ACUTE EFFECTS OF DIFFERENT WARM-UP METHODS ON JUMP PERFORMANCE IN CHILDREN

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AUTHOR: Gelen E.

Sakarya University, School of Physical Education and Sport, Sakarya, Turkey

Reprint request to:
Ertugrul Gelen
Sakarya University
School of Physical Education and Sport
54187 Esentepe Kampusu, Sakarya, Turkey
TEL:+90 264 2956640
FAX:+90 264 2956642
E-mail: gelen@sakarya.edu.tr

ABSTRACT: The aim of this study was to determine the acute effects of static stretching and dynamic warm-up exercises on vertical jump performance. Sixty-four children (mean age 13.3 ± 0.5 years) were assigned randomly to 3 different warm-up routines on non-consecutive days. The warm-up methods used were 5 minutes of jogging and 5 minutes of static stretching (SS), 5 minutes of jogging and 10 minutes of dynamic exercises (DYN), and finally only 5 minutes of jogging as the control (NS). After each warm-up session, all the children were made to undertake a vertical jump test. Data were analysed using repeated measures analyses of variance (ANOVA), and a statistically significant difference between the NS, SS and DYN groups with regards to vertical jump performance was established ($p<0.05$). Based on these results, static stretching performed after aerobic exercises of mild intensity was found to hinder vertical jump performance, while dynamic warm-up was found to have a positive effect.

KEY WORDS: static stretching, dynamic exercise, power, post-activation potentiation, children

INTRODUCTION

Many athletes perform warm-up (WU) exercises before any sporting event both to improve performance and for protection against injuries. The basic principle of WU is to increase muscle temperature, muscular blood flow and physiological responses. A traditional WU regimen for athletes consists of moderate aerobic exercise followed by static stretching. Studies have shown that static stretching increases musculoskeletal flexibility by modifying both the mechanical [20] and neurological [15] characteristics of the muscle-tendon unit (MTU). However, in recent years a shadow of doubt has been cast on the actual value of pre-event static exercise.

Studies on both children and adults have established that pre-event static stretching inhibits performance by decreasing power, strength and high-speed production [2,3,8,10,11,19,22,27,29]. For example, McNeal and Sands [22] reported that static stretching in trained girl gymnasts decreased lower extremity strength by 9.6%. Similarly, Faigenbaum et al. [10,11] reported on the negative effects of static stretching on vertical jump performance in pre-adolescent and teenage athletes. Siatris et al. [29] also demonstrated a significant decrease in mean running speed of young gymnasts after static stretching. The most widely accepted explanation for this decrease in performance is that static stretching softens the MTU, thus decreasing muscle stiffness. This decrease in stiffness may lead to acute neural inhibition as well as a decrease in signals transmitted to muscles, which in turn lower power, strength and high-speed production [2,18,20,27].

Recently, dynamic WU exercises such as skipping, hopping and bouncing have interested investigators, coaches and sports specialists a lot more than static stretching. Previous studies have shown that voluntary contractions of gradually increasing intensity, as with dynamic WU exercises, activate neuromuscular function, thus increasing power production and improving performance [7,10,11,16,22,29,30,33]. This phenomenon has been labelled as “post-activation potentiation” or PAP. PAP can be described as temporary potentiation of subsequent muscle contractility after a short session of contraction [28]. The main mechanism involved in PAP is phosphorylation of light chain myosin, which promotes better interaction between actin and myosin, while another mechanism that has been proposed is neurological excitability [14,28].

When the varying responses to the different pre-event WU methods and the reported detrimental effects of static stretching on the power and speed performances of adolescents are taken into consideration, it may be concluded that there is a dire need for studies on the effect of WU in children. The main aim of this study was to determine the acute effects of static and dynamic WU routines performed after a general WU exercise on jump performance in children. Taking into account the many reports on the negative effects of static stretching on muscle strength and power performance, it was assumed that static stretching performed after a general WU routine would still detrimentally affect jump performance in children. It was also predicted that dynamic exercise in addition to a general WU would improve performance.

MATERIALS AND METHODS

This study was designed to determine the acute effects of 3 different WU methods (SS, DYN and control [NS]) on vertical jump performance. The three WU methods consisted of (a) static stretching, (b) dynamic exercises, and (c) only aerobic exercises of mild intensity (without static stretching or dynamic exercises involved) performed after aerobic exercise of low intensity (jogging). All the children underwent a vertical jump test designed to measure lower extremity power after each WU routine. The tests were performed under the supervision of experienced physical education and sports teachers, and the children completed the 3 different WU methods on non-consecutive days. All the participants as well as their parents were informed about all the risks involved with the study, and informed consent was obtained in writing before each test. The Helsinki declaration was abided by throughout the study.

Subjects

The study was performed on 71 healthy male volunteers. Seven children were excluded for failing to take part in all the components of the study. Statistical analysis was completed on 64 children. Their mean age, height and body weight (mean ± *SD*) were 13.3 ± 0.5 years, 158.8 ± 5.3 cm, 51.4 ± 6.6 kg, respectively. Most of the participants (71%) were taking part in sport activities such as basketball, volleyball and football 3 days a week, besides the physical education and sports lessons they were already taking in school.

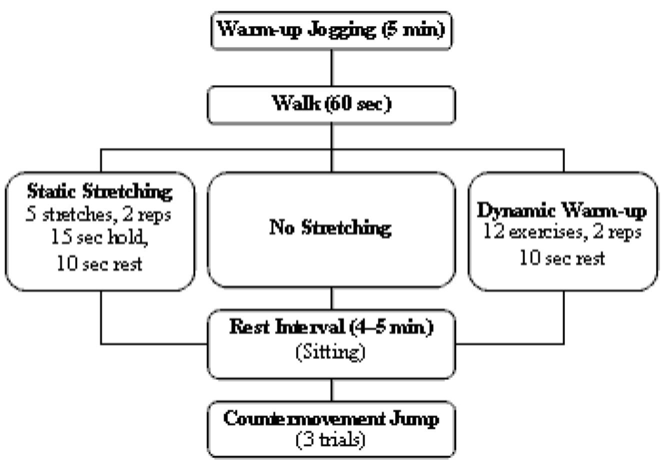

FIG. 1. SUMMARY OF THE EXPERIMENTAL METHOD

Procedures

The participants were initiated on the WU procedures and the vertical jump test 2 days before the actual test, which was followed by

TABLE 1. STATIC STRETCHING EXERCISES

Calf stretch	The subject stands straight on both feet at a distance of 2- steps distance from a wall, . one One leg is stretched in its place while taking a step forward with the other leg, using both hands on the wall for balance. Care must be taken not to lift the heels of the stretched foot off the ground. The same process is then repeated for the other leg (#21).
Quadriceps stretch.	The subject stands and touches a wall or stationary object for balance. The top ankle or forefoot is grasped from behind, and then pulled towards the buttocks. The hip is then straightened by moving the knee backward and held in this position. The same is repeated for the opposite side (#91).
Adductor stretch	While seated on the ground the subject bends both legs putting both feet together. The knees are then lowered sideways as far as possible with the help of the elbows (#64).
Hamstring stretch	The subject sits on the ground with both legs straight out in front, and bends forward while keeping the back straight (#46).
Hip rotator stretch	The subject lies on his/her back, with both knees bent and feet flat on the floor. The ankle bone of the left leg is rested on the right thigh just above the knee. The left knee is pushed downwards until a stretch is felt in the hip. The same procedure is repeated for the opposite leg (#118).

TABLE 2. DYNAMIC WARM-UP EXERCISES

Light skip	While running with a slight skip, the knees are raised slowly, with arms swinging in rhythm.
High knee pull	While walking each knee is pulled towards the chest with the help of both hands.
Light butt kicks	While running, the heels are raised to touch the buttocks, with arms swinging in rhythm.
Light high knees	While running, the knees are raised slightly with every step, with the arms swinging in rhythm.
Walking lunge	While walking hands behind head, with every step forward the body is lowered by flexing the knee and hip until the knee of the other leg is in contact with floor. The same is repeated with the opposite leg.
Straight leg kick	While walking with both arms outstretched forward, each leg is raised up straight until toes touch palms.
High glute pull	While walking, each leg is pulled towards the chest from the ankle using both hands.
A-skip	While running, with every skip as each knee goes up, the opposite hand goes up, and the elbows remain bent, swinging in rhythm with the legs.
B-skip	The same as the A-skip with legs kicked forward after knee is raised.
Rapid high knees	The subject pulls knees towards chest as fast as possible while running.
Carioca	The subject runs sideways while crossing both feet in front of each other. This is repeated in both directions.
Power skip	The subject jumps pulling his knees towards his chest while running, with arms moving in rhythm.

practice sessions, all with the aim of minimizing learning differences among the participants. WU sessions were held at 11.00 am in groups of 10. The vertical jump test was performed 4-5 minutes after each WU session, preceded by a period of passive resting (sitting). A summary of the experimental procedure is given Figure 1.

All 3 WU methods were assigned randomly on non-consecutive days. For convenience purposes the three methods were named Method A, Method B and Method C, each of which included an initial session of aerobic jogging of mild intensity. This was for the sole purpose of increasing core body and muscle temperatures, although the temperatures of participants were not measured in this study. The children were made to jog around the sports facility for 5 minutes with a target heart beat rate of 120 per minute. Three randomly assigned subjects from each of the groups of ten had heart-rate monitors (Polar Electro Inc., Finland) attached, by which the intensity of the WU was monitored. Low-intensity jogging was followed by 60 seconds of active resting.

Method A consisted of 5 minutes of aerobic jogging of low intensity and a series of static stretching techniques aimed at the muscles of the lower extremity. Static stretching procedures were performed twice with 10 seconds in between. Each stretch was performed slowly (active stretching), with a 15-second pause at the pain threshold. The static stretching procedures were chosen based on Alter's [1] reported method (Calf #21, Quadriceps #91, Adductor #64, Hamstring #46 and Hip Rotator #118] (Table 1).

Method B involved 5 minutes of aerobic jogging of low intensity followed by 12 dynamic WU exercises (Table 2). The dynamic WU exercises were chosen to target muscles of the lower extremity, since they are mainly involved in the vertical jump. The children performed these dynamic WU exercises twice for a distance of 15 m, with increasing intensity. After resting for 10 seconds, they were asked to repeat the same exercise back to their initial starting point [11].

Method C comprised 5 minutes of aerobic jogging of low intensity, without involving stretching or dynamic exercises of any kind. The children were passively rested (seated) for 4-5 minutes before being put through a vertical jump test.

Vertical Jump Test

The countermovement jump (CMJ) technique was used for the vertical jump test. Jumps were performed on a jump platform (Newtest, Oulu, Finland) where flight and landing times were recorded. Jump height was calculated from flight time (t) using the formula "$h = g\,t^2/8$" (h= height of rise of the centre of gravity; g = acceleration of gravity $9.81\ ms^{-2}$). The children's hands were on their hips throughout the test, and they were encouraged to jump as high as they could. The test was repeated 3 times, and the best performance was recorded and included in the statistical analysis [9].

Statistical Analysis

Descriptive statistics (mean ± SD) were formulated for the variables age, height, body weight and vertical jump. Data obtained for each of the 3 WU methods were analysed using repeated measures analyses of variance (ANOVA). Methods A and B made up the study group, while method C was designed as the control group. When a significant F value was achieved, post-hoc comparisons were accomplished via a least significant difference (LSD) test to identify specific differences between trials. Statistical significance was set at $p>0.05$, and all analyses were carried out using the Statistical Package for the Social Sciences version 10.0 (SPSS, Inc. Chicago, IL).

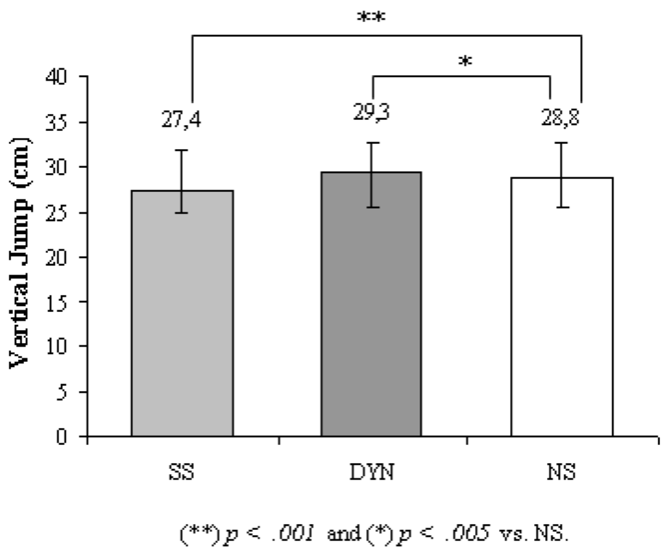

FIG. 2. VARIATIONS IN HEIGHT OF VERTICAL JUMPS ACCORDING TO DIFFERENT WARM-UP METHODS

RESULTS

Descriptive statistics on vertical jump data have been summarized in Figure 2. With regards to height of the vertical jump in children, while methods C and A resulted in a difference of 1.40 cm (-4.9%), the difference with methods C and B was 0.50 cm (1.8%). These differences were statistically significant ($p<0.001$ and $p<0.012$ respectively). It would appear that static stretching performed after aerobic jogging hinders vertical jump performance, while dynamic WU exercises have a positive effect.

DISCUSSION

This study was conducted to establish the effects of static stretching and dynamic WU exercises preceded by aerobic jogging of mild intensity on vertical jump performance. The study's most remarkable result was that while the static stretching routine resulted in a significant decrease in vertical jump height, dynamic WU exercises produced a significant increase. This report presents further evidence that dynamic WU exercises are a superior preparation method to static stretching, especially for activities that require high power production, such as the vertical jump.

Static stretching following a WU routine of aerobic jogging of mild intensity resulted in a 4.9% decrease in vertical jump test performance when compared to aerobic jogging alone. This is consistent with previously reported results of studies on children [10,11,22,29] and adults [6,12,19,21,23,26,30,31] alike, which have demonstrated the detrimental effects of static stretching on power and speed performance.

Faigenbaum et al. [11] tested the effects of different WU protocols including separate static stretching and dynamic WU routines on the fitness performance of children, similar to those utilized in the study. They observed that static stretching resulted in vertical jump heights 6.5% less than with dynamic WU exercises. McNeal and Sands [22] investigated the effects of static stretching on lower muscle strength of trained girl gymnasts, and for this purpose they used the drop jump. Static stretching was found to decrease jump performance by up to 9.6%. Yet another study reporting on the detrimental effects of static stretching on power performance was conducted by Faigenbaum et al. [10]. In this study on teenage athletes the acute effects of different WU protocols on anaerobic performance were investigated. One of the test protocols used was the vertical jump test, and they reported on the negative effects of static stretching on vertical jump performance. Siatras et al. [29] also reported a significant decrease in mean running speeds of young gymnasts following static stretching.

The 4.9% decrease in vertical jump performance after static stretching observed in this study is in compliance with other vertical jump oriented studies on children. From among the studies on adults, Nelson et al. [24] reported on the negative effects of static stretching on the vertical jump. On the other hand, in a study on the effects of static stretching on maximal power production, investigators observed that it resulted in a decrease in 1-RM of both knee extension and flexion [19], while also hindering maximal isokinetic torque momentum [25]. Similarly, a slower short-distance running speed has been reported with WU routines which incorporated static stretching [12,23].

The mechanism responsible for the decrease in power, strength and speed performance observed after static stretching has yet to be conclusively established. However, studies have attempted to attribute this to the acute negative effect of static stretching on neuromuscular transmission and/or the biomechanical characteristics of muscles [2,19,20,31,32].

Kubo et al. [20] claimed that static stretching modifies the biomechanical structure of the muscle tendon, making it more compliant, thus decreasing the speed of power production, which in turn causes delays in muscle activation. Muscle stiffness is of extreme importance for the jump technique utilized in this study. Kokkonen et al. [19] have reported that a stiff MTU could be better than a compliant MTU at transmitting power generated during muscle contraction. Wallmann et al. [31] and Avela et al. [2] have both supported this notion by documenting decreases in electromyographic excitability during muscle contraction after static stretching exercises. Wilson et al. [32] also claim that for concentric muscle activities it was possible to enhance the capacity to generate power by optimizing particular characteristics of contractile components of a stiff system, such as muscle length and contraction speed, i.e., the contracting muscle is placed in a more favourable position on the power-speed and power-length curves in terms of power generation speed. In this study, it would seem that static stretching performed after a general WU routine resulted in an unfavourable corresponding point on the power-speed and power-strength curves for the lower extremity muscle groups, thus negatively affecting vertical jump performance.

When the CMJ technique is analysed, it can be seen that in the eccentric phase of the initial stretch, the MTU expands and elastic energy is temporarily stored. The combination of the excess energy that accumulates during the eccentric phase of this technique and the power produced during the ensuing concentric phase determines the vertical jump performance [4,5]. Cornwell et al. [8] attempted to illustrate that the decrease in vertical jump performance observed after static stretching was essentially due to a decrease in the ability of the MTU to accumulate elastic energy. The more flaccid the muscle becomes after static stretching, the less the elastic energy that is stored during the eccentric phase [4,5]. This study has led to the belief that static stretching exercises performed after a general WU routine primarily affect the eccentric component of movement by decreasing elastic recoil of the stretch shortening cycle.

One of the possible mechanisms could be that after muscles are stretched, joint proprioceptors result in a reflex inhibitory effect on the muscle itself and its synergists. In parallel with the results of this study, Knudson et al. [18] also reported on the negative effects of static stretching on vertical jump performance. However, since they did not manage to detect any variations in movement kinematics after static stretching, they claimed that the decrease in vertical jump performance was due to decreases in neural transmission, i.e. acute neural inhibition, or in other words, decrease in neural signals transmitted to the muscle. According to a report by Rosenbaum and Henning [27], the decrease in maximal power production associated with static stretching is probably attributable to neuromuscular factors. The findings of the study support the neurological explanation for the decrease in performance after stretching.

The findings of this study seem to show that dynamic WU exercises performed after aerobic jogging of mild intensity affect vertical jump performance, and thus power performance, positively. A vertical jump test performed after a combination of low-intensity aerobic jogging and dynamic WU exercises showed an enhancement of 1.8% in performance when compared to aerobic exercise alone. Even though the actual difference was 0.50 cm, this was deemed statistically significant ($p<0.012$). The results of recent studies on children have all pointed to an enhanced vertical jump performance that could be attributed to pre-test dynamic WU exercises of progressively increasing intensity [10,11]. In a study by Burket et al. [7] aimed at determining the most ideal WU method for the vertical jump, it was reported that WU involving high-intensity contractions resulted in an increase in vertical jump height of 1.67 cm. Young et al. [34], on the other hand, incorporated 1 set of 5-RM squats in this WU routine, and they also observed an increase of 2.8% in jump height. Gullich and Schidtbleicher [16] also reported a 3.3% increase in vertical jump height after voluntary maximal contractions of high intensity. Similarly, a 2.4% improvement in jump performance was observed by Gorgoulis et al. [13] after half-squats of gradually increasing intensity. In all of the above studies, it was claimed that dynamic loading of muscles stimulates the central nervous system, which in turn facilitates the explosive application of force needed for activities requiring high power, such as the vertical jump.

Despite the obvious need for further studies, it has been well documented that dynamic WU exercises boost explosive power generation by enhancing neuromuscular function. The mechanisms which initiate PAP are still under scrutiny. However, current theories state that transient chemical, neuromuscular and mechanical changes influence contractile characteristics of muscle tissue [14,16,28]. Besides the mechanism responsible for potentiation, studies have shown that characteristics such as the individual's physical condition as well as the distribution of fibre type may also determine the ability to induce PAP [16,17,28]. Furthermore, some studies have shown that predominantly fast-twitch muscles show better potentiation when compared to slow-twitch variants, making it natural that activities such as jumping are affected [16,17]. In the study, it would seem that the dynamic WU exercises performed after low intensity aerobic jogging increase excitability of the fast-contracting units of the targeted muscles, and by priming these units, they in turn play an important role in improving performance in activities such as the vertical jump.

CONCLUSIONS

The results of this study show that static stretching performed after mild intensity aerobic exercises would negatively affect vertical jump performance in children. On the other hand, dynamic WU exercises could potentially improve strength performance. It would seem that the increase in athletic performance of children following PAP associated with dynamic WU exercises holds great potential for future research on the subject. The relationship between the extent and method of PAP required to improve performance in adults and children shows great variability, which is why research into the ultimate WU exercise would benefit researchers, trainers and sports teachers alike. In conclusion, for children to achieve success in sporting fields which require maximal power production, rather than performing static stretching exercises aimed at the target muscle, a dynamic WU exercises would result in a far more favorable outcome.

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