

Warm-up: A case study on maximal oxygen consumption as it relates to acute stretching

By
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The aim of this study was to determine the acute effects of static and Proprioceptive Neuromuscular Facilitation (PNF) stretches on maximal oxygen consumption (VO_2 max). Ten physically active men (mean \pm SD, 23.80 ± 1.54 years, 70.60 ± 9.70 kg, $1.74.60 \pm 5.23$ m), who were healthy students volunteered to take part in the study. The participants were subjected to Static and PNF stretching exercises. After the interventions, the Bruce treadmill protocol was applied to measure VO_2 max values. The expired gases were collected and analyzed continuously using the Cortex Metalyzer II. Analysis of variance showed significant main effects for interventions ($F_{(2,18)}=10.74$, $p<.05$) on VO_2 max. The main result of this study showed that both static and PNF stretching exercises improved VO_2 max values.

Key Words: stretching, PNF, maximal oxygen uptake

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Introduction

Static and Proprioceptive Neuromuscular Facilitation (PNF) stretching exercises are largely used in sports activities and rehabilitation as a part of the warm-up routine with the principal intent to prevent injuries and improve muscular performance. Static stretching is performed by the application of gentle stretches of a particular muscle or muscle group. This technique involves slowly elongating the muscle to a tolerance point where the muscle is stretched to its greatest allowed, and thus tolerated length, and held in that position for a period of time. Through this process a stress relaxation occurs, with a static tension also being placed on the muscle–tendon, which in turn activates the golgi tendon organ. Autogenic inhibition is thereby generated on the stretched muscle (Bandy and Irion, 1994; Moore and Hutton 1980; Magnusson and Renstrom, 2006). Like static stretching, PNF is a common technique used during sports activities and rehabilitation. The contractility of the muscle supplies flexibility of the muscle by changing its viscoelastic properties. Autogenic and reciprocal inhibition mechanisms occur during the PNF stretching technique application. An isometric contraction of stretched muscle during PNF stretching causes an inhibition of the muscle's autogenic inhibition mechanism, thereby reducing muscle tension through the stimulation of Golgi tendon organs. In addition, tension during a maximum isometric contraction of the stretched muscle results in less resistance to length changes in the same muscle (Prentice, 1983; Moore and Hutton, 1980; Etnyre and Abraham, 1986). Recent studies have shown that acute static and PNF stretching of muscles may increase the range of motion (ROM) (Magnusson et al., 1995; McNair and Stanley, 1996; Halbertsma et al., 1996; Feland et al., 2001). Both mechanical and neural adaptation mechanisms are responsible for these changes during stretching (Guissard et al., 2004). Although acute static and PNF stretching exercises have been shown to be effective in enhancing ROM, they may also result in the reduction of the rate of force production, power output, maximal voluntary contraction (MVC) and jump performance (Power et al., 2004; Wallmann et al., 2005; Fowles et al., 2000; Church et al., 2001). Despite the well documented facts of the acute effects of static and PNF stretching on power, torque, and MCV, the efficacy of static and PNF stretching technique on aerobic performance is still questioned with its on-going debates in the scientific community. VO_2 max is reported as one of the primary indicators of aerobic performance. It is defined as a measure of the highest rate at which oxygen can be used by the body during exercise per minute (Billat et al., 1996; Bangsbo, 2000; Vella et al., 2006). Limited numbers of studies have shown, although inconclusively, stretching to cause changes in

favor of aerobic performance (Stewart and Sleivert, 1998; Guidetti et al., 2007). But the reported articles on this subject have not assessed the acute effects of static and PNF stretching on maximal oxygen uptake. Hence, the purpose of this study was to further investigate the acute effects of static and PNF stretches on maximal oxygen uptake.

Material and Method

Ten physically active men (mean \pm SD, 23.80 \pm 1.54 years, 70.60 \pm 9.70 kg, 1.74.60 \pm 5.23 m), who were healthy students at a School of Physical Education and Sports, volunteered to take part in the study. The participants were all well accustomed to the experimental procedure and had no signs of any neurological, orthopedic or systemic complications or disorders. All participants were informed about the experimental procedures. Written consent was obtained from the participants after which they were informed of the purpose, procedure and risks of participating in the study. They were also informed that they could withdraw from the study at any time.

The total intervention time was seven days per participant. In particular, they were exposed to a test schedule which involved a 48 hours rest interval between each intervention. All data collection took place under laboratory conditions. Ambient atmospheric conditions of the laboratory included temperature of 25° \pm 1° C and pressure of 919 \pm 1 mbar. The first intervention (Int1) was a treadmill test (Bruce protocol) in order to determine the VO₂ max value of each participant. After the first rest interval period, in the second intervention (Int2), the participants underwent an 18 min. passive static stretching of lower extremities, followed by the same treadmill test (Bruce protocol). After the last rest interval period, the participants went through an 18 min. hold-relax PNF stretching of lower extremities (Int3), followed again by the Bruce protocol. The Bruce protocol, which is a validated test for estimating VO₂ max from a maximal performance, was performed on a treadmill (h/p/ cosmos mercury; 0- 22.0 km/hr speed, 0- 24 % angle of inclination, 150cm x 50cm running surface). The test started at a speed of 2.74 km/hr at a 10% degree of inclination. At three minute intervals the degree of inclination on the treadmill increased by 2 %, reaching a maximum inclination of 22 %. The treadmill speed also increased progressively in the following sequence: 4.02, 5.47, 6.76, 8.05, 8.85, 9.65 km/hr. (Maud and Foster, 1995). During the exercise test, expired gases were collected and analyzed continuously using the Cortex Metalyzer II (Cortex Biophysik, Leipzig, Germany). Cortex MetaLyzer II, is a cardiopulmonary exercise apparatus used for pulmonary gas exchange measurements in a stationary environment. During the experimental tests participants wore a small face mask, and

breathed out through a volume transducer fixed to the face mask. Direct measure of gas exchange included O₂, CO₂ concentration of expired / inspired air, ambient temperatures, and pressure. Before the testing session, the gas analyzers were calibrated against a precision analyzed gas mixture (Reference / calibration gas from cortex calibration kit or span gas with 4-6 % CO₂, 14-16 % O₂, bal. in N₂).

Passive Static Stretching

At the beginning of the stretching, the participants were informed about the stretching techniques. In the passive static stretching exercises each of the subject's lower extremity muscles, including the hips (Gluteus maximus, gluteus medius, gluteus minimus, iliopsoas, sartorius, tensor fasciae latae), thighs (quadriceps, hamstrings, gracilis), and calves (gastrocnemius, soleus, tibialis anterior) were stretched by a trained assistant. The following were passive static stretching exercises done before the second intervention; 1. Hamstring stretch for each leg (3 x 30 sec for one leg) 2. Quadriceps stretch for each leg (3 x 30 sec for one leg) 3. Calves stretch for each leg (3 x 30 sec for one leg) 4. Groin stretch (3 x 30 sec) 5. Lying lower back stretch (3 x 30 sec.) 6. Lying glute stretch for each leg (3 x 30 sec for one leg) 7. Lying hip flexor stretch for each leg (3 x 30 sec for one leg). Stretching exercises were performed at the maximum pain tolerated by the participants. For each leg, the stretching was repeated three times with a rest period of 10 seconds between stretches. In this study, static stretching volume refers to 18 min; 30 sec. hold (Bandy and Irion, 1994; Cornwell et al. 2002; McNeal and Sands, 2003) and comfort level not exceeding 5 on a standard Visual analogue scale (VAS).

Hold Relax PNF Stretching

For the hold relax stretching exercises the subject's lower extremity muscles (as mentioned above) were stretched. Hold relax technique began with a passive pre-stretching that is held at a tight sensation for 10 seconds (Holcomb, 2002). Following 10 seconds, the participants maintained a maximal isometric tension against a manual resistance (applied by the same assistant) for 5 seconds. Then, each subject was asked to relax and a passive stretch was done for 15 seconds. PNF stretching exercises were performed at the maximum range tolerated by the participants. For each leg (3 x 30 seconds for one leg), the stretching was repeated three times with a rest period of 10 sec between stretches. Like the static stretching exercise procedure, the hold relax PNF stretching exercise was also conducted over a total period time of 18 min.

Statistics

Descriptive statistical methods were used to calculate the means and standard deviation of the variables involved in this study. Repeated Measures of ANOVA was applied to test significant levels of dependent variables. This test examined the effectiveness of static and PNF stretching on VO₂ max. The Repeated Measures included the following points: baseline (int1), static stretching (int2), and hold relax PNF stretching (int3). For statistically significant mean differences, a Paired- Sample t-test was run. The alpha level was set at .05 for this study.

Results

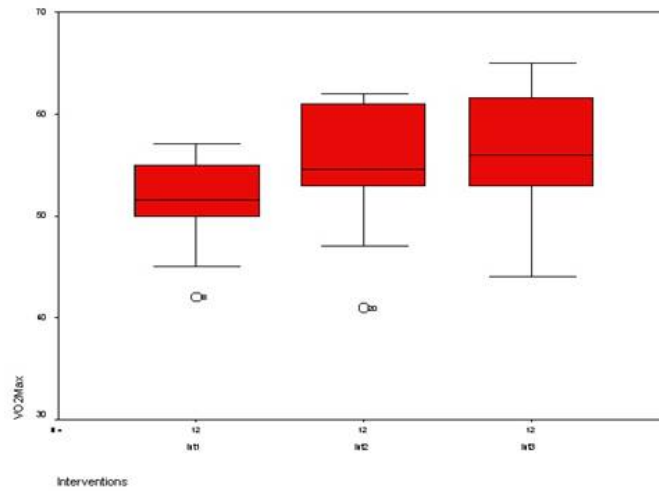
Descriptive statistics for VO₂ max and time to exhaustion were represented in Table 1 and Figure 1 respectively. Table 1 depicts a summary of descriptive statistics for all three interventions on VO₂ max, including the time to exhaustion in minutes. Repeated Measures of ANOVA analysis showed a significant main effect within subjects for VO₂ max ($F_{(2,18)}=10.74$, $p<.05$).

Table 1

Descriptive statistics of the interventions

	N	VO ₂ Max(ml.kg ⁻¹ min ⁻¹) Mean ± SD	Time to exhaustion (min) Mean ± SD
Intervention 1	10	50.90 ± 4.67	15.93 ± .76
Intervention 2	10	55.00 ± 6.84	16.43 ± 1.14
Intervention 3	10	56.70 ± 6.70	16.56 ± 1.06

The results of the Paired t- test are shown in Table 2. As seen from the table, there were statistical mean differences between Int1 – Int2 ($t = -3.20$; $p <.05$) and Int1- Int3 ($t = -3.87$; $p <.05$). However, no statistical significant difference was observed between Int2– Int3 ($t = -1.62$; $p > .05$). The result of this statistic indicated that both Int2 and Int3 showed pronounced, statistically significant increases in VO₂ max when compared with Int1.

**Fig 1.**

Descriptive statistics of the interventions on VO₂ max values

Table 2

Paired t- test results for all interventions on VO₂ Max (ml. kg⁻¹.min⁻¹)

	Mean ± SD	Mean	SD	t	df	P
Intervention 1	50.90 ± 4.67					
Intervention 2	55.00 ± 6.84	-4.10	4.04	-3.20	9	.01*
Intervention 1	50.90 ± 4.67					
Intervention 3	56.70 ± 6.70	-5.80	4.73	-3.87	9	.001*
Intervention 2	55.00 ± 6.84					
Intervention 3	56.70 ± 6.70	-1.70	3.30	-1.62	9	.13

*P < .05

Discussion

The effect of stretching exercise on VO₂ max has important implications in sport performance and rehabilitation. The present study was designed to assess the acute effects of two different stretching techniques on VO₂ max. The obtained results showed that both static and hold relax PNF stretching exercises caused an increase in VO₂ max values.

Scientific researches have been conducted on the effects of different type of warm-up activities (Bishop et al 2001, Church et al 2001, Genovely and Stamford 1982). In a broad sense, these kinds of activities are classified as passive warm-up (e.g., external heating) and active warm-up (e.g., running,

swimming, stretching). A number of studies have demonstrated that aerobic performance did not change after some types of warm-up with different intensities:

Genovely and Stamford (1982) determined the effects of prolonged warm-up exercise (with pedalling the Monarck cycle ergometer) at above (68 %) and below (40 %) anaerobic threshold. At the end of the study, they found that neither above anaerobic threshold (AT) warm-up nor below AT warm-up contributed to an improved maximal performance. This was attributed to glycogen depletion of fast twitch muscle fibers.

Moreover, in a study by Teubes et al. (1992) different warm-up protocols (40 %, 57 %, and 67 % of VO_2 max, respectively) were examined. Their results indicated that varying intensity and duration of warm-up did not cause a significant difference on VO_2 .

Similarly, Bishop et al. (2001) examined the effect of three different warm-up intensities (i.e., warm-up for 15 min at aerobic threshold, anaerobic threshold, and a intensity between aerobic and anaerobic threshold) on kayak ergometer performance. No significant differences were observed on average power, peak VO_2 , total VO_2 , total VCO_2 , and accumulated oxygen deficit. It was concluded that despite the degree of metabolic acidosis, it might be necessary to increase O_2 kinetics; however if the warm-up is too intense, it may spoil supramaximal performance by reducing anaerobic energy contribution and affecting muscle contractile process. It should be noted that the differences between the findings reported above and the findings of the present study may be due to the differences in employed methodological designs. Additionally differences in the intensity of the warm-up techniques could play a significant role in the discrepancy of our results. This study utilized low intensity stretching techniques, whereas the above studies applied different high intensity warm-up techniques.

On the other hand, some studies reported that aerobic performance was improved by active warm-up activities.

Ingjer and Stromme (1978) found a significant higher oxygen uptake, and lower lactate concentration when the work was preceded by active warm-up as compared with passive or no warm-up.

Gray and Nimmo (2001) found that total oxygen consumption during the 30 s exercise bout was significantly greater after the active warm-up, causing an elevation in muscle temperature (consisting of cycling at 40 % maximal power output for 5 min. then 15-s sprints at 120 % maximal power output). Active warm-up also resulted in a decreased blood lactate response during high-

intensity exercise. This finding is similar to that previously reported by Robergs et al. (1991), who showed a great increase in aerobic contribution to a standard high intensity exercise bout after an active warm-up. The majority of these effects were reported as a result of elevation in muscle temperature which indicated a potential blood flow to active muscles (Robergs et al., 1991; Takizava and Ishii, 2006). Furthermore, findings by Takizava and Ishii (2006) pointed out significant changes in oxyHb/Mb and deoxyHb/ Mb due to warm-up exercises, which in turn, may improve high intensity aerobic performance.

Only a limited number of studies have examined the effects of different types of short-term stretching on running economy and maximal oxygen consumption: Below, the results of our present study are compared with previously, relevant studies reported in the literature. Stretching prior to maximal exercise in the present study increased aerobic performance in agreement with the following studies:

Godges et al. (1989) examined the effect of increased hip flexibility by using static stretching and soft tissue mobilization with PNF on gait economy and submaximal oxygen consumption. Godges et al. found that there was a significant increase in gait economy at 40 %, 60 %, and 80 % VO_2 max following the static stretching exercise. These results suggested that increases in performance were related to increases in the balance of muscle and fascia about the pelvis hip.

Stewart and Sleivart (1998) examined anaerobic capacity (time to fatigue at 13 km/hr and 20 percent grade) after a warm-up (15 min running at 60, 70, or 80 percent VO_2 max, followed by a lower limb stretch). Their results showed that a 15 min warm-up at an intensity of 60 – 70 percent VO_2 max enhanced anaerobic performance.

Similarly Guidetti et al. (2007) reported that in dance exercises preceded by warm-up, the contribution of anaerobic metabolism decreased, while aerobic energy sources increased (from 26 to 39%, $p < .01$). These changes were attributed several major factors. One of them included no rest between warm-up and ballet exercise, which could have decreased the availability of high energy phosphates which might result in a slow upward drift of VO_2 .

Also, improvements in aerobic performance through acute stretching exercises are likely related to a decreased oxygen deficit when a task was preceded by warm-up. Thus warm-up could serve in raising the baseline oxygen consumption, by preserving more of the potentially available anaerobic process for later stages (Andzel, 1982).

Based on the literature shown and discussed above, the reported increase of VO_2 max values in this study, which resulted after static and PNF stretching

exercises may be explained by an increased blood flow to active muscle, a decreased muscle lactate concentration and muscle temperature related factors.

Conclusions

The main result of this study showed that both static and PNF stretching exercises improved VO₂ max values. These findings encourage the use of stretching exercises as a warm-up in sports and rehabilitation activities not only to prevent possible sports related injuries as it is commonly used today. Moreover, an increased VO₂max value will result in postponing fatigue thereby improving the overall sport performance. However, further studies should attempt to provide further evidence as to which stretching technique might be most advantageous in sports and exercise settings. Hence, the importance of determining the most efficient and effective stretching technique to achieve desired outcomes, needs further research.

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