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Research article

Acute effects of three different stretching protocols on the Wingate test performance

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Abstract

The purpose of this study was to examine the acute effects of different stretching exercises on the performance of the traditional Wingate test (WT). Fifteen male participants performed five WT; one for familiarization (FT), and the remaining four after no stretching (NS), static stretching (SS), dynamic stretching (DS), and proprioceptive neuromuscular facilitation (PNF). Stretches were targeted for the hamstrings, quadriceps, and calf muscles**.** Peak power (PP), mean power (MP), and the time to reach PP (TP) were calculated. The MP was significantly lower when comparing the DS (7.7 ± 0.9 W/kg) to the PNF (7.3 ± 0.9 W/kg) condition ($p < 0.05$). For PP, significant differences were observed between more comparisons, with PNF stretching providing the lowest result. A consistent increase of TP was observed after all stretching exercises when compared to NS. The results suggest the type of stretching, or no stretching, should be considered by those who seek higher performance and practice sports that use maximal anaerobic power.

Key words: Static stretching, proprioceptive neuromuscular facilitation, dynamic stretching, anaerobic power.

Introduction

Many athletes perform stretching exercises as part of a warm-up prior to physical activity in order to prevent injuries and enhance their performance through an increase in flexibility (Alter, 1997; Herbert and Gabriel, 2002). However, recent investigations have reported acute stretching may reduce athletic performance by decreasing muscle strength (Behm et al., 2004; Evetovich et al., 2003; Kokkonen et al., 1998), muscle endurance (Franco et al., 2008; Nelson et al., 2005), vertical jump (Church et al., 2001; Cornwell et al., 2001; Young and Behm, 2003), and sprint performance (Nelson et al., 2005). This is important, as the muscle force presented in different outputs (maximal, endurance, and explosive) constitutes a determining factor of the performance achieved in sport.

It has been proposed prolonged stretching is associated with a decrease in neural input into the muscles being stretched, resulting in acute reductions in performance (Fowles et al., 2000). For instance, Avela et al. (1999) reported prolonged passive stretching (PS) of the ankle plantar-flexor muscles decreased its maximal voluntary contraction (MVC) force for up to 1 hour due to reduced motor unit activation and force-generating capacity. Similar results were observed by Fowles et al. (2000) after participants repeated a prolonged static stretching routine. In their study, MVC and electromyography (EMG) activity of the triceps surae muscles decreased following stretching. In addition, Costa et al. (2009) reported significant decreases in hamstring peak torque across the velocities of 60, 180, and 300deg·s^{-1} following static stretching.

A relatively moderate amount of static stretching has not been shown to alter lower body strength (Behm et al., 2004; Muir et al., 1999; Yamaguchi and Ishii, 2005). For example, Yamaguchi and Ishii (2005) reported no adverse effects on muscular power in the leg press exercise after one set of 30 s using five passive stretching exercises. Moreover, Ogura et al. (2007) compared two static stretching durations (30 s and 60 s) on the quadriceps. The 30 s of stretching did not affect muscular performance; however, 60 s caused a significant decrease in strength. Hence, it appears the volume of stretching (stretch duration) may be a significant factor. Thus, different results have been found across different studies with relatively longer stretching protocols typically producing lower performance results (Behm and Chaouachi, 2011). Furthermore, the number of repetitions, duration of each repetition, muscle involved in stretching sessions, and the type of stretching may be additional factors explaining conflicting findings presented in the literature (Franco et al., 2008).

Despite the use of various stretching techniques, including static stretching, ballistic stretching, proprioceptive neuromuscular facilitation (PNF), and dynamic stretching (Alter, 1997), few studies have investigated the influence of the type of stretching on athletic performance. Marek et al. (2005) investigated the differences between static and PNF stretching on isokinetic leg extension in recreationally-active males and females and reported negative effects of equal magnitude from both stretching protocols. Conversely, Yamaguchi and Ishii (2005) reported static stretching applied in moderate duration did not affect post-stretching performance, whereas dynamic stretching increased the power developed in the leg press. In contrast, Unick et al. (2005) compared the influence of static and ballistic stretching on vertical jump and found no significant effects on jump performance. Finally, Franco et al. (2008) investigated the effects of different types and durations of stretching on muscular endurance and found negative effects with one set of 40 s of static stretching and PNF stretching.

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Muscular performance and its enhancement, such as changes in force, speed of contraction, and power, have been of interest to those who investigate stretching and its effects on muscles. Regarding sports and athletic performance, dynamic muscle actions are typically the most observed. The Wingate test (WT) is a common dynamic test used to evaluate an athlete's anaerobic performance. Ramirez et al. (2007) compared the results of the WT (30 s) performance after static stretching exercise to those after a conventional cycling warm up protocol and found lower peak power (PP) and mean power (MP) with the stretching intervention. Similarly, O'Connor et al. (2006) investigated the acute and sub acute effects of static stretching on cycle performance when participants performed an adapted WT (10 s; WT10 s). The PP, total work (TW), and time to reach the peak power (TP) were assessed at 5, 20, 40, and 60 minutes after one of two warm up protocols. In one protocol, the participants performed a conventional cycle warm up, whereas in another they performed a conventional cycle warm-up and stretching exercises. The stretching exercises were aimed at the muscles involved in cycling. The PP and TW were greater and the TP occurred earlier when static stretching was performed compared to when it was not.

The findings from these two studies appear contradictory, and one might attribute the conflicting results to the different methods employed. Thus, a novel finding of an increase in muscle power after static stretching suggests the need of new studies to further clarify this question. Therefore, the purpose of the present investigation was to examine and compare the acute effects of three different stretching exercises on a maximal anaerobic WT. It was hypothesized any stretching exercise would lead to a loss in strength and consequently, a loss of power throughout the anaerobic cycle performance.

Methods

This study was designed to examine and compare the acute effects of three different stretching protocols on muscle power performance during a dynamic activity. A repeated measurements design was followed, where the effects of different types of stretching were assessed during five separate visits. Hence, the variables peak power, mean power, and the time to reach peak power were assessed during the Wingate test after a static stretching, dynamic stretching, PNF stretching, and a no stretching condition.

Subjects

Fifteen recreationally-active male participants with a mean (SD) age of 25 (3.3) years old volunteered for the study (see Table 1 for the main anthropometric characteristics). The participants had a previous general recreational exercise experience of at least six months. However, none of the subjects were engaged in any regular or structured stretching program. Written and oral consent from each participant was obtained prior to the start of the study after the subjects were informed of any possible risks from the experiment. The experimental protocol was approved by the Ethics Committee of the University. The participants were not informed of the results until the study was completed.

Table 1. Mean (±SD) of the main physiological and anthropometric characteristics of the sample that comprised the experiment, along with the mean power (MP) and peak power (PP) obtained in the non- stretching (NS) condition.

Height (m)	1.79 (.08)
Body Mass (Kg)	78.3 (7.9)
FM (%)	15.4 (3.5)
MP ($W \cdot Kg^{-1}$)	7.7 (0.7)
PP ($W \cdot Kg^{-1}$)	9.9 (1.2)

FM: Fat mass

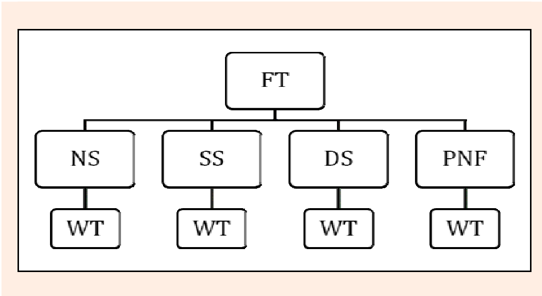

Figure 1. Flow chart illustrating the study's research design and randomly-ordered conditions. FT – Familiarization trial; NS – Non-stretching condition; SS – Static Stretching; DS – Dynamic stretching; PNF – Proprioceptive neuromuscular facilitation; and WT – Wingate test.

Procedures

The participants performed five traditional WT on five non-consecutive days (see Figure 1 for illustration of the test design) with a rest period of 48- to 72-hr between tests. Three WT were performed after stretching conditions and two WT were performed after no stretching. Each WT was performed on a cycle ergometer designed for immediate-load resistance with toe clips to prevent foot slippage (Monark Ergomedic 828E, Sweden). For each participant, the first test was without stretching or warm-up and was used strictly for the purpose of familiarization (FT) to the WT protocol. The muscles stretched were the hamstrings, the quadriceps, and the calf muscles (Table 2 and 3). The three stretching protocols were: 1) a static stretching (SS) exercise consisting of three sets of 30 s; 2) a dynamic stretching (DS) exercise consisting of three sets of five slow repetitions followed by 10 fast repetitions completed as fast as possible; and 3) a proprioceptive neuromuscular facilitation (PNF) exercise. The PNF exercise was performed three times with the participant achieving maximum tolerable range of motion of the targeted muscle while an experimenter provided an opposing force for eight seconds, followed by relaxation. In addition, a no stretching exercise (NS) condition was included as a control. The order of conditions (NS, SS, DS, and PNF) was randomly selected. The WT was performed in the seated position, and the participants were instructed to pedal as fast as possible against a load corresponding to 7.5% of body mass (Inbar et al., 1996).

During the WT, video was digitally recorded by a camera (A410, Cannon, Japan), stored in a personal computer, and further analyzed at the rate of 10 Hz, allowing the calculation of the power signal as the product

Table 2. Procedures used for static stretching and proprioceptive neuromuscular facilitation for the targeted muscles.

Calf Subject remained in the supine position with knee fully extended while the tester dorsiflexed the ankle joint of the subject.	
Hamstrings The subject remained in the supine position with knee fully extended while the tester flexed the hip joint of the subject.	
Quadriceps The subject's heel touched his buttock, and then the knee was lifted up such that the hip joint was extended. The tester fully flexed the knee joint of the subject in the prone position.	

of the load and the speed with a 0.1 s of resolution. The speed was determined by means of the product of the frequency of cycling and the perimeter of the wheel. From the calculated power signal, the data of PP and MP were determined according to methods previously reported (Inbar et al., 1996). In addition, the time elapsed between WT initiation and PP was recorded (TP). The data of PP and MP from each subject were normalized in reference to respective body mass in order to reduce the inter-subject variability.

Statistical analyses

Data from FT and NS were used to examine the reliability of the protocol regarding PP, MP, and TP by means of test-retest procedures. This included paired t-tests, standard error of measurement, and intra-class correlation (ICC). The latter was calculated according to the model of one-way random and computed as:

$$ICC = (MS_B - MS_W)/[MS_B + (k-1).MS_W)]$$

where MS_B and MS_W are components of ANOVA (Akimoto et al., 2000). Repeated measures ANOVAs were used to compare PP, MP, and TP among all stretching and no stretching conditions and, when applicable, the Mauchley's Sphericity test with the correction of Huynh-Feldt was employed. When appropriate, Tukey HSD post hoc tests were used. In addition, the effect size (ES) was calculated using Cohen's d. An alpha level of $p \leq 0.05$ was considered statistically significant for all comparisons.

Results

The sphericity test revealed to be significant only in the TP ($p = 0.003$) but not in the remaining variables ($p = 0.25$ and 0.18, for MP and PP respectively), and thus for such variable the correction was implemented in the ANOVA.

The results for FT and NS revealed high reliability for all variables examined (Table 4). The results for the dependent variable MP demonstrated a statistically significant effect among the stretching exercises ($p = 0.015$; ES = 0.51), which was due to the higher value of DS (7.7 ± 0.9 W·kg^{-1}) when compared to PNF (7.3 ± 0.9 W·kg^{-1}), as revealed by further post hoc testing (Figure 2).

Table 3. The procedures for dynamic stretching for the targeted muscles.

Calf First step: the subject raised one foot from the floor and fully extended the knee. Second step: the subject contracted his dorsiflexors intentionally and dorsiflexed his ankle joint such that his toe was pointing upward.	
Hamstrings The subject contracted the hip flexors intentionally with knee fully extended and flexed his hip joint such that his leg was swung up to the anterior aspect of his body.	
Quadriceps First step: the subject raised a foot from the floor and lightly flexed his hip joint with the knee lightly flexed. Second step: the subject then contracted his hip extensors intentionally and extended his hip and knee joints such that his leg was extended to the posterior aspect of his body.	

Table 4. Results (mean [SD]) obtained on all variables from the non-stretching conditions of familiarization (FT) and no stretching (NS), along with the results of test-retest, intraclass correlation coefficient (ICC), based on repeated measures ANOVA. The *p* values were obtained from paired t-tests.

	MP (W·kg^{-1})	PP (W·kg^{-1})	TP (s)
FT - Mean (SD)	7.67 (0.78)	9.61 (1.26)	4.19 (0.37)
NS – Mean (SD)	7.68 (0.70)	9.85 (1.15)	4.19 (0.34)
ICC	0.96	0.87	0.98
SEM	0.14	0.46	0.06
p <	0.853	0.909	.879

MP – Mean power output; PP – Peak power output and TP – Time to reach the peak power output.

Similarly, the PP demonstrated a statistically significant effect among the stretching exercises (p = 0.003). However, differently from MP, this was due to differences between more than two variables (Figure 2), but PNF tended to have the lowest values of power compared to the other stretching protocols, and showed a moderate effect size (ES = 0.72).

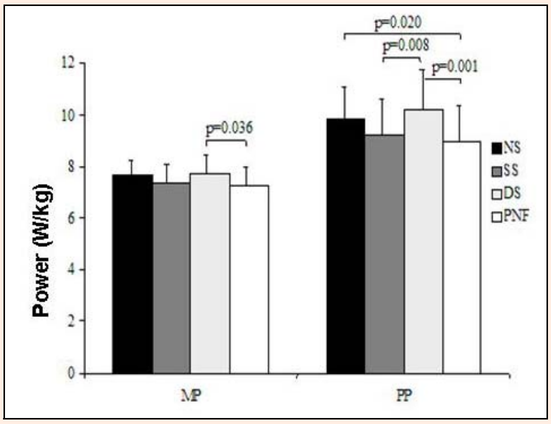

Figure 2. Mean (bars) and SD values (w/kg) of the mean power (MP) and peak power (PP) from the Wingate Test trials performed after no stretching (NS), static stretching (SS), dynamic stretching (DS), and proprioceptive neuromuscular facilitation (PNF).

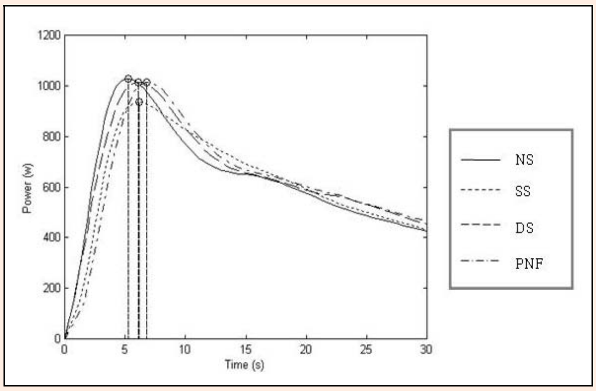

Figure 3. Results of the Wingate Test trials from one participant highlighting instant where the peak power where found (circles), allowing one to observe that stretching tends to delay peak power.

The TP presented the most consistent pattern in terms of differences across stretching conditions because a consistent delay of this peak was observed after all stretching exercises (Figure 3). The ANOVA performed for correction of non sphericity revealed the differences among tests to be statistically significant (p = 0.004), which was due to several comparisons (Figure 4). The only comparisons that did not present statistical significance were between SS and PNF. The no stretching condition resulted in the lowest values for TP (p < 0.001). Large effect sizes were observed in SS (ES = 3.87) and PNF (ES = 2.05).

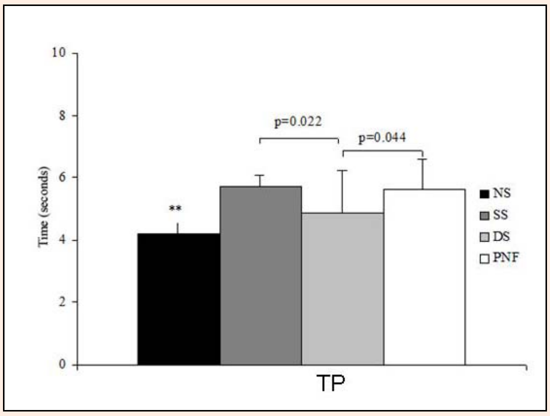

Figure 4. Mean (bars) and SD values of the time (in seconds) taken to reach PP from the beginning of each Wingate Test (WT) trial : WT trials performed after no stretching (NS), static stretching (SS), dynamic stretching (DS), and proprioceptive neuromuscular facilitation (PNF) are presented.
** represents the significant statistical difference (*p* < 0.001) found between NS and all other exercises.

Discussion

The main findings of the present investigation were that stretching decreased performance by lowering PP whereas TP increased. Many studies have been conducted investigating the effects of stretching on the performance of recreational sports and athletes due to changes in muscular capacity, which can be evaluated by means of different muscle performance variables. From these variables, strength has been widely investigated, whereas little attention has been given to endurance (Franco et al., 2008) and power (Marek et al., 2005; Yamaguchi and Ishii, 2005). The latter depends not only on force generated by the muscle, but also on the speed of muscular contraction. In addition, few studies have attempted to investigate the effect that the type of stretching exercise has on performance, (Marek et al., 2005; Yamaguchi and Ishii, 2005). In the present study, the influence of stretching exercises on lower body power through three parameters (MP, PP, and TP) of WT was addressed and some effects were found.

Alternatively, several studies have demonstrated that relatively longer stretching interventions result in acute reductions in performance, with an associated decrease in the neural input to the muscle (Avela, et al., 1999; 2004; Fowles et al., 2000). A recent investigation proposed these effects would depend on the number of sets, stretching duration, and type of stretching (Franco et al., 2008).

Negative effects of static stretching has been observed such as a reduction in strength (Behm et al., 2004; Evetovich et al., 2003; Kokkonen et al.,1998) and the height of a vertical jump (Church et al., 2001; Cornwell et al., 2001 ; Young and Behm, 2003). Ramirez et al. (2007) compared two performances of WT, one test following a static stretching exercise and the other following a conventional cycle warm up, and found a decrease in PP and MP when comparing stretching with a conventional warm up. Conversely, in the present study, only PNF reduced PP, when compared with NS. The static procedure did not reduce PP when compared to NS and the decrease was only seen when compared with DS, which is similar to the findings reported by Ramirez et al. (2007), who found reduced PP after SS when compared to DS.

O'Connor et al. (2006) evaluated the effects of stretching on an adapted Wingate test, or the WT for 10 s (Akimoto et al., 2000; Odland et al., 1997). The participants performed the modified WT after 5, 20, 40, or 60 minutes following one of two different warm up protocols: one consisting of a conventional cycle warm-up and another comprising of static stretching exercise for the involved muscles. They found greater results for MP and PP when the stretching was performed. These findings are not in agreement with the results from the present study, nor with the results from Ramirez et al. (2007). Perhaps, the use of a specific warm-up by the authors (O'Connor et al., 2006) before performing the stretching intervention had the potential effect of improving the results rather than the stretching protocol itself.

Unfortunately, not many Wingate stretching studies are found in the literature to compare with the present investigation. Therefore, a comparison of our findings with related studies using single movement power tests may be appropriate. Church et al. (2001) investigated the acute effect of SS on vertical jump performance and reported no significant difference on height, when static stretching was compared to no stretching. Yamaguchi and Ishii (2005) compared the power output on a leg press performed after static stretching and dynamic stretching aimed for the quadriceps, hamstrings, gluteus, and calf muscles. The stretching exercises comprised of one set of five stretches for 30 s each, while the dynamic stretching comprised of five slow and 10 fast repetitions of the same stretches. The authors found an improvement of power output with dynamic stretching. However, no significant differences for static stretching exercises were reported. In a different approach, Yamaguchi et al. (2007) examined the power output of the knee extensors after dynamic stretching at three different intensities; 5%, 30%, and 60% of MVC, and found higher power output for all intensities when dynamic stretching was performed compared to no stretching. In the present study, when speed was the goal with a fixed load, and a very similar dynamic stretching intervention was performed, comparable results were found. However, differently from Yamaguchi et al. (2007), although the dynamic exercises were found to be more efficient than the other stretching exercises, it was not more efficient than no stretching. The hypothesis for such a divergence is that the present study required maximal instead of sub maximal effort. In addition, after previous contractile activities, a transient improvement in muscular performance has been shown to occur termed postactivation potentiation (PAP) (Robbins, 2005; Sale, 2002). The principal mechanism of PAP is the phosphorylation of myosin regulatory light chains, which renders the actin-myosin interaction to be more sensitive to Ca^{2+} released from the sarcoplasmic reticulum. Increased sensitivity to Ca^{2+} has the greatest effect at low myoplasmic levels of Ca^{2+}, improving muscular performance (Robbins, 2005; Sale, 2002).

Regarding PNF stretching, the studies that investigated its effects on strength (Marek et al., 2005), vertical jump height (Church et al., 2001), and endurance (Franco et al., 2008), showed the effects on these variables to be negative. For instance, Marek et al. (2005) compared static stretching with PNF during isokinetic leg extension, and found a decrease in the peak torque and mean power output in both types of stretching when compared with no stretching. This was also observed in the present study, as PNF presented the most divergent results. The theory of autogenic and reciprocal inhibition has been used to explain the larger range of motion gained by PNF when compared to other methods (Chalmers, 2004) and has been reported elsewhere as the probable reason for the decrease in endurance, as this is somehow associated to the decrease in force (Franco et al., 2008). Also, the lengths of the fascicles can lead to a change in length-tension muscle curve, which would shift the optimum range of length for force generation, and as a consequence, bring the muscle to work in a range of a reduced ability to generate force (Cramer et al. 2007). This means that as PNF reaches higher muscle stretching it imposes the higher reduction in force. However, as this study is regarded more to physiological rather than mechanical outputs, the loss of force alone could not fully explain the decrease in performance, and thus new approaches should be addressed to explain such high differences found. One could speculate that some other mechanical factors may mediate the decrease of such muscle performance, such as changes in the elastic properties of muscular structures and a decrease in muscle-tendinous stiffness, previously reported by Magnusson et al. (1996), which somehow has an influence on the physiological requirements for power production

One important finding in the present study is the difference observed in TP between the no stretching and the stretching conditions, except in the DS condition. The TP is the time from the start of the test until peak power is reached. The lowest value of TP was found with no stretching. Although this variable is rarely quantified in the standard use of the Wingate test, one might speculate when performing sports that need explosive power, the use of SS, or PNF, and DS could delay this peak, probably reducing velocity and consequently negatively affecting performance. The WT is a maximum anaerobic test, such that not only force but also velocity is essential to obtain maximal performance. Thus, as the power depends on force and speed, the changing in this power kinetics might be related to any modification in the length-tension relationship for high speeds due to the successive stretching procedures applied, which may alter the viscoelastic properties of the muscle. O'Connor et al. (2006) also found a decrease in TP in the adapted WT10s, when comparing static stretching with no stretching. However, as previously suggested, the major source of such a finding might be most likely due to the specific warm up procedure employed before static stretching exercises and not due to the stretching itself.

Conclusion

In summary, the results from the present study revealed an influence of PNF and SS on PP and TP. These changes observed in some variables of WT after stretching may be due to distinct changes in power kinetics. In addition, TP was also increased after DS. Although dynamic stretching was not better than no stretching in the present study, rather it had a negative effect on TP, cyclists commonly use stretching exercises before cycling. Static and PNF stretching appear to have the most negative influence on WT performance, and this might be possibly extended to other sports that require high power performance. Therefore, these results may help recreational and professional athletes choose the most appropriate type of stretching exercise, or perhaps no stretching, before carrying out maximal anaerobic sports.

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Key points

- The mean power was significantly lower when comparing dynamic stretching.to proprioceptive neuromuscular facilitation
- For peak power, significant differences were observed between more comparisons, with proprioceptive neuromuscular facilitation stretching providing the lowest result.
- A consistent increase of time to reach the peak was observed after all stretching exercises when compared to non-stretching.
- The type of stretching, or no stretching, should be considered by those who seek higher performance and practice sports that use maximal anaerobic power.

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