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Effects of running, static stretching and practice jumps on explosive force production and jumping performance

W. B. YOUNG[1], D. G. BEHM[2]

Aim. **The interaction between running, stretching and practice jumps during warm-up for jumping tests has not been investigated. The purpose of the present study was to compare the effects of running, static stretching of the leg extensors and practice jumps on explosive force production and jumping performance.**

Methods. **Sixteen volunteers (13 male and 3 female) participated in five different warm-ups in a randomised order prior to the performance of two jumping tests. The warm-ups were control, 4 min run, static stretch, run + stretch, and run + stretch + practice jumps. After a 2 min rest, a concentric jump and a drop jump were performed, which yielded 6 variables expressing fast force production and jumping performance of the leg extensor muscles (concentric jump height, peak force, rate of force developed, drop jump height, contact time and height/time).**

Results. **Generally the stretching warm-up produced the lowest values and the run or run + stretch + jumps warm-ups produced the highest values of explosive force production. There were no significant differences ($p<0.05$) between the control and run + stretch warm-ups, whereas the run yielded significantly better scores than the run + stretch warm-up for drop jump height (3.2%), concentric jump height (3.4%) and peak concentric force (2.7%) and rate of force developed (15.4%).**

Conclusion. **The results indicated that submaximum running and practice jumps had a positive effect whereas static stretching had a negative influence on explosive force and jumping performance. It was suggested that an alternative for static stretching should be considered in warm-ups prior to power activities.**

KEY WORDS: Muscle, skeletal, physiology - Leg, physiology - Muscle, skeletal, physiopathology.

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Warm-up prior to physical activity is a common practice believed to reduce the risk of injury and enhance performance.[1, 2] This is thought to be achieved by various mechanisms such as increased muscle temperature and associated effects [1, 2] increased neural activation and joint range of motion (ROM),[2, 3] as well as reduced musculotendinous stiffness should be.[4-6] Most warm-ups typically contain a relatively low intensity aerobic component that is general in nature such as jogging followed by stretching of specific muscles, and some rehearsal of the activity about to be performed at similar intensities. Although the use of a warm-up before maximum effort explosive type exercise is rarely questioned, the precise protocol leading to optimum performance has not been thoroughly investigated.

While static stretching has been found to be effective for increasing the acute ROM at a particular joint,[6-8] recent research indicates that it can produce significant decrements in the strength and power production of the stretched muscle groups.[8-15] These findings have led some researchers to recommend against the practice of stretching prior to strength/power activities.[7, 8, 10, 11, 14]

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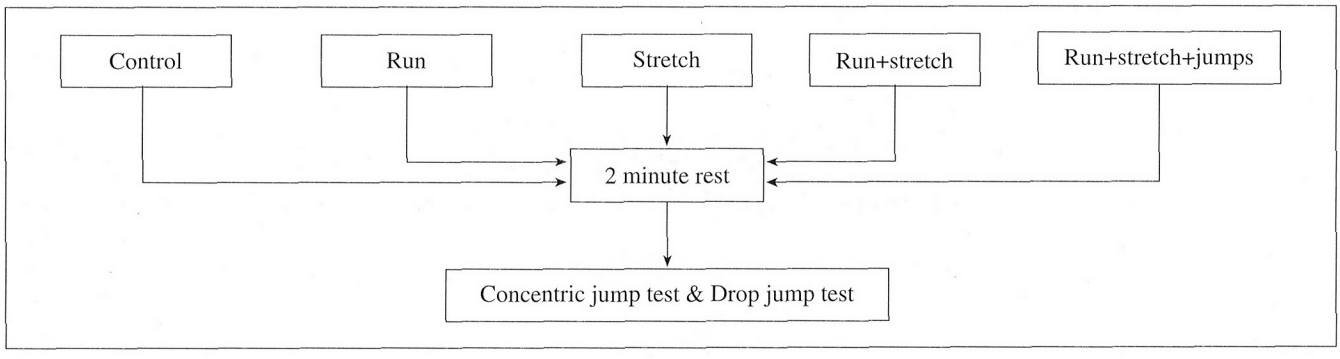


Figure 1.—Scheme of research design.

However these recommendations may be questioned since the stretching protocols used in many of these studies were not representative of the typical warm-up methods used by athletes to prepare for exercise or competition. For example, stretch treatments of 15 minutes or longer for a single muscle group have been employed,[8, 12, 13] which is greater than the duration commonly used by athletes. Further, some studies observed performance decrements following stretching with no aerobic component preceding the stretching,[8, 11, 13-15] or little if any practice trials of the test activity.[7, 9, 11-15] While this research design is necessary to isolate the influence of stretching, it is possible that the aerobic and practice components of a warm-up may offset any potential negative effects of the stretching. The interactive effects of an aerobic, stretching, and practice components of a warm-up are not yet known. Therefore the purpose of this study was to compare the effects of running, static stretching of the leg extensors and practice jumps on explosive force production and jumping performance.

Materials and methods

Participants

Thirteen males and four females (mean ± SD age = 26.0±8.5 years, height = 175.0±9.2 cm, weight = 76.6±12.5 kg) provided informed consent and participated in this study which was approved by the University Human Research and Ethics Committee. All subjects provided informed consent to participate, were free of injury, and had some experience with weight training and explosive type activities.

General study design

Participants attended the laboratory on six occasions. The first session was conducted to allow familiarisation with the testing procedures. The subjects then completed five different warm-up conditions, performed on different occasions, 6-72 h apart. The warm-ups were followed by a 2 min rest (standing) and the performance of two jumping tests conducted in a random order. The 5 warm-up conditions were control, run, static stretch, run + stretch, and run + stretch + practice jumps, and were performed in a randomised order. These warm-up protocols were selected to allow the specific effects of running, stretching and practice jumps to be observed in isolation and in combination (Figure 1). All warm-ups and testing took place in a laboratory with a room temperature of 18-21°C.

Warm-ups

Control

The control condition served as a baseline from which to compare the other treatments. It was considered potentially harmful to conduct tests involving fast force production in a completely rested state. Therefore the subjects were required to walk at a "comfortable pace" for 3 min and perform 5 squats and 5 heel raises with no added resistance as a form of nominal activity.

Run

This warm-up involved running indoors for 4 min. The speed of the run was not controlled but participants were instructed to run at a pace that would allow them to feel warm enough to induce sweating.

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Stretch

The stretching treatment involved four exercises designed to stretch the ankle plantar flexors and the quadriceps, which are significantly involved in vertical jumping.[16]

1) The subject leaned forward against a wall so that the ankle of the target leg was dorsi flexed to the smallest angle possible without the heel coming off the floor.

2) The same exercise as in 1 was used except that the knee of the target leg was flexed. This exercise was designed to stretch the soleus as previously used.[6]

3) While lying in a prone position, one of the investigators manually flexed the subject's knee by pushing the ankle toward the gluteals.

4) The same exercise as in 3 except that the thigh of the target leg was placed on a wedge shaped support with a 15° angle to produce hyperextension at the hip. This was intended to target the rectus femoris muscle.

All stretches were taken to the "pain threshold" as indicated by the subject so that the muscle-tendon system was stretched to its limit without pain. Once this point was located, the stretch was held for 30 sec, then repeated on the other leg. This procedure was repeated so that each of the four exercises involved 1 min of static stretching per leg, giving a total of 2 min per leg for the plantar flexors and 2 min for the quadriceps.

Run + stretch

This warm-up involved performing the run immediately followed by the stretch, as described above.

Run + stretch + jumps

This warm-up involved the run + stretch as described above, and was immediately followed with practice jumps of the two jumping tests. The subjects were instructed to perform 4 warm-up/practice jumps, 1 at approximately 80% and 3 at 100% of maximum effort. This warm-up condition was designed to contain the three components of a warm-up that are typically used prior to vigorous exercise or sport; aerobic, stretching and some rehearsal of the specific activity about to be performed.

Jump tests

Two vertical jumping tests were conducted to assess the explosive force production capabilities of the knee extensors and ankle plantar flexors during concentric and stretch-shortening cycle (SSC) muscle actions.

Concentric jump

This test involved jumping with a 10 kg bar on the shoulders performed on a modified Smith machine. A Kistler force platform (Z4852/C) operating at 1000 Hz measured the force generated by the participant during the push-off phase of the jump. The peak force and the maximum rate of force developed (RFD) over 5 msec samples during the ascending portion of the curve were recorded as explosive force production variables.[9] The subject was required to hold a static squat position at a 100° knee angle, measured by a manual goniometer for a 2 sec period, and then jump for maximum height while extending the legs as fast as possible. In the bottom position the bar rested on metal stops and was standardised for all treatment conditions. Since the bar could only rise, the jump involved pure concentric actions of the leg muscles.

Drop Jump

A drop jump (DJ) was performed from a 0.30 m high box. The subjects were instructed to keep their hands on the hips and jump off the box with a straight leg to ensure the fall commenced from a 30 cm height. They were instructed to jump for maximum height and minimum ground contact time to maximise the height divided by contact time. These instructions have been shown to produce relatively short ground contact times (<200 msec) and significantly changes the nature of the jumping task compared to jumping for height only.[17, 18] The jump height and contact times were assessed by a contact mat system (Swift Performance Equipment) as previously described.[9] Three trials for each test were administered with the average of these trials being retained as a representative result.

EMG analysis

During data collection, apparent differences between warm-ups were observed. It was therefore decided to explore the electromyographic (EMG) output from the stretched muscle groups during two of the warm-ups for one subject. Surface EMG recording electrodes (MediTrace Pellet Ag/AgCl electrodes, Graphic Controls Ltd., Buffalo, NY) were placed approximately 2 cm over the mid-belly of the rectus femoris, lateral

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TABLE I.—*Mean and standard deviation results for both jumping tests for all warm-ups.*

Tests	Control (m±SD)	Run (m±SD)	Stretch (m±SD)	Run + stretch (m±SD)	Run + stretch + jumps (m±SD)
Concentric jump					
Jump height (cm)	29.3±3.7	30.2±3.7	28.3±3.5	29.2±3.2	30.2± 3.4
Peak force (bw)	1.80±0.29	1.88±0.28	1.73±0.25	1.83±0.26	1.86±0.28
Max RFD*(N/s)	14983±4327	17784±7057	14581±5286	15408±4068	17096±6950
Drop jump					
Jump height (cm)	26.5±5.5	27.7±6.4	25.7±5.9	26.5±5.6	27.8±5.9
Contact time (s)	0.176±0.02	0.175±0.01	0.175±0.02	0.174±0.02	0.169±0.02
Height/time (cm/s)	155±38	160±38	149±40	155±39	166±41

* RFD is rate of force developed.

gastrocnemius and superior to the triceps surae-Achilles tendon intersection for the soleus. Ground electrodes were secured on the tibial (rectus femoris) and fibular (gastrocnemius) head and lateral malleolus (soleus). Thorough skin preparation for all electrodes included removal of hair with a commercially available razor, dead epithelial cells with an abrasive (sand) paper around the designated areas, followed by cleansing with an isopropyl alcohol swab. EMG activity was amplified, monitored and stored on an IBM Thinkpad computer. The computer software program (AcqKnowledge III, Biopac Systems Inc., Holliston, MA, USA) rectified the EMG signal and calculated the root mean square (RMS) of the EMG signal. The RMS of the EMG was measured during the push-off phase of the concentric jump as well as the landing and take-off phase of the drop jump.

Statistics

An Analysis of Variance (ANOVA) with repeated measures was conducted to determine if there were significant differences between the warm-up protocols in explosive force production and jumping performance. Significance was set at $p<0.05$ and if this occurred, pairwise comparisons for least significant differences were used to identify specific differences between the warm-up conditions.

Results

One of the female participants indicated that the two quadriceps stretches "were not challenging" and could not be taken to the pain threshold. In an effort to maintain a consistent stretching treatment, the data from this subject was not retained, leaving a sample of 16 subjects. The means and standard deviations for all warm-ups are shown in Table I. The ANOVA revealed significant differences for all variables except the contact time in the drop jump test. The significant differences ($p<0.05$) between the various warm-ups and percentage differences are indicated in Table II.

TABLE II.—*Variables associated with significant differences between warm-ups.*

Warm-up significant differences	Variables	Difference (%)
Run >control	Concentric jump height	3.1
	Concentric force	4.4
	Concentric RFD	18.7
	DJ jump height	4.5
Run + stretch + jumps >control	Concentric force	4.4
	DJ height/time	7.1
Run >stretch	Concentric jump height	6.7
	Concentric force	8.7
	Concentric RFD	22.0
	DJ jump height	7.8
	DJ height/time	7.4
Run + stretch >stretch	Concentric force	5.8
Run + stretch + jumps >stretch	Concentric jump height	6.7
	Concentric force	7.5
	Concentric RFD	17.2
	DJ jump height	8.4
	DJ height/time	11.4
Control >stretch	Concentric force	4.0
Run + stretch + jumps >run + stretch	Concentric jump height	3.4
	DJ height/time	7.1
Run >run + stretch	Concentric jump height	3.4
	Concentric force	2.7
	Concentric RFD	15.4
	DJ jump height	3.2

DJ: drop jump.

The RMS from the EMG analysis and the associated performance results for the individual subject is shown in Table III. The results show a reduction

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TABLE III.—*Root mean square EMG output and jump test results for one subject from the run and run + stretch warm-ups.*

Parameters	Run	Run + stretch
Concentric jump		
Jump height (cm)	38.0	33.8
Peak force (bw)	2.03	1.9
Max RFD (N/sec)	15602	12203
Drop jump		
Jump height (cm)	38.3	35.0
Contact time (sec)	0.174	0.164
Height/time (cm/sec)	220	214
RMS EMG		
Concentric jump		
Rectus femoris (mv)	0.93	1.00
Gastrocnemius (mv)	1.15	1.00
Soleus (mv)	1.08	0.95
Drop jump		
Rectus femoris (mv)	0.77	0.72
Gastrocnemius (mv)	1.01	0.90
Soleus (mv)	0.93	0.85

in muscle activity corresponding to the performance in the run + stretch condition, compared to the run warm-up.

Discussion

The results indicate several significant differences between the warm-ups but these differences were not always statistically significant for all measured variables. However, a clear pattern emerged from the mean data (Table I). Generally the run and run + stretch + jumps warm-ups produced the best explosive force and jumping performances, whereas the stretch warm-up always produced the lowest values.

A comparison of the run and control conditions indicates that running produced a positive effect on performance. This was expected since submaximum running has previously been found to increase anaerobic performance.[19] Although muscle temperature was not measured, it is likely that the run induced such an increase, which has been found to be associated with improved muscle power performance.[20-22] The optimum intensity of the running component of the warm-up was not investigated in the present study and should be considered in future research.

The effects of the static stretching can be observed by comparing the stretch and control warm-ups as well as the run with the run + stretch warm-ups. The control warm-up produced a better performance than the stretch in all variables except contact time, but this reached statistical significance only for concentric peak force (Table II). This tendency toward impairment due to the stretching is supported by previous research.[8-15] The lack of significant differences for the other explosive force variables might be because the stretching treatment was not applied to the hip extensors, which would have partially contributed to the jumping performances. However the run warm-up was clearly superior to the run + stretch condition (3-15%) for 5 of the performance variables, indicating a negative influence from the stretching. Further, in the comparison of these two warm-ups in the case study, the EMG analysis indicated some neural inhibition from the run + stretch warm-up. This finding is consistent with reduced neural activation reported previously following static stretching,[12, 13, 23] although the exact neural mechanism remains elusive.[12] Some researchers have eluded to the possibility that stretching may decrease musculotendinous stiffness, which might cause an increased "slack" to reduce the speed of force transmission from muscle to the skeletal system.[7, 8, 11, 24] However McNair and Stanley [6] reported that while stretching increased ankle joint ROM, it had no effect on the active stiffness of the musculotendinous unit, as measured by a damped oscillation technique. Therefore the mechanisms associated with muscle performance decrements following static stretching remain equivocal.

An interesting finding was that the run + stretch warm-up produced very similar mean results to the control warm-up, and were not significantly different for any variable. The run + stretch warm-up might be viewed as being made up of a positive influence (run) and a negative influence (stretch), which tend to counteract each other.

The influence of practice jumps was examined by comparing the run + stretch with the run+ stretch + jumps warm-ups, with the latter producing greater mean results. These differences were significant for concentric jump height (3.4%) and DJ height/time (7.1%), and suggest that there is some advantage to including practice trials of the activity about to be performed. It is possible that this treatment would have been somewhat more powerful and yielded a more positive influence if more than 1 submaximum and 3 maximum practice trials were used. The optimum number of practice trials may be dependent on the nature of the activity. It is possible that rehearsal of

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the skill to be performed during a warm-up has the effect of "opening up" specific neural pathways to facilitate motor unit activation thereby enhancing the readiness of the neuromuscular system. It is known that the performance of maximum voluntary contractions can induce a postactivation potentiation [25-27] which may lower the recruitment threshold of motor units [28] and enhance vertical jump performance.[27, 29]

The run + stretch + jumps warm-up which was designed to simulate a "typical" warm-up used by athletes, produced better results than the control warm-up for all variables but was significantly better for concentric jump height and DJ height/time. This somewhat unconvincing superiority is likely to be explained by a negative influence from the stretching. Further, this warm-up produced similar results to the run warm-up, and was not significantly different. This might be explained by a counterbalancing effect of the stretch (negative influence) and jumps (positive influence). It could be hypothesised that a warm-up consisting of run + jumps (2 positive influences) would be optimum for the jumping tests used in the present study. This warm-up was not included in the present study to limit the total number of warm-up combinations, however the inclusion of this condition is warranted in future research.

Conclusions

Two minutes of static stretching per muscle group appeared to elicit a negative influence on concentric and SSC explosive force measures and jumping performance.

In contrast, submaximum running and practice jumps had a positive influence on muscle performance. Some practical recommendations may be drawn from the present study. The practice of performing some submaximum general activity such as running and practicing the skill about to be performed during a warm-up was supported by the present study, at least for jumping activities. One of the purposes of stretching during a warm-up is to reduce the risk of injury, although the effectiveness of this has been challenged.[30, 31] McNair and Stanley [6] reported that static stretching produced a significant acute increase in joint ROM but not in musculotendinous stiffness. Hunter *et al.*[5] speculated that static stretching may influence the non-contractile tissues that influence passive flexibility but not the contractile tissues that influence active stiffness. It has been argued that the injury prevention benefit of warm-up may reside in a reduction in active stiffness caused by increased muscle temperature, rather than from the effect of stretching.[6, 32]

Therefore if any prophylactic benefits of static stretching can be achieved by alternative methods, it would seem prudent to investigate such protocols for warm-ups prior to explosive activity. Dynamic warm-up exercises have been suggested as a replacement for static stretching,[33] but the utility of this approach has not been investigated.

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