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Effects of Physical Education Programs on Strength and Endurance

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Abstract: *Strength-endurance is one of the key motor qualities that can be developed by an athlete, which probably explains why it was included in the training cycle of combat sports at the level of top-level competition. In striking combat sports, such as boxing or taekwondo, it is possible to suggest that an increase in dynamic strength-endurance will lead to an improvement in repeating explosive attacking movements. On the other hand, grapplers have to develop their strength-endurance since a lot of time during the fight is spent in the grip fight, and the outcome of this struggle ultimately determines the success of the athlete. In addition, in the case of mixed combat sports, when both striking and grappling techniques are allowed, participants have to perform dynamic or static exercises throughout the match, and strength-endurance is vital for them. Thus, in this chapter, it was decided to cover the aspects of strength-endurance in combat sports, including the tests for its assessment, reviews and longitudinal studies undertaken to prove the possibility of improvement and the methods which can be used for development.*

Keywords: Martial arts; combat sports; muscular endurance; training; performance; core zone.

I. INTRODUCTION

Strength-endurance is one of the fundamental trainable physical qualities correlated with the requirements of the sport performance, which is included in the periodization of training processes of athletes at a high level [1]. In other words, strength-endurance is a property of the organism that allows the person to resist a certain number of repetitions of exercises or single movements in a short period until failure or to maintain the same movement for a relatively long time with the same amplitude and speed [2]. At the same time, strength-endurance is the ability to resist muscular effort, which can be maintained for a prolonged period, while the duration of this effort varies from thirty seconds to two minutes [3].

The authors Martin et al. put forward the point of view that strength-endurance performance is determined by two key elements. The first is the absolute strength, associated with the range and duration of the load [4]. The second is the time of this load during which the athlete can resist muscle fatigue, which is associated with the energy supply of the muscles [5]. Accordingly, by varying the time of load with a given resistance, which causes muscle fatigue, it is possible to obtain optimal performance results in terms of strength-endurance due to active metabolic processes [5]. Each sport has its own unique characteristics that determine which particular physical qualities are most in demand. This refers to the strength-endurance component of physical health, which plays a decisive role in many sports, including combat ones, especially grappling sports [6]. In striking combat sports, such as boxing, the development of dynamic strength-endurance allows the boxer to perform various boxing movements, for example, direct and cross punches, that is, to implement attacks, which is extremely important during the match, since the number of attacks directly correlates with the number of points scored by the attacking boxer [7, 8].

In contrast to striking combat sports, judo is a grappling sport, where the objective is to throw the opponent, maintaining control over him during the match. Both dynamic and static muscular endurance are essential during a judo match. Thus, the study of the authors' Martin et al. shows that variations in strength-endurance performance can serve as predictors of performance during judo matches [9]. In other words, a dynamic increase in resistance is needed to implement the movements of pulling or pushing a judoka in order to score points or throw an opponent. For wrestlers,

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controlling matches using a grip on the opponent's head and arms is a powerful tool for maintaining a distance, for throwing, and for attacking the opponent. In this regard, measures of strength-endurance may be of much importance in assessing individual performance in Greco-Roman and freestyle wrestling [3, 10, and 11]. Finally, in mixed combats, such as mixed martial arts (mma), where the athletes use a wider range of both striking and grappling techniques, mainly using the upper part of the body, the ability to fight using dynamic or isometric movements for a relatively long time during the match is also extremely important.

It is especially important for mma fighters to show good results in terms of strength-endurance since, in this combat sport, all moves are made against the background of physical fatigue due to the high intensity of the match. As a result, athletes need to have a high level of muscular endurance in order to be able to withstand the efforts both of their own and of their opponent to maintain a fight [12]. Consequently, this study discusses strength-endurance and its role in combat sports, responses to training, and tests for its assessment. Moreover, we will also go into detail on the findings of longitudinal studies on the development of strength-endurance of combat sports athletes, as well as consider methods for developing this component of the physical health of athletes.

II. STRENGTH–ENDURANCE REQUIREMENTS IN STRIKING AND GRAPPLING COMPETITION

Understanding how specific physical capacities—neuromuscular or metabolic—respond in particular situations, whether in simulated or actual competition is crucial for identifying performance patterns and their impact on the effectiveness of techniques in combat sports. This knowledge allows coaches and strength trainers to design more effective training periodization strategies. In wrestling, typical actions during a match involve upper-body and trunk-based movements such as pulling, pushing, stabilizing an opponent, and leg-driven lifts [15]. Moreover, offensive moves in both Greco-Roman and freestyle wrestling require controlling the opponent through defined contact points—such as the upper body, head, waist, or lower limbs—making upper-body and trunk strength-endurance particularly important [16,17].

The repetitive nature of these actions can lead to fatigue that impairs strength-endurance, as noted by Nilsson et al. [18], who found significant muscle fatigue among competitors at the Greco-Roman Wrestling World Championship, especially in the forearm flexors and anterior deltoid. In judo, actions occur both upright (tachi-waza) and on the ground (ne-waza). A large portion of match time is spent in grip fighting, averaging 14±15 seconds and accounting for 58% of standing time and 28% of total match duration, including pauses [19]. This places high demands on upper-body strength-endurance, particularly dynamic and isometric endurance in the forearm muscles [20]. Similarly, ground-based control techniques also rely heavily on this physical attribute [21]. To assess how match length (1 to 5 minutes) affects upper-body dynamic strength-endurance, Julio et al. [22] tested twelve male judokas using the judogi chin-up test before and six minutes after matches.

They observed a decline in strength-endurance post-match compared to baseline, though no significant differences emerged across durations. Additionally, Kons et al. [23] found no distinction between medalists and non-medalists in perceived local exertion during an official tournament; however, both groups reported greater strain in the upper body than the lower body. Medalists most frequently cited fingers, abdomen, and anterior tibia as fatigued areas, while non-medalists pointed to the forearm and fingers. Studies on Brazilian jiu-jitsu athletes have examined isometric strength-endurance responses during matches of varying lengths (2, 5, 8, and 10 minutes) [24], as well as in simulated competitive settings [25].

III. STRENGTH–ENDURANCE ASSESSMENT TESTS FOR COMBAT SPORTS ATHLETES

The assessment of an athlete's physical fitness, the analysis of the training load's influence on a particular physical ability, or even the differentiation of individuals according to their sporting performance level (e.g., elite vs. non-elite), may be made using various physical tests. The more specific they are for a particular combat sport type, the more accurate the results of these tests will be for assessing combat sport athletes' performance. However, despite the

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existence of specific tests for some combat sports, none of the indexed studies describe such tests for mixed combative activities.

However, regardless of the specificity of each combat sport type, it may be possible to use the same tests developed for grappling and striking combative activities for mixed fighting events. Taekwondo is one of the combative activities that significantly differ from the rest, as most of the techniques involve mainly leg movements, and a considerable number of them are aimed at targeting an opponent's thorax and head. Such techniques require an athlete to jump and turn, making these movements explosive. The kicks account for 100% of all scoring techniques in an Olympic Taekwondo match [29]. It means that the lower limbs' fatigue plays a significant role in an athlete's performance during a taekwondo match because of the large number of jumps and changes of direction [30].

Nevertheless, the introduction of the electronic body protector allowed registering some scoring techniques with upper body parts, including punches. As taekwondo techniques are characterized by a strong focus on lower body movements, there are several studies investigating the strength-endurance of the lower body muscles in taekwondo athletes. However, some researchers try to assess the upper body and core muscle groups' performance, as they are used in taekwondo to target an opponent's upper body (chests) and protect one from punches delivered to the thorax. Core or trunk muscles play an essential role in performing many taekwondo techniques, including turning kicks, as well as in the ability to withstand and assimilate the effect of an opponent's strike [31]. For example, in a study aiming to determine female Croatian taekwondo athletes' strength-endurance and analyze their relationship with sport performance, Markovic et al. [32] analyzed 13 athletes' push-ups and sit-ups performance for 60 seconds, dividing them into two groups according to their sport performance.

According to the results, no significant differences were found between two groups of athletes in both tasks. Therefore, the authors concluded that the upper body strength-endurance is not critical for taekwondo performance. In contrast, core muscle group strength-endurance seems to benefit taekwondo performance. In another study, Suzana and Pieter [33] assessed Malaysian taekwondo athletes' motor skills. The researchers worked with athletes in junior (n = 10) and adult (n = 10) categories and aimed to identify whether there are any differences in the number of performed sit-ups for 60 seconds. However, the results demonstrated that no significant differences were found between two study groups.

The specific motor skills used in wrestling are integrated into a test proposed by Utter et al. [36]. This test includes throwing exercises performed as in combat, namely, the subjects have to perform five sets of five different technical movements used in matches in a circuit. Three of the exercises are only applicable in freestyle wrestling, while the other two may also be applied in Greco-Roman style. The test also involves pairs of competitors who should be of the same weight class; one competitor is the performing one, while the other is only a recipient of throws. This design allows the performing competitor to do all the movements to quickly return to the starting position, which ensures the highest possible speed of the performance. The movements include double-leg takedown, single-leg takedown, fireman's carry, stomach-to-back lift, and hip toss. The clock starts when "go" is announced by the judge, and the competitor has to perform five repetitions of the first movement, followed by the other four exercises in a circuit.

The classification of the competitor's fitness level depends on the recorded time, which reflects the number of repetitions of the 25 total movements needed to finish the task. Generally, the shorter the time, the better the competitor's conditioning. Subsequently, the number of repetitions and the time can be used to estimate the specific strength-endurance of athletes in both wrestling styles. However, there are no general tables for classifying performance in this test according to the weight class, sex, and level of the competitor. Upper-body strength-endurance plays a crucial role in judo performance, as gripping the opponent's judogi is fundamental for executing throws and maintaining control during matches [37]. Franchini et al. [38] introduced judo-specific assessments to evaluate upper-body isometric handgrip strength and dynamic strength-endurance. One test evaluates the ability to sustain a judogi grip, while the other measures the number of chin-ups performed using a judogi grip. To examine differences between team and state-level Brazilian judo athletes, Franchini et al. [9] applied these tests, focusing on maximum hang time with a judogi grip and the total chin-up repetitions possible.

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Recently, classification tables for both isometric and dynamic judogi-grip strength-endurance have been developed for male and female competitors [39, 40], providing benchmarks for athletes aged 18 to 40 across state, national, and international levels. In contrast, the study by Agostinho et al. [40] includes data from cadet and junior athletes in both Brazil and Serbia, broadening the applicability of the findings. This information can support judo athletes and strength coaches in evaluating individual progress and comparing performance against established standards. It is important to recognize that lighter athletes often achieve higher absolute scores in repetition and endurance tests, while heavier athletes may perform better when results are normalized per body mass (e.g., repetitions per kilogram). Therefore, comparisons across weight categories should be made with caution.

Another study conducted by Bonitch-Góngora et al. [41], who examined the differences and similarities between young judo players and their non-elite counterparts in isometric handgrip strength-endurance. Eight sets of 10 seconds of isometric muscle contractions with 10 seconds of passive rest in between on an electronic dynamometer were performed by the participants. The sample size consisted of 73 male and female judo players. According to the authors, elite judo athletes can develop greater levels of handgrip strength and utilize more effective tactics in sustaining contraction after contraction, which is typical during a judo match. Silva et al. [42] performed a test-retest reliability study of two tests that measure strength-endurance when gripping the kimono in Brazilian jiu-jitsu athletes. The same tests as in the judo study [38] were used: a) a maximal sternum suspension time (MSL) test that requires maximal elbow flexion and grip around the bar in which the kimono is rolled up, and b) a maximal number of repetitions (MNR) test that consists of a maximal number of complete elbow flexion-extension movements using a fixed bar grip around the kimono.

The results showed that the isometric strength-endurance chin-up test can differentiate between isometric strength-endurance levels of the four categories of the Brazilian jiu-jitsu competitors. Meanwhile, the dynamic strength-endurance test can only differentiate the strength-endurance of the more considerable difference groups (advanced and non-advanced compared to recreational and novice).

IV. STRENGTH–ENDURANCE DEVELOPMENT METHODS FOR STRIKING, GRAPPLING, AND MIXED COMBAT SPORTS ATHLETES

Striking combat sports

It is for the trainer and/or strength and conditioning professional to decide what primary methods for the development of the physical qualities needed to distinguish between the winner and loser in combat sports should be adopted. Indeed, the current format of the boxing matches has determined the shifting of attention to the improvement of the performer's ability to express the dynamic strength-endurance, mainly through the enhancement of the frequency of punches delivered at the beginning of the rounds, thereby influencing the overall number during combats [50]. In turn, the number of punches thrown on the bag during the specified time indicates the level of specific dynamic strength-endurance in boxing. It can be suggested that the improvement of this aspect will lead to an increase in the number of attacks in combat sportspersons [7, 8].

However, it is still not known whether the number of attacks during the fight is correlated with the success in boxing competitions. At the same time, it is possible to assume that this growth will transfer to the performance in the boxing match, thus securing victory. Circuit training can be proposed as a method for the development of dynamic strength-endurance for boxing. In the literature, there is a mention of the application of circuit training by American fighters who participated in the Olympic Games in Atlanta in 1996. They performed it for all the muscle groups once a week, as a part of the basic preparation, in order to develop their strength-endurance [51]. According to Chaabène et al. [13], in karate, due to the higher perceived exertion during the fight, the fighters experience greater fatigue in their lower body. Therefore, it can be suggested that a specific training program focusing on these parts with the use of modalities specific to karate and a special emphasis on the time structure should be implemented.

In addition, as the boxing match simulation produces lower levels of perceived exertion in comparison to the official fight, it might be useful to add the strength-endurance exercises (e.g. squat) during the breaks in the simulated bouts in

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order to increase the load and make it closer to the competition one. Finally, plyometric training, according to Turner et al. [52], can also be beneficial for the enhancement of the competitive endurance in combat sports. This is explained by the better utilization of the stretch-shortening cycle which leads to a higher production of force and, consequently, to the improved ability to perform repetitive power movements with less energy cost.

Grappling combat sports

Grappling combat sports demand exceptional levels of both dynamic and isometric strength-endurance due to the intense nature of the actions performed and the short intervals between them, which makes this ability to be of particular significance for achieving success in the sport and for its development during the preparatory period of the competition [53]. A variety of methods are implemented by the coaches and the strength and conditioning (S&C) specialists to improve judo players' strength-endurance, mostly concerning the enhancement of the kumi-kata (judogi grip) during the fight. According to Miarka et al. [19], the changes of judogi grip during the match are constant and take the considerable amount of time during the fight. The correct performance and maintenance of these actions can guarantee the success in the match [37], while the reduction of the degradation of their performance during the match or the competition is the goal to strive for.

For this reason, judo players' training periodization should be planned in such a way to ensure the maintenance of their strength levels throughout the match, which requires the development of their strength-endurance abilities of the forearm flexor muscles [54]. The development of a strength-endurance in a specific muscle group can be achieved through the increase in the volume of the training with multiple sets of moderate (10-15) or high (15-20 or more) repetitions with the short (less than 1 min) or moderate (1-2 min) rest intervals between them, respectively [55]. Moreover, the circuit strength training has also been proved to be highly efficient due to minimal rest between the exercises, as it is sufficient to move to the next station in the circuit. Concerning the training frequency, the recommendations for the advanced level athletes can be implemented, suggesting a high frequency of training, namely 4-6 training sessions per week with the emphasis on different muscle groups in each session [2]. Therefore, it is suggested to include the upper body exercises, which involve pulling or pushing movements as they are the primary patterns of movement in judo match, in the physical preparation of the judo players in accordance with the recommendations mentioned above.

In fact, the circuit training is often used in judo to develop strength-endurance. The circuit training sessions can be individualized according to the specific demands of the sport and in accordance with the ratio of the effort to the rest. Thus, they can include exclusively the strength exercises or be combined with conditioning (i.e., sprint intervals, shadow uchi-komi, etc.) [56]. Lahart and Robertson [57] suggest that a judo-specific circuit can last 5 min and include 10 exercises, each of which should be performed for 20 s with 10-s rest in between and repeated two or three times with 10 min rest in between the sets. For the wrestlers, circuit training is also suggested to be implemented to simulate the specific energy cost of the match and to create the environment close to the competition one in order to improve the strength-endurance of the athletes as it is essential for their performance, and it can be considered as a suitable method since it prepares the body to the physiological stresses of the competition [2].

V. NON-CONVENTIONAL TRAINING METHODS FOR STRENGTH–ENDURANCE ENHANCEMENT IN COMBAT SPORTS

Training that involves unconventional exercises can be used to enhance performance, as such training forms were used to develop the necessary physical capabilities for combat sports, as the exercises performed during such training are aimed at being transferred to the sport and have analogous motor patterns typical of the events [6]. The unconventional power training method consists of multi-joint, multi-muscle group exercises that are performed at an angle and plane of motion similar to those inherent in the objective modality, unlike conventional weight training, which is traditionally used by bodybuilders and focuses on training specific muscle groups and single-plane movements [6].

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VI. EXERCISES FOR THE CORE ZONE

In combat sports, the region around the center of mass is particularly important as it is associated with a transfer of power from the lower to the upper part of the body [56]. This area was defined in the literature as the core area/core zone, stabilization center/core stability or power zone/power area and was mainly composed of gluteus, abdominal, thigh, and lumbar muscles [59, 60]. It has been reported that the development of these muscles was essential to reduce injury risk and to optimize the protection of the spine and hips during high-power movements [60]. Another crucial aspect related to the need for the development of these muscles is the necessity to perform (e.g., when executing a circular kick) and protect oneself (e.g., when defending an opponent's throwing technique) from rotatory forces and therefore should be included in the training of combat sports athletes [59, 61].

Indeed, judo players demonstrated significantly higher trunk extensor isokinetic strength and exhibited less trunk rotation after anterior trunk loading [62, 63]. Thus, trunk extensor strength and trunk stability are discriminant variables for judo players which can be a starting point for further research investigating other grappling combat sports. McGill et al. [64] suggested that strikes' performance rely on impact and speed, and while the former is governed by the stiffness of the musculature, the latter is dictated by its relaxation. Consequently, the relaxation of the muscles is a crucial determinant of a successful strike; however, the stiffness is equally important to increase the effective mass of the striking limb. As such, the double-peak pattern of the force development is optimal to elicit both stiffness and relaxation during a strike. Indeed, in a study conducted by the same researchers [64], it was reported that high-level MMA athletes exhibited the double-peak pattern for the most common striking techniques including the back kick, the roundhouse kick, the jab with the straight right, and the ground and pound.

Since core muscles play a central role in these techniques, Lee and McGill [65] examined how six weeks of either isometric or dynamic core training—compared to no specific training—affect Muay-thai fighters. Participants were assigned to one of three groups: an isometric core training program (including plank, bird dog, and torsion buttress in weeks 1–2; anterior and posterior Pallof press, suitcase hold, and anti-rotation Pallof press in weeks 3–4; and stir the pot, inverted row, kettlebell unilateral rack walk, and half-kneeling woodchop in weeks 5–6), a dynamic core program (featuring curl up, superman, side curl up, and twisting curl up in weeks 1–2; advanced curl up, back extension, and Russian barbell twist in weeks 3–4; and curl up twitch, superman twitch, lateral medicine ball throw, and rotational medicine ball throw in weeks 5–6), or a control group with no structured core training. Training occurred four times per week in weeks 1 and 3 through 6, with seven sessions in week 2.

The isometric program consisted of five to ten sets of 10-second holds, while the dynamic program involved five sets of 5 to 10 repetitions. Before and after the intervention, participants performed pre- and post-tests for jab, cross, jab-cross combination, and knee strikes, during which peak force, peak velocity, and EMG activity of key core muscles were recorded. Results showed that isometric training enhanced impact force, whereas dynamic training improved striking speed. Both training types led to increased EMG activity in core muscles. Additionally, a shift from a single-peak to a double-peak activation pattern in muscle activity was observed after training. Thus, core stability training could be beneficial to increase striking impact force while muscle relaxation training enhances performance speed, and the combination of both seems to increase both determinants of performance. However, as the effect of isometric and dynamic training differed, the researchers suggest that practitioners in the fields of strength and conditioning should consider the specific goal of the core training when prescribing exercise.

VII. FINAL CONSIDERATIONS

Strength-Endurance is an essential component of combat sports that differ depending on the prevailing type of activities, wrestling or striking. Hence, the analysis of the requirements to the structure of muscular endurance for the selected modality and individual characteristics of the athlete and the assessment of his or her readiness level are the basis for its development. The current procedures and the specific exercises recommended in this chapter contribute to the practical implementation of strength-endurance training, but there is a need for constant awareness of the necessity

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to develop and update the knowledge and skills for promoting the development of this important component of athletic performance.

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