [22,54]. This systematic review examines the mechanistic pathways through which these structured neuromuscular interventions modulate cardiovascular parameters, specifically blood pressure and heart rate, while simultaneously investigating their influence on recovery chronology and physiological adaptation processes [59,19].

The investigation synthesizes current evidence regarding the integration of NMAEs within established clinical protocols to enhance cardiovascular regulation, accelerate recovery trajectories, and optimize functional adaptation in populations presenting with non-communicable pathologies [64,71]. Through critical analysis of methodological approaches and physiological outcomes, this review contributes to the emerging evidence base supporting targeted neuromuscular interventions in clinical rehabilitation contexts. Since NCDs often disrupt the heart's normal regulation, NMAEs may serve as a key tool in maintaining cardiovascular health and supporting physical strength [6,35].

The effectiveness of NMAEs lies in their ability to tap into the body's natural nerve-to-muscle connections. By targeting specific neural pathways responsible for muscle movement, these exercises activate a range of muscle fibers through varied contraction patterns, thereby improving both muscle strength and joint stability, which is a fundamental aspect of controlling BP and HR [43,56]. Concentric contractile protocols, characterized by myofibrillar shortening during force production, effectively stimulate hypertrophic responses and enhance muscular endurance parameters [10]. In contrast, eccentric contractile modalities defined by controlled myofibrillar lengthening under external load application present particularly advantageous metabolic efficiency profiles for individuals diagnosed with non-communicable diseases [18].

This enhanced efficiency derives from their substantially reduced energy utilization requirements and consequent minimization of myocardial workload demands (*Timmons, et al*., 2018). The attenuated cardiovascular strain associated with eccentric exercise protocols represents a clinically significant consideration in rehabilitation programming for patients presenting cardiovascular pathologies (*Edwards, et al*., 2023; *Carlson, et al.,* 2014). This physiological advantage facilitates enhanced functional performance capacities without inducing potentially deleterious elevations in myocardial oxygen consumption or hemodynamic stress responses [20].

The implementation of strategically designed eccentric loading protocols therefore constitutes an evidence-based approach to optimizing therapeutic exercise prescription in clinical populations where cardiovascular reserve capacity represents a limiting factor in rehabilitation progression [35]. Furthermore, isometric exercises characterized by muscle contractions without any change in muscle length have been shown to lower both systolic and diastolic BP by decreasing vascular resistance and improving blood flow, which is crucial for managing high blood pressure and other heart-related challenges common among NCD patients [6,43].

Efficient recovery from physiological stress relies on several critical factors. For instance, hemoglobin, the protein responsible for transporting oxygen to muscle tissues, is indispensable for proper recuperation. Reduced hemoglobin levels can slow muscle repair and destabilize blood pressure [59]. Equally, efficient glucose metabolism is essential; when glucose regulation falters, inflammatory responses may intensify, and tissue repair can be delayed [71]. Empirical investigations reveal gender-independent therapeutic benefits, with longitudinal exercise adherence correlating directly with quantifiable reductions in both systolic and diastolic pressure measurements [22].

Enhancing insulin sensitivity via neuromuscular activation exercises has been shown to accelerate recovery while stabilizing both blood pressure and heart rate [54]. Elevated inflammatory markers such as C-reactive protein indicate chronic inflammation that further impairs oxygen delivery to muscles and hinders repair processes [6].

There are additional factors affecting recovery. High levels of uric acid, for example, may lead to joint pain and reduced circulation, while increased homocysteine levels can damage cardiac tissue and further slow recovery. When performed correctly, neuromuscular activation exercises can improve joint health, reduce inflammation, and support overall vascular function [20,64].

The incorporation of structured neuromuscular activation protocols within standardized physical activity regimens demonstrates significant efficacy in facilitating recovery processes and enhancing physiological adaptation mechanisms, particularly among populations presenting with non-communicable disease pathologies [35,59]. These strategically implemented exercises facilitate homeostatic regulation of cardiovascular parameters, specifically blood pressure and heart rate, while simultaneously promoting myofibrillar repair processes and reducing myocardial strain indices [10,43].

Of particular clinical significance, eccentric contractile modalities have demonstrated the capacity to enhance vascular integrity through upregulation of endothelial function, while isometric resistance protocols produce comparable improvements in vascular performance metrics and blood pressure regulation [18,19]. These physiological adaptations collectively contribute to enhanced functional capacity and increased autonomy in activities of daily living [71].

The research also shows a temporary elevation in heart rate following the exercise. In males, heart rate may rise by about 3 beats per minute (BPM) in the first few minutes after exercise, then return to normal within 9-12 minutes. Women may experience a higher initial increase of BPM of around 14 beats, normalization, though, occurs within the same time period [6].

Conclusion

This research was focused on understanding the role of neuromuscular and musculoskeletal activation exercises in stabilizing heart rate and blood pressure control, which are critical factors in promoting physical adaptation and recovery. By improving physical adaptation, this intervention could increase functional independence and enhance overall quality of life.

The neuromuscular and musculoskeletal activation exercises have positive and long-term effects on blood pressure control, heart rate stabilization, and physical adaptation in individuals with NCDs. These exercises support cardiovascular health and recovery. The study provided a crucial intervention to help individuals with NCDs regain physical independence, improve their overall quality of life, and enhance antiaging mechanisms.

The findings support the hypothesis that neuromuscular and musculoskeletal activation exercises effectively reduce systolic and diastolic blood pressure in individuals with NCDs. However, while these exercises improve blood pressure regulation, heart rate stabilization was not consistent, particularly after the initial post-exercise phase.

The findings have important implications for clinical practice and health interventions, especially in promoting physical activity among populations at risk for or living with NCDs and antiaging and bioregenerative medicine.

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