Journal of Strength and Conditioning Research Publish Ahead of Print
DOI: 10.1519/JSC.0000000000002319

SEQUENCING EFFECTS OF NEUROMUSCULAR TRAINING ON PHYSICAL FITNESS IN YOUTH ELITE TENNIS PLAYERS

Authors: Jaime Fernandez-Fernandez[1], Urs Granacher[2], David Sanz-Rivas[3], Jose Manuel Sarabia Marín[4], Jose Luis Hernandez-Davo[4] and Manuel Moya[4]

Institutions:

[1] Department of Physical Education and Sports, Faculty of Physical Activity and Sports Sciences; University of León, Spain.

[2] Division of Training and Movement Sciences, Research Focus Cognition Sciences, University of Potsdam, Potsdam, Germany

[3] Spanish Tennis Federation, Madrid, Spain

[4] Sports Research Centre, Miguel Hernandez University, Elche, Spain.

Corresponding author:

Jaime Fernandez-Fernandez, Phd

Faculty of Physical Activity and Sports Sciences. University of León

C/ Campus de Vegazana, S/N. 24.071. León (Spain)

E-mail: jaime.fernandez@unileon.es

Running title: Neuromuscular training before or after tennis

Conflicts of interest: The authors declare there are no conflicts of interest with the findings in this manuscript.

ABSTRACT

The aim of the present study was to analyze the effects of a 5-week neuromuscular training (NMT) implemented before or after a tennis session in pre-pubertal players on selected components of physical fitness. Sixteen elite and well-trained tennis players with a mean age of 12.9 ± 0.4 years participated in this study, and were assigned to either a training group performing NMT before tennis specific training (BT; n=8) or a group that conducted NMT after tennis specific training (AT; n=8). Pre and post-tests included: speed (5,10 and 20 m); modified 5-0-5 agility test; countermovement jump (CMJ); overhead medicine ball throw (MBT); and serve velocity (SV). Results showed that the BT group achieved positive effects from pre- to post-test measures in speed (d = 0.52, 0.32 and 1.08 for 5, 10 and 20 m respectively) 5-0-5 (d = 0.22), CMJ (d = 0.29), MBT (d = 0.51) and SV (d = 0.32), while trivial (10 m, 20 m, CMJ, SV, MBT) or negative effects (d = -0.19 and -0.24 for 5 m and 5-0-5 respectively), while trivial or negative effects were reported for the AT group. The inclusion of a NMT session before the regular tennis training led to positive effects from pre- to post-test measures in performance-related variables (i.e., jump, sprint, change of direction capacity, as well as upper body power), while conducting the same exercise sessions after the regular tennis training was not accompanied by the same improvements.

INTRODUCTION

Tennis is an intermittent sport characterized by repetitive high-intensity efforts (i.e., accelerations, decelerations, changes of direction (COD), and strokes) during a variable period of competition time (i.e., on average 90 min), which demands high levels of physical fitness in components such as speed, agility, muscle power, and cardiovascular fitness to achieve high performance levels (13). At an early age already (i.e., under 14 players [U14]), players spend a great amount of training time mastering their individual sport-specific skills, with technical and tactical sessions often exceeding 15–20 h per week (36). Additionally, match scheduling along with participation in multiple draws (singles and doubles) as well as high training volumes (i.e., > 8 months per year)(20) require elite youth tennis players to often complete numerous training sessions and/or competitive matches on consecutive days (16).

The daily training practices of young tennis players often involves the realization of inadequately planned training sessions conducted within close proximity, and foresees players to conduct athletic training before or after a sport-specific tennis training, with a break in between sessions that rarely exceeds 30 min. Moreover, due to the above mentioned high training volumes, restricted fitness training time, and other tennis specific limitations (e.g., availability of appropriate training facilities and/or equipment), it is not always possible to conduct training sessions for single physical fitness components (i.e., muscular strength, cardiovascular fitness) on separate days.

From a physiological point of view, the mere exposition to a sport-specific tennis training sufficiently stimulates aerobic capacity provided that match intensity is high enough and rest periods remain relatively low (38). Previous studies have shown that pre-pubertal children involved in cardiovascular fitness programs or in sport-specific programs were able to improve their aerobic capacity (1, 3, 26). More specifically, Sanchis-Moysi et al. (38), reported that pre-pubertal male tennis players enhanced their maximum oxygen uptake (VO_{2max}) by 7% compared to their non-active peers. Thus, the completion of two training bouts within relatively close succession may create considerable metabolic stress and a fatigued state, compromising physiological adaptations (i.e., muscle strength and/or power) (41).

Physical fitness components such as speed, and muscle power are also important performance-determinants in tennis (11). Consequently, the optimal design and implementation of training strategies that enhance these fitness components are of significant interest to tennis as well as strength and conditioning coaches. In accordance with Myer et al. (33), NMT incorporates general (e.g., fundamental movements) and specific (e.g., exercises targeted to motor control deficits) strength and conditioning activities, such as resistance, dynamic stability, core focused strength, plyometrics and agility, that are designed to enhance health and skill-related components of physical fitness. Thus, based on previous research, NMT is an effective means to enhance these components of physical fitness and to prevent injuries in youth athletes (9, 33). To the best of our knowledge, only few studies were conducted in youth tennis players elucidating the effects of NMT (4, 5) on physical fitness. These studies showed significant improvements in measures of dynamic balance, agility, speed, and muscle strength following six weeks of NMT. Based on these findings, a similar type of training regimen should be implemented in young players daily training routine.

To the authors' knowledge, no studies have examined the within session sequence of NMT and sport-specific training in youth tennis. As a result, little is known about habitual training practices within tennis or the effect of these training interventions. Therefore, the aim of the present study was to analyze the effects of a 5-week NMT implemented before or after a tennis session in pre-pubertal players on selected components of physical fitness. Our hypothesis was that NMT conducted prior to tennis training and in an unfatigued state leads to higher performance improvements in physical fitness compared to NMT implemented after tennis training and thus in a fatigued condition within elite youth tennis athletes (22).

METHODS

Experimental approach to the problem

A 2-group, matched, experimental design was used in this study. Study participants were assigned to either a training group performing NMT before tennis specific training (BT; n=8) or a group that conducted NMT after tennis specific training (AT; n=8). After an appropriate familiarization period, laboratory tests, and a specific range of physical-performance tests were completed one week before and after a 5-week training period. Physical tests (ie, 20-m sprint (with 5- and 10-m splits), counter-movement jump (CMJ), 5-0-5 Agility Test, 2 kg overhead medicine ball throw (MBT), and serve velocity (SV) were conducted before (Pre-tests) and 4 days after the intervention (Post-tests). Between the last training session and the post-tests, only light on-court training combined with injury-prevention sessions (eg, core training, shoulder strengthening, and flexibility) was performed. The research was conducted during the second part of the preparatory period (January-February). All tests were conducted on an outdoor synthetic court. To reduce the interference of uncontrolled variables, all the subjects were instructed to maintain their habitual lifestyle and normal dietary intake before and during the study. They were told not to exercise on the day before a test and to consume their last (caffeine-free) meal at least 24 hours before the scheduled test time.

Participants

Sixteen elite and well-trained male tennis players with a mean age of 12.9 ± 0.4 years participated in this study (body mass 46.0 ± 5.7 kg, body height 157.0 ± 5.1 cm). Thirteen players were right-handed and three were left-handed. Participants had a mean training background of 3.0 ± 1.2 years and participated, on average, in 8–10 h of tennis training per week, focused on the development of on-court technical/tactical tennis skills, as well as the enhancement of tennis-specific cardiovascular fitness. Players were eligible to be included in this study if they did not suffer from any severe injuries, had surgeries, or conducted any sport related rehabilitation during the 12 months prior to the start of the study. In addition, subjects were not allowed to participate in any formal strength training programs (e.g., plyometric or core exercises) during the four weeks before the start of the study. Study participants were assigned to either a training group performing NMT before tennis specific training (BT; n=8) or a group that conducted NMT after tennis specific training (AT; n=8). Due to organizational limitations in the tennis clubs, no randomization of groups was possible, although pretests were used to control the initial status of players. All players were ranked among the 200 best players in their respective national singles ranking category (U14). Prior to the start of this investigation, a written consent was obtained from both, children and their parents/legal guardians and all participants were fully informed about the testing and training protocols. The procedures were approved by the institutional ethics review committee and conformed to the code of ethics of the World Medical Association (Declaration of Helsinki).

Testing procedures

Maturity status

Body height was measured using a fixed stadiometer (± 0.1 cm; Holtain Ltd., Crosswell, UK), sitting height with a purpose-built table (± 0.1 cm; Holtain Ltd., Crosswell, UK), and body mass with a digital balance (± 0.1 kg; ADE Electronic Column Scales, Hamburg, Germany) (34). Pubertal timing was estimated according to the biological maturation of each individual using the predictive equation described by Mirwald et al.(29) (standard error of measurement [SEM] = 0.592). The age of peak linear growth (age at peak height velocity) is an indicator of somatic maturity representing the time of maximum growth in stature during adolescence (29). Calculating the biological maturation of each participant (years) was achieved by subtracting the chronological age at the time of measurement from the chronological peak-velocity age (27). Therefore, a maturity age of –1.0 indicates that the player was measured one year before their peak height velocity; a maturity of 0 indicates that the player was measured at the time of their peak height velocity; and a maturity age of +1.0 indicates that the participant was measured 1 year after their peak height velocity (27).

Speed test

Time during a 20-m dash (with 5 and 10 m split times) in a straight line was measured by means of single beam photocell gates placed 1.0 m above the ground level (DSD Sport system, Spain). Each sprint was initiated 50 cm behind the photocell gate which then started a digital timer. Each player performed two maximal 20-m sprints with at least 2 min of passive recovery in between the two trials (12). The best performance was recorded. The Intraclass correlation coefficient (ICC) for this test was 0.96.

Modified 5-0-5 agility test.

The abilities of the athletes to perform a single, rapid 180° change of direction over a 5 m distance was measured using a modified version (stationary start) of the 5-0-5 agility test (16). Players started in a standing position with their preferred foot behind the starting line, followed by accelerating forward at maximal effort without a racquet. One trial pivoting on both left and right feet was completed and the best time recorded to the nearest 0.01 s (DSD Sport system, Spain). Two minutes of rest was allowed between trials. The ICC was 0.92.

Vertical jumping

A countermovement jump (CMJ) without arm swing was performed on a contact-time platform (Ergojump®, Finland) according to Bosco et al. (6). Each player performed two maximal CMJs interspersed with 45 s of passive recovery. The best height for each subject was recorded for further analysis. The ICC of the CMJ was 0.96.

Overhead medicine ball throw test (MBT)

An overhead MBT was set up and administered using a 2-kg ball following the protocol outlined by Ulbricht et al. (40). The distance from the line to the point where the ball landed was measured and the best performance out of two test trials was recorded to the nearest 5 cm. Thirty seconds of rest was permitted between trials. The best value of the two trials was used for further statistical analysis. The ICC for this test was 0.88.

Serve velocity test.

A radar gun (Stalker Professional Sports Radar, MN, USA) was used to measure serve velocity. This procedure was done according to the previously introduced guidelines in (40). The radar gun was positioned to face the centre of the baseline, 3 m behind the server, and aligned with the approximate height of ball contact (~2.2 m) and pointing down the centre of the court. After 5 min of specific serve warm-up, including upper body mobility and two sets of first and second serves (8 repetitions each), the players performed 3 sets of 10 maximum speed serves. All serves were executed on the deuce side of the court. Players used their own racquets and a set of new balls which were provided (Babolat Gold, France) to them for the test. In order for measurements to be recorded, serves had to land within 1 m of the centre service line. The serve with the highest velocity was used for subsequent statistical analyses. The ICC for this test ranged from 0.91 to 0.94.

Neuromuscular training intervention

The BT group undertook the NMT program at an outdoor testing facility between 16:00 and 17:00 hours while the AT group between 18:30 and 19:30 hours at the same facility. For both groups, a 30-min recovery period was set between training bouts, during which participants were allowed to consume water and a 6% carbohydrate/electrolyte drink ad-libitum. To ensure familiarization with the training and testing procedures, all participants completed two orientation sessions (i.e., 1 h each) one week before the baseline testing period. In addition to their regular tennis training, all participants performed NMT three times per week for five consecutive weeks. Regular tennis training lasted on average 64.7 ± 4.4 minutes and was characterized by a ~10-minute specific warm-up (i.e., including general mobility, ground strokes, volleys, and low-intensity smashes), ~10 minutes of technical adjustments (i.e., service technique), and ~45 minutes of specific drills (i.e., mixed open/closed technical/tactical drills). For the most part, the tennis training portion of this study was designed by the tennis instructors with the goal to address the specific needs of each athlete, including more technical/tactical drills (i.e., designed to focus on improvements to a specific quality in stroke technique or tactical approach). On the other hand, the tennis coaches were advised to avoid a more physical approach to their training sessions (i.e., high volumes of open and/or high-intensity drills), which could affect the results obtained for this particular study.

NMT sessions (Table 1) consisted of combining plyometric training protocols with acceleration/deceleration/COD drills. Prior to the start of NMT, participants conducted a standardized warm-up protocol that comprised of low-to-moderate-intensity (self-perceived) running exercises including forward/backwards movements, sidestepping and general mobilization activities (i.e., arm circles, leg kicks). These movements were followed by 5 minutes of dynamic stretching (i.e., straight leg march, forward lunge with opposite arm reach, trunk rotations), conducted from low-to-high intensity and performed in a controlled manner through a range of motion (2). Plyometric training consisted of 2-3 sets of 4-10 repetitions, including maximal CMJ, box Jumps, drop landings (20 cm), medicine ball throws (2 kg), multi-jumps (20-60 cm hurdles); drop jumps (20-40 cm), ½ ankle jumps, line jumps, and lateral bounds with stabilization. Each repetition and set was interspersed with at least 15-20 s and 60 s of passive recovery, respectively. The progressive overload principle was added to the program by increasing the number of foot contacts and varying the complexity of the exercises in accordance with previous training guidelines (10, 12, 35). For all plyometric exercises, subjects were instructed to exercise at maximal effort with minimal ground contact times. After 3-4 min of passive recovery, players also performed a combination of acceleration/deceleration and agility/COD drills, including speed-ladder exercises (10 s), 8-10 s agility exercises (e.g., colour/number tag, right-to-left direction, with 2-3 COD), and 8-10 s partner drills (e.g., chasing runs, “mirror” drills). At least a 25 to 30 s rest period was allowed between repetitions and 90 to 120 s after each set. Overall, NMT sessions averaged 32.4 ± 7.3 minutes, ranging from 20 min in the first week to 40 min in the fifth week.

******Insert Table 1 near here******

The training load for each subject during the intervention was calculated using the session rating of perceived exertion (s-RPE) and training load was also established post-session through multiplication of s-RPE (Borg CR-10) and duration (15). For the training intensity distribution, s-RPE data were divided into three intensity zones. In accordance with Seiler and Kjerland (39), results from the CR-10 scale were divided into three zones: zone-1 (low intensity): ≤4 Arbitrary Units (AU); zone-2 (moderate intensity): >4 and <7 AU; and zone-3 (high intensity): ≥7 AU. For inclusion in post-testing analysis, participants were required to complete >85% of the prescribed training sessions.

Statistical analyses

ICC was obtained by using a specific spreadsheet available on www.sportsci.org and interpreted as poor (0-0.49) moderate (0.5−0.69) high (0.7−0.89), and very high (> 0.9) (32). Results are presented as means and standard deviations. All data were log-transformed for analysis to reduce bias arising from non-uniformity error and then analyzed for practical significance using magnitude-based inferences (18). Chances that any performance change was greater/similar/smaller than the other group was subsequently calculated [using standardized difference (0.2) and its 90% confidence limits (CL)]. Qualitative assessment of the magnitude of change was also included. If the 90% CL overlapped, indicating smaller positive and negative values, the magnitude of the correlation was termed unclear; otherwise it was deemed as the observed magnitude. For more clarity, all improvements are presented as positive changes, so that both positive (i.e. increased CMJ height) and negative differences (i.e. reduced time in a sprint test) are in the same direction. All analyses were performed using specific spreadsheets (i.e. pre-post parallel groups) available at www.sportsci.org. Effect sizes (ES) were also calculated to determine the magnitude of differences between the groups or experimental conditions for each variable using the method previously described (19) (i.e., ES of < 0.4 = small; 0.41–0.7 = moderate; >0.7 = large magnitudes of change, respectively).

RESULTS

All subjects received treatment conditions as allocated. None reported any training or test related injuries. Overall, players completed more than 90% of the training sessions, demonstrating excellent adherence with the program. Years from PHV were –1.2 ± 0.3 (estimated age at PHV: 14.0 ± 0.3) and –1.1 ± 0.5 (age at PHV: 14.1 ± 0.4) for the BT and AT, respectively.

Within group changes in the performance variables tested are shown in Table 2. BT group showed positive effects from pre- to post-test measures in all the variables, with standardized differences ranging from d = 0.22 to 1.08. Nevertheless, the AT group showed trivial effects on six out of the eight collected variables, and possibly negative effects on the remaining two variables.

******Insert Table 2 near here******

Between group comparisons showed that the BT group produced substantially larger positive effects in all tested variables (Figure 1). More specifically, the AT group achieved positive effects on 10 m sprint (*d* = 0.28; CL: 0.01-0.54), likely positive effects on 5-0-5 test (*d* = 0.26; CL: 0.16-0.35), very likely positive effects on 5 m sprint (*d* = 0.58; CL: 0.27-0.81), CMJ (*d* = 0.28; CL: 0.21-0.35), SV (*d* = 0.41; CL: 0.25-0.56) and MBO (*d* = 0.48; CL: 0.30-0.66), and most likely positive effects on 20 m sprint (*d* = 1.14; CL: 0.87-1.40).

******Insert Figure 1 near here******

Regarding the training load induced by both training conditions, it appeared that the BT group showed probable trivial effects (*d* = 0.01; CL: -0.68 to 0.71) on the tennis session TL (246.7 ± 43.4 arbitray units (AU) vs. 244 ± 30.5 for the BT and AT groups, respectively), while most likely positive effects (*d* = 2.41 CL: 1.80-3.02) on the NMT session (157.0 ± 66.4 vs. 188.6 ± 77.1 AU for the BT and AT groups, respectively).

DISCUSSION

To the best of our knowledge, this is the first study analyzing within the session sequencing of NMT and regular practice in tennis players, comparing the training responses to two "typical" training scenarios used in an applied environment. The major finding of the present study is that sequencing 5 weeks of NMT prior to the regular tennis training (BT group) in ~13-year-old players resulted in performance enhancements in all the variables, with standardized differences ranging from 0.22 to 1.08, compared to tennis training prior to NMT (AT group). In fact, results showed no performance enhancements for any of the variables measured in the participants allocated to the AT group (see table 2).

Since this is the first study analyzing the within session sequence of NMT and regular practice in tennis players, it is not possible to compare our results to previous studies. The lack of improvement in the AT group could be related to different factors. First, although the sport-specific training was designed to avoid high volumes of high-intensity activity, these sessions could lead to a fatigued state and therefore, reduce and/or impair the quantity and quality of subsequent (i.e., NMT) training sessions (17), especially with short recovery periods (e.g., 30 min). We can speculate that the acute fatigue provoked by the previous tennis session could lead players to underperform during the NMT sessions, as power production requires a "fresh" or "rested" neuromuscular system (14). In this regard, although the inclusion of high-intensity drills was avoided during the tennis sessions, the training intensity distribution (i.e., through heart rate monitoring) was not conducted, and this could be a limitation of the present study. On the contrary, using the training intensity distribution through session RPE data, results indicated that the total training time during tennis sessions accounted for almost 70% of the time in zone 1 (i.e., ≤ 4), while ~30% and ~2% in zones 2 and 3, respectively. These findings are in agreement with a previous study suggesting that the majority of the training sessions in young tennis players (~18 years) were performed at low-to-moderate intensity zones, based on heart rate and RPE intensities (30). The outcome of RPE and training load results showed possibly negative values for the AT group (RPE: 5.6 ± 0.1; training load: 188.6 ± 77.1 AU) compared to the BT group (RPE: 4.6 ± 0.3; training load: 157.0 ± 66.4 AU) after the NMT session. Based on these results and taking into account that training sessions, for both, sport-specific training and NMT, were similar we can suggest that players in the AT group were performing the NMT sessions in a more "fatigued" state, resulting in a lack of improvement after the intervention.

Results obtained in the BT group are in line with previous research conducting NMT programs in different youth athletes (e.g., soccer, basketball) (14), and more recently, similar to a previous study conducted with young tennis players (4), with 2 to 10% improvements in the different physical qualities measured. In this regard, a current systematic review and meta-analysis reported that plyometric training, as part of the NMT, can lead to significant (with small-to-medium ES) improvements in muscle strength, vertical jump, sprint, agility, and sport-specific performance in youth athletes (21). It seems important to highlight that the training intervention lead to significant improvements in the serve velocity (2%) and MBT (6.7%) in the BT group, while no changes were reported in the AT group. In this regard, upper-body strength and power (i.e., MBT and serve velocity) seems to be among the most important physical components related to tennis performance in adolescent tennis players (i.e., ranking). These training interventions aimed at increasing upper-body power are highly recommended at this stage of development (40). Although improvements are lower than in a previous study we conducted with similar tennis players (~13 years)(12), the training volume of the present study is also lower (2 x week and 30-40 min per session), suggesting that combined training programs (e.g., NMT) are really effective at pre-PHV stages (24). More specifically, plyometric training provides the required stimuli to train the stretch–shortening cycle (SSC) mechanism and can enhance explosive contractions in pre-pubertal populations (25). Thus, part of the increased performance observed in the BT group was probably because of an improvement in various neuromuscular adaptations (i.e., increased neural drive to the agonist muscles, intermuscular coordination, and a better synchronization of body segments) (23). Additionally, if we analyze the age of players and their maturation characteristics, they were ~1.2 years before PHV. Thus, growth and maturation can be also linked to these improvements, as it has been suggested that an adolescent performance spurt in strength and power development occurs about 1.5 years before PHV (28).

The changes in sprint and COD performance found in this study for the BT group, with significant improvements in 5 m (2.4%), 10 m (1.4%) and 20 m (4.9%) sprint as well as in the COD (1.5%), are similar to those obtained in previous studies conducting speed and agility training programs alone (8, 31), and also similar to a study conducted with elite junior tennis players (10), with moderate to large ES after training in sprint distances ranging from 5 to 30 m. Speed in tennis comprises the ability to move at high velocity in different directions around the court, with initial acceleration as a key component of performance, as most tennis movements are within a 3 to 4 m radius and there is rarely a chance for players to reach maximum speed (11). Together with the positive impact that plyometric training can have to speed improvement (37), exercises prescribed here consisted in multidirectional movements which may had an impact on the acceleration component together with the capacity to change direction faster. Therefore, improvements are likely to be related to the neural component (e.g., inter-lower limbs muscle coordination, stride frequency), together with an improvement in the eccentric strength of the thigh muscles (7), which have been shown in other studies to provide a short-term improvement in speed and change of direction qualities (4, 10, 12, 31).

In conclusion, the inclusion of a NMT session before the regular tennis training led to positive effects from pre- to post-test measures in performance-related variables (i.e., jump, sprint, COD capacity, as well as upper body power), while conducting the same exercise sessions after the regular tennis training was not accompanied by the same improvements. Nevertheless, it is important to note that there are several limitations associated to the present study. First, no physiological measurements were taken (e.g., electromyography, muscle stiffness), only speculations are possible, and the underlying adaptations induced by the NMT remain hypothetical. Secondly, the initial fitness status of the participants could be related to the differences obtained after the training intervention, as the BF group showed significantly better results in some of the pre-tests (i.e., 5 and 10 m sprint; 505) compared to the AT group. Due to organizational limitations in the tennis clubs, no randomization of groups was possible, although those differences were taken into consideration through the statistical analyses conducted.

Although it is acknowledged that there are a number of limiting factors which may account for the present findings, we believe that the present design has high levels of ecological validity and may offer a starting point to suggest practical applications to strength and conditioning as well as to the tennis training. As always, additional research is required to investigate how players respond to habitual training routines in a short/long term, in the applied setting.

PRACTICAL APPLICATIONS

Based on the present findings, it would be more effective for coaches and strength and conditioning coaches that wish to implement NMT for their young tennis players, to conduct it before the regular tennis training in order to avoid excessive levels of fatigue and, above all, to obtain improvements in tennis performance-related factors (e.g., sprint, jumping performance, serve velocity). Thus, coaches can implement NMT sessions before the tennis training, combining plyometric training protocols (e.g., 1-2 kg medicine ball throws; bilateral and unilateral CMJs to 20-cm box; multilateral hops with hurdles; ankle jumps, line jumps, etc), with acceleration/deceleration/COD drills (short sprints (15-20 m) with 2-3 COD, and short rest periods (25 s)). From a practical point of view, NMT-oriented sessions should not exceed a total volume of 40 min (including the warm-up) and an appropriate resting time before the following tennis training should be above 30 min.

REFERENCES

1. Ara I, Vicente-Rodriguez G, Jimenez-Ramirez J, Dorado C, Serrano-Sanchez J, and Calbet J. Regular participation in sports is associated with enhanced physical fitness and lower fat mass in prepubertal boys. *International journal of obesity* 28: 1585-1593, 2004.
2. Ayala F, Moreno-Pérez V, Vera-Garcia FJ, Moya M, Sanz-Rivas D, and Fernandez-Fernandez J. Acute and time-course effects of traditional and dynamic warm-up routines in young elite junior tennis players. *PloS one* 11: e0152790, 2016.
3. Baquet G, Van Praagh E, and Berthoin S. Endurance training and aerobic fitness in young people. *Sports Medicine* 33: 1127-1143, 2003.
4. Barber-Westin S, Hermet A, and Noyes F. A six-week neuromuscular and performance training program improves speed, agility, dynamic balance, and core endurance in junior tennis players. *J Athl Enhancement 4* 1: 2, 2015.
5. Barber-Westin SD, Hermeto AA, and Noyes FR. A six-week neuromuscular training program for competitive junior tennis players. *The Journal of Strength & Conditioning Research* 24: 2372-2382, 2010.
6. Bosco C, Luhtanen P, and Komi PV. A simple method for measurement of mechanical power in jumping. *European journal of applied physiology and occupational physiology* 50: 273-282, 1983.
7. Brughelli M, Cronin J, Levin G, and Chaouachi A. Understanding change of direction ability in sport: a review of resistance training studies. *Sports medicine* 38: 1045-1063, 2008.
8. Buchheit M, Mendez-Villanueva A, Delhomel G, Brughelli M, and Ahmaidi S. Improving repeated sprint ability in young elite soccer players: repeated shuttle sprints vs. explosive strength training. *The Journal of Strength & Conditioning Research* 24: 2715-2722, 2010.
9. Faigenbaum AD, Farrell A, Fabiano M, Radler T, Naclerio F, Ratamess NA, Kang J, and Myer GD. Effects of integrative neuromuscular training on fitness performance in children. *Pediatric exercise science* 23: 573-584, 2011.
10. Fernandez-Fernandez J, Sanz-Rivas D, Kovacs MS, and Moya M. In-season effect of a combined repeated sprint and explosive strength training program on elite junior tennis players. *Journal of strength and conditioning research/National Strength & Conditioning Association*, 2014.
11. Fernandez-Fernandez J, Sanz-Rivas D, and Mendez-Villanueva A. A review of the activity profile and physiological demands of tennis match play. *Strength & Conditioning Journal* 31: 15-26, 2009.

12. Fernandez-Fernandez J, Sanz-Rivas D, Saez dVE, and Moya M. The Effects of 8-Week Plyometric Training on Physical Performance in Young Tennis Players. *Pediatric exercise science*, 2015.
13. Fernandez-Fernandez J, Sanz D, Sarabia JM, and Moya M. The Effects of Sport-Specific Drills Training or High-Intensity Interval Training in Young Tennis Players. *International journal of sports physiology and performance* 12: 90-98, 2017.
14. Fort-Vanmeerhaeghe A, Romero-Rodriguez D, Lloyd RS, Kushner A, and Myer GD. Integrative Neuromuscular Training in Youth Athletes. Part II: Strategies to Prevent Injuries and Improve Performance. *Strength & Conditioning Journal* 38: 9-27, 2016.
15. Foster C, Florhaug J, Franklin J, Gottschall L, Hrovatin L, Parker S, Doleshal P, and Dodge C. A new approach to monitoring exercise training. *The Journal of Strength & Conditioning Research* 15: 109-115, 2001.
16. Gallo-Salazar C, Del Coso J, Barbado D, Lopez-Valenciano A, Santos-Rosa FJ, Sanz-Rivas D, Moya M, and Fernandez-Fernandez J. Impact of a competition with two consecutive matches in a day on physical performance in young tennis players. *Applied physiology, nutrition, and metabolism = Physiologie appliquee, nutrition et metabolisme,* 2017.
17. Garcia-Pallares J and Izquierdo M. Strategies to optimize concurrent training of strength and aerobic fitness for rowing and canoeing. *Sports Med* 41: 329-343, 2011.
18. Hopkins W, Marshall S, Batterham A, and Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise* 41: 3, 2009.
19. Hopkins W, Marshall S, Batterham A, and Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Medicine+ Science in Sports+ Exercise* 41: 3, 2009.
20. Jayanthi NA, LaBella CR, Fischer D, Pasulka J, and Dugas LR. Sports-specialized intensive training and the risk of injury in young athletes: a clinical case-control study. *The American journal of sports medicine* 43: 794-801, 2015.
21. Lesinski M, Prieske O, and Granacher U. Effects and dose–response relationships of resistance training on physical performance in youth athletes: a systematic review and meta-analysis. *British journal of sports medicine* 50: 781-795, 2016.
22. Leveritt M and Abernethy PJ. Acute Effects of High-Intensity Endurance Exercise on Subsequent Resistance Activity. *The Journal of Strength & Conditioning Research* 13: 47-51, 1999.
23. Lloyd RS, Meyers RW, and Oliver JL. The natural development and trainability of plyometric ability during childhood. *Strength & Conditioning Journal* 33: 23-32, 2011.
24. Lloyd RS, Oliver JL, Faigenbaum AD, Myer GD, and Croix MBDS. Chronological age vs. biological maturation: implications for exercise programming in youth. *The Journal of Strength & Conditioning Research* 28: 1454-1464, 2014.
25. Lloyd RS, Oliver JL, Hughes MG, and Williams CA. Age-related differences in the neural regulation of stretch–shortening cycle activities in male youths during maximal and sub-maximal hopping. *Journal of Electromyography and Kinesiology* 22: 37-43, 2012.

26. McManus A, Cheng C, Leung M, Yung T, and Macfarlane D. Improving aerobic power in primary school boys: a comparison of continuous and interval training. *International journal of sports medicine* 26: 781-786, 2005.
27. Mendez-Villanueva A, Buchheit M, Kuitunen S, Douglas A, Peltola E, and Bourdon P. Age-related differences in acceleration, maximum running speed, and repeated-sprint performance in young soccer players. *Journal of sports sciences* 29: 477-484, 2011.
28. Meylan C and Malatesta D. Effects of in-season plyometric training within soccer practice on explosive actions of young players. *Journal of strength and conditioning research / National Strength & Conditioning Association* 23: 2605-2613, 2009.
29. Mirwald RL, Baxter-Jones AD, Bailey DA, and Beunen GP. An assessment of maturity from anthropometric measurements. *Medicine and science in sports and exercise* 34: 689-694, 2002.
30. Moreira A, Gomes RV, Capitani CD, Lopes CR, Santos AR, and Aoki MS. Training intensity distribution in young tennis players. *International journal of Sports Science & Coaching* 11: 880-886, 2016.
31. Mujika I, Santisteban J, and Castagna C. In-season effect of short-term sprint and power training programs on elite junior soccer players. *Journal of strength and conditioning research / National Strength & Conditioning Association* 23: 2581-2587, 2009.
32. Munro BH. *Statistical methods for health care research.* Lippincott Williams & Wilkins, 2005.
33. Myer GD, Faigenbaum AD, Ford KR, Best TM, Bergeron MF, and Hewett TE. When to initiate integrative neuromuscular training to reduce sports-related injuries in youth? *Current sports medicine reports* 10: 155, 2011.
34. Olds T, Carter L, and Marfell-Jones M. International Society for the Advancement of Kinanthropometry: International standards for anthropometric assessment. *International Society for the Advancement of Kinanthropometry*, 2006.
35. Ramirez-Campillo R, Andrade DC, and Izquierdo M. Effects of plyometric training volume and training surface on explosive strength. *Journal of strength and conditioning research / National Strength & Conditioning Association* 27: 2714-2722, 2013.
36. Reid M, Crespo M, Lay B, and Berry J. Skill acquisition in tennis: Research and current practice. *Journal of Science and Medicine in Sport* 10: 1-10, 2007.
37. Rumpf MC, Cronin JB, Pinder SD, Oliver J, and Hughes M. Effect of different training methods on running sprint times in male youth. *Pediatric exercise science* 24: 170-186, 2012.
38. Sanchis-Moysi J, Dorado C, Arteaga-Ortiz R, Serrano-Sanchez J, and Calbet J. Effects of training frequency on physical fitness in male prepubertal tennis players. *Journal of Sports Medicine and Physical Fitness* 51: 409, 2011.
39. Seiler KS and Kjerland GO. Quantifying training intensity distribution in elite endurance athletes: is there evidence for an "optimal" distribution? *Scand J Med Sci Sports* 16: 49-56, 2006.
40. Ulbricht A, Fernandez-Fernandez J, Mendez-Villanueva A, and Ferrauti A. Impact of fitness characteristics on tennis performance in elite junior tennis players. *The Journal of Strength & Conditioning Research* 30: 989-998, 2016.

41. Wilson JM, Marin PJ, Rhea MR, Wilson SM, Loenneke JP, and Anderson JC. Concurrent training: a meta-analysis examining interference of aerobic and resistance exercises. *The Journal of Strength & Conditioning Research* 26: 2293-2307, 2012.

TABLE AND FIGURE LEGENDS

Table 1. Description of the Neuromuscular Training (NMT) Program.

Table 2. Changes in performance variables for after tennis training group (AT, n = 8) and before tennis training group (BT, n = 8).

Figure 1. Comparison of changes in performance tests between after tennis training (AT) and before tennis training (BT) group. CMJ: countermovement jump; SV: serve velocity; MBO: Overhead medicine ball throw; GS: grip strength.

Table 1. Description of the Neuromuscular Training (NMT) Program.

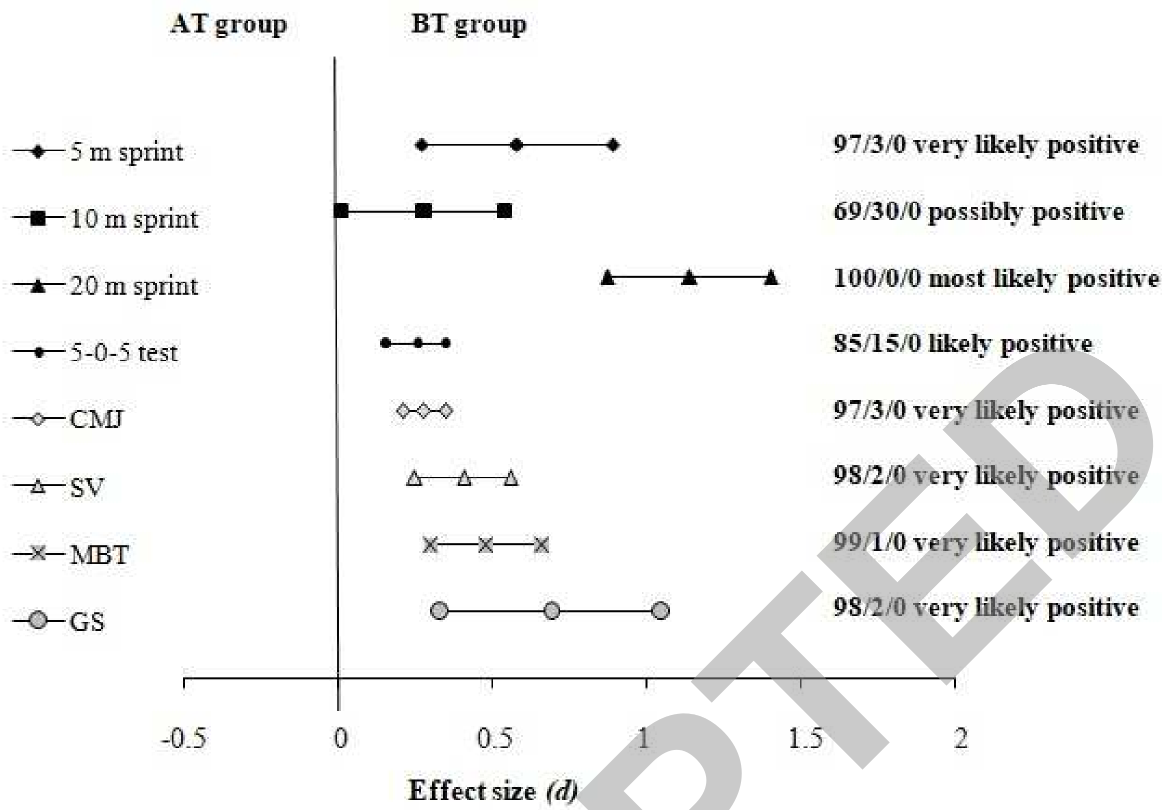
Week	Workouts	Volume	Rest
1	**Plyometrics**	**Sets × reps**	
	Box Jumps	3×6	15-20 s (reps)
	Drop Landings	3×6	60 s (sets)
	MB Throws	3×6	
	Multi-plyo jumps (hurdles)	2×10	
	Acc/Dec/COD		**3 min**
	± 10 s drills	2×4	45 s (reps); 90 s (sets)
2	**Plyometrics**	**Sets × reps**	
	CMJ	3×6	15-20 s (reps)
	MB Throws	2×10	60 s (sets)
	½ ankle jumps	3×6	
	Line Jumps	2×10	
	Acc/Dec/COD		**3 min**
	Ladder Drills	1×3	25 s (reps)
	± 10 s drills (1 COD)	2×5	30 s (reps); 90 s (sets)
3	**Plyometrics**	**Sets × reps**	
	DJ (20 cm)	3×6	25 s (reps)
	MB Throws	3×8	60 s (sets)
	Leg box hopping	3×8	
	Line Jumps	3×6	
	Acc/Dec/COD		**3 min**
	Ladder Drills	1×3	25 s (reps)
	± 10 s drills (2-3 COD)	2×6	30 s (reps); 90 s (sets)
4	**Plyometrics**	**Sets × reps**	
	MB Throws	3×10	15-20 s (reps)
	Lat. Bounds + Stabilization	2×10	90 s (sets)
	Hurdle Jumps (60 cm)	3×5	
	DJ (40 cm)	3×5	
	Acc/Dec/COD		**4 min**
	Ladder Drills	1×3	25 s (reps)
	± 8 s Partner drills	3×5	30 s (reps);120 s (sets)
5	**Plyometrics**		
	DJ (40 cm)	3×6	15-20 s (reps)
	Multi-plyo jumps (hurdles)	3×10	90 s (sets)
	Lat. Bounds + Stabilization	3×10	
	MB Throws	3×10	
	Acc/Dec/COD		**4 min**
	Ladder Drills	1×4	25 s (reps)
	± 10 s Partner drills	3×5	30 s (reps);120 s (sets)

MB: Medicine ball; Plyo: plyometric; Reps: repetitions; Acc: Acceleration; Dec: Deceleration; COD: Change of Direction; CMJ: Counter-movement Jump; DJ: Drop Jumps; Lat: Lateral

Table 2. Changes in performance variables for after tennis training group (AT, n = 8) and before tennis training group (BT, n = 8). Values are presented as mean ± SD.

	BT group (n = 8)					AT group (n = 8)				
Variables	**Pre**	**Post**	**Standardized Difference (90% CL)**	**Chances**	**Qualitative Assessment**	**Pre**	**Post**	**Standardized Difference (90% CL)**	**Chances**	**Qualitative Assessment**
5 m (s)	1.15 ± 0.05	1.12 ± 0.05	0.52 (0.21; 0.84)	95/4/0	Very likely positive	1.22 ± 0.06	1.23 ± 0.06	-0.19 (-0.44; 0.06)	1/54/45	Possibly negative
10 m (s)	1.97 ± 0.08	1.94 ± 0.05	0.32 (0.06; 0.58)	79/20/0	Likely positive	2.05 ± 0.08	2.05 ± 0.07	0.01 (-0.17; 0.20)	5/92/3	Likely trivial
20m (s)	3.44 ± 0.14	3.27 ± 0.14	1.08 (0.82; 1.34)	100/0/0	Most likely positive	3.54 ± 0.16	3.56 ± 0.14	-0.12 (-0.26; 0.02)	0/85/15	Likely trivial
5-0-5 (s)	2.75 ± 0.16	2.71 ± 0.16	0.22 (0.18; 0.27)	80/20/0	Likely positive	3.03 ± 0.05	3.05 ± 0.06	-0.24 (-0.58; 0.11)	2/40/58	Possibly negative
CMJ (cm)	31.7 ± 3.7	33.0 ± 3.5	0.29 (0.22; 0.37)	99/1/0	Very likely positive	27.9 ± 3.9	27.8 ± 3.8	-0.03 (-0.07; 0.01)	0/100/0	Most likely trivial
SV (km·h)	145.1 ± 8.0	148.0 ± 8.5	0.32 (0.24; 0.40)	99/1/0	Very likely positive	138.5 ± 4.6	138.1 ± 5.3	-0.08 (-0.29; 0.13)	2/83/15	Likely trivial
MBT (m)	6.82 ± 8.0	7.28 ± 7.1	0.51 (0.33; 0.69)	99/1/0	Very likely positive	6.88 ± 8.3	6.89 ± 8.1	0.02 (-0.02; 0.06)	0/100/0	Most likely trivial

CMJ = counter-movement jump; SV = serve velocity; MBT = overhead medicine ball throw; CL: Confidence Limits


AT group
BT group
5 m sprint
10 m sprint
20 m sprint
5-0-5 test
CMJ
SV
MBT
GS
97/3/0 very likely positive
69/30/0 possibly positive
100/0/0 most likely positive
85/15/0 likely positive
97/3/0 very likely positive
98/2/0 very likely positive
99/1/0 very likely positive
98/2/0 very likely positive
-0.5
0
0.5
1
1.5
2
Effect size (d)