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Use of closed chain exercises, eccentric exercises, and proprioceptive muscle facilitation to prevent elbow injuries in climbers: a randomized control trial

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Abstract

Introduction. The study aimed to determine the influence of exercises in a closed kinematic chain, exercises in the eccentric mode in combination with proprioceptive muscle facilitation on the level of elbow injuries and technical skills of amateur climbers.
Methods. The participants were 84 male amateur rock climbers aged 18–19 years; 40 athletes were in the intervention group and 44 were in the control group. In the intervention group, a developed injury prevention program was used. The program included the application of neuromuscular training. Exercises for proprioceptive muscle facilitation were also performed. We determined the elbow injury incidence rate and confidence intervals and the reliability of the influence of the technique mastery level on the number of injuries by the Cochran and Mantel-Haenszel methods.
Results. The use of our program reduced the incidence rate ratio in climbers for mild, moderate, and severe elbow injuries; a significant decrease was found for moderate and severe injuries. There was also a significant improvement in the results of biomechanical analysis of the climbing technique in athletes in the intervention group ($p < 0.001$). A high reliability was determined of the influence of the technique mastery level on the number of injuries ($p < 0.001$).
Conclusions. The use of exercises in a closed kinematic chain, exercises in the eccentric mode in combination with proprioceptive muscle facilitation reduces the incidence rate ratio of elbow injuries and increases technical skills among amateur climbers.
Key words: climbing, trauma, injury, neuromuscular training, physical therapy

Introduction

Rock climbing is included in the program of the Olympic Games [1]. However, at present, numerous data have been accumulated in the literature which indicate a high susceptibility to injuries of the upper extremities in rock climbing [2–6]. This implies the need to develop injury prevention programs. Currently, techniques for the prevention of injuries in rock climbing are beginning to be developed [7, 8]. Therefore, literature data on the prevention of injuries in rock climbing are insufficient.

Improper technique is one of the main causes of injury [4, 5, 8]. In this regard, the tasks of preventing injuries in rock climbing will be to improve the technique of movements in combination with special exercises that affect the neuromuscular regulation of movements.

For other sports, neuromuscular training has been shown to be the most effective injury prevention program [9–11]. Neuromuscular training involves the activation of motor control by the central nervous system when performing movements [12].

One of the important components of neuromuscular training programs for injury prevention are exercises in a closed kinematic chain [13–16]. Coppack et al. [13] showed the effectiveness of exercise in a closed kinematic chain compared with exercises in an open kinematic chain for the prevention of injuries. Augustsson et al. [14] also demonstrated the effectiveness of closed chain exercises compared with open chain exercises for gaining muscle mass and increasing the upward jump. Lee and Han [15] observed that an inward movement of the chin with a closed kinetic chain was more effective in activating the deep neck flexor than an open kinetic chain. An and Roh [16] found that closed chain exercise was a more effective therapeutic intervention than open chain exercise for improving sensorimotor function of the lower extremities and gait functions such as gait speed and symmetry.

Our previous research [17, 18] shows that in a one-arm hang in bouldering, the angle between the shoulder and the collarbone should be about 90–120°. In this case, more muscles are involved in providing the hang. If the angle is greater, the hang is provided mainly by the ligaments of the shoulder. This is dangerous for the ligaments and can lead to injury. In addition, the muscles of the trunk and legs are included in the correct hang. This helps the muscles of the shoulder girdle work. Then, a kinematic chain is created, consisting of links: fingers, forearm, shoulder, trunk, legs. At a large angle, the chain consists of a small number of links, without involving the muscles of the trunk and legs. Exercises in a closed kinematic chain make it possible to use all the links in the

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kinematic chain. Thus, conditions are created to form the skill for the whole body to work to ensure the correct hang. Closed chain exercises can be more effective for climbing than for other sports. Climbing itself involves purely closed kinematic chain work.

Exercises in the eccentric mode are an important addition to exercises in a closed kinematic chain [19, 20]. Exercises in the eccentric mode are more stressful for neuromuscular regulation compared with exercises in the concentric mode. This is because with concentric muscle contraction, the myofilaments actin and myosin converge. This is a more natural case for the neuroregulation of muscle contraction. In the eccentric mode, the myofilaments actin and myosin are removed from each other. But when removed, they should still interlock with each other, and this is possible only when they come together [20–22]. Therefore, in the eccentric mode, the muscle contracts discretely, and not smoothly (as is typical of the concentric mode). The myofilaments must come close to bond with each other and then move away from each other again to provide the eccentric mode. This is much more difficult, and therefore creates the conditions for increasing strength and for improving neuromuscular regulation more than contractions in the concentric mode – and, for the prevention of injuries, neuromuscular regulation is of primary importance. In addition, eccentric exercises tend to work more on the ligaments. This helps to strengthen the ligaments and prevent injury [21, 22].

Moreover, there is evidence in the literature on the effectiveness of various physical therapy modalities for injury recovery. In our opinion, some of the trauma recovery exercises can also be used to form functional (rational) movements to prevent trauma. For example, one of the modern concepts of rehabilitation of the musculoskeletal system after injuries is proprioceptive neuromuscular facilitation (PNF) [23–25]. PNF, one of the methods of movement therapy, allows to restore functional connections between the nervous system that controls the motor act and the muscles that directly perform the movement [26]. The whole method is based on manual work, i.e. on a direct contact of the therapist's hands with the patient's body. Basically, all the movements that are performed during the PNF procedure follow a certain trajectory, called 'diagonal'. The spiral-diagonal character of natural movements is due to the structure of the musculoskeletal system. Most muscles are arranged in a spiral around bones, so, when they contract, they usually make a spiral motion [27, 28]. The primary movements of newborns (the reflex of sucking fingers and toes, turning over, crawling, and others) are mainly spiral-diagonal in nature. With the verticalization of man, these movements become more linear in appearance, but at their core they remain complex (walking, running, swimming, etc.). The use of 'diagonals' of PNF allows in the most physiological mode to use functional muscle chains and restore the 'programs' of primary movements, which contributes to a more effective restoration of motor functions [28, 29].

The basis of the method was the position of the proprioceptive nervous system. In all muscles, joints, ligaments, there are proprioceptors that respond to stretching or compression. With the help of certain manipulations, these receptors are affected. As a result, the receptors are stimulated. This makes it easier to perform the movement of the whole body or limb. Owing to stimulation, movement is formed and consolidated at higher levels of the central nervous system, which means that new, correct static and dynamic stereotypes appear and motor activity increases [24, 26, 29].

Our previous studies [30–32] have shown the effectiveness of using closed chain exercises in combination with eccentric exercises for the prevention of shoulder injuries in climbers. For the prevention of elbow injuries, it is important not only to strengthen the muscles which provide exercises in the eccentric mode and to acquire the skill of working with the whole body, which is ensured by exercises in a closed kinematic chain, but also to develop the skills of synergistic work of arm and leg muscles. In the context of the basic concept of PNF regarding the activation of spiral-diagonal synergies, we hypothesized that the application of the PNF technique would be an effective addition to the use of closed chain exercises to improve the hanging technique in climbing and prevent injuries.

The study objective was to determine the influence of exercises in a closed kinematic chain, exercises in the eccentric mode in combination with proprioceptive muscle facilitation on the level of elbow injuries and technical skills of amateur climbers.

Subjects and methods

Participants and randomization

The participants of the study were 84 male students (aged 18–19 years) who had been practising amateur climbing for 2–4 years. The health of the athletes was checked during the first 2 weeks of the study with the help of regular medical examinations conducted by a therapist. The subjects were also observed for 6 months to assess the basic frequency of injuries and the basic level of the technique of hanging on one arm [17, 18].

An independent statistician conducted a parallel randomization of athletes into a control group and an intervention group with a random distribution method using an online random number generator program. As a result of the randomization, 40 athletes were assigned to the intervention group and 44 were assigned to the control group.

The groups were compared in terms of body height, body weight, climbing experience, indicators of the technique of hanging on one arm in accordance with expert assessment and the results of biomechanical analysis, and the number of injuries before the start of the experiment for 6 months. For all these indicators, the groups did not differ significantly from each other.

In the control group, the athletes' body height was 172.5 ± 8.5 cm and body weight equalled 65.2 ± 6.5 kg; in the intervention group, the respective values were 173.4 ± 8.7 cm and 66.1 ± 6.6 kg ($p > 0.05$). The groups trained in accordance with the generally accepted plan, 3–4 times a week, and the number of training hours was the same in both groups. At the beginning and at the end of the experiment, an analysis of the technique of performing one-arm hang was conducted by experts in both groups. The number of elbow injuries in both groups was also recorded.

We found that the baseline number of all elbow injuries observed within 6 months before the start of the experiment was 11 in the control group and 15 in the intervention group. We presented the injury rate indicators as the number of injuries per 1000 AEs, and we defined the AE indicator as the number of athletes multiplied by the number of all training sessions in which they participated [AE = athlete × exposure (training sessions, competitions)] [33]. In our case, the number of trainings and competitions was the same in the control and the intervention groups and equalled 75 before the experiment and 150 during the experiment. The number of climbers was 40 for the intervention group and 44 for the

Table 1. Comparison of elbow injuries in rock climbers between the control (n = 44) and the intervention group (n = 40) within 6 months before the experiment

Injury intensity	Control group			Intervention group			IRR (95% CI)[a;b] OR (95% CI)[c]	p^d
	Injuries (n)	AEs (n)	Injury rate[a]	Injuries (n)	AEs (n)	Injury rate		
Mild	6	3300	1.82	7	3000	2.33	1.047 (0.870–0.1259)[a]	0.425[d]
							0.779 (0.286–2.124)[b]	
							0.744 (0.227–2.437)[c]	
Moderate	5	3300	1.52	6	3000	2.00	1.043 (0.882–1.233)[a]	0.432[d]
							0.758 (0.250–2.292)[b]	
							0.726 (0.203–2.594)[c]	
Severe	1	3300	0.91	2	3000	1.33	1.047 (0.870–0.1259)[a]	0.425[d]
							0.779 (0.286–2.124)[b]	
							0.744 (0.227–2.437)[c]	

AEs – athlete × exposure (training sessions, competitions), injury rate – number of injuries per 1000 AEs, IRR – incidence rate ratio, OR – odds ratio
[a] IRR for cohort (injuries = no), [b] IRR for cohort (injuries = yes),
[c] OR for group (control/intervention), [d] by Fisher's exact test

control. The injury rate was defined as the number of injuries per 1000 AEs [33].

The number of AEs for 6 months before the experiment was 3300 in the control group and 3000 in the intervention group. The injury rate per 1000 AEs in the control and the intervention groups for mild, moderate, and severe injuries exhibited no significant differences (Table 1).

Procedure

Initially, elbow injuries were recorded in both groups for 6 months to determine the initial level of injuries [30, 31]. Then, the experiment was started and lasted for 1 year. The groups trained in accordance with the generally accepted plan, 3–4 times a week; the number of training sessions was the same in both groups during the year and equalled 150. In the intervention group, a developed program of injury prevention was applied. The number of elbow injuries in both groups was also recorded.

Method to determine the level of athletes' technical skills

The method of biomechanical analysis of the hanging technique in climbing was used to evaluate the hanging technique in the control (n = 44) and the intervention group (n = 40) in order to determine the effectiveness of the developed program of injury prevention. The computer program Kinovea 0.8.15 served to assess the kinematic characteristics of the technique of hanging on one arm in climbing. The one-arm hang was chosen for the analysis of the technique because this element is basic for other technical factors in climbing. Also, the technique of performing this element was substantiated in our previous studies [17, 18]. The technique of hanging on one arm was determined by the magnitude of the angles between the shoulder and clavicle, as well as between the spine from the middle of the chest to the coccyx and the vertical axis. The analysis of angles was performed from the moment of capturing the hook to the stable fixation of the hang (t = 30 s, the number of analysed frames was 10, the frames were selected at equal intervals). For each athlete, 5 attempts were analysed and the arithmetic mean of the 5 attempts was taken as the analysed indicator.

The sportsmen were climbing on a specially designed track in bouldering. The track was constructed in such a way that all participants could climb it. At the beginning of the track, the athlete jumped up from a standing position and clung to the hold with his hand. Then he climbed to the indicated mark in accordance with the bouldering rules. The main element in the technique evaluation is the angle between the shoulder and the collarbone at the moment of the very first grab of the toe after a jump.

The analysis of the frames was carried out from the moment when the hook was captured before the stable fixation of the hang (t = 30 s, the number of analysed frames was 10, the frames vibrated with the same interval of an hour). For each athlete, 5 samples were analysed; in the quality assessment of the analysed indicator, the arithmetic mean of the 5 samples was taken.

Our previous research [17, 18] shows that in a one-arm hang in bouldering, the angle between the shoulder and the collarbone should be about 90–120°. Therefore, the value of 120° was taken as the critical value of the angle. If the angle was more than 120°, the hanging technique was considered incorrect; if the angle was less than 120°, the hanging technique was considered correct.

The technique of performing high jump on one arm was visually assessed by 4 experts – leading climbing coaches of Ukraine. The evaluation involved a 12-point system. The sum of the scores given by all 4 experts was used as a quantitative characteristic.

The level of technique below the average according to expert assessment (less than 25 points) in combination with the values of the angle between the shoulder and clavicle of more than 120° was conventionally marked as 1 ('wrong technique'); the level of technique above the average according to expert assessment (more than 25 points) in combination with the values of the angle between the shoulder and clavicle of less than 120° was conventionally marked as 2 ('correct technique').

Injury registration method

Cases of injuries and diseases of the upper extremities were first recorded for 6 months to determine the initial level of injury in both groups, and then for a year in both groups. The following injuries were registered: injuries and diseases of the elbows in terms of intensity: mild, moderate, severe. Mild injuries included those that healed in less than 1 month, moderate injuries were those that healed in 2–3 months, and severe injuries involved those that healed within 6–12 months. Injuries were recorded by interviewing athletes and coaches [30–32].

Intervention program

The basic program in which the control and intervention groups were trained was the same. In the intervention (experimental) group, the athletes performed additional exercises proposed by us. These were conducted at each workout (3–4 times a week). The intervention program took 15 minutes for each workout. The participants and coaches recorded the fact of applying the intervention program in their diaries.

On the basis of the biomechanical analysis of the hanging technique in climbing [17, 18], tools to prevent elbow injuries were selected and systematized. The tools were physical exercises performed independently and with a physical therapist. All means were conditionally divided into 2 groups: means of sport (climbing) and means of physical therapy (Figure 1).

The sport-related means comprised neuromuscular training. Neuromuscular training involves the activation of motor control during exercise. It aims to increase the motor control of muscles that support the position of the limb in space, as well as muscles that ensure the stability of the limb at each moment of movement [8, 9].

We used the following groups of exercises specific to climbing: (1) exercises in closed kinematic chains; (2) exercises in the eccentric mode with the exception of the concentric phase.

Exercises in a closed kinematic chain [10]

1. Push-ups on the rings. Starting position: support with 2 straight hands on gymnastic rings, feet rest on toes, spine straight. Flexion and extension of the arms in focus on the rings. Keep the spine straight, do not take your feet off the floor. Number of repetitions: 10–20, depending on the level of preparedness.

2. Pulling-up in an emphasis. Starting position: hold the horizontal bar (150–180 cm high) with your hands straight, with your feet on the floor. The spine is straight. Flexion and extension of the arms. Keep the spine straight, do not take your feet off the floor. Number of repetitions: 10–20, depending on the level of training.

Exercises in closed kinematic chains act on the entire kinematic chain completely, more evenly distribute the load on all links of the chain [15, 17]. The program also involved a conscious concentration on the inclusion of all the muscles of the closed kinematic chain in the process of performing each movement.

Exercise in the eccentric mode with the exception of the concentric phase [30, 31]

Starting position: sitting on a chair, back straight. Hold your hand with a dumbbell on a stand up to your waist (dumbbell weight: 2–5 kg, depending on the level of fitness). (1) Perform a return of the brush with a dumbbell to the outside (turn outward) (supination) without the support of the dumbbell with the other hand (eccentric mode). (2) Return the brush to its original position (turn inward) with the support of the dumbbell with the other hand (excluding the concentric phase). Number of repetitions: 8–12, depending on the level of fitness. Number of series: 2–5, depending on the level of fitness.

Exercises in physical therapy (*proprioceptive neuromuscular facilitation*)

1. Synchronization of the shoulder blade and pelvic patterns by using a PNF pattern (Figure 2). The exercise is performed with the help of a physical therapist. The athlete is lying on his side. The physical therapist puts one hand on the athlete's pelvis, the other hand touches the patient's shoulder blade. The therapist presses one hand on the subject's pelvis, returning him to himself. With the other hand, the physical therapist presses on the athlete's shoulder blade, turning his torso away from him. Do the same in the other direction. The subject concentrates on the details of the movement performed simultaneously by the pelvis and the shoulder blade.

2. Synchronization of the patterns of the shoulder blade and pelvis with the patterns of the torso (with flexion and extension synergy) (Figure 3). The exercise is performed with

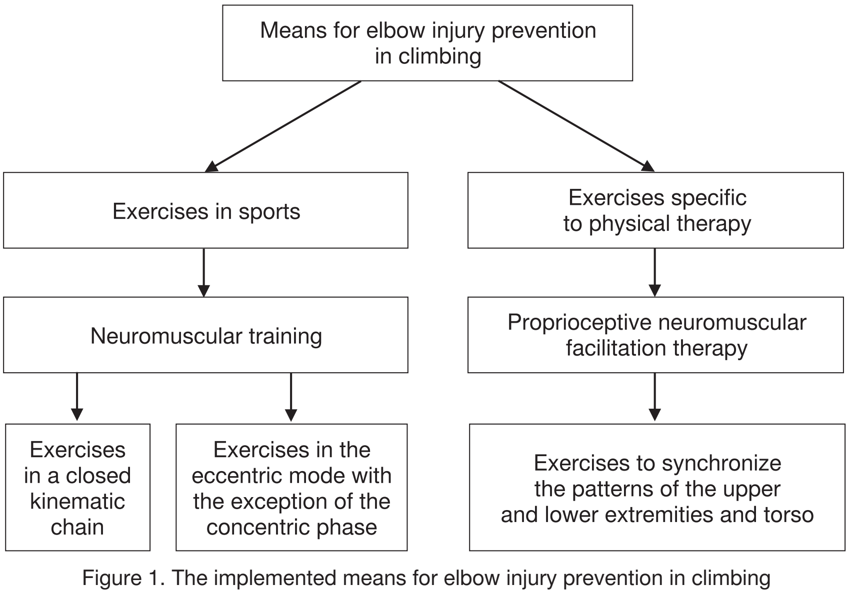

Figure 1. The implemented means for elbow injury prevention in climbing

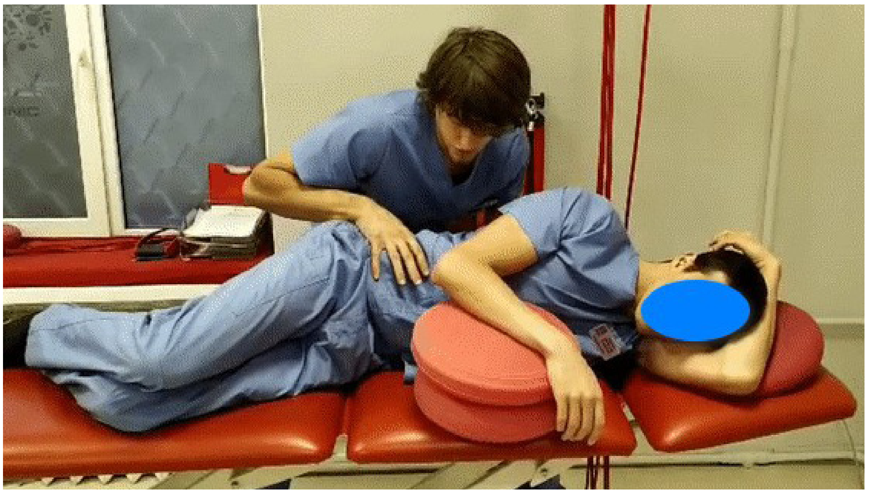

Figure 2. Synchronization of the shoulder blade and pelvic patterns by using a proprioceptive neuromuscular facilitation pattern

Figure 3. Synchronization of shoulder and pelvic patterns with torso patterns (with flexion and extension synergy)

the help of a physical therapist. The athlete is sitting on a couch. The physical therapist puts one hand on the patient's pelvis and the other hand on the patient's shoulder. The therapist presses one hand on the subject's pelvis, returning him to himself. With the other hand, the physical therapist presses on the athlete's shoulder, turning his torso away from him. The patient keeps his back straight. Do the same in the other direction. The athlete concentrates on the details of the movement performed simultaneously by the pelvis, shoulder blade, and torso.

Other program details

As a biomechanical technique in climbing, neuromuscular training was used in combination with exercises of PNF therapy. A special educational program was also set up. The educational program of injury prevention provided:

1. Knowledge of dynamic anatomy.
2. Acquisition of the laws of movement control.
3. Understanding the causes and means of injury prevention. Theoretical classes revealed the basic and clinically significant concepts of biomechanics and functional anatomy in motion models. The degrees of freedom of movement of the upper and lower extremities, torso, neck, and pelvis were also considered; the structure of joints and features of their movements were analysed. Each muscle that provides movement to the upper extremities was then examined in terms of anatomy and the performed function. At the end of the characterization of each muscle, the main pathologies associated with the muscle were presented. At the next stage, manual and functional methods of physical therapy to prevent injuries and diseases, as well as to restore function were studied.

We conducted a seminar 'Therapeutic biomechanics in climbing' for athletes, coaches, and university teachers of climbing 2 weeks before the experiment. The athletes, coaches, and university climbing teachers who agreed to participate in the study in the intervention group were participants in the seminar. We provided theoretical information on the causes of injuries in climbing, as well as on the correct technique of hanging on one arm in climbing [17, 18]. We also taught the participants of the intervention program exercises in closed kinematic chains and exercises performed in the eccentric mode. In addition, we presented the physical therapy exercises to the athletes and coaches.

Statistical analysis

To assess the impact of the developed program on the risk of injury, the following indicators were determined: risk (incidence) of injury, chance of injury, relative risk, and odds ratio. The computer program SPSS-17, Crosstabs option, was used.

For the entire sample, we applied Fisher's exact test and Pearson's chi-square test to compare the injury rates between the intervention group and the control group. We calculated the number needed for training to prevent 1 injury as the inverse of the difference between the percentages of injured players in the control and intervention groups. We considered bilateral $p < 0.05$ statistically significant.

The significance of differences in the number and risk of injuries between the control and intervention groups was determined by the Fisher's exact test and the Pearson's chi-square test [33].

Injury risk (incidence) was defined as the ratio of the number of injuries to the total number of athletes in the analysed group. Relative risk (control group / intervention group) was determined by the ratio of risk in the control group to the risk in the intervention group and vice versa (chances in the intervention group to chances in the control group). The chance of injury was defined as the ratio of the number of injuries to the number of uninjured athletes in the analysed group [33]. The relative chance was defined as the ratio of the chances of injury in the control group to the chances of injury in the intervention group. These indicators were determined separately for all analysed types of injuries and diseases of the elbow (mild, moderate, and severe).

The Pearson correlation coefficient between the expert assessment of the technique and the value of the angle between the shoulder and the clavicle when performing hanging in climbing was also established.

The influence of the prior technique on the number of injuries was determined by the methods of Cochran and Mantel-Haenszel. The technique level that was below average according to the expert assessment (less than 25 points) in combination with the values of the angle between the shoulder and the clavicle (more than 120°) was conventionally denoted as 1; the technique level above average according to the expert assessment (more than 25 points) in combination with the values of the angle between the shoulder and clavicle (less than 120°) was conventionally denoted as 2.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the H.S. Skovoroda Kharkiv National Pedagogical University, Kharkiv, Ukraine (decision No.: 26 of May 25, 2021).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

The total number of all registered elbow injuries during the 1 year of the experiment was 29 in the control group and 5 in the intervention group. The number of registered injuries of varying intensity was as follows: in the control group: 12 mild injuries, 10 moderate injuries, 7 severe injuries; in the intervention group: 3 mild injuries, 2 moderate injuries, 0 severe injuries.

The rate of mild elbow injuries per 1000 AEs during the 1 year of the experiment equalled 1.82 (95% CI: 1.071–2.403) in the control group and 0.5 (95% CI: 0.064–0.979) in the intervention group. The incidence rate ratio for cohort (injuries = no) for mild elbow injuries was 0.786 (0.643–0.962) (Tables 2, 3). We also found that the rate of moderate elbow injuries per 1000 AEs during the 1 year of the experiment equalled 1.52 (95% CI: 0.247–1.883) in the control group and 0.33 (95% CI: 0.089–1.272) in the intervention group. The incidence rate ratio for cohort (injuries = no) for moderate elbow injuries was 0.813 (0.683–0.968; $p = 0.039$) (Tables 2, 3). Our study also showed that the rate of severe elbow injuries per 1000 AEs during the 1 year of the experiment equalled 1.06 (95% CI: 0.134–1.795) in the control group and 0 in the intervention group (severe injuries were not detected in the intervention group).

The incidence (risk) of injuries and diseases of the elbow of mild intensity equalled 0.273 in the control group and 0.075 in the intervention group. The chances of injuries and diseases of the elbow of mild intensity were 0.375 in the control group and 0.081 in the intervention group. The relative risk (control group / intervention group) of injuries and diseases of the elbow of mild intensity in the control group was 3.636 times higher (95% CI: 1.106–11.959; p (Fisher) = 0.017) compared with the intervention group (Table 2). Relative risk – the probability of injury (intervention group / control group) equalled 0.786 (95% CI: 0.643–0.962; p (Fisher) = 0.017) (Table 2). The relative chance of injuries and diseases of the elbow of mild intensity in the control group was 4.625 times higher (95% CI: 1.143–27.324; p (χ^2) = 0.028) compared with the intervention group (Table 2).

The incidence (risk) of injuries and diseases of the elbow of moderate intensity equalled 0.227 in the control group and 0.050 in the intervention group. The chances of experiencing injuries or diseases of the elbow of moderate intensity were 0.294 in the control group and 0.053 in the intervention

Table 2. Indicators of risk of injuries and diseases of the elbow in the control (n = 44) and the intervention group (n = 40) during the experiment year

Group	Mild injuries						Moderate injuries						Severe injuries					
	Yes	No	IR	OR	AEs (n)	Injury rate	Yes	No	IR	OR	AEs (n)	Injury rate	Yes	No	IR	OR	AEs (n)	Injury rate
CG	12	32	0.27	0.37	6600	1.82	10	34	0.23	0.29	6600	1.52	7	37	0.16	0.19	6600	1.06
IG	3	37	0.07	0.08	6000	0.50	2	38	0.05	0.05	6000	0.33	0	40	0.00	0.00	6000	0.00
IRR (95% CI) p	0.786 (0.643–0.962)[a] 3.636 (1.106–11.959)[b] p (Fisher) = 0.017[d]						0.813 (0.683–0.968)[a] 4.545 (1.059–19.506)[b] p (Fisher) = 0.02[d]						0.841 (0.739–0.956)[a,b] p (Fisher) = 0.008[d]					
OR (CI) p	4.625 (1.198–17.854)[c] p (χ^2) = 0.023[e]						5.588 (1.143–27.324)[c] p (χ^2) = 0.028[e]						p (χ^2) = 0.013[e] –					

CG – control group, IG – intervention group, IRR – incidence rate ratio, OR – odds ratio, yes – number of people injured, no – number of people not injured, IR – injury rate (without indicating the number of injuries per 1000 AEs), AEs – athlete × exposure (training sessions, competitions), injury rate – number of injuries per 1000 AEs

[a] IRR for cohort (injuries = no), [b] IRR for cohort (injuries = yes), [c] OR for group (control/intervention), [d] by Fisher's exact test, [e] by Pearson's chi-square test

Table 3. Indicators of the level of the hang technique in climbing in the control (n = 44) and the intervention group (n = 40) before and after the experiment

Performance indicators	Group	$\bar{x} \pm SD$ Before the experiment	$\bar{x} \pm SD$ After the experiment	t	p
Expert evaluation	Control	19.05 ± 3.72	26.8 ± 3.9	2.01	< 0.01
	Intervention	19.5 ± 3.9	32.15 ± 5.31	5.54	< 0.001
Statistical indicators of comparison of control and intervention groups	t	0.38	3.69	–	–
	p	> 0.05	< 0.01	–	–
Angle between the shoulder and clavicle in one-arm hang	Control	131.91 ± 24.71	127.23 ± 9.87	0.82	> 0.05
	Intervention	137.18 ± 6.40	116.32 ± 14.55	5.87	< 0.001
Statistical indicators of comparison of control and intervention groups	t	0.97	2.82	–	–
	p	> 0.05	< 0.05	–	–
Relationship between technical expertise and the angle between the shoulder and clavicle	r	–0.95		–	< 0.001

group (Table 2). The relative risk (control group / intervention group) of injuries and diseases of the elbow of moderate intensity in the control group was 4.545 times higher (95% CI: 1.059–19.506; p (Fisher) = 0.02) compared with the intervention group (Table 2). The relative risk – the probability of injury (intervention group / control group) was equal to 0.813 (95% CI: 0.683–0.968; p (Fisher) = 0.020) (Table 3). The relative chance of experiencing injuries and diseases of the elbow of moderate intensity in the control group was 5.588 times higher (95% CI: 1.143–27.324; p (χ^2) = 0.028) compared with the intervention group (Table 2).

The incidence (risk) of injuries and diseases of the elbow of severe intensity was 0.09 in the control group and 0.05 in the intervention group. The chances of injury and disease of the elbow of severe intensity equalled 0.159 in the control group and 0 in the intervention group (no injuries or diseases of the elbow of severe intensity were found in the intervention group) (Table 2). The relative risk – the probability of injury (control group) was equal to 0.841 (95% CI: 0.739–0.956; p (Fisher) = 0.008) (Table 2). The relative risk (control group / intervention group) and the odds ratio were not determined because no severe elbow injuries were observed in the intervention group.

Thus, our research has shown that the use of our program reduced the incidence rate ratio of elbow injuries in the amateur climbers. The incidence rate ratio decreased for mild, moderate, and severe elbow injuries, but a significant decrease was found for moderate and severe injuries. Severe elbow injuries were not detected in the intervention group during the course of the experiment.

Prior to the experiment, the average expert assessment of the technique of performing the technique of climbing was 19.05 ± 0.78 in the control group and 19.5 ± 0.87 in the intervention group (p > 0.05), which indicates that before the experiment, the groups did not differ significantly in terms of the hanging technique level. After the experiment, the average expert evaluation equalled 26.8 ± 0.83 in the control group and 32.15 ± 1.18 in the intervention group (p < 0.05) (Table 3), which implies a positive effect of the means of injury prevention in climbing for the formation of biomechanically functional techniques of hanging.

The results of the biomechanical analysis of the technique of performing hang in climbing by using the indicators of the angle between the shoulder and clavicle confirmed the results of expert evaluation of the technique of hanging. The correlation coefficient between the value of the analysed angle and the value of the expert assessment was –0.95 (p < 0.001) (Table 3), which indicates a coincidence of the subjective assessment of the hanging technique by experts and the objective indicators of the hang technique in climbing.

There was a significant decrease in the angle between the shoulder and clavicle in the intervention group (p < 0.001), while in the control group, these changes were not significant (p > 0.05) (Table 4). Before the experiment, the groups did not differ significantly in the angle between the shoulder and clavicle (p > 0.05). After the experiment, a significant difference was found between the control and intervention groups in terms of the angle between the shoulder and clavicle (Table 3).

Prior to the experiment, the angle between the shoulder and clavicle equalled 131.91 ± 24.71 in the control group and 137.18 ± 6.40 in the intervention group (p > 0.05), which indicates that the groups did not differ significantly from each other. After the experiment, the average value of the angle between the shoulder and clavicle was 127.23 ± 9.87 in the control group and 116.32 ± 14.55 in intervention group (p < 0.05) (Table 3), which implies a positive effect of applying the program to prevent injuries in climbing on the formation of biomechanically functional techniques of hang.

The influence of the technique level at the end of the experiment on the number of injuries by the Cochran and Mantel-Haenszel methods was also determined. There was a high reliability of the influence of the technique mastery level on the number of injuries (p < 0.001) (Table 4). Before the experiment, the groups did not differ significantly in the mastery level of climbing techniques, but it can be noted that at the end of the experiment, the technique level significantly affected the number of injuries.

Table 4. The impact of the technique level on the number of injuries (n = 245)

Processing method	χ^2	p
Cochran	65.070	0.000
Mantel-Haenszel	52.990	0.000

In accordance with the conditional assumption of independence, the Cochran statistic is asymptotically distributed as a χ^2 1 *df* distribution only if the number of layers is fixed, whereas the Mantel-Haenszel statistic is always asymptotically distributed as a χ^2 1 *df* distribution. Continuity correction is removed from the Mantel-Haenszel statistics when the sum of the differences between the observed and the expected is 0.

Discussion

To the best of our knowledge, our study is one of the first on injury prevention for climbers. It is also one of the first to use PNF – therapy for injury prevention in sports. The research confirmed the effectiveness of closed chain exercises, eccentric exercises in combination with neuromuscular facilitation exercises to improve technique and prevent elbow injuries in climbing.

We obtained a significant reduction in injury rate, incidence rate ratio, and odds ratio for moderate elbow injuries and in incidence rate ratio for severe injuries. It should be noted that no severe elbow injuries were detected in the intervention group. Data on the effectiveness of neuromuscular training for the prevention of injuries in physical culture and sports have been confirmed [9, 10].

Our program is based on the standpoint formulated in our previous works [17, 18]. In skilled climbers, the total force that provides the position of suspension is much greater than in unqualified athletes. This is because in skilled athletes, not only the muscles of the upper limb (as in unskilled athletes), but also the muscles of the torso and legs are involved in maintaining the position of one-arm suspension when climbing, which creates another link in the kinematic chain. Accordingly, the upper limb bears less load than among unqualified athletes. This has provided a theoretical basis for the formation of the most effective climbing techniques that ensure the achievement of sports results and injury prevention. Therefore, to include not only the arm muscles, but also the muscles of the legs and torso in the action, it is advisable to apply exercises in a closed kinematic chain.

Our study confirmed the theory of motor control [34–36], which points out that the basis of injury prevention is the effective organization of motor control by the central nervous system. Motion control follows the principle of sensory correction. From this point of view, PNF therapy exercises act precisely on the activation of spiral-diagonal synergies, which forms the necessary skills of correct synergies and thus provides an improvement in the mechanism of sensory corrections.

In addition, our work confirmed the theory of motion control [37–39] provisions on the need to use exercises in the eccentric mode in combination with exercises to strengthen muscles in order to prevent injuries and improve the factors affecting movements, namely: the initial state of the muscles (because strengthening muscles improves their initial condition) and the interaction with reactive and inertial forces (as the use of exercises in the eccentric mode promotes the sequential involvement of the muscles and does not allow the muscles to remain without brain control when switching from one movement to another). Muscle tone regulation and intermuscular coordination are among the main conditions for injury prevention, and so are the perception of self and limbs in space, as well as agonistic-antagonistic muscle interactions.

On this basis, it can be stated that the paper confirms the data on the need for biomechanically sound movement techniques and the movement control theory on the need for rational techniques to prevent injuries [34, 38, 39]. The research expands and supplements the data [9–11] on the use of neuromuscular training for injury prevention in various sports, in particular in climbing.

Our study also includes a program for the prevention of injuries in climbing. This is a new acquisition because, as far as we know, this is one of the first studies to develop and justify an injury prevention program in climbing.

Limitations

The study was conducted among recreational climbers. Therefore, the results obtained refer exclusively to this group of athletes. To identify the influence of climbing technique on the level of injuries in qualified athletes, additional research is needed. Also, further research is warranted to determine the effect of the use of exercises in a closed kinematic chain, exercises in the eccentric mode in combination with PNF therapy exercises on the number of injuries in qualified climbers. In addition, the obtained data do not refer to athletes of other sports. This issue also requires more research.

Conclusions

1. Applying exercises in a closed kinematic chain, eccentric exercises in combination with PNF exercises helps reduce elbow injuries in amateur climbers. The implementation of our program lowered the incidence rate ratio of elbow injuries in amateur climbers. The incidence rate ratio decreased for mild, moderate, and severe elbow injuries, but a significant decrease was found for moderate and severe injuries. Severe elbow injuries were not detected in the intervention group during the course of the experiment.
2. There was also a significant improvement in the results of the biomechanical analysis of climbing technique in the intervention group: after the experiment, the angle between the shoulder and clavicle decreased significantly ($p < 0.001$), while in the control group, these changes were not significant ($p > 0.05$). The study demonstrated a high reliability of the influence of the technique mastery level on the number of injuries ($p < 0.001$).

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Conflict of interest
The authors state no conflict of interest.

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