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Effects of static stretching on leg power during cycling

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Aim. **This study investigated the effects of warm-up involving static stretching on leg power. It was expected that the inclusion of static stretching in the warm-up would decrease leg power.**
Methods. **Twenty-seven healthy volunteers (16 male, 11 female) participated in the study. A prospective, repeated measures design was implemented where volunteers underwent 2 testing sessions at least 24 hours apart. One testing session involved a control warm-up (5 min submaximal cycling) followed by 4 10-s leg power tests at 5, 20, 40 and 60 min postwarm-up. For the other testing session, the subjects performed 5 min of submaximal cycling followed by 15 min of lower body static stretching and then the four leg power tests. Relative peak power, time to peak power and relative total work were measured for each leg power test.**
Results. **Peak power and total work were significantly greater after the static stretching warm-up compared to the control warm-up on all power tests. Peak power was achieved more quickly for the static stretching warm-up compared to the control warm-up on the 5 min test only.**
Conclusion. **A warm up that includes static stretching has beneficial effects on anaerobic power events in comparison to submaximal cycling alone.**
Key words: Stretching - Warm-up -, Leg power - Anaerobic exercise.

Static stretching can be defined as stretching where the muscle is taken to the end of its range of motion and held in that position for some period of time.[1]

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Stretching results in improved flexibility due to the greater compliance of the muscle tendon unit without any structural breakdown of the tissue.[2] This apparent improvement in flexibility may assist performance by improving posture and allowing a more efficient technique to be adopted.[3, 4] However, the use of stretching exercises in a warm-up has recently been questioned with reports that static stretching within 60 min of performance causes a negative impact on maximal performance.[5-10]

Rosenbaum *et al.*[5] reported that stretching had a detrimental effect on force production, possibly due to an increase in tendon slack and musculotendinous compliance. They proposed that a reduction in peak force indicated an improved stretch absorbing capacity that could be beneficial in the prevention of injury. Others have also reported a negative effect of stretching with 33 min of maximal stretching of the ankle plantarflexors significantly decreasing voluntary strength for up to 60 min.[8, 9] The authors suggested that this strength deficit was partly due to impaired neural activation and partly due to decreased contractile force generating capacity.[8, 9] A decrease in knee flexion and extension

1RM following 20 min of static stretching involving the hip, thigh and calf muscle groups has also been reported.[6] Similarly, quadricep maximum voluntary contraction and quadricep and hamstring electromyographic activity were significantly decreased 5-10 min after a warm-up of 5 min submaximal cycling coupled with 20 min of quadricep stretching.[10]

It has been suggested that the effects of stretching on performance may be influenced by the speed of activity.[11] Previous studies have shown that a warm-up containing static stretching significantly decreased drop jump performance [11, 12] and concentric jump performance [12] compared to other warm-up procedures such as walking, jogging, proprioceptor neuromuscular facilitation stretching and maximal isometric contraction. Therefore, it was concluded that activities like the depth jump, which have a rapid stretch shortening cycle, may be negatively affected by static stretching where the stiffness of the muscle is reduced.

Given the contradictory evidence currently available to coaches and athletes regarding warm up procedures, this study examined the effects of warm-up involving static stretching on leg power. In order to simulate current practice, the static stretching protocol was preceded by a general warm up. The optimal time for cessation of warm up prior to the commencement of athletic performance was also investigated. It was hypothesized that the inclusion of static stretching in a warm up would decrease the power and work achieved during a cycling leg power test.

Materials and methods

Subjects

Healthy university students (n=27; 16 male and 11 female), average (±SE) age 21.4±3.5 years and weight 71.8±2.4 kg, gave their written informed consent to participate in the study. The study was approved by the James Cook University Ethics Committee.

Procedures

The subjects attended 2 testing sessions a minimum of 24 hours apart. These sessions consisted of a leg power tests following either a submaximal cycle warm up (control) or a warm up involving static stretching. Subjects previously underwent a familiarization session where they were coached in the execution of each stretch. All subjects were asked to abstain from any other activity on the testing days.

Control test protocol

The control test involved a 5 min submaximal warm-up at a moderate pace (50 W for females; 75 W for males) on an air-braked cycle ergometer (Repco Cycle Co., Huntingdale, Australia) followed by a series of 4 maximal 10 s leg power tests.[12] The 10 s leg power tests were performed 5, 20, 40 and 60 min after completion of the warm-up. Each power test began from a stationary start and was performed in a standing position with the feet secured by pedal straps. All subjects received verbal encouragement throughout each test. Peak power relative to body weight (W/kg), time to peak power (s) and total work relative to body weight (J/kg) were recorded for each leg power test using a Repco Supermonitor (Repco Cycle Co., Huntingdale, Australia). The subjects were asked to refrain from activity between tests.

Static stretching protocol

The static stretching protocol was preceded by a 5 min warm-up on the cycle ergometer identical to that performed in the control test. Stretching commenced immediately after the cycling warm-up. The stretching protocol consisted of 11 lower body static stretches including: standing quadriceps stretch, hip flexor stretch in the lunge position, groin stretches in kneeling and supine positions, kneeling and seated hamstring stretches, kneeling Achilles tendon stretch, seated lower back and gluteus maximus stretch with torso rotated, seated gluteus maximus stretch leaning forward with one foot on the knee, standing hip rotator and gluteus maximus stretch with one leg on a table and standing calf stretch. Detailed descriptions of the stretches can be found in Alter [13] (stretches 20, 45, 50, 121, 127, 138, 155, 162) and O'Connor [14] (stretches 10, 16 and 22). Each stretch was held for 10 s and performed twice on each leg with 10 s rest between stretches. The stretching protocol was performed over a 15 min period to mimic a common stretching routine performed by athletes prior to competition. At 5, 20, 40 and 60 min after completion of the stretching protocol, the subjects performed the 10 s leg power tests in an identical manner to that of the control session.

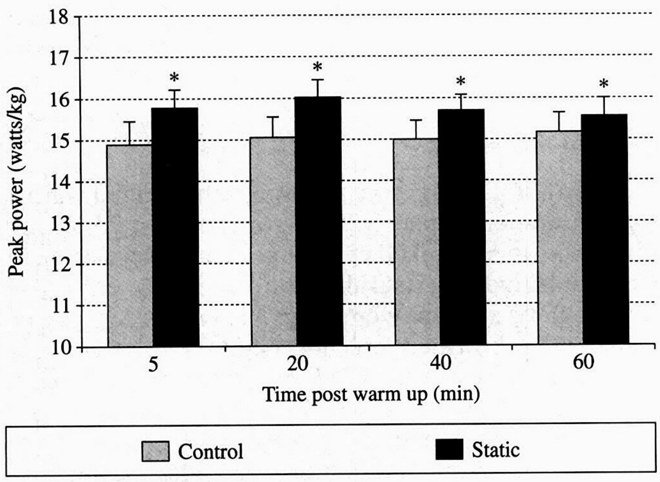

Figure 1.—Mean (±SE) relative peak power (W/kg) generated during the 10 s leg power tests at 5, 20, 40 and 60 min following the control and static warm-up. * Significantly different from the respective control warm-up.

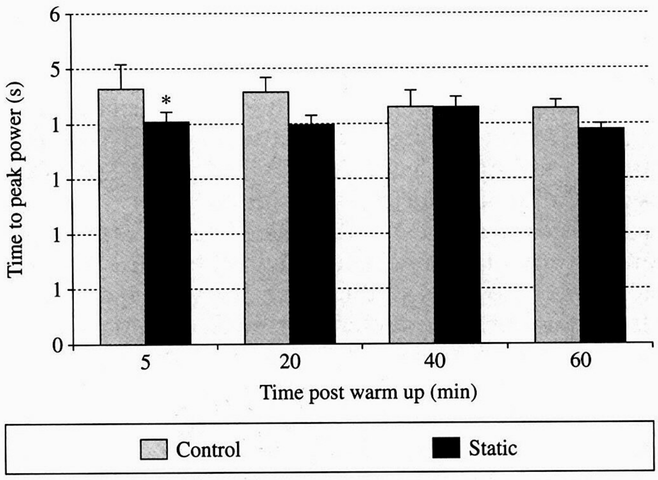

Figure 2.—Mean (±SE) time to reach peak power (s) during the 10 s leg power tests at 5, 20, 40 and 60 min following the control and static warm-up. * Significantly different from the respective control.

Statistical analysis

All data were analyzed using a 2×4 (condition×time) factorial ANOVA with repeated measures. Pairwise posthoc comparisons were made using t-tests. The analyses were performed using the SPSS for Windows software. Significance was set at $P<0.05$ and all data are presented as means±SE.

Results

Relative peak power

Data analysis revealed a significant effect of condition for relative peak power ($P<0.05$). Peak power at 5 ($P<0.01$), 20, 40 and 60 min ($P<0.05$) after the static stretching warm-up was significantly higher than that achieved after the control warm-up at the same respective time (Figure 1).

Time lapsed after completion of the warm-up had no significant effect on relative peak power for the control warm-up with no significant differences in peak power at 5, 20, 40 or 60 min after the control warm-up. However, this was not the case for the static warm-up. Greatest peak power was achieved within 5 min of the static warm-up and maintained at 20 min but had significantly decreased by 40 min postwarm-up ($P<0.05$) and remained significantly decreased at 60 min postwarm-up ($P<0.05$; Figure 1).

Time to peak power

There was a significant effect of condition for time to peak power during the 10 s leg power tests ($P<0.05$). Posthoc analysis revealed that the static ($P<0.05$) warm-up caused a significant reduction in the time taken to reach peak power compared to the control warm-up at 5 min postwarm-up (Figure 2). The 10 s leg power tests performed at 20, 40 and 60 min postwarm-up showed no significant difference in time to peak power between either of the warm-up procedures.

Relative total work

There was a significant effect for condition on the relative total work (J/kg) achieved during the 10 s leg power tests ($P<0.05$). Posthoc analysis revealed that at 5 min ($P<0.01$), 20 min ($P<0.001$), 40 and 60 min ($P<0.05$) postwarm-up, the total work achieved after the static warm-up was significantly greater than that achieved with the respective control warm-up (Figure 3).

Time lapsed after completion of the warm-up had no significant effect on relative total work for the control warm-up. For the static warm-up, there was no significant difference between the total work achieved at 5 and 20 min. However, there was a significant decrease in the total work from the 20 min test to the 40 and 60 min tests ($P<0.05$).

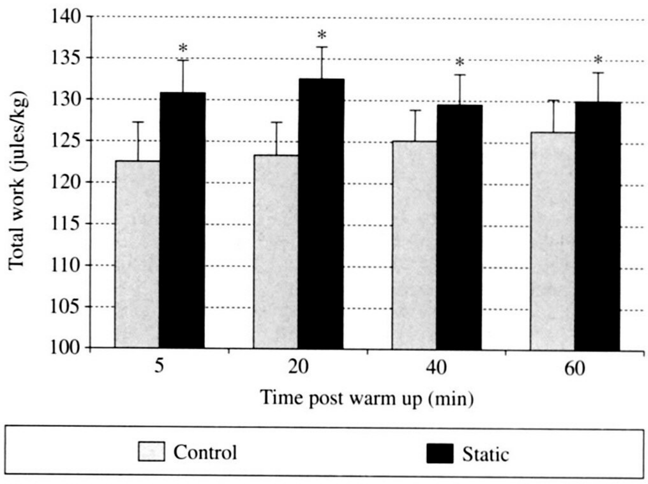

Figure 3.—Mean (+SE) relative total work (J/kg) generated during the 10 s leg power tests at 5, 20, 40 and 60 min following the control and static warm-up. * Significantly different from the respective control.

Discussion and conclusions

There is little consensus in the literature as to the optimum warm-up procedure for maximal athletic performance. The current study aimed to determine whether the inclusion of static stretches in a warm-up would provide subsequent benefit to power and work output in a maximal leg power test. The results showed that a static stretching warm-up significantly increased peak power and total work when compared to a 5 min moderate cycling warm-up. Furthermore, peak power was achieved more rapidly after the static stretching warm-up compared to the control warm-up but only for the leg power test at 5 min postwarm-up. It appears that 5 min is the optimal time for cessation of a stretching warm up prior to the commencement of maximal short-term performance. In terms of peak power and total work, a recovery period of either 5 min or 20 min post-warm up resulted in improved performance. However, if time to reach peak power is important then 5 min prior to performance is the recommended time to cease warm up. This supports a recent recommendation [15] of a 5 min recovery following a moderate warm up (5-10 min at 40-60% $\dot{V}O_{2max}$) for optimal short term ($\leq$ 10 s) performance.

Static stretching has long been an accepted part of warm-up for athletic performance. However, a number of recent studies reporting decreased maximal strength and muscle force after static stretching [7-10] have caused athletes and coaches to question the inclusion of static stretching in precompetition warm-up. The current study showed that 15 min of static stretching prior to anaerobic cycling performance had no detrimental effects on subsequent maximal leg power. Indeed, power output and total work were significantly greater after submaximal cycling combined with static stretching compared to submaximal cycling alone. These findings contradict past studies and may be explained by differences in the nature and speed of the test activity and possible differences in muscle temperature.

Both stretching and warm-up activities are known to increase muscle compliance.[16-18] One potential benefit of increased musculotendinous compliance is that a greater force is required to tear the muscle [17] and peak forces during an imposed stretch will be lower. Thus, the more compliant muscle is less likely to be injured. However, one potential negative effect of greater musculotendinous compliance is that more intrinsic force is required to take up the slack to generate muscle force during contraction [7, 19] unless the slack is taken up by an imposed stretch as occurs in some muscles during running.[20, 21] Thus, peak force and maximal strength may decline after static stretching as has been previously shown.[8-10] The speed at which an activity is performed has been suggested to affect whether or not an increase in musculotendinous compliance has a positive or negative effect on performance. Rapid stretch shortening activities such as the depth jump have been reported to be negatively affected by static stretching [11, 12] whereas slower activities such as the bench press have been reported to be enhanced by static stretching exercises.[22] During a rapid stretch shortening cycle, the series elastic elements of muscle (such as tendon and cross bridges) are able to store energy during the stretch phase of the cycle and use this elastic energy to enhance the contraction phase.[20, 21] It follows that a greater proportion of this elastic energy could be utilized by a stiffer musculotendinous unit as energy would not be lost in taking up the slack, as would be the case in a more compliant muscle. The current study did not utilize a full stretch shortening cycle as the agonist muscle group, the quadriceps, undergo little stretching during cycling due to simultaneous hip and knee flexion. Thus, the role of elastic energy is not an issue here. Similarly, full stretch shortening activities were not utilized in the previously cited research which reported negative effects of passive, static stretching on performance.[8-10] Therefore, mechanisms other than the storage and utilization of elastic energy need to be considered when examining the varying effects of static stretching on performance.

In addition to a more compliant muscle, performance of warm-up activities results in a number of other effects primarily as a result of the increased muscle temperature. These effects include increased muscle blood flow, increased speed of enzymatic reactions, increased nerve impulse speed, increased neural receptor sensitivity, and increased unloading of oxygen from hemoglobin and myoglobin.[15] All of these processes combine to enhance muscular contractions. A possible explanation for the contrasting findings of the current study compared with those of others [8-10] may relate to the fact that these studies utilized passive stretches and had a much longer duration of static stretching which may have resulted in a lower muscle temperature than in the current study. Thus, a resultant warmer muscle temperature may have facilitated greater peak power and total work compared to previous studies. Future work should examine muscle temperature when investigating the effects of warm-up on performance.

In conclusion, a warm-up comprising 15 min of static stretching significantly enhanced the power and work output during anaerobic performance when compared with a 5 min submaximal cycling warm-up. Importantly, this shows that a typical pre-event static stretching routine does not have a negative effect on subsequent power performance during cycling.

References

1. Shellock FG, Prentice WE. Warming-up and stretching for improved physical performance and prevention of sports-related injuries. Sports Med 1985;2:267-78.
2. Stanish W, Hubley-Kozey CL. Neurophysiology of stretching. In: D'Ambrosia R, editor. Prevention and treatment of running injuries. New Jersey: Charles B. Slack; 1982.p.209-19.
3. Lasorsa R. KSU track and field flexibility program. Track Field Quart Rev 1994;94:60-2.
4. Reilly T. Sports fitness and sports injuries. London: Faber and Faber; 1981.
5. Rosenbaum D, Henning EM. The influence of stretching and warm-up exercises on Achilles tendon reflex activity. J Sports Sci 1995;13:481-90.
6. Nelson A, Cornwell A, Heise G. Acute stretching exercises and vertical jump stored elastic energy. Med Sci Sports Exerc 1996;28:S156.
7. Kokkonen J, Nelson AG, Cornwell A. Acute muscle stretching inhibits maximal strength performance. Res Q Exerc Sport 1998;69:411-5.
8. Fowles JR, Sale DG. Time course of strength deficit after maximal passive stretch in humans. Med Sci Sport Exerc 1997;29:S26.
9. Fowles JR, Sale DG, MacDougall JD. Reduced strength after passive stretch of the human plantarflexors. J Appl Physiol 2000;89:1179-88.
10. Behm DG, Button DC, Butt JC. Factors affecting force loss with prolonged stretching. Can J Appl Physiol 2001;26:262-72.
11. Young W, Elliott S. Acute effects of static stretching, proprioceptive neuromuscular facilitation stretching, and maximum voluntary contractions on explosive force production and jumping performance. Res Q Exerc Sport 2001;72:273-9.
12. Young WB, Behm DG. Effects of running, static stretching and practice jumps on explosive force production and jumping performance. J Sports Med Phys Fitness 2003;43:21-7
13. Alter MJ. Sport Stretch. 2nd ed. Champaign: Human Kinetics; 1998.
14. O'Connor DM. Fitness for referees. Canberra: Australian Touch Association; 1995.
15. Bishop D. Warm up II: performance changes following active warm up and how to structure the warm up. Sports Med 2003;33:483-98.
16. Hill AV. Living machinery. New York: Harcourt, Brace and World; 1927.
17. Safran MR, Garrett WE, Seaber AV, Glisson RR, Ribbeck BM. The role of warmup in muscular injury prevention. Am J Sports Med 1988;16:123-9.
18. McHugh MP, Magnusson SP, Gleim GW, Nicholas JA. Viscoelastic stress relaxation in human skeletal muscle. Med Sci Sports Exerc 1992;24:1375-82.
19. Wilson GJ, Murphy AJ, Pryor JF. Musculotendinous stiffness: its relationship to eccentric, isometric and concentric performance. J Appl Physiol 1994;76:2714-9.
20. Hill AV. The series elastic component of muscle. Proc Roy Soc Lon, Series B 1950;137:273-80.
21. Griffiths RI. Shortening of muscle fibres during stretch of the active cat medial gastrocnemius muscle: the role of tendon compliance. J Physiol 1991;436:219-36.
22. Wilson GJ, Elliot B, Wood GA. Stretch shorten cycle performance enhancement through flexibility training. Med Sci Sports Exerc 1992;24:116-23.