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Literature Review

Neuromuscular Training in Football: A Literature Review

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Summary

Introduction: Neuromuscular training (NT) involves a series of functionally focused exercises that address aspects such as postural stability, sensory perception, and muscle strengthening. These exercises are incorporated as an integral part of a currently used training protocol.

Objective: To review the main effects of NT on injury prevention in soccer players and its impact on related physical performance. Methods: Review of the literature describing different studies on NT in soccer. The following databases were used to search and retrieve the scientific articles: PubMed, Scopus, and Ebsco. Combinations of the following keywords were used to perform the search ("neuromuscular training" OR "proprioceptive training" OR "sensorimotor training") AND ("soccer" OR "football" OR "soccer players" OR "football players").

Results: A positive trend is observed in NT for the prevention of knee and ankle injuries, in addition to improving muscle strength and motor skills such as agility and coordination.

Conclusion: This review managed to identify that NT is effective in reducing the risk of injury in soccer players; however, the literature has mainly addressed lower extremity injuries. Therefore, it may be necessary for future investigations to focus on the upper extremity and trunk. Likewise, it was determined that NT has a potential impact on improving physical performance, with the variables of strength, power, speed, agility, and balance being the most studied.

More Information

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Introduction

Football stands as the most widely embraced sport globally, drawing millions of participants and enthusiasts alike. Its immense popularity has led to extensive research, as evidenced by almost 14,000 citations on Pubmed [1]. A systematic review and meta-analysis of epidemiological data on injuries in men's professional football found that the incidence of injury during matches (36 injuries/1000 hours of exposure) was almost 10 times higher than the incidence rate of injury during training (3.7 injuries/1000 hours of exposure), lower extremity injuries had the highest incidence rates (6.8 injuries/1000 exposure hours) and the most common types of injuries were muscle/tendon (4.6 injuries/1000 exposure hours), which were frequently associated with traumatic incidents [2]. Because of this, injuries and illnesses can affect the health and performance of players and can also have a major financial impact on teams [3].

Injury rates in children's football, while they may range from moderate to high compared to other sports, reveal a striking disparity when compared to injuries afflicting elite adult football, the latter being 3 to 7 times more frequent [4-6]. In this context, several randomized controlled trials have been conducted that have shown that neuromuscular training (NT) can effectively prevent lower extremity injuries in both youth and adult football players [5,7-10].

Sports injuries are not simply an isolated issue, but a worrying public health challenge that demands highly specialized attention [4,11,12]. Despite the extensive research conducted on soccer injuries and their prevention in both youth and adult players, a consensus remains elusive regarding the optimal dosage of neuromuscular training (NT) interventions. Additionally, the impact of NT on physical performance is an emerging and evolving area within the field of sports science [13-15].

NT could be defined as an intervention enhancing unconscious motor responses by stimulating both afferent signals and central mechanisms responsible for dynamic joint control [16]. This is based on providing adequate information to mechanoreceptors so that the integration of muscle responses is more efficient. For this, this training uses balance, proprioception, and strength exercises on stable and unstable surfaces [17]. It has been reported that NT can contribute to

the improvement of physical performance in athletes, such as postural stability, in both static and dynamic dimensions [18,19]. Additionally, it has been shown that NT can decrease the risk of lower extremity injuries in athletic individuals, and can be used for preventive purposes in relation to these injuries [20,21].

Methods

This research has a qualitative, descriptive approach. Its design corresponds to a review of the literature where different studies on neuromuscular training in soccer are described.

Search strategy

In the period from September to October 2022, an exhaustive search of the scientific literature was carried out on the effects of neuromuscular training on soccer players. To search and obtain academic articles, the following databases were used: PubMed, Scopus, and Ebsco. Combinations of the following keywords were used to perform the search ("Neuromuscular training" OR "proprioceptive training" OR "sensorimotor training") AND ("soccer" OR "football" OR "soccer players" OR "football players").

Study selection

The selected articles are in English and published between the years 2002 and 2022. The selection was carried out using three filters: 1) the articles found in the databases were initially selected by their titles, and publications that were clearly not related to them were discarded. The objective of the study; 2) Next, the abstracts were read, and the studies that were directly related to the central interest of this work (neuromuscular training and soccer) were chosen. The full texts of potential articles were then retrieved to pass through the final filter; 3) in this phase, a critical reading, analysis, and evaluation were carried out in each study, to verify methodological veracity and quality. Each study was evaluated independently by the 2 authors. Finally, duplicates were discarded and to develop each component of this study, publications with the greatest relevance and importance were included.

Results

The exhaustive review of the literature obtained during the search of the databases consulted yielded a total of 803 potentially eligible articles divided into Pubmed 126, Scopus 163, and EBSCO 514, from which a sample of 59 articles was taken in which the authors supported their findings with the best theoretical bases, in addition to using an effective methodology and having greater scientific relevance.

Characteristics of neuromuscular training

To fully appreciate the breadth of the concept of NT it is important to note that in sports, humans must achieve a high level of integration in areas such as balance, agility, and speed. These skills are made possible by the unconscious integration of sensory information that allows the central nervous system to execute movements efficiently and accurately, this process is known as sensorimotor control with the contribution of multiple subsystems [22]. In terms of sensorimotor control afferents, the vestibular system is responsible for detecting angular and linear accelerations and providing feedback that allows the generation of ocular and postural adjustments, meanwhile, the visual system is responsible for anticipating and planning movements [23]. The function of the proprioceptive system is to transmit information from the joints and muscles that allow the development of kinesthetic awareness. This information is then processed and directed through an efferent output to precisely perform the planned, necessary, and intended action through motor control [23]. In sports, neuromuscular control describes the body's ability to process afferent inputs and efferent signals to achieve stability and guidance during static and dynamic activities [24]. NT therefore, demands both general and specific exercises, covering aspects such as agility, balance, plyometric skills, power, stability, and strength [25]. In addition, more contemporary concepts are now being used to describe them as combined programs that incorporate elements such as balance, plyometrics, agility, and sport-specific exercises [12].

Research shows that proprioceptive exercises are relevant in NT sessions and play an essential role in the development and maintenance of lower extremity strength, neuromuscular control, and dynamic joint stability [26,27]. These exercises involve controlled stress on the joints through exercises performed on unstable surfaces, with the aim of stimulating the proprioceptive systems and nerve centers responsible for maintaining balance in postural control, generating in the athlete a timely and appropriate activation of the muscles involved and consequently an increase in strength [28].

Neuromuscular training in football

Child and adolescent athletes: NT performed as part of the warm-up two to three times a week (for 20 minutes) in children, compared to a traditional warm-up, has been shown to reduce the incidence of acute injuries by 32% in the intervention group compared to the control group [13]. In addition, significant reductions in injury incidence, especially in acute non-contact injuries such as ankle injuries and joint/ligament injuries, have been observed in both the experimental and control groups. It is essential to note that for these results to be statistically significant, good adherence to NT is of paramount importance [13]. There is added support in the research support for the application of a comprehensive NT approach in children. This approach focuses on several components, including dynamic stability, strength, plyometrics, coordination, speed, agility, and fatigue resistance, with the aim of preventing injury and enhancing performance [29].

NT can reduce the risk of injury in youth football. Implementing an NMT prevention program in youth football is effective in reducing the injury burden and leads to a considerable reduction in medical costs for clubs [30].

Currently, youth NT programs include aspects of balance, neuromuscular control, agility, and strength. Most of the studies of these trainings have shown a protective effect of the intervention with a reduction in injuries ranging from 32% to 88% [10,31-35]. Within the youth population, females are at higher risk for ankle and knee sprains than males [4]. The effectiveness of NT interventions in terms of neuromuscular control and performance depends on several dosage parameters. It has been observed that intervention periods with a higher number of sessions (between 20 and 60 sessions over a 6-month period), and of longer duration appear to be more effective than those of shorter duration. Improvements in ankle and hamstring flexibility were noted [15,36].

Elite players: In elite athletes who underwent NT for a period of 6 weeks, positive effects on their physical performance were observed. Training programs with a frequency of two days per week that included horizontal exercises, such as weighted sprints and change of direction exercises, showed benefits in time reduction in linear sprints of 10, 20, and 30 meters, as well as in agility and lower body strength [37]. On the other hand, the training program focused on vertical exercises, such as half squat, lateral squat with is inertial device, and vertical box jump, has shown significant improvements in mean propulsive velocity evaluated by a linear encoder, as well as countermovement jump [37].

Performed intensively twice daily for three weeks, followed by two sessions per week for five months, NT demonstrated significant improvements in postural control in professional football players as assessed by a force platform. These improvements were manifested by a reduction in the swing path of the total center of pressure of the foot while performing a monopodial stance for 30 seconds, both with eyes open and eyes closed. The training protocol included core exercises focused on balance, agility, coordination, neuromuscular control, and plyometric training [38]. However, some research bases NT programs on balance and stabilization exercises [39].

Roso-Moliner, et al. [40], in their 10-week study, performed three times per week and incorporated exercises from six different categories, such as mobility, dynamic stability, anterior chain strength, posterior chain strength, lumbopelvic control, and change of direction, benefits in body composition were observed in elite female players. This program resulted in an increase in lean muscle mass and a decrease in fat mass. Similar results have been observed in the relationship between body composition, vertical jump performance, and the ability to generate repetitive sprints in football players [41,42]. Athletes with lower body fat tend to have superior performance in terms of acceleration, sprinting speed, and jumping ability. For this reason, an NT program designed to increase body strength or reduce body fat can improve the strength-to-mass ratio, resulting in significant improvements in performance parameters in soccer players [42,43]. In addition, female football players who incorporate proprioceptive exercises into their training experience significant improvements in neuromuscular control and strength parameters, leading to an increase in dynamic joint stability. This training approach has been shown to be beneficial in the female gender, not only in terms of preventing and recovering from muscle injuries but also in terms of improving physical performance [28]. A 15-minute NT program performed twice a week has been shown to improve lower extremity strength in female soccer players. It is important to keep in mind that NT is currently an effective strategy to protect ligaments, especially the ACL, considering all the factors, both hormonal and biomechanical, that increase the risk of ligamentous injuries in women. These risks can be reduced by improving the agonist-antagonist activity of the musculature at the level of the joint [44].

Neuromuscular training and injury risk

Currently, NT has gained great importance in the prevention of injuries, especially in the knee joint complex, in both female and male soccer players. A remarkable reduction in the incidence of anterior cruciate ligament (ACL) injuries in female players has been documented, with a 13% reduction. There was also a 21% reduction in the incidence of acute injuries in female players and an 8% reduction in male players [45]. It has been shown that soccer players who undergo NT experience up to a sevenfold reduction in injury frequency compared to a control group. These findings suggest that this type of training could be established as a standard in pre-season programs and implemented throughout the season [46]. NT increases electromyographic activity in the hamstring muscles, particularly the semitendinosus, both 10 and 50 milliseconds before lateral canter and 10 milliseconds after landing. This early activation of the semitendinosus contributes to the reduction of excessive dynamic valgus and plays a protective role in the knee joint complex. This pattern of neuromuscular adaptation during lateral canter may potentially reduce the risk of non-contact ACL injury [47]. Given the current evidence, there are consistent results supporting the ability of warm-up programs that include NT prior to training sessions to reduce acute lower extremity injuries. This reduction ranges from 29% to 60% in youth sports. In addition, randomized clinical trials have shown that these programs have a protective effect on ankle joint complex injuries [46]. On the other hand, Labella, et al. [48] found that after NT, the injury rate per 1000 in young athletes was 0.25 compared to athletes who did not receive NT (0.74). This represents a 66% reduction in non-contact ankle sprains [48]. Similar conclusions are reached with NT, as it significantly reduces the risk of ankle injury in football players, regardless of a history of ankle sprain [12].

The implementation of an intensive, twice-daily, three-week preseason training regimen that includes balance, coordination, agility, core control, and trunk control exercises has been shown to improve postural balance while contributing to the reduction of lower extremity injuries in elite soccer [38]. However, there are fewer intensive studies that performed an NT program of 20 minutes, 2 times per week versus athletes with a 10-minute program, which concluded by a group that no significant differences were shown in the level of injury incidence between athletes at these training dosages. They also found no differences between the groups in the incidence rate of severity, location, type, and mechanism of injury [12].

Effect of neuromuscular training on knee injuries

Knee injuries are common among soccer players worldwide, regardless of age, gender, or level of competition and the consequences of a serious knee injury include a long absence from football and an increased risk of re-injury [49-53]. A serious injury can also put an end to a football career [51]. Female players have a well-documented increased risk of knee injury, with a marked increase in risk during late puberty [7,51]. Thus, the prevention of knee injuries in soccer has focused primarily on NT programs [5,54].

ACL injuries in football are associated with a high economic cost to athletes and a significant interruption in their athletic activities. In addition, these injuries are associated with comorbidities such as long-term persistent symptoms and a significant increase in the incidence of osteoarthritis. They are common injuries in sports such as soccer, which involve abrupt changes of direction, rapid decelerations, and forced landings after jumps [30]. For this reason, it is important to study the effects of NT on ACL injuries. Studies have shown that knee valgus and tibial rotation may play a key role in ACL rupture, one of the most common causes of ACL injury [55,56]. Dynamic valgus per se refers to an altered pattern of motion or alignment of the lower extremity. Factors that can cause this altered motion in the knee complex include decreased ankle dorsiflexion and deficiencies in the strength or activation of the hip abductors and adductors. Specifically, weakness in the hip abductors and external rotators [57,58]. It has been proposed that NT focused on the abductors and external rotators would reduce dynamic knee valgus and consequently the risk of ACL injury in young football players [59]. An NT program has been shown to be effective in preventing cruciate ligament (CL) injuries in young female soccer players. In Sweden, this program was implemented nationwide in 2010. During the observation period, there was a significant decrease in the incidence of knee and ACL injuries in both sexes at the national level. Specifically, when comparing the 5-year period before the large-scale implementation of the nationwide educational program with the period after, a significant reduction in the incidence of knee and LC injuries was demonstrated by the NT program [45].

In a prospective study of 600 soccer players divided into 40 teams, NT showed that the experimental group, subjected to a proprioceptive exercise program with varying levels of difficulty, had a 7-fold reduction in the incidence of ACL injuries compared to the control group, which followed conventional training. These results support the success of incorporating proprioceptive exercises in the prevention of ACL injuries [60]. Among the factors that may contribute to reducing the incidence of ACL injuries in young female populations, NT injury prevention and performance enhancement programs that replace the traditional warm-up stand out. These programs include stretching techniques for the lower extremities and trunk, strengthening exercises, plyometric activities, and soccer-specific agility drills. It has been shown that the incidence rate of ACL injuries in the group that participated in this program was 0.05 injuries per athlete per 1000 hours of exposure. On the other hand, the control group had an incidence rate of 0.47 ACL injuries per athlete per 1000 hours of exposure. This represents an overall reduction of 88% in ACL injuries per individual athlete. This study, conducted over a 2-year follow-up period, demonstrates that an NT program is highly effective in significantly reducing ACL injuries in young female soccer players [4].

Similarly, by presenting a population of adolescent female players, who adhered to an NT program, they demonstrated an overall rate of anterior cruciate ligament reductions of 64%. An overall rate of anterior cruciate ligament reduction of 64%, as well as a reduction in the rate of serious knee joint complex injuries [5]. One of the most prominent preventive aspects of NT in female athletes is related to the modification of the neuromuscular activation pattern in the lower extremities during specific movements, such as lateral canter. This pattern, characterized by dynamic valgus, may be an important risk factor for ACL injuries [47]. A twice-weekly NT program with 20-minute sessions showed a significant change in electromyographic activation of the semitendinosus muscle. NT markedly increased before activity and landing activity electromyography of the semitendinosus, while quadriceps EMG activity remained unchanged. This selective increase in semitendinosus electromyographic activity during lateral canter represents an important adaptive mechanism, as it potentially reduces the risk of dynamic valgus and, therefore, the risk of anterior cruciate ligament injury [47].

Effect of neuromuscular training on ankle injuries

The ankle is a common site for sports injuries, with ankle sprains being the most common injury to this joint complex. These sprains account for approximately 30% of all sports injuries [61]. The most common mechanism leading to these sprains is forced inversion resulting from a sudden movement. Due to the limited stability of the ankle joint, this type of motion places maximum stress on the anterior talofibular ligament, which is one of the most vulnerable ligaments within the capsuloligamentous complex and is often compromised in these injuries [61]. It is common for athletes with sprains

to experience chronic ankle instability, including recurrent sprains and balance problems associated with reinjury. Current evidence supports NT as a successful technique for improving balance, stability, and postural control, thereby reducing the incidence and recurrence of sprains in athletic populations [12].

Gender differences in ankle injuries have been identified, with females being more susceptible. These differences include greater joint and ligamentous laxity in the lateral ankle, greater range of motion, and variations in hormone levels that may occur with the onset of puberty. These factors may contribute to changes in ligament strength and/or underlying biomechanical differences in the ankle during motion [12].

Among strategies to address the unpredictability associated with ankle injuries, NT has been shown to significantly reduce the incidence of ankle sprains, with a 32% reduction. This information is consistent with current evidence in youth sports, where a protective effect in the prevention of ankle sprains ranging from 29% to 73% has been observed [46]. However, in the adolescent population who have suffered or have a history of previous ankle sprains, this is an important protective factor against suffering a new ankle sprain [12].

Effect of neuromuscular training on muscle strength and power

Female football players significantly increase lower extremity strength when they undergo an NT program designed specifically for soccer. This training program, which focuses on proprioceptive exercises and is performed twice a week for 15 minutes, improves strength as assessed by jumping tests (single distance jump and cross jump) in female football players [62]. A 6-week NT program significantly improves athletic performance in jumping tests, according to several studies [28,62]. NT plays a fundamental role in the development and maintenance of lower extremity strength, making it a critical element of athletic performance. This type of training is effective in preventing and recovering from muscular injuries as well as improving physical performance. The NT technique is based on the controlled loading of joints through exercises performed on unstable surfaces. Therefore, NT should be planned in such a way as to challenge the athlete, cause him/her to lose balance in a controlled manner, activate the muscles involved in a timely and appropriate manner, and promote increased muscular strength [28]. Recently, it has been proposed that the incorporation of NT along with a resistance training program, performed twice a week for a period of 6 weeks, may contribute to improved performance in terms of strength. Specifically, balance training has been observed to increase the rate of force development (RFD) and jump performance in untrained recreationally active individuals and trained individuals. In addition, some studies have reported that NT has increased strength in individuals with motor deficits and in young, untrained individuals [63].

Twenty minutes of integrative NT in the adolescent population, focusing on core strength, stabilization, and strength of the hip and knee musculature with an emphasis on eccentric hamstring strength, can significantly improve leg strength, reduce change of direction times, speed, lower extremity muscle power, and soccer performance. Similar rates of improvement in speed performance have been reported with plyometric and strength training [64]. NT focused on eccentric contraction, plyometric, and acceleration strength exercises performed on soccer players twice a week for 7 weeks demonstrated significant improvements in both eccentric and concentric hamstring strength, as well as an increase in the functional relationship between the hamstrings and quadriceps. These results are consistent with previous studies that have observed an increase in peak eccentric hamstring torque at 60 seconds, with increases ranging from 11% to 21% following a hamstring-focused strength training program [31,65]. This increase in strength at the hamstring level can be targeted to prevent common injuries with a sprint training program [66]. Integrative NT, favoring work on the lower limb musculature with emphasis on eccentric strength, improves 10 m sprint times. Other studies have shown significant improvements in the maximal strength of the lower limb muscles that are associated with an increase in short sprint performance [64]. The NT program with a focus on balance, accompanied by a 6-week strength-resistance program, achieved a significant increase in jump height, evaluated using the squat jump [63]. Another study showed that 8 weeks of NT in adolescents resulted in statistically significant improvements in single- and double-leg horizontal (forward) jumping, which translates into an increase in explosive strength [67].

The NT for balance, combined with high resistance training, applied in men for 6 weeks, has improvements in the balance capacity, evaluated through a strength platform. A decrease in the displacement of the center of pressure in the anteroposterior and mid-lateral axes, more specifically in the anteroposterior and mid-lateral axes, was observed. Specifically in the anteroposterior axis [63]. In addition, a relationship has been reported between muscular strength and balance, where specifically balance improves significantly after muscular strength training, these trainings focused on proprioceptive programs have shown that there is a decrease in musculoskeletal injuries in the lower limbs and an increase in balance ability in young players who are intervened twice a week for 20 minutes each session [68,69].

Effect of neuromuscular training on other motor performance variables

Agility is an essential factor in soccer performance, consisting of perceptual and decision-making elements such as visual scanning and anticipation, among others. Although traditionally defined as the ability to change direction quickly, agility is a key factor in football performance, Agility

is a complex property that involves temporal and spatial uncertainty [70]. Although many athletes often classify agility as any movement that involves rapid changes of direction, a more precise definition has recently been adopted that defines it as a rapid change of direction (COD) in response to a sport-specific stimulus. Agility is characterized as a rapid movement involving the whole body with changes in speed or direction in response to a stimulus. Consequently, agility includes a COD component [71], and a perception and decision component [72]. Agility is generally defined as the ability to perform quick and efficient body transfers in space, including sudden changes of direction, acceleration, and deceleration. In the context of football, a player can change direction approximately every 2-4 seconds, for a total of 1200-1400 changes of direction during a match [73]. It has been shown that improved balance should be considered as one of the key attributes for the development of agility. Agility is influenced by several trainable physical attributes such as strength, power, and technique, as well as cognitive components such as visual scanning skills, visual scanning speed, anticipation, and proprioception. Ultimately, it can be seen as the result of a systemic integration of neuromuscular coordination, reaction time, speed, strength, balance, and proprioception [74]. Powerful, precise, and controlled movements are fundamental elements of soccer. This sport, like any other intermittent sport, requires a combination of physiological attributes and motor skills such as agility, sprinting, rapid acceleration and shooting. Improving these skills is essential to achieving the main objective of the game: scoring goals against the opposing team. This involves making accurate passes, whether short or long, which require careful technique along with the right speed of movement. To increase the success rate in soccer, it is crucial to focus on improving players' passing, agility and running speed skills [74]. Proprioceptive training conducted over an 8-week period in adolescents has shown positive results on average agility levels, with statistically significant improvements observed after the intervention [75].

NT study of 14-year-olds using the Bosu ball, conducted over 8 weeks of 30-minute sessions, showed improvements in the performance of soccer-specific skills such as coordination and speed with the ball, as assessed by the short dribbling test [67]. Finally, NT has proven to be an effective tool for improving soccer-related skills such as passing, shooting, and ball control [76].

Conclusions and future directions

Scientific evidence supports the use of effective NT programs that focus on multiple components such as dynamic stability, strength, plyometrics, coordination, speed, agility, and fatigue resistance. These programs are beneficial in both preventing injury and significantly improving athlete performance.

In addition, they help mitigate the loss of motor skills that can occur because of long-term injury and its long-term negative consequences. Therefore, NT is not only beneficial for the recovery of traumatic injuries but can also generate adaptations in the organism specific to the postural mechanisms required in sports, thus reducing the risk factors associated with sports practice. This review managed to identify that NT is effective in reducing the risk of injury in soccer players; however, the literature has mainly addressed lower extremity injuries. Therefore, it may be necessary for future investigations to focus on the upper extremity and trunk. Likewise, it was determined that NT has a potential impact on improving physical performance, with the variables of strength, power, speed, agility, and balance being the most studied.

This review recommends the following guidelines for the implementation of NT in football players. The duration of the sessions should be at least 10-15 minutes, with a frequency of 2-3 times per week, in a weekly training volume of 30-60 minutes, if this intervention does not interfere with the tasks required by the sport.

Scientific evidence should follow the influence of NT in injury prevention compared to other strategies such as eccentric training. In addition, NT should be considered with caution in performance enhancement, as it needs to be more fully supported and compared to other tools such as plyometric or change of direction training.

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