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Beneficial Acute and Lingering Effects of a Dynamic Stretching Protocol within a Pre-Competition Warm Up On Neuromuscular Performance Capacity in Professional Soccer Players

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Abstract

Background: Despite the vast literature for the effects of dynamic and/or static stretching modalities on performance, their effects when being within a comprehensive pre-competition warm up, replicating what athletes actually do still need to be elucidated. The objective of this study was to compare the effects of a static and a dynamic stretching regime within a pre-competition warm-up on neuromuscular performance capacity in professional soccer players.

Methods: Twenty soccer players, members of a Greek Super league team, completed three experimental conditions. Initially the control condition (no-stretching; CWU) was performed, followed by 2 experimental sessions in which players performed either a low-volume static stretching protocol (SWU) or a low-volume dynamic stretching protocol (DWU) within a comprehensive warm up, just prior to and immediately after a 45-min friendly soccer competition. Measurements included squat-jump (SJ), countermovement-jump (CMJ), and percent pre-stretch augmentation (PPA), 10m speed and, 20m speed.

Results: Analysis of our results revealed that after the pre-competition testing no difference was evident between CWU and SWU in none of the measured parameters ($p>0.05$), whilst the DWU resulted in acutely increased SJ, CMJvalues, and reduced 10m and 20m sprint times compared to both CWU (SJ:$p<0.001$; CMJ:$p<0.001$; 10m:$p<0.001$; 20m:$p<0.001$) and SWU (SJ:$p<0.001$; CMJ:$p=0.002$; 10m:$p<0.001$; 20m:$p<0.001$) conditions. The obtained post competition data revealed that this effect was retained showing an beneficial effect of the DWU vs. the SWU in all measured parameters (SJ:$p<0.001$;CMJ:$P=0.002$;10m:$p<0.001$;20m:$p<0.001$). No significant differences were evident for PPA ($p>0.05$) between any testing conditions throughout the study.

Conclusions: Our findings indicate that the employed DWU acutely enhanced neuromuscular performance compared to the SWU, and that this effect was retained after 45-min of play. In addition, the low-volume SWU, in agreement with the recent literature, does not result in power performance deterioration. These observations are of major importance for players since in elite soccer level slight changes in performance may determine the outcome of a competition.

Keywords: Dynamic stretching; Static stretching; Soccer; Pre-competition warm-up; Neuromuscular performance

Abbreviations: PAP: Post Activation Potentiation; MTU: Muscle Tendon Unit; CMJ: Countermovement Jump; SJ: Squat Jump; PPA: Percent Pre-Stretch Augmentation; DWU: Dynamic Warm Up; SWU: Static Warm Up

Introduction

A comprehensive pre-competition soccer warm-up routine typically consists of a short-duration low to moderate intensity aerobic activity (usually running), stretching of the major muscle groups (static and/or dynamic), and sport specific skill-based drills that are executed at game intensity, aiming to prepare players for the forthcoming competition [1]. Traditionally, static stretching has been the prominent feature of the warm up routines including soccer [2], however, recently this method of preparation has received much scrutiny with its effect on neuromuscular performance being challenged [3,4]. Overwhelming amounts of literature exist suggesting how static stretching performed prior to an athletic event, may result in the deterioration of several speed and power based performance indices (e.g. sprint, jump, reaction time [4,5]). These suggested decrements have been attributed to a combination of mechanical and neural factors which could lead to up to 7.5% reduction in neuromuscular performance capacity [5].Contrastingly, evidence suggests that dynamic forms of stretching, characterized as functional movements that stretch specific muscles groups through the active range of motion for each joint [3], may facilitate power, sprint, and jumping performance [2,3,4]. Although the physiological effects behind these desirable outcomes of dynamic stretching on performance still need to be elucidated, mechanisms such as increased post activation potentiating (PAP), temperature-related mechanisms, decreased muscle tendon unit (MTU) stiffness, and neural induce-adaptations have been suggested to underpin these effects [3,5,6]. In view of the recent evidence, there has been a shift towards inclusion of dynamic stretching in the pre-activity warm up from sport performance professionals, with this consensus also supported by sport related scientific societies including the European College of Sports Sciences and American College of Sports Medicine [7].

However, recent well designed studies and literature reviews indicate that the inferences drawn from the effects of the various stretching-related literature on several performance indices are subject to several issues [3,5,7]. Regarding static stretching, several methodological differences have been recognized, indicating decreased ecological validity of a great part of the literature. In general, despite the great variety of protocols regarding the volume and/or duration of the performed stretching activities in the literature, the majority of those are practically not relevant with those employed by professional athletes, failing to replicate the ones carried out in pre-event warm-ups [6,8]. These methodological differences include among others, the failure to replicate the comprehensive pre-event warming-up phase through absence of a sports specific component after the static stretching modality; the various volumes and intensities employed of this component [5,6]; the type of the performance indices assessed(either performance related measures or muscle function measures);the time elapsed after the warm-up for the subsequent testing [3,7]; and the duration of the static stretching modality. Regarding the duration of the static stretching modality, there is evidence showing that athletes in real time situations employ a minimum of one bout of 10 seconds per muscle group [7,9-12] which contradicts the vast majority of the available literature. Within soccer, evidence based on notational analysis from UEFA and domestic competitions, reveal that it is extremely uncommon for players to perform stretch activities for more than 10-second duration in specific muscle sites, and moreover to employ repeated series of stretching in the same muscle group during the pre-competition/activity warm up [7,9-13]. Considering the above and the observation that static stretching durations ≤60 sec per muscle are either resulting in marginal performance decreases (-1.1%) or do not seem to have any effect [3,5,7], is questioning the suggestion for exclusion of static stretching from a comprehensive pre-competition warm up routine. In addition, despite the general consensus of the detrimental effects of static stretching on performance, athletes is several sport disciplines including soccer, still show a preference of this type of modality in their pre-warm up routine [5,7,11], which further questions the suggestion for static stretching exclusion from pre-warm up routines.

Regarding the dynamic stretching modality more research is also needed to further elucidate the suggested positive effects of the implementation of these activities specifically within a comprehensive pre-competition warm up on exercise performance capacity. This need is due to the observed evidence questioning its beneficial action when implemented within a full warm up routine just reporting neutral effects [7,14,15]. In addition, although a strong body of evidence supports either a trivial to small positive effect (approximately 1.3%) or neutral effect of dynamic stretching on subsequent muscular performance [3] according to the Canadian Society for Exercise Physiology recommendations, no robust evidence exists for substantial performance enhancements [5]. The observation that in the available literature there is a great variability in several methodological issues including the duration, volume, and frequency [3,5,7,16,17] of this type of modality does not allow us to reach in definitive statements at this time.

The majority of literature in this area have examined the acute effects of stretching on exercise performance, where a limited number of studies have attempted to examine the potential lingering effects (i.e. the time course of the induced effects), of different stretching modes revealing inconsistent findings [4,8]. Neuromuscular performance decrements have been found to continue to worsen and/or to remain affected for up to 120 minutes [6,8,18,19]. Furthermore, in-effective effects of this modality were has been evident even 24 hours after the intervention with concomitant retained effects of the dynamic stretching protocol in this study [20]. On the contrary, the deficits due to static stretching have been found to subside within 10-15 min [5]. Similarly, [21] reported no difference when comparing vertical jump height immediately after static stretching and after 20 minutes of supplemental basketball play. Adding to the controversy, [22] observed a fully recovered jumping ability 15 minutes after all stretching conditions whilst recently, [8], reported that inclusion of dynamic vs static stretching as part of a comprehensive tennis-warm resulted to superior performance of the dynamic protocol and this enhancement was evident after 30' & 60' of a simulated match-play.

With respect to soccer, to the best of the author's knowledge, there is no available evidence to determine the potential acute and lingering effects of an actual pre-competition comprehensive warm up including the static and/or dynamic stretching modalities

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that reflect those implement by top level competitive players. Therefore, the aim of our study was to examine the possible acute and lingering effects of two different warm up routines which employed short duration/volume of either static (Static warm up [SWU]) or dynamic stretching activities (Dynamic warm up [DWU]), just prior to and immediately after a 45-min duration soccer game (soccer half) on countermovement jump (CMJ), squat jump (SJ), 10m, 20m sprint performance and on percent pre-stretch augmentation (PPA) capacity performance. The study hypotheses proposes that the SWU will not affect neuromuscular performance parameters and PPA whilst the DWU would result in marginal but substantial performance enhancement, and that effects would be retained after 45-min of game.

Materials and methods

Participants

Twenty elite professional soccer players (age=24.7±4.9 years; height=1.80±0.07m, body weight=78.15±9.94 kg; body fat percentage=7.38±2.04) members of a Greek Super league team participated in this study. Height was measured using a stadiometer (Charder HM210D, Charder Electronics CO, LTD, Taiwan) and weight (kg) was obtained using an electronic weight scale (Seca Alpha 770, Seca Vogel, Hamburg, Germany). Body fat percentage was assessed by skin fold thickness measurement (Lange Skinfold Caliper, Cambridge Scientific Instruments, and Cambridge, UK) according to standard procedures [23]. Before testing, written informed consent was obtained from all participants. The study was conducted in strict accordance with the ethical guidelines of the Helsinki Declaration and was approved by the Ethical Scientific Committee of the University Hospital of Heraklion, Crete, Greece. Two followed by during this session the anthropometric characteristics of the players were assessed.

Procedures

In order to address the hypotheses of the study counter-balanced repeated measures design including a control group was employed. Players participated in three experimental sessions, consisting of a control warm up session (CWU; no-stretch condition) and two experimental conditions with the implementation of either a short dynamic or static stretching modality within the pre-competition comprehensive warm up. The no-stretching condition was performed three days after the conclusion of the competition season. It should be highlighted that the no-stretch (control) session as this is not typical sports practice. Although players were familiarized with all testing procedures, as they had been measured repeatedly throughout the last competitive season, this session also served as a familiarization session of the specific sequence/order testing was performed. Three days later the second experimental testing was performed. After a period of five days the third experimental testing took place. The last two experimental sessions included a friendly soccer game of 90-min duration (two 45-min halves) against the same Greek Super league team, starting at the same time (17:00 pm) in each testing day. Players were assigned in two groups of 10 (goalkeepers were excluded) and completed one 45-min game in each testing session. Each group of players participated in the same of the two 45-min halves (i.e. 1st half [1st Group/Starters] and 2nd half [2nd Group/Non-Starters]) during each experimental period. In the second experimental session the 10 players that participated in the first half of the friendly game performed the warm up protocol with the inclusion of static stretching Static Warm Up [(SWU]), whereas the following 10 players performed the warm up protocol that employed the dynamic stretching activities (Dynamic Warm Up [DWU]). This order was reversed in the third experimental period. Exercise performance testing was performed just prior to and after the end of each 45-minute session to examine the acute and the possible lingering effects of the warm up routines. Approximately ten minutes after the completion of each warm up session and each 45-min session, players were tested for jumping ability and sprint performance, in order to avoid any fatigue effects that would interfere with our findings and furthermore aiming to replicate as closely as possible what might occur in the sporting environment. Measurements were performed for the assessment of SJ, CMJ, percent pre-stretch augmentation (PPA), 10 and, 20m sprint performance, and were performed in that specific order. Before each experimental session players were instructed to avoid any caffeine or alcohol beverages at least 3 hours prior to each testing. The relative humidity and the temperature at the beginning of the first the second and the third experimental sessions were also measured and were as follows: 68% & 29°, 67% & 26°, and 70% & 28° respectively. To reduce the interference of uncontrolled variables, players were asked to maintain their habitual dietary intake during the study. In order to determine whether the training stress was similar in all testing sessions for each group of players, and thus fatigue would not interfere with our post-game collected data, the physiological demands (internal load) of each 45 min period in the two experimental sessions were monitored with heart rate (HR) measurements (Polar Team system 2, Polar Electro, Kempele, Finland) and the usage of a multiple-camera vision-based motion analysis system (VIS.TRACK, Impire AG, Ismaning, Germany) (External Load).

Comprehensive pre-competition Warm up protocol

The pre-competition warm up protocol consisted of a 4-minute jogging at a self-selected pace followed by an approximately 2-minute period (~120 seconds) employing either static or dynamic stretching activities, or just rest (control group/no-stretch condition). Afterwards players performed the same soccer specific activities which were as follows: a) 2 minutes passes (two players with one ball) in a self-paced intensity, b) two 75-seconds duration small sided games (field dimensions: 30x15m) with the instruction to be performed with 3 contacts maximum, interspersed by 45 seconds of rest, c) 5 minutes crosses and shots (performed in an identical form by all players

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in the two experimental sessions), and d) five 5m sprint from a standing position with 45 seconds rest in between. Ten minutes after the completion of each warm up session and each 45-min session, players were tested for jumping ability and sprint performance. This time period was employed in order players to avoid any possible fatigue effects, and furthermore to closely simulate soccer pre-competition routines.

Implemented Static and Dynamic Stretching Activities

The DWU and the SWU protocols incorporated stretching activities targeting the following muscle groups: adductors, abductors (including and synergist muscles), hamstrings, quadriceps, gluteus, and gastrocnemius [Tables 1&2]. In the SWU protocol each player stretched the target muscle of one leg slowly and cautiously until a position of mild discomfort was reached for 10 seconds. Immediately after, the same procedure was repeated on the respective target muscle of the other leg. This sequence was performed once (i.e. 1 set). After a 3-4 seconds rest period players stretched the next target muscle group. The dynamic stretching activities were performed in a high velocity rhythmic manner, following a straight line. In each one of the chosen dynamic stretching activities players executed one set consisting of five repetitions for the right leg and five repetitions for the left leg of approximately 10 seconds duration. Afterwards players had to jog slowly back, at the starting point (~3-4 seconds), and performed the next dynamic stretching activity.

Table 1: Description of the static stretching activities.

Muscle	Stretching procedure	Duration (sec)	Sets
Quadriceps	From a standing position, keeping torso erect, bend one knee and bring heel up toward buttock; hold using ipsilateral hand	10	1
Hamstrings	Take a step forward with the left leg and reach toward the left foot by bending at the waist. Both knees are slightly bent and the arms are straight on either side of the forward leg. The trunk remains straight with the head in a neutral position. Repeat on the opposite side.	10	1
Abductors	To perform the stretch for the left hip, sit on the field with the right leg straight and place the left foot on the field to the outside part of the right knee. Twist the torso to the right and place the right triceps against the outside of the left thigh to push further into the stretch. Repeat on the opposite side	10	1
Adductors	Stand with feet as wide apart as is comfortable, shifting body weight from one side to the other as knee flexed and then reach towards extended foot and hold Lay down in supine position (face up) and flex the knees. lex the right hip thereby bringing the right knee closer to the body; position the right ankle just below the flexed left knee Move the upper body off the ground and towards the knees until stretch can be felt in the buttocks, place arms behind the body on the ground to hold position	10	1
Gastrocne-mius	In a standing position with ankle in 5° approximately 1 m from co-player, lean against the co-player with both hands, keeping the leg straight	10	1
Gluteals	In one-leg-long sitting position, with the other leg bent, cross the ankle of the bent leg over the knee of the straight leg, drawing the knee of bent side to the contralateral shoulder	10	1

Table 2: Description of the dynamic stretching activities.

Muscle	Stretching Procedure	Duration (sec)	Sets
Quadriceps	Heel ups. Rapidly kick heels toward the buttocks while moving forward	10	1
Hamstrings	Walking while actively swinging the leg to be stretched forward into hip flexion until a stretch is felt in the posterior thigh while keeping the knee extended and the ankle in plantar flexion	10	1
Abductors	While moving each perform hip abduction with fully extended legs, trunk circles and passive ankle rotation	10	1
Adductors	Hurdler's knee raises forward movement. While traveling forward, the participant raises the trailing leg and places the hip in flexion (90°) in an abducted and externally rotated position, with the knee flexed at 90°. In this position, the limb is displaced forward as though the participants were stepping over an object just below waist height and returned to the normal walking stride position	10	1
Gluteals	Walking high bringing knee to chest. While walking, lift the knee toward the chest, raise the body on the toes of the opposite extended leg	10	1
Gastrocnemius	Tip-toe walking. Traveling forward while completing alternating plantar flexion (tip toe) with every step forward. The aim is to raise the body as high as possible through tip toeing	10	1

Ergometry tests

The jumping capacity (SJ, CMJ) of the players was assessed with a jumping mat, and the sprinting ability (10m, 20m) was measured with infrared photoelectric cells (Power timer, New test Ltd., Oulu, Finland) according to standard procedures [23]. The PPA was assessed form the following formula: ((CMJ-SJ)/SJ) ×100). Maximal heart rate (HRmax) was assessed on a motorized treadmill with the use of set procedures of a standard protocol to exhaustion [23].

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Heart Rate Responses and Vision motion analysis

The assessment of the HR values for determining the internal-physiological load of each experimental session was performed using a portable HR monitor. The HR was continuously monitored on outfield players throughout the 45-minute sessions and recorded at 1-second intervals. The HR values for determining the physiological load of soccer players was expressed as a percentage function of the maximum HR (%HRmax).

Each 90 min friendly game was analyzed using a multiple-camera computerized tracking system. In order to evaluate the physiological demands of each 45-min session the following locomotors categories were used: total distance covered, high intensity running (>14km/h), and sprinting (>24km/h), which are similar to movement categories described by others [24,25].

Statistical Analysis

Statistical analysis was performed using the software program SPSS 23.0 (SPSS Inc, Chicago, USA). Results are presented as means ±SD. Differences at baseline between the measured loco motor activities in the two intervention sessions were examined in the context of univariate ANOVAs. A repeated-measures analysis of variance (ANOVA) was used to investigate the possible acute effects of the employed three conditions regarding on performance measures. After the ANOVA, a pair wise comparison post hoc test was performed with a Bonferroni adjustment. The level of significance was set at $p<0.05$.The changes between the experimental periods in the measured parameters regarding the lingering effects between the DWU and the SWU were analyzed by the paired samples t-test for normally-distributed data, and by Mann-Whitney test for non-normally-distributed data with Bonferroni adjustment in order to control the Type-1 error rate. Results were considered significant at a level of significance $p<0.008$ (a=0.05/6). Additionally, effect sizes were calculated and classified to determine the magnitude of changes among experimental conditions as proposed by Cohen: A value of d below 0.20 is considered small, 0.50 medium, and 0.80 large. For all the pair wise comparison in our study.

Results

Vision based motion analysis data and Heart Rate Responses

In regard to the measured locomotors activities [Tables 3&4], analysis of our result did not show any significant difference between the first and the second experimental session in the first and the second groups of players (i.e. starters vs non-starters respectively) for the total distance covered ($p=0.089$ and $p=0.043$ respectively), high intensity running distance ($p=0.79$ and $p=0.74$ respectively), and sprinting distance ($p=0.95$ and $p=0.88$ respectively). Similarly, the comparison of the %HRmax values did not show any significant difference between the first and the second experimental session for both the first group of players($p=0.42$) and the second group of players($p=0.29$).

Table 3: Mean (±SD) of Vision motion analyses and %HRmax values for test conditions.

HR responses VMA	Group A			Group B		
	1st Experimental Session	2nd Experimental Session	P	1st Experimental Session	2nd Experimental Session	P
TD (km)	5.86±0.31	5.72±0.34	0.08	5.63±0.33	5.58±0.21	0.43
HIR (m)	373.8±174	359.6±165.1	0.79	373.0±171.4	359.9±161.6	0.74
SD (m)	102.1±64.52	103.1±54.85	0.95	101.5±61.26	99.2±51.37	0.88
%HRmax	85.6±0.96	86.0±1.41	0.42	84.9±0.44	85.5±0.84	0.29

Table 4: Mean (±SD) of performance measures for test conditions.

Ergometrics	CWU	Pre Competition SWU	Pre Competition DWU	Post Competition SWU	Post Competition DWU
Jumping ability					
SJ (cm)	38.25±2.09	38.75±2.67	40.7±2.^{a,b}	37.15±2.45	37.9±2.3^{c}
CMJ (cm)	41.35±3.36	41.6±3.36	43.3±2.93^{a,b}	39.25±2.78	40.40±2.92^{c}
Speed					
10 m (sec)	1.78±0.07	1.78±0.07	1.74±0.07^{a,b}	1.84±0.07	1.81±0.07^{c}
20m (sec)	3.04±0.06	3.03±0.06	3.00±0.06^{a,b}	3.09±0.05	3.07±0.05^{c}

Insert: a significant difference vs Pre Competition CWUat the level p<0.05; b significand difference vs Pre Competition SWU at the level p<0.05; c significant difference at the level p<0.008 vs SWU.

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Ergo metrics

The comparison between the three protocols (Table 4) revealed that there was a significant positive effect of the DWU compared to both SWU and CWU values (mean ±SD) prior to the 45-competition periods on SJ ($p<0.001$; d=0.78 & $p<0.001$; d=1.11 respectively), CMJ ($p=0.002$; d=0.53 & $p<0.001$; d=0.061 respectively), 10m ($p<0.001$; d=0.509 and $p<0.001$; d=0.550 respectively), and 20m ($p<0.001$; d=0.506 and $p<0.001$; d=0.56 respectively). No significant differences were observed for any of the examined parameters between the CWU and the SWU conditions(SJ: $p>0.05$; CMJ: $p>0.05$; 10m: $p>0.05$; 20m: $p>0.05$). no significant differences were observed for the PPA (mean ±SD) between all three conditions (DWU vs SWU: 10.7±0.05 vs. 10.7±0.6, $p>0.05$; DWU vs. CWU: 10.7±0.5 vs 10.8±0.5, $p>0.05$; SWU vs CWU: 10.7±0.6 vs 10.8±0.5, $p>0.05$). Notably, in all measured parameters the SWU resulted only in slight % performance benefits compared to the CWU condition (SJ: 1,3%; CMJ: 0.6%; 10m: 0.16%; 20m; 0.18%).

Analysis of our findings regarding the obtained post-competition data revealed that the positive effect of the DWU vs the SWU on performance was retained. In particular, the DWU compared to the SWU resulted to significant post-competition higher values for SJ ($p<0.001$; d=0.31) and CMJ ($p=0.002$; d=0.43), and a significant decrease in 10m ($p<0.001$; d=0.46), and 20m ($p<0.001$;d= 0.35) sprint times(No significant differences were observed for PPA (mean ±SD) between the two treatments (SWU vs DWU) after the 45-min competition period (1.07±0.07 vs 1.06±0.07; $p>0.05$).

Discussion

The purpose of the current study was to examine the acute and the lingering effects of static and dynamic stretching as components of a typical pre-competition soccer warm-up routine. The principal results of this study support our hypothesis. It was observed acutely, that the SWU and DWU protocols resulted in an unaffected and enhanced sprinting ability, and jumping capacity respectively with these effects being retained after 45-min of play. Contrastingly to the study hypothesis, PPA did not significantly differ in any occasion between the SWU and DWU protocols. To the best knowledge of the authors, this study is the first to examine the acute and potential lingering effects of dynamic and/or static stretching within a comprehensive pre-competition soccer warm up in professional soccer players. Findings from the study regarding the unaffected performance under the SWU contradict the observation of several previous studies revealing compromised power related performance measures [3,5]. However, this lack of effect observed in this study is comparable with the available literature showing that when a sport specific warm-up is applied after the static stretching modality, it does not induce detrimental effects on neuromuscular performance [5,7,9,26,27]. From a soccer perspective, there is evidence showing that sprint ability, jumping capacity and agility performance was not compromised by the inclusion of static stretching within a full-warm up routine [2,15,28]. This is also supported by studies in other athletic populations showing that static stretching within a comprehensive warm up does not affect power related performance indices including jumping ability and sprint [6,14, 27,29, 30]. Interestingly, there are some evidence coming from studies including well trained individuals and soccer players that have even reported improvements in maximal performance efforts [6,9,16,28,31]. In our study, although there was not any significant effect as a result of the SWU, there was observed acutely a very trivial % increase in SJ, CMJ 10m, and 20m values compared to control (1.3%; 0.6%; 0.16%; 0.18%;respectively). Although of small magnitude, this increase could be advantageous for competitions since at elite soccer level even slight changes in performance could determine/affect the outcome of the competition. Support to this notion comes from the suggestion that from Kallerub and Gleeson [32] those even detrimental effects of a 0-4 % magnitude that can be observed in sprint and jump performance could impact adversely on competitive outcomes. It should be mentioned that there are also evidence showing that despite the employment of a secondary warm up after static stretching modalities there is deterioration in performance measures [1,18, 33,34]. However, the decrements in exercise performances in these studies could be attributed to the fact that the employed sport-specific warm-ups were either brief in nature or of moderate duration and/or intensity, and the that the no-activity period after the completion of the employed protocol was of a very low duration compared to the one used by athletes just prior to actual competitions. Results from the current investigation are in accordance and provide further supportive evidence to the reported dose-response relationship between static stretching duration and performance response indicating that the inclusion of short durations of static stretching (<60 seconds per muscle group) is unlikely to affect sprint running and jumping performance, and that this effect is further documented when it is performed as part of a comprehensive physical preparation routine [5,7]. Based on the aforementioned evidence, we could suggest that the observed neutral effect of the SWU protocol was most probable a result of the employed short duration stretching (i.e. 10 second static-stretch duration in each of the chosen muscle groups) and the replication of the comprehensive warm up routine (by using the exact sport specific activities performed by players prior to a competition) that could eliminate any potential negative effects of static stretching (if any) [35]. Apart from the aforementioned parameters, another possible explanation could be based on the observation that highly trained individuals, as our professional soccer players, have been found to be more resistant to the static-stretching induced deficits [29] and thus less susceptible to performance reductions. Lastly, this observed non-significant performance impairment under the SWU protocol could also have been an influence by a players expectancy that this type of warm up would not negative affect performance capacity [10]. Actually, this implies a "placebo

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effect" which is well documented and suggests that performance capacity could be modified based on an athlete's expectation as to a given task or treatment [10]. The importance on our finding regarding static stretching relies on its suggested small-to-moderate protective effect for muscle-tendon injury risk (by increasing flexibility), mainly in running-based sports such as soccer [7].

Although findings from this study are comparable with the widely accepted suggestion that dynamic activities acutely improve neuromuscular performance compared to static and/or to no-stretching conditions [4,8,34, 36], there are inconsistent findings regarding the effects when these two stretching regimes are employed within a comprehensive warm up [7,27,28,34]. In accordance to our findings recent studies on soccer players revealed that both sprint and jumping performance were enhanced either after the implementation of dynamic stretching within a comprehensive warm up [8,36] or not [2]. Notably, Little and Williams [15] reported a non-significant tendency of jumping ability and sprint performance to increase after a dynamic protocol compared to the static protocol, and a significant increase compared to the no-stretching protocol in these measures, leading them to the conclusion that dynamic stretching as a preparation for subsequent high speed-performance (i.e. jumping ability and 10m speed) was more effective compared to the static stretching protocol in professional soccer players. Increased jumping ability and speed compared to static stretching and significantly enhanced sprint performance and an % only increase of CMJ compared to no-stretching [11] has been also reported in soccer players but without the implementation of a secondary warm up routine. In regard to jumping ability and speed our findings are partially supported by the observations of two studies in healthy individuals from the same laboratory [18,34]. The authors reported that dynamic stretching activities followed by a secondary warm up resulted to enhanced jumping ability [18,34] and, although not-significant, to moderate increases in 20m sprint times compared to the static stretching protocol [34]. However, evidence from other studies reported that neither jumping ability nor sprint performance showed any tendency to differ as a result of static and dynamic stretching protocols when combined with secondary activities and/or being parts of a comprehensive pre-competition warm up [7,29,33,35]. These observed discrepancies between the available literature and our own findings could be the result of the different methodological issues used [37] including the protocol employed and the mode of exercise (power or strength measures) and both the training status and the type of the participants. The differences between the findings in this study and the studies that have revealed only a tendency for increased jump height [15] and speed [15,34] or even no-effect could be also accounted to the employed velocity of the executed dynamic stretching activities. In our study, players were instructed to perform all dynamic stretching activities with a high velocity which was not evident in the latter two studies. Although velocity was not measured in our study, according to the findings of Fletcher [38] a comparison between a low velocity versus a high velocity dynamic stretching protocols revealed that the high-velocity protocol resulted to more pronounced increases in SJ and CMJ. Thus, we could speculate that the high velocity used in our study could be the reason for a further observed enhancement in performance by the dynamic protocol, leading to the observed significant increases compared to the studies of Little and Williams [15] and Pearce and associates [34] Furthermore, according to several investigators [4,32,37,38] the observed discrepancies could have been a result of several other parameters that have been reported to affect the responses of different stretching protocols such as the mode of the sport-specific warm up, the nature of the employed secondary activities, the different training status of the participants, the total volume of the stretching regimes used, and also the fact that in several studies participants were instructed to perform the dynamic stretching modalities while standing still and not walking, as in our study, that has been suggested to be more beneficial [3,5,39].

In regard to the DWU, the suggested neuromuscular performance improvements have been related with several hypothetical physiological mechanisms such as elevated muscle and body temperature, stimulation of the nervous system, positively altered PAP, enhanced muscular tendinous unit (MTU) stiffness, improved proprioception, and lastly increased reused elastic energy during exercises involving the stretch-shortening cycle (SSC) [20,40,41]. However, in our study we should exclude the possibility that elevated muscle and body temperature contributed to the observed elevations in performance. The majority of the studies which have reported that temperature related mechanisms played a significant role in performance alterations did not use comprehensive pre-competition warm up [34] and furthermore, the time under (volume) the static and the dynamic stretching was much higher than ours [32] which could indeed favor a temperature related positive effect of the dynamic protocol. In our study it could be rather unlikely the employed low volume of stretching activities to had any effect on core and muscle temperature. Furthermore, our players followed in both stretching protocols a general and sport specific warm up respectively of approximately 20min duration (rest periods including) which could have increased muscle and core temperature in a similar degree. Similarly, we should also exclude the hypotheses that our observed findings were also related with any DWU induced positive effect on the SSC. The PPA, which is calculated from the CMJ and SJ performance measures, has been suggested to be an indicator the utilization of the SSC in athletes [42]. Therefore, the unaltered PPA values under the two stretching protocols suggest that no alterations regarding the SSC were evident. Thus, we could speculate that our observed performance enhancement under the DWU protocol should be accounted to a combined effect of the other suggested physiological mechanisms i.e. stimulation of the nervous system, PAP, enhanced MTU stiffness, and improved proprioception, which all have been well demonstrated to be of vital importance for neuromuscular performance capacity [43-45].

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To the best knowledge of the authors this is the first study to examine the potential lingering effect of a pre-competition warm up after a 45-min soccer game. Although there is a lack in the available evidence regarding this topic, the observed significant improvements in all examined performance indices under the DWU protocol are comparable by the observations of a recent study on professional Tennis players [8].The authors reported that the use of dynamic stretching as a part of tennis-specific WU results in superior performance levels both prior to and during a 60 min simulated match-play, suggesting a retained effect. Further supportive evidence comes from three studies that have reported enhanced jumping ability and sprint performance due to different dynamic stretching protocols after 30 min [18], 120 min [40] and 24 hours [20] compared to the employed static stretching condition respectively. Notably, no secondary activity was performed in the aforementioned studies after the stretching protocols, making difficult the association with our findings. However, the observation that performance enhancement under the DWU compared to the SWU was retained indicates that the suggested positive effects of the DWU seem to persist over a long period of time providing support to our findings. It should be mentioned that our observations that the physical demands of each experimental session was similar, based on the comparison of the collected %HRmax, HR mean values, total distance covered, and both sprint and intensive runs distance, exclude the possibility of any variations in post-performance outcomes due a differential fatigue induced effect.

The mechanisms underpinning the observed differences after the 45-min game are purely speculative. However, it could be hypothesized that the same mechanisms that were responsible for the acute beneficial effects of the DWU i.e. enhanced PAP, MTU stiffness, and neural activation, could have been partially retained after the 45-min period. Indeed, there is some evidence allowing us to support this suggestion. It has been reported that after training-induced fatigue in well trained athletes the pre-exercise MTU stiffness is retained to a similar degree to pre-exercise [46]. Taking into account that our participants were highly trained professional soccer players we could suggest that any beneficial alteration of the MTU stiffness under the DWU was retained after the 45-min game. Furthermore, since changes in the MTU stiffness have been considered to be the primary reason resulting to alterations in neuromuscular performance due its effects on myolectrical potentiating, mediated by changes in reflex activity [4,8,32], could also suggest retained positively altered neural activation. In regard to PAP, there is evidence to support that training-induced increases in its levels are retained for up to a 20 min period and that as a result of this alteration subsequent neuromuscular performance is enhanced [47]. Collectively, the significant observed differences in favor of the DWU protocol could be a retained effect of acutely positively affected pre 45-min period PAP, MTU stiffness, and neuromuscular coordination.

In conclusion, our findings suggest that the implementation within a pre-competition warm up of a low-volume dynamic stretching regime compared to static stretching activities of similar volume, results to acutely enhanced jumping ability, sprinting capacity, and that these effects are retained after 45 minutes of play in professional soccer players. These observed differences should be most probable linked to positive changes in PAP, neural activation, and possible enhanced MTU stiffness, but not to alterations in the capacity of the muscle to store elastic energy and to temperature related mechanisms. Regarding static stretching, our results indicate that when characterized by short durations like those that are usually employed by soccer players, its implementation within a soccer pre-competition warm up routine does not negatively affect performance but even can result in slight improvements in jumping and sprinting ability, that although statistically insignificant, could be beneficial in high level competitive players.

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