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The effect of a neuromuscular vs dynamic warm-up on physical performance in young players

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Abstract:	The aim of this study was to examine performance enhancing (i.e., training) effects of a neuromuscular warm-up (NWU) compared with a dynamic WU (DWU) in young tennis players. Twenty-eight well-trained male tennis players with a mean age of 15.09 ± 1.16 years participated in this study and were assigned to either a training group performing NWU (n=14), or a group that followed DWU (n=15) before tennis-specific training, for 8 weeks. Pretest and posttest included: speed (5, 10, and 20 m); modified 5-0-5 change of direction (COD) test; bilateral/unilateral countermovement jump (CMJ); 2 kg overhead, forehand and backhand-side medicine ball throw performance (MBT); serve velocity (SV), and shoulder strength and range-of-motion (ROM) performance (i.e., internal (IR)/external (ER) rotation). Results showed that both groups, NWU and DWU, significantly improved their sprint performances (5 to 20 m; ($p < 0.05$; $d = 0.83$ to 1.32)), CMJ (bilateral and unilateral (dominant side) ($p < 0.005$; $d = 1.27$ to 1.59)), overhead MBT ($p = 0.014$; $d = 1.02$), and some shoulder strength (i.e., IR dominant side (D), ER D, ER/IR ratio ($p < 0.05$; $d = 0.86$ to 1.59)) and ROM (i.e., ER D, TROM D ($p < 0.05$; $d = 0.80$ to 1.02)) values. However, the interaction effects revealed that NWU compared with DWU produced greater performance gains in most of the analyzed parameters (i.e., 5-10 m sprint, CMJ, overhead MBT, serve speed). The inclusion of a NWU characterized by a relatively low volume (~20 to 35 min), including general mobility, core and shoulder strength exercises, combined with neuromuscular-related exercises (e.g., plyometric and acceleration/deceleration/COD drills) can be

	recommended to obtain positive effects in tennis performance-related variables.
Response to Reviewers:	We would like to thank the reviewers for their constructive comments. Reviewer #1: Title - suggest adding word Dynamic to Traditional Warm-up Comment acknowledged and changes made as suggested. Based on the comments from bot reviewers we also think that it´s more appropriate to change the names of the different interventions as there were confusing and even contradictory. We defined the TWU as neuromuscular warm-up (NWU) and the traditional as dynamic warm-up (DWU). line 18/19 - even tho this is the abstract, perhaps you can simply list the variables that were much better in the TWU than with the DWU for the reader Comment acknowledged and changes made as suggested. line 31 - "limited evidence" as there are not alot of studies Comment acknowledged and changes made as suggested. Line 39 month Comment acknowledged and changes made as suggested. Line 62 - delete first part of sentence and just start with "We hypothesize...... " Comment acknowledged and changes made as suggested. Line 99/100 - did TWU also do the DWU also ? just want to be really clear on who did what here in the methods. Comment acknowledged. We made some modifications in order to clarify the methods section. Line 127 - photo might be indicated here with this test and set-up ? Comment acknowledged. We added a figure of the testing set up. Line 144 - abducted in the coronal plane (assuming you used this plane not scapular but please specify as this makes a difference for sure) Comment acknowledged. As we followed previously used protocols and descriptions (Fernandez-Fernandez et al. Physical Therapy in Sport 35 (2019) 56-62; Moreno-Perez et al., 2015. Manual Therapy, 20, 313-318), we are not sure if it´s necessary to change the description. However, if the reviewer thinks that it´s necessary we would change it accordingly. Line 148 - Was any overpressure used ? How was the end point determined ? gravity ? or pressure from the examiner Comment acknowledged. Although the examiner held the participant's shoulder against the bench to stabilize the scapula, an overpressure was avoided. We added this into the text. Line 183 - 2 or 1 handed for all the throws ? - photo of each might be indicated here as well ? Comment acknowledged. We added “using both hands” when necessary. We honestly think that the description is very clear and a picture seems not necessary. Line 216 - Might be good to show a flow diagram of what steps all players in each of the two groups went through ? Ordering etc.... Comment acknowledged. We modified the section in order to clarify the different interventions. Hope it works. Line 425 - factors Comment acknowledged and changes made as suggested Line 449 after parenthesis ..... is recommended. That completes the sentence..... -- Comment acknowledged and changes made as suggested Reviewer #2: The paper is well written and this is an important topic. The main issue I have is how the differences between the two warm-up programs were explained. Currently it is not clear what makes one of the programs "Tennis specific" and the other "not specific to tennis". We would like to thank the reviewer for the constructive comments. We try to modify the different sections according to the suggestions and we hope that after the review, the paper will be more clear. Page 5 - Line 91 - Participants - In the methods and abstract you state 14 participants in each group. In the participants section you state 27 right-handed and 2 left handed (29 total) and then in the same paragraph you state 17 in one group and 15 in another. I may be missing it, but I don't see an explanation for these differences anywhere. This needs to be clarified. Comment acknowledged. We apologize for the mistake, as there were 29 players, with

	15 and 14 players in the different groups. We modified that, thanks. Pages 9 & 10 - I am a little confused in the differences in the warm-up programs outlined for the two groups. The tennis specific warm-up performs: - 5-8 mins of general mobility - 5-8 mins of core strengthening - 5-8 mins of jumps, throws and acceleration/decelerations The traditional warm-up group performs: - 5-8 mins of dynamic movements - 5-8 mins of ballistic movements such as jumps, accelerations/ decelerations - 6-8 minutes of on-court hitting Is this correct? Or are the groups mislabeled? If this is listed correctly in the paper then why is the traditional warm-up group performing on-court hitting? That would seem to be more appropriate for the tennis specific warm-up group. What specifically makes the tennis specific warm-up more tennis specific? Both groups performed some dynamic warm-up movements, both groups performed ballistic movements such as jumps, and accelerations and decelerations. The main difference appears to be that one group did on court hitting, while one group did core strengthening. And the group that did the on court hitting is not the tennis specific group? I would recommend including a table that outlines exactly what was done in each group. As it is written now it is difficult to see what the real differences between the two programs are other than core training vs on court hitting. Comment acknowledged. We want to thank the reviewer for these comments, as helped us to improve this section a lot. First of all, we decided to rename the different interventions as there were confusing and even contradictory (i.e., the inclusion of on-court hitting), as suggested. We defined the TWU as neuromuscular warm-up (NWU) and the traditional as dynamic warm-up (DWU). We also clarified the training programs and added a figure, which together with the text, clarifies what was done in each group. Second, and answering your first question here, the traditional WU (dynamic WU now) program includes, in an unstructured way, as was a coach-selected WU, 5-8 min of dynamic and ballistic movements, which is different from the tennis-specific (Neuromuscular WU now), not two blocks of 5-8 min. Moreover, and we would like to apologize for that, a 5 min block of shoulder strength (using elastic bands) was also conducted in the DWU. We added that in the text. On the other hand, the tennis-specific (Neuromuscular WU now), included 3 sets of differentiated neuromuscular work, focusing on thoracic mobility, shoulder and core strength, as well as combined plyometrics and acceleration/deceleration/COD drills. In our point of view, there are main differences between both routines. It is true, however, that we had to clarify that the traditional WU (dynamic WU now) supplemented the WU with on-court-hitting. Thus, maintaining the combined dynamic and ballistic exercises, more on-court hitting was supplemented through the weeks. Page 14, Line 334, "Since one of the main parts of the TWU..." - Didn't both groups perform acceleration/deceleration drills and multidirectional plyometrics? Comment acknowledged. As previously mentioned, the traditional WU (dynamic WU now) program includes, in an unstructured way, 5-8 min of dynamic and ballistic movements. The tennis-specific (Neuromuscular WU now), included a specific block of combined plyometrics and acceleration/deceleration/COD drills, for 5-8 min. Therefore, we think that the training stimulus is higher in the NWU than in the DWU in order to provoke

Title page

The effect of a neuromuscular vs dynamic warm-up on physical performance in young players

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Conflicts of interest:

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

The effect of a neuromuscular -vs dynamic warm-up on physical performance in young players

ABSTRACT

The aim of this study was to examine performance enhancing (i.e., training) effects of a neuromuscular warm-up (NWU) compared with a dynamic WU (DWU) in young tennis players. Twenty-eight well-trained male tennis players with a mean age of 15.09 ± 1.16 years participated in this study and were assigned to either a training group performing NWU (n=14), or a group that followed DWU (n=15) before tennis-specific training, for 8 weeks. Pretest and posttest included: speed (5, 10, and 20 m); modified 5-0-5 change of direction (COD) test; bilateral/unilateral countermovement jump (CMJ); 2 kg overhead, forehand and backhand-side medicine ball throw performance (MBT); serve velocity (SV), and shoulder strength and range-of-motion (ROM) performance (i.e., internal (IR)/external (ER) rotation). Results showed that both groups, NWU and DWU, significantly improved their sprint performances (5 to 20 m; ($p < 0.05$; $d = 0.83$ to 1.32)), CMJ (bilateral and unilateral (dominant side) ($p < 0.005$; $d = 1.27$ to 1.59)), overhead MBT ($p = 0.014$; $d = 1.02$), and some shoulder strength (i.e., IR dominant side (D), ER D, ER/IR ratio ($p < 0.05$; $d = 0.86$ to 1.59)) and ROM (i.e., ER D, TROM D ($p < 0.05$; $d = 0.80$ to 1.02)) values. However, the interaction effects revealed that NWU compared with DWU produced greater performance gains in most of the analyzed parameters (i.e., 5-10 m sprint, CMJ, overhead MBT, serve speed). The inclusion of a NWU characterized by a relatively low volume (~20 to 35 min), including general mobility, core and shoulder strength exercises, combined with neuromuscular-related exercises (e.g., plyometric and acceleration/deceleration/COD drills) can be recommended to obtain positive effects in tennis performance-related variables.

KEY WORDS: athletic performance, intermittent sport, mobility, neuromuscular qualities

INTRODUCTION

Tennis is an intermittent sport in which players require a mixture of physical components, such as speed, agility, muscle power, and cardiovascular fitness, in order to achieve high levels of performance (20). Because of the demands placed on the body during training and/or competition, tennis players are susceptible to a range of injuries including chronic overuse conditions and acute traumatic injuries (25). There is limited evidence that total body and lower extremity warm-up (WU) programs have the potential to acutely enhance performance and prevent injuries (2,36). This injury preventive effect has particularly been shown for WU programs such as FIFA 11+ and Harmoknee in amateur soccer (2,4). In contrast, there is a lack of research on the use of WU exercises to prevent upper body injuries. Based on a previous systematic review analyzing warm-up in a population of sport athletes (i.e., from youth to adult athletes) (36), there is evidence that dynamic, high-load upper body WU has the potential to enhance strength and power outcomes. More recently, Andersson et al. (1) examined the effects of a shoulder-injury prevention program, implemented 3 times per week, during a 7 month handball season. The results of this study showed that the intervention compared with the control group experienced a 28% lower risk of sustaining shoulder problems and a 22% lower risk of substantial shoulder problems.

Prior to sport-specific training and competitions, tennis players, like most athletes from different sports, perform warm-up routines with the goal to achieve high levels of explosive force and power prior to a competitive activity (48). These acute performance enhancing effects can be caused by increases in intra-muscular temperature, nerve conduction velocity and metabolic reactions (10,35). A previous study showed that a dynamic WU protocol (i.e., cardiovascular activation followed by dynamic stretching [DS] and tennis-specific exercises) compared to traditional WU strategies (i.e., including static stretching) resulted in improvements (3.9% to 11%) in jump and sprint performances as well as in serve speed in elite junior tennis players (3). Similarly, other studies that incorporated dynamic stretching within a warm-up routine also showed enhancements in physical qualities (e.g., vertical jump height, 20 meters sprint times, serve speed (26,53,54)).

As previously mentioned, there is evidence that WU programs have positive acute to long-term effects on selected performance measures in some team sports (i.e., football, netball) (2,4,37,57). However, to the best of our knowledge, no previous research analyzed the long-term effects of a neuromuscular WU (NWU) program (i.e., including a combination of fundamental movements and specific strength and conditioning activities (e.g., dynamic stability, core focused strength, plyometrics, and agility)) on physical performance in youth tennis. Although the main purpose of NWU is injury prevention (41), it is timely to examine WU-related training effects (e.g., changes in upper and lower body strength) to identify the potential mechanisms underlying the injury preventive effect in a short or long-term perspective. Thus, the aim of this study was to examine performance enhancing (i.e., training) effects of DWU compared with a dynamic WU in young tennis players. We hypothesized that NWU would result in significant performance gains after an 8 weeks training period.

MATERIALS AND METHODS

Experimental approach to the problem

A 2-group, matched for age and maturity status, experimental design was used in this study. Study participants were randomly assigned to either a training group performing NTWUNWU (n=14; age 14.96 ± 0.88 years, body mass 60.34 ± 9.13 kg, height 172.50 ± 7.08, estimated age at peak height velocity (PHV) 14.03 ± 0.61 years), or a group that followed a dynamic WU (DWU; n=15; age 15.21 ± 1.40 years, body mass 59.50 ± 10.90 kg, height 172.57 ± 7.90 cm, estimated age at peak height velocity 14.38 ± 0.90 years). The study was conducted during the second part of the preparatory period (January-March). Both WU programs were carried out before the tennis specific training sessions. After an appropriate familiarization period, physical fitness tests were completed one week before and after the 8-week training period. Test time during the day was similar during pre and post-tests to avoid performance fluctuations due to the circadian rhythm. Pre and post intervention, tests were conducted for the assessment of 20-m sprint performance with 5- and 10-m split times, countermovement jump (CMJ) performance, 5-0-5 change of direction (COD) test, 2 kg overhead, forehand and backhand-side medicine ball throw performance (MBT), serve velocity (SV) performance, shoulder strength and range-of-motion (ROM) performance (i.e., internal/external rotation). All fitness tests were performed on an outdoor synthetic court at the same time of day (pre vs post-tests). Between the last training session and the post-tests, only light on-court training combined with injury-preventive exercises (e.g., core training, shoulder strengthening, and flexibility) were scheduled. To reduce interference from uncontrolled variables, all athletes 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

Twenty-nine well-trained male tennis players aged 15.09 ± 1.16 years participated in this study (body mass 59.90 ± 9.91 kg, body height 172.53 ± 7.38 cm; ± age at PHV 0.88 ± 0.94). Twenty-seven players were right-handed and two were left-handed. Participants had a mean training background of 5.0 ± 1.2 years and participated in 18-20 h of tennis training per week. The main focus of tennis training was the development of on-court technical/tactical tennis skills, as well as the enhancement of tennis-specific fitness. Players were eligible to be included in this study if they were free from any severe injuries, did not have surgeries or did not conduct any sport-related rehabilitation programs during the 12 months prior to the start of the study. Study participants were randomly assigned to either a training group performing the NWU (n=14) or an active control group that followed a DWU (n=15). Tennis specific training was always conducted after the WUs. Baseline tests were used to control for the initial fitness status of the players. All players were ranked among the 250 top players in their respective national singles ranking category (U16). Prior to the start of this investigation, written informed consent was obtained from both, participants and their parents/legal guardians. All participants were fully informed about the testing and training protocols. The procedures were approved by the institutional ethics review committee (RFET19/1) and in agreement with the ethics code 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). Pubertal timing was estimated according to the biological maturation of each individual using the predictive equation described by Mirwald et al.(38). 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 (51). Therefore, a maturity age of –1.0 indicates that the player was measured one year before their PHV; a maturity of 0 indicates that the player was measured at the time of their PHV; and a maturity age of +1.0 indicates that the participant was measured 1 year after their PHV (51).

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 which were placed 1.0 m above the ground level (DSD Sport system, León, Spain). Each sprint was initiated 50 cm behind the photocell gate. The digital timer started after the player crossed the gate. Each player performed two maximal 20-m sprints with at least 2 min of passive recovery in between the two trials (55). The best performance was recorded and used for offline analysis. The intraclass correlation coefficient (ICC) for this test was 0.96.

Modified 5-0-5 change of direction 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 test (43). Players started without a racquet in a standing position with their preferred foot 1 m behind the timing gate (DSD Sport system, León, Spain). After they crossed the photocell, the digital timer started and they accelerated at maximal effort. One trial pivoting on both left and right feet was completed and the best time recorded to the nearest 0.01 s (Figure 1). A 2 minutes rest was allowed between trials. The ICC was 0.92.

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

Vertical jump test

A counter-movement jump (CMJ) without arm swing was performed on a contact-time mat (Ergojump®, Finland) according to the procedures as described by Bosco et al. (11). Each player performed two maximal CMJs interspersed with 45 s of passive recovery. The best jump height was recorded for each athlete and used for further analysis. The ICC of the CMJ was 0.96.

Shoulder range of motion (ROM) test

The passive glenohumeral rotation was assessed following the methodology as previously described using a manual inclinometer (ISOMED inclinometer, Portland, Oregon) (13). For this purpose, each participant was in supine position on a bench, with the shoulder 90º abducted and the elbow flexed to 90º (forearm perpendicular to the bench). From this starting position, an examiner held the participant's proximal shoulder region (i.e. clavicle and scapula) against the bench to stabilize the scapula, avoiding an overpressure. Another examiner rotated the humerus in the glenohumeral joint to produce maximum passive external (ER) and internal (IR) rotation (39). Two attempts were performed for IR and ER as well as for the dominant and non-dominant sides. Performance in degrees (º) were averaged over both repetitions, and then used to calculate both, total range of motion (TROM), the bilateral difference in IR (side-to-side asymmetry = dominant - non-dominant) as well as the glenohumeral internal rotation deficit (GIRD) (i.e., loss in dominant shoulder IR that is greater than 18–20˚, with a corresponding loss of TROM greater than 5˚ when compared with the non-dominant shoulder) (15). ICC ranged from 0.78 to 0.91.

Shoulder strength test

Isometric internal and external shoulder rotation strength levels of the dominant and non-dominant limb were assessed with a portable handheld dynamometer (Nicholas Manual Muscle Tester, Lafayette Indiana Instruments). Participants were in supine lying position on a plinth with the shoulder abducted at 90º and the elbow flexed at 90º. This procedure has been described previously (14). The average of two maximal trials (5 s) was used for subsequent statistical analyses. There was a 30-s rest period between trials. A side-to-side difference higher than 10% was defined as bilateral asymmetry. Moreover, shoulder rotational strength values were additionally normalized to body mass and expressed as N/kg (15). ICC ranged from 0.78 to 0.88.

Serve velocity test

Serve velocity was measured using new tennis balls (Babolat Team) with a radar gun (model SR3600, Homosassa, FL, USA; range 80 to 232 km/h). In accordance with the manufacturer's specifications, the radar gun was calibrated prior to each test session. In line with previous research (22), the radar was positioned on the center of the baseline, 3 m behind the server, aligned with the approximate height of ball contact (~ 2.2 m) and pointing down the center of the court. Each participant carried out 3 sets of 10 maximal flat serves (i.e., slice was not allowed) to the advantage court with a 30 s rest between each set and approximately 10 s between each serve. To be eligible for analysis, serves had to fall into the service box within 1 m of the center service line. Direct feedback of the respective serve velocity was provided to encourage maximal effort. Before testing, a specific 5 min serve warm-up time was allowed that included upper body mobility and 2 sets of 8 first and second serves. Finally, the average velocity of the 8 best trials was used for further analysis. The ICC for this test was 0.88.

Medicine ball throw test (MBT): Overhead, forehand, and backhand

For the overhead MBT, the players held a 2 kg medicine ball, with both hands, in front of their chest and they stood on a line facing towards the throwing direction with their feet side-by-side and shoulder-width apart. The throwing motion was started with a countermovement behind the head. Thereafter, the ball was vigorously accelerated until it left the hands. The players were not allowed to cross the line. Additionally, players performed a forehand and backhand MBT throw which was in accordance with a previous study (55). For this purpose, players stood sideways to the starting line and simulated a forehand-backhand stroke. They tossed the ball as far as possible, using both hands, without crossing the line with their feet. For all MBT trials, the distance was taken to the nearest 5 cm from the line to the point where the ball landed. The best performance out of two trials for each condition was taken for further analysis. A 45-s rest period was granted between trials. The ICC of these tests ranged from 0.88 to 0.93.

Warm-up programs

Both experimental groups (i.e., NWU and DWU) exercised in an indoor facility, between 4 and 5 pm. The warm-up programs were scheduled before the tennis-specific training. For both groups, a 10-minute recovery period was allowed between WU programs and the tennis training, during which participants were asked to consume water and a 6% carbohydrate/electrolyte drink *ad libitum*. To ensure familiarization with the training and testing procedures, all participants completed 2 familiarization sessions (i.e., ~ 1 hour each) 1 week before baseline testing.

In addition to their regular tennis training (i.e., 4 sessions/week), all participants performed the WU protocols 3 times per week for 8 consecutive weeks. Regular tennis training lasted on average 75.5 ± 6.4 minutes. Tennis training started with a 8 min WU that included general mobility exercises, ground strokes, volleys, and low-intensity smashes. Thereafter, players performed technical drills (i.e., service technique) for another 10 minutes. This was followed by ~50 minutes of specific drills (i.e., mixed open/closed technical/tactical drills) (18). The tennis training portion was designed by the tennis coaches with the goal to address the specific needs of each athlete, stressing technical/tactical drills (i.e., designed to focus on improvements to a specific quality in stroke technique or tactical approach), and/or sessions including a more physical approach (i.e., relatively high volumes of open and/or high-intensity drills (21)). Together with the tennis-specific sessions, players performed 1 to 2 sessions/week of strength training. Due to the fact that only some of the participants had previous strength-training experience, guidelines for novices were chosen, based on previous research (16). Each session comprised a 10-minute warm-up and approximately 30 minutes of machine-based exercises (i.e., low pulley dead lifts, leg-press, chest-press, lat pull-down), with two sets of 12 repetitions each (9). The intensity was related to the load that could be lifted 15 times with a proper technique throughout the full range of motion (ROM) (32), leaving at least 3 repetitions aside in order to avoid fatigue (50). In terms of volume and intensity, strength-training was similar between the experimental groups.

Each warm-up intervention lasted from 20 min during week one to 32 min during the last week. In both experimental sessions (~~TWU~~NWU-NWU and DWU), participants started by performing self-paced rope jumping for 4-5 min (i.e., including forward/backwards movements, unilateral jumps, sidestepping and double jumps), followed by a group-specific ~~warm-up~~WU exercises. Figure 2 shows the schematic representation of both WU programs.

N~~TWU~~NWU participants performed the following exercises, always supervised by an experienced S&C specialist:

a) 5 to 8 min of general mobility, including arms and shoulder (i.e., wall slides), thoracic mobility exercises (i.e., 3 sets of different exercises such as the cat camel, extension with foam roller, trunk rotation x 15 repetitions each).

b) 5 to 8 min of core, hip and shoulder strength exercises (i.e., 3 sets of 3 exercises x 15 repetitions: core (i.e., plank, side plank and sit-ups); hip (i.e., abduction and adduction with a mini-band); and shoulder (i.e., low-row, inferior glide, "lawnmower", ER using elastic tubbing).

c) 5 to 8 min of neuromuscular-related exercises (i.e., 2-3 sets x 6-10 repetitions of upper and lower body exercises, including 1-2 kg medicine ball throws; bilateral and unilateral jumps (i.e., CMJs to 20-cm box; multilateral hops with hurdles; ankle jumps, line jumps), as well as ~ 10 s acceleration/deceleration/COD drills) (18).

Participants in the DWU performed a coach-selected and supervised warm-up program that consisted of 5-8 min of dynamic movements (i.e., arm circles, leg kicks, multidirectional skippings), some ballistic exercises (e.g., single hop jumps [5 repetitions], alternate leg bounds (multidirectional x 5 repetitions), service motion throws without a tennis ball (5 repetitions each arm) and short (2-3 m) accelerations and decelerations in different directions (3 repetitions forwards and 5 repetitions side to side). A short protocol (5 min) of shoulder strength exercises (i.e, external/internal rotation; shoulder extension and rowing) was also included. The rest of this WU consisted on ~~, and 6-8 min of~~ tennis-specific activities (e.g., on-court hitting against an opponent performing ground strokes, volleys and serves).

Insert Figure 2 near here

The training volume, in terms of duration, of the two warm-up programs was similar across the intervention period. Thus, players included in the DWU, supplemented their programs with more tennis-specific activities to balance the NWU group. Both groups finished the routine with light stretching exercises for the plantar flexors (principally gastrocnemius and soleus), hip flexors (hamstrings), hip extensors (gluteals), hip adductors, quadriceps, posterior shoulder, triceps, shoulder external, pectoralis, deltoid, biceps brachii, and forearm extensors and flexors. Exercises were selected based on previous literature and performed in similar order, repeated 2 times and performed for 5-6 s (52). A 10-s recovery period was provided between each exercise. No rest period was allowed when the limb was changed. Stretching intensity was held at the point of discomfort.

Statistical analyses

Descriptive statistics were presented as means and standard deviations (SD). Data normality and variance equality were assessed through the Shapiro-Wilk and Levene tests, respectively. When assumptions were violated, log-transformations were computed. In order to examine the effects of a structured tennis-specific warm-up protocol, a two-way repeated measures ANOVA with one between factor (training group: ~~TWU~~NWU vs DWU) and one within factor (time: pre-training vs. post-training) was used for each dependent variable. If a significant F value was identified for group-by-time interactions, Bonferroni corrected post hoc tests were calculated to identify pairwise differences. The significance level was set at $p \leq 0.05$. In addition, effect sizes (Cohen's d) were calculated from eta-squared using the ANOVA output. Moreover, within-group effect sizes were computed using the following equation: Effect size = (mean_post - mean_pre)/SD. Threshold values for Cohen's d statistics were 0.20, 0.60, 1.20, 2.0 and 4.0 for small, moderate, large, very large, and extremely large effects, respectively (28). The statistical analyses were carried out using SPSS (SPSS 17.0 version, Chicago, Illinois, USA).

RESULTS

All participants received treatment as allocated. No significant between group baseline differences were identified for all analyzed measures ($p > 0.05$).

Physical fitness tests

The analysis did not reveal a statistically significant main effect of time nor a significant group-by-time interaction for the backhand MBT and 505 on the dominant and non-dominant side ($p >$

0.05; d = 0.06 to 0.74). A significant main effect of time was observed for 20 m sprint time ($F_{(1,27)}$= 11.657; p = 0.002; d = 2.27), CMJ on the non-dominant side ($F_{(1,27)}$= 23.497; p < 0.001; d = 1.87) and forehand MBT ($F_{(1,27)}$= 9.775; p = 0.004; d = 1.20). There was a significant group-by-time interaction for 5 m ($F_{(1,27)}$= 10.560; *p* = 0.003; d = 1.25) and 10 m ($F_{(1,27)}$= 4.683; *p* = 0.039; d = 0.83) sprint times, CMJ ($F_{(1,27)}$= 17.002; *p* < 0.001; d = 1.59), CMJ on the dominant side ($F_{(1,27)}$= 10.832; *p* = 0.003; d = 1.27), overhead MBT ($F_{(1,27)}$= 6.951; *p* = 0.014; d = 1.02), and SV (F (1,27) = 4.693; *p* = 0.039; d = 0.83). Post-hoc tests revealed that improvements in 5 m (Δ = -3.5% [p < 0.001; d = -0.73] vs. -1.0% [p = 0.069; d = -0.18]) and 10 m (Δ = -2.2% [p < 0.001; d = -0.63] vs. -1.0% [p = 0.020; d = -0.22]) sprint times, CMJ (Δ = 11.2% [p < 0.001; d = 0.75] vs. 2.5% [p = 0.103; d = 0.18]), CMJ on the dominant side (Δ = 19.3% [p < 0.001; d = 1.23] vs. 5.5% [p = 0.058; d = 0.26]), overhead MBT (Δ = 10.2% [p < 0.001; d = 0.49] vs. 4.8% [p = 0.004; d = 0.16]) and SV (Δ = 7.7% [p = 0.002; d = 0.82] vs. 0.7% [p = 0.734; d = 0.06]) were larger for ~~TWU~~NWU than DWU, respectively (Table 1).

Insert Table 1 near here

Shoulder Strength

The statistical analysis did not reveal a significant main effect of time nor a significant group-by-time interaction for shoulder ER relative strength and shoulder ER/IR ratio on the non-dominant side (*p* > 0.05; d = 0.06 to 0.76). A significant main effect of time was observed for shoulder IR ($F_{(1,27)}$= 9.255; p = 0.005; d = 1.17) and shoulder ER ($F_{(1,27)}$= 4.967; p = 0.034; d = 0.86) absolute strength on the non-dominant side. There was a significant group-by-time interaction for shoulder IR absolute ($F_{(1,27)}$= 7.926; *p* = 0.009; d = 1.08) and relative strength ($F_{(1,27)}$= 10.226; p = 0.004; d = 1.23), shoulder ER absolute ($F_{(1,27)}$= 12.368; p = 0.002; d = 1.35) and relative strength ($F_{(1,27)}$= 16.947; p < 0.001; d = 1.59), as well as for ER/IR ratio ($F_{(1,27)}$= 5.044; p = 0.033; d = 0.86) on the dominant side. There was also a significant group-by-time interaction for shoulder IR relative strength ($F_{(1,27)}$= 16.207; p < 0.001; d = 1.55) on the non-dominant side. Post-hoc tests showed that the increases in shoulder IR absolute (Δ = 5.1% [p < 0.001; d = 0.31] vs. 1.9% [p = 0.082; d = 0.11]) and relative strength (Δ = 4.8% [p < 0.001; d =

0.37] vs. 0.3% [p = 1.000; d = 0.00]), shoulder ER absolute (Δ = 12.5% [p < 0.001; d = 0.61] vs. 2.9% [p = 0.149; d = 0.15]) and relative strength (Δ = 12.2% [p < 0.001; d = 0.86] vs. 0.6% [p = 0.868; d = 0.02]), and ER/IR ratio (Δ = 6.9% [p = 0.002; d = 0.51] vs. 1.1% [p = 0.716; d = 0.03]) on the dominant side were greater in ~~TWU~~NWU compared with DWU. Further, the increases in shoulder IR relative strength (Δ = 1.6% [p = 0.019; d = 0.11] vs. % [p = 0.003; d = -0.11]) on the non-dominant side was also superior in ~~TWU~~NWU compared with DWU.

Shoulder ROM

There was no significant main effect of time nor a significant group-by-time interaction for shoulder IR and ER ROM on the dominant side, TROM on the non-dominant side, TROM Diff and GIRD on both, dominant and non-dominant sides (p > 0.05; d = 0.02 to 0.75). A significant main effect of time was found for shoulder IR ROM on the dominant side ($F_{(1,27)}$= 12.257; p = 0.002; d = 1.35). There was a significant group-by-time interaction for shoulder ER ROM ($F_{(1,27)}$= 4.277; p = 0.048; d = 0.80) and TROM ($F_{(1,27)}$= 7.067; p = 0.013; d = 1.02) on the dominant side. The analyses showed that the increases in shoulder ER ROM (Δ = 2.0 % [p = 0.037; d = 0.16] vs. -0.5 % [p = 0.484; d = -0.07]) and TROM (Δ = 4.2 % [p < 0.001; d = 0.45] vs. 0.9 % [p = 0.336; d = 0.13]) on the dominant side for the ~~TWU~~NWU were greater than those observed in DWU (Table 2).

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

DISCUSSION

To the best of our knowledge, this is the first study that examined the effects of a structured tennis-specific WU compared with a more traditional DWU on physical performance in young tennis players. As was hypothesized, our results showed that ~~TWU~~NWU resulted in significant performance gains (i.e., 5 and 10 m sprint, CMJ, overhead MBT, serve speed, shoulder strength and ROM) after an 8-week training period. Moreover, although trivial to small improvements were also reported in the DWU, several improvements were greater in ~~TWU~~NWU.

Because this is the first study analyzing the effects of a ~~TWU~~NWU compared with a DWU in tennis players, it is not possible to compare our results with previous studies. Both groups, ~~TWU~~NWU and DWU, improved their sprint performances (5 to 20 m), CMJ (bilateral and unilateral [dominant side]), overhead MBT, and some shoulder strength (i.e., IR D, ER D, ER/IR ratio) and ROM (i.e., ER D, TROM D) values. With reference to our findings, we postulate that the inclusion of a regular and supervised WU program is capable of enhancing physical fitness in this group of young athletes, as previously reported for other sports (4,37,45,57). However, the interaction effects revealed that ~~TWU~~NWU compared with DWU produced greater performance gains in most of the analyzed parameters.

The observed small-to-moderate effects of ~~TWU~~NWU on sprint performance are in line with previous studies conducting neuromuscular training programs in different sports (6,12,40,49), including tennis (5,18,56). These studies showed moderate-to-large training-related effects in sprint distances ranging from 5 to 20 m. Since one of the main parts of the ~~TWU~~NWU included multidirectional plyometric and acceleration/deceleration/COD drills, we can speculate that improvements are likely to be related to the neural component (e.g., inter-lower limb muscle coordination and stride frequency) (44,47). Results also showed differences between groups in sprint performance, which can be related to the lack of specific exercise drills in DWU compared with ~~TWU~~NWU. In this regard, players in DWU performed some accelerations and decelerations together with tennis-specific activities. However, DWU also improved in almost the same sprint parameters than ~~TWU~~NWU, with trivial to small changes. It is important to highlight that both groups conducted 12 strength-training sessions during the present intervention, and this could be a limiting factor to interpret the results. Both groups probably obtained positive benefits from this additional training stimulus, since the connection between strength training and motor performance skills is well known, especially at young ages (8,30). Moreover, if we analyze the age at peak height velocity (PHV) of the participants, they were 0.9 ± 1.1 and 0.82 ± 0.8 years after the PHV, for the ~~TWU~~NWU and DWU, respectively. Thus, growth and maturation can be also linked to these strength and power improvements because it has been suggested that after the onset of puberty, adolescents will undergo a performance spurt in strength and power (33).

None of the groups significantly improved 505-test performance, for both, D and ND sides. In spite of the relevance of COD ability in tennis (34), the ~~TWU~~NWU adopted in the current study involved a relatively low volume of plyometric exercises (5 to 8 min of 2-3 sets x 6-10 repetitions of upper and lower body exercises). In this regard, it was previously shown that, for example, in young soccer players, COD performance is related to higher volumes of horizontal and vertical jumps (e.g., 5–8 sets and 10–15 repetitions) (42). Accordingly, in previous tennis-specific studies (18,23,56), a higher training volume (~40 min per session) led to significant COD improvements. Thus, the low volume of plyometric stimuli incorporated to the ~~TWU~~NWU routine appeared to be sufficient to induce positive changes (i.e., improvements in stretch-shortening cycle mechanism (44)) in the linear acceleration and sprint abilities of young tennis players, which can be very effective for tennis as well as S&C coaches in order to design their training schedules. However, enhanced linear sprint speed did not translate into improved COD performance, thus confirming that they are different abilities (31), and that the latter demands specific training strategies.

Upper-body strength and power seem to be determinant in serve performance of tennis players, since early ages (19,24,55), with MBTs as strong predictors of serve speed, together with the absolute IR and ER shoulder strength (19). Moreover, MBT and SV seem to be among the most important physical components related to tennis performance in adolescent tennis players (i.e., ranking) (24,55). Results of the present study showed that ~~TWU~~NWU led to significant improvements in the serve velocity, overhead MBT, IR and ER of the dominant side, with small to moderate ES (0.5 to 0.8), compared to the DWU, although trivial changes were also found for this group. Previous studies conducted with young tennis players reported significant improvements in the serve velocity (4–5%) after training interventions, including plyometric training or combined strength training (e.g., core stability, elastic tubing, and plyometric exercises) (9,17,23). In general, improvements in both groups can be explained, as previously mentioned, by the combination of the strength-training program conducted and the associated gains in strength due to the maturation process. However, results highlighted significant differences between groups, with the ~~TWU~~NWU showing greater improvements, suggesting that the 12 strength-training sessions undertaken by the players were not enough to induce better serve performance. Therefore, the inclusion of low-volume explosive exercises (e.g., upper body PT) in the WU routine, performed at relatively high speeds, seems to elicits movement-specific adaptations (i.e., force-vector specificity) and possibly enhanced intermuscular coordination, resulting in an improved force transfer through the kinetic chain (23).

Due to the importance of the shoulder complex in tennis (13), it seems important to highlight that results showed significant improvements in shoulder strength and ROM values, with greater increases in the dominant shoulder IR and ER strength and ER/IR ratio, as well as in the dominant shoulder ER ROM and TROM. The analyses showed that the increases in ~~TWU~~NWU (small ES) were greater than those observed in DWU (trivial ES). To the best of our knowledge, there is no previous study analyzing the effects of a structured WU in tennis, including a combination of shoulder mobility and strengthening exercises. Regarding shoulder strength levels, intensive tennis practice and competition lead to an unbalanced shoulder function profile, with higher IR strength compared to the ER on the dominant side (19). Present results showed that the inclusion of a ~~TWU~~NWU maintained ER/IR ratios around 0.7, which can be considered as a “healthy” ratio (i.e., cut-off values ranged <0.60 to 0.85) (14). The ~~TWU~~NWU included shoulder strengthening exercises aimed to an increase in absolute strength values for shoulder rotators and greater muscle balance (15). In this regard, a recent study conducted with swimmers, showed that a dry-land shoulder strengthening program led to an increase in shoulder rotators balance and ER endurance (7).

Extensive research has shown that excessive or limited shoulder ROM may lead to shoulder injuries, such as instability and impingement, in overhead athletes (13,15,39). The current results showed reductions in IR ROM in the dominant shoulder, which are in line with previous tennis-specific studies (13,19), and can be considered a normal adaptation of these athletes (15). In this regard, research has identified IR limitations and injury risk when there is a loss of rotation greater than 18º to 20º, with a corresponding loss of TROM greater than 5º when compared bilaterally (15). In the present study, players showed pre-intervention average values of ~11º for both groups, which could be considered "normal", from a pathological point of view (15). However, individual values can be considered dangerous, with bilateral differences exceeding more than 20º in some cases. Thus, the introduction of prevention measures in order to balance these shoulder deficits seems necessary. In this regard, only a single previous study reported significant shoulder IR/ER ROM changes (>5%) after a 6-week intervention, including a supervised stretching program, conducted 3 times per week (17). Interestingly, a significant main time effect was observed for shoulder IR ROM of the dominant side and GIRD in both groups, ~~TWU~~NWU and DWU, although increases in ~~TWU~~NWU (small ES) were greater than those observed in DWU (trivial ES). Both groups included some stretching exercises in their programs including "problematic" muscles (i.e. stretching of the pectoralis minor, posterior capsule) (15), and this could be related to the improvements reported. Moreover, the ~~TWU~~NWU included shoulder and thoracic mobility exercises, which can be related to the greater increases compared to the DWU. In this regard, recent findings provide evidence of thoracic spine movement contributing to upper limb functional movement (1,27). More research is definitively needed in this area, analyzing the effects of a shoulder-specific training program to address the imbalances created by intensive tennis training and competition.

In conclusion, a ~~TWU~~NWU resulted in significant performance gains (i.e., 5 and 10 m sprint, CMJ, overhead MBT, serve speed, shoulder strength and ROM) after an 8-week training period compared to a DWU. Nevertheless, it is important to note that there are several limitations associated with this study. First, there were several factors that could affect the results obtained, including the parallel strength training program, or the maturation status of the players. Future studies should isolate the intervention more, although it is true that in the present context it was not possible to cancel the additional training conducted by the players. Moreover, the inclusion of a third group, acting as a control group, could bring more information in order to discuss the present results. However, we believe that the present design has high levels of ecological validity and may offer a starting point to suggest practical applications to the tennis professionals. As always, additional research is required to investigate how players respond to the inclusion of medium to long- term training protocols, including an analyses of the injury prevention potential of the ~~TWU~~NWU.

PRACTICAL APPLICATIONS

Based on our results, it can be postulated that coaches and strength and conditioning experts implement a tennis-specific WU for young tennis players before the start of regular tennis training. ~~TWU~~NWU is characterized by a relatively low training session duration, ranging from 20 to 35 min. The WU program should include general mobility (e.g., arms, shoulder as well as thoracic mobility exercises), core (e.g., plank variations, sit-ups), hip (e.g., abduction/adduction with resistance), and shoulder (e.g., exercises focused on the posterior rotator cuff and scapular stabilizers using elastic tubbing) strength exercises. Furthermore, a combination of neuromuscular-related exercises (e.g., plyometric oriented exercises (1–2 kg medicine ball throws, bilateral and unilateral multidirectional jumps, with or without hurdles, etc.), and acceleration/deceleration/COD drills (short sprints [15–20 m] with 2–3 COD, and short rest periods [25 seconds]) is also introduced in the ~~TWU~~NWU. Moreover, although there is not enough evidence to support that a stretching program reduces the incidence of recurrent shoulder injury (15), the inclusion of active, passive or manual therapy forms of stretching at the end of the training sessions (e.g., physical and tennis-specific sessions) is recommended. These routines are recommended to improve posterior shoulder tightness and GIRD in the short-term for asymptomatic young athletes who are active in overhead sports such as tennis.

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TABLES AND FIGURES LEGENDS

Table 1. Physical fitness parameters before (pre-training) and after (post-training) the study period (8 weeks) with relative changes (Δ) and Cohen's d values for time effect, group effect and interaction effect.

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Figure 1. Structure and dimensions of the 505 change of direction test. m = meters.

Figure 2. Schematic representation of warm-up (WU) programs.

Tables 1 and 2

Table 1. Physical fitness parameters before (pre-training) and after (post-training) the study period (8 weeks) with relative changes (Δ) and Cohen's d values for time effect, group effect and interaction effect.

	~~TWU~~ NWU Group			DWU Group			Time Effect	Group Effect	Interaction Effect
Physical Fitness	Pre	Post	Δ (%)	Pre	Post	Δ (%)	Cohen's d	Cohen's d	Cohen's d
505 D (s)	2.77 ± 0.08	2.73 ± 0.11	-1.41	2.83 ± 0.12	2.84 ± 0.11	0.08	0.667	0.834	0.739
505 ND (s)	2.87 ± 0.08	2.83 ± 0.09	-1.57	2.88 ± 0.11	2.89 ± 0.11	0.33	0.424	0.403	0.629
Sprint 5 m (s)	1.10 ± 0.05	1.06 ± 0.04	-3.50	1.11 ± 0.06	1.10 ± 0.05	-0.99	2.265	0.496	1.250††
Sprint 10 m (s)	1.87 ± 0.06	1.83 ± 0.05	-2.21	1.91 ± 0.08	1.89 ± 0.08	-0.98	2.158	0.606	0.834††
Sprint 20 m (s)	3.23 ± 0.11	3.19 ± 0.07	-1.21	3.28 ± 0.12	3.25 ± 0.11	-0.79	1.316*	0.598	0.293
CMJ (cm)	31.26 ± 4.04	34.48 ± 2.59	11.23	29.95 ± 3.84	30.67 ± 3.67	2.49	2.491	0.759	1.586††
CMJ D (cm)	16.04 ± 2.14	18.85 ± 1.12	19.25	16.73 ± 2.96	17.56 ± 2.69	5.52	2.326	0.142	1.266††
CMJ ND (cm)	15.25 ± 2.22	16.16 ± 1.61	7.04	14.51 ± 1.80	15.15 ± 1.74	4.61	1.865*	0.501	0.327
MBTo (m)	7.77 ± 1.37	8.48 ± 1.15	10.22	7.80 ± 1.91	8.13 ± 1.82	4.78	2.726	0.110	1.016††
MBTf (m)	10.51 ± 0.88	11.09 ± 0.78	6.00	10.57 ± 1.41	10.78 ± 1.37	2.06	1.204*	0.127	0.569
MBTb (m)	10.04 ± 1.02	10.24 ± 1.01	2.91	10.25 ± 2.12	10.53 ± 1.89	3.21	0.544	0.168	0.063
Serve speed ($km \cdot h^{-1}$)	153.45 ± 12.25	164.09 ± 7.86	7.72	156.23 ± 16.84	157.28 ± 17.26	0.66	1.016	0.168	0.834†

N~~T~~WU: ~~tennis-specific~~neuromuscular warm-up group; DWU: ~~traditional~~ dynamic warm-up group; D: dominant side; ND: non-dominant side; CMJ: countermovement jump; MBTo: medicine ball throw overhead; MBTf: medicine ball throw forehand; MBTb: medicine ball throw backhand; †† indicates significant group-by-time interaction effect ($p \leq 0.05$); * indicates significant main effect of time ($p \leq 0.05$).

Table 2. Shoulder strength and range of motion (ROM) measures before (pre-training) and after (post-training) the study period (8 weeks) with relative changes (Δ) and Cohen's d values for time effect, group effect and interaction effect.

	NTWU Group			DWU Group			Time Effect	Group Effect	Interaction Effect
Shoulder Strength	Pre	Post	Δ (%)	Pre	Post	Δ (%)	Cohen's d	Cohen's d	Cohen's d
IR D ($N \cdot m^{-1}$)	169.17 ± 24.48	177.22 ± 22.07	5.10	159.32 ± 21.83	161.80 ± 18.21	1.95	2.049	0.610	1.084††
IR D ($N \cdot m^{-1} \cdot kg^{-1}$)	2.83 ± 0.35	2.96 ± 0.38	4.80	2.72 ± 0.40	2.72 ± 0.34	0.33	1.232	0.496	1.232††
IR ND ($N \cdot m^{-1}$)	150.99 ± 26.80	152.79 ± 26.13	1.31	142.19 ± 18.49	142.57 ± 18.36	0.30	1.170*	0.434	0.763
IR ND ($N \cdot m^{-1} \cdot kg^{-1}$)	2.51 ± 0.35	2.55 ± 0.37	1.62	2.46 ± 0.47	2.41 ± 0.45	-2.10	0.168	0.238	1.549††
ER D ($N \cdot m^{-1}$)	119.16 ± 21.64	133.24 ± 21.22	12.53	126.39 ± 19.67	129.59 ± 17.55	2.87	2.150	0.090	1.353††
ER D norm ($N \cdot m^{-1} \cdot kg^{-1}$)	1.99 ± 0.29	2.24 ± 0.38	12.18	2.18 ± 0.45	2.19 ± 0.42	0.63	1.674	0.191	1.586††
ER ND ($N \cdot m^{-1}$)	113.74 ± 22.91	125.03 ± 30.10	10.77	112.44 ± 20.44	114.79 ± 18.84	2.36	0.857*	0.271	0.561
ER ND norm ($N \cdot m^{-1} \cdot kg^{-1}$)	1.89 ± 0.26	2.06 ± 0.41	9.95	1.94 ± 0.46	1.91 ± 0.43	-1.13	0.553	0.127	0.756
ER/IR ratio D	0.71 ± 0.08	0.75 ± 0.09	6.87	0.80 ± 0.13	0.81 ± 1.11	1.11	1.062	0.770	0.863††
ER/IR ratio ND	0.76 ± 0.09	0.82 ± 0.17	9.49	0.80 ± 0.17	0.81 ± 0.16	-0.21	0.625	0.063	0.663
Shoulder ROM									
IR D (º)	54.25 ± 11.46	59.75 ± 9.12	12.30	56.90 ± 11.46	58.50 ± 9.53	3.87	1.347*	0.063	0.739
IR ND (º)	65.79 ± 13.32	66.71 ± 9.67	5.53	68.20 ± 13.63	68.57 ± 11.67	1.98	0.155	0.220	0.020
ER D (º)	143.86 ± 14.04	146.20 ± 10.38	1.95	137.77 ± 10.27	137.03 ± 10.26	-0.52	0.419	0.710	0.797††
ER ND (º)	132.68 ± 10.96	133.18 ± 11.20	0.39	132.33 ± 9.76	132.13 ± 9.52	-0.04	0.155	0.063	0.238
TROM D (º)	198.11 ± 16.57	205.95 ± 13.35	4.19	194.67 ± 11.79	195.53 ± 10.53	0.87	1.549	0.532	1.022††
TROM ND (º)	198.46 ± 17.56	199.89 ± 14.38	0.85	200.43 ± 16.79	200.70 ± 15.71	0.46	0.142	0.142	0.020
TROM Diff (%)	-0.36 ± 10.01	6.06 ± 15.42	-59.44	-5.77 ± 20.59	-5.17 ± 19.94	9.25	0.752	0.544	0.606

GIRD (º)	-11.54 ± 6.76	- 6.96 ± 12.58	-40.75	-11.30 ± 11.60	-10.07 ± 10.16	19.22	0.582	0.180	0.414

NWU: neuromuscular warm-up group; DWU: dynamic warm-up group; D: dominant side; ND: non-dominant side; IR: internal rotation; ER: external rotation; norm: normalized values; TROM: total range of motion; GIRD: glenohumeral internal rotation deficit; †† indicates significant group-by-time interaction effect ($p \leq 0.05$); * indicates significant main effect of time ($p \leq 0.05$).

Figures 1 and 2

Figure 1. Structure and dimensions of the 505 change of direction test. m = meters.

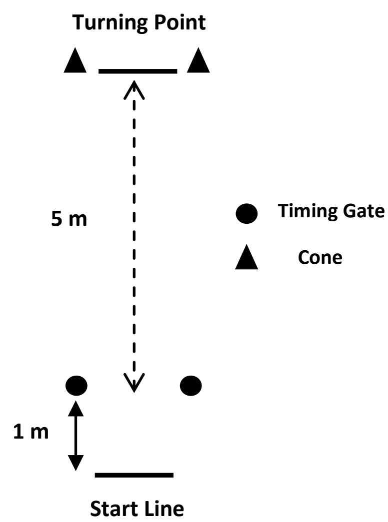
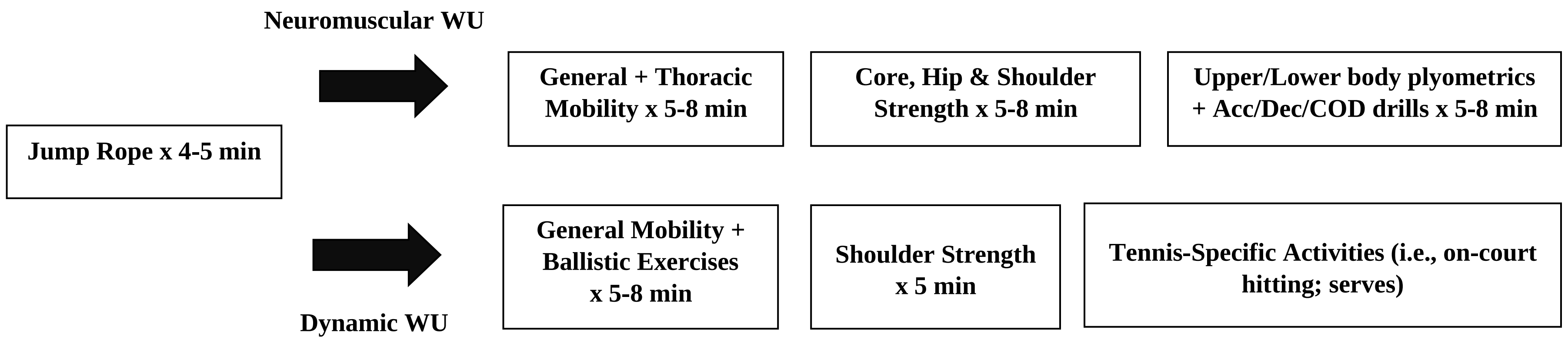


Figure 2. Schematic representation of warm-up (WU) programs.



Cover letter

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The effect of a structured tennis-specific vs traditional warm-up on physical performance in young players

To whom it may concern,

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Kind regards,

Dr. Jaime Fernandez-Fernandez