Acute Static Vibration-Induced Stretching Enhanced Muscle Viscoelasticity But Did Not Affect Maximal Voluntary Contractions in Footballers

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Abstract

Jemni, M, Mkaouer, B, Marina, M, Asllani, A, and Sands, WA. Acute static vibration-induced stretching enhanced muscle viscoelasticity but did not affect maximal voluntary contractions in footballers. *J Strength Cond Res* 28(11): 3105–3114, 2014–The aim of this study was to compare the effects of acute vibration-enhanced static stretching and/or static stretching alone on the strength and flexibility of the hamstrings and quadriceps muscles. Twenty-one male footballers participated in this study (21.9 ± 1.8 years; 75.54 ± 7.3 kg; 178.7 ± 6.5 cm). The experiment started with 5 minutes standardized warm-up followed by (a) baseline flexibility pretest (Split Test); (b) maximal voluntary flexion and extension (isokinetic strength) of the knee; (c) Treatment or Sham involving 45-second stretch with or without vibration for the hamstring and quadriceps muscle groups with 10-second rest between; and (d) posttest repeating the measures of the pretest. Each player randomly performed both trials on separate occasions. The vibration device operated at 35 Hz with 2 mm amplitude. Stretching with vibration statistically increased hamstring flexibility by 7.8% ($p \leq 0.05$) when compared with stretching without vibration. No statistical differences for hamstring or quadriceps strength were noted between treatment conditions. There was no statistical correlation between flexibility and strength measurements. In conclusion, flexibility increased with vibration-enhanced static stretching; however, no change was evident in the maximal voluntary contractions of the knee flexors and extensors.

Key Words local vibration, flexibility, isokinetic strength, muscle inhibition, football

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Introduction

New emerging technologies aiming at the enhancement of the muscle's viscoelastic characteristics have appeared lately (vibration treatment, peristaltic pulse compression, bracing equipment, elastic bands, etc). Whether in clinical setting (rehabilitation of muscle injuries) or in the fitness and wellness sector, most of these technologies are based on similar physiological concepts: The Golgi tendon organ inhibits the muscle's excitability that could lead to an autogenic inhibition of the fibers, which in turn, leads to enhancing its passive viscoelastic characteristics, i.e., flexibility and range of motion of the joints. It is assumed that once the muscle is inhibited, the feedback mechanism from the muscle to the central nervous system is interrupted/disturbed. Within these moments, muscle fibers could be stretched over their limit of tolerance and therefore enhance the range of motion. Stretching is often prescribed to athletes for reduction of muscle soreness, relaxation, and injury prevention.

Flexibility is defined as the range of motion in a joint or a related series of joints (32,34). It is the outcome whereas stretching serves as the stimulus and is determined by several factors: connective tissue microstructure, age, sex, joint structure, activity levels, and many more. Women tend to be more flexible than men; young people tend to be more flexible than older people (1). Flexibility is considered one of the pillars of fitness characteristics. It is required for many sports to express and achieve unusual postures and/or elegant positions (32,33). It increases mental and physical relaxation, helps develop body awareness, reduces risk of joint and muscle strains, reduces muscle tension and speeds up recovery from training (1). However, stretching and flexibility are currently undergoing conceptual revisions. Its role in injury prevention, for example, might be overrated (10,11,16,18). Some authors have shown that acute stretching harms performance, whereas chronic stretching enhances it (27,33). Others have demonstrated that dynamic stretching is replacing static stretching in many sport contexts (14,22,23).

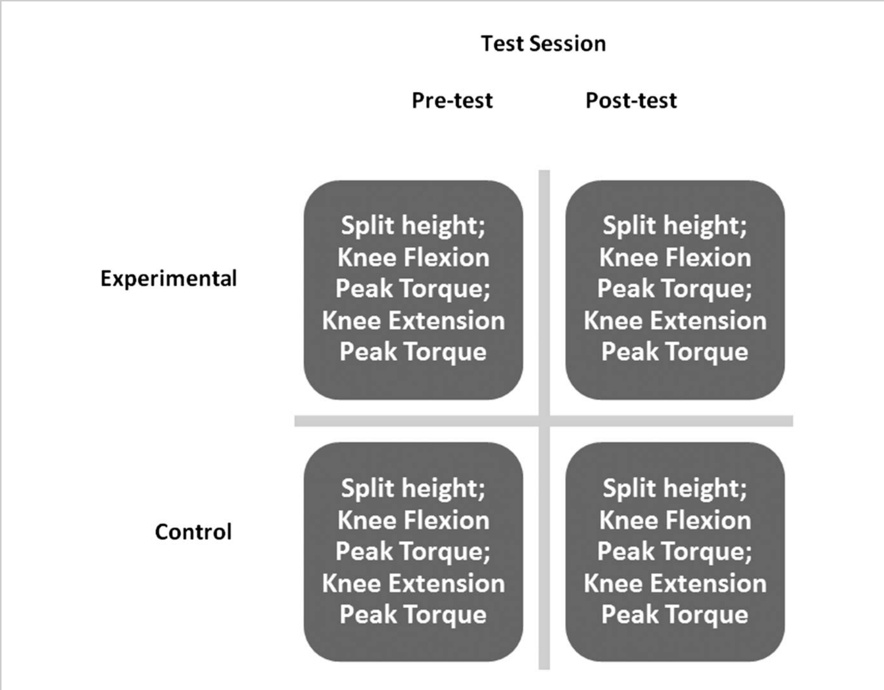

Figure 1. The study design.

Hamstring muscle injury is common in football. They are a powerful muscle group at the back of the thigh that arises from the ischial tuberosity of the pelvis and inserts through strong tendons to the superior tibia and fibula. They bend the knee and assist in hip extension when the pelvis is tilted anteriorly; otherwise, it is a hip adductor. With many muscular injuries occurring in football, physician and therapists are always seeking technologies to save time and help the athletes return to training following recovery of strength and range of motion. However, physicians and physiotherapists are still keen to use traditional static stretching. Static stretching is indeed one of the most common ways to improve flexibility (29). Static stretching occurs when a large range of motion is achieved without active muscle tension; this kind of stretch is usually attained through gravity or inertia (33). Although static stretching is commonly used after exercise, it has been linked to acute reductions in muscle strength (7). Dynamic stretching occurs when a large range of motion is achieved by muscle tension moving the limb into an extreme position against antagonist muscle tension and/or gravity (33). It has been attributed as "best" for preexercise stretching (39). Whether static or dynamic stretching is used may depend on what one does between stretching and the strength and/or explosive activities. If one puts transitional aggressive activities between stretching and the target activity, this tends to diminish the effects of the previous stretching (29). Passive and active flexibility of the lower limbs can be assessed by a variety of methods as recently described by Jemni (20). For the purpose of this study, the forward split test has been adopted. This is a widely used test for a talent identification program in USA Gymnastics (31).

Figure 2. Forward split flexibility test.

Whole-body or local vibration training has recently been introduced to a wider range of settings, gyms, fitness centers,

Figure 3. Hamstring and quadriceps isokinetic strength assessment.

soccer clubs, or even as a home-based training. Vibration provides a mechanical stimulus that may affect the musculoskeletal system systemically or locally. In this context, the application of new vibration stretching technology has been shown to increase the range of motion at the involved joint (s) similarly or better than without vibration (9,13,33). Exceptional results were found in studies performed with elite and highly trained athletes (19,33,35,37). Sands et al. (36,37) have found statistical differences in the range of motion following vibration-enhanced static stretching among gymnasts, elite synchronized swimmers, and figure skaters when compared with static stretching alone. The previous training experience of the aforementioned athletes could suggest that vibration-enhanced stretching benefits occur only among those who are already accustomed to stretching. Few authors suggested that vibration causes a stimulation of the spindle within the extrafusal fibers (4). Others put forward a presynaptic inhibition of group Ia afferent fibers, which is created when both vibration and stretching nerve traffic occupy the same Ia pathways (5). Nevertheless, there is a paucity of research investigating the effects of vibration-induced stretching on muscular strength in its various aspects (maximal strength, limit strength, relative strength, elastic strength, endurance strength, speed strength, stability strength, functional strength and core strength) (40,41).

Practitioners may be confused by the apparent conflicts in the lay and research literature on the role of flexibility in training and performance. Stretching and flexibility lack a theoretical framework, and there are misunderstandings inherent when stretching is applied for conflicting purposes and widely differing sports. Like strength training, stretching and flexibility may cut across all sports to some degree. The purpose of this study was to ascertain the potential effectiveness of vibration-enhanced static stretching on a team sport–football. In addition, current consensus indicates that stretching reduces strength and may not be associated with injury prevention or enhanced performance in nonesthetic sports. This study sought to compare the effects of vibration on stretching and flexibility, and further, to ascertain the effects of this type of stretching on subsequent strength performance. Most directly, this study aimed to compare the effects of acute static vibration-induced stretching and/or static

Figure 4. Hamstring stretching treatment (with or without vibration).

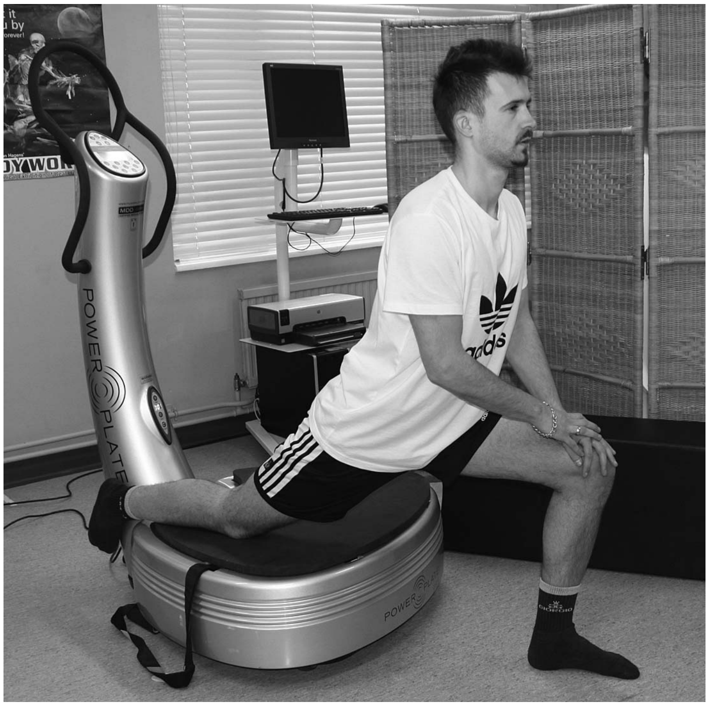

Figure 5. Quadriceps stretching treatment (with or without vibration).

stretching on the strength and flexibility of the hamstrings and quadriceps muscles.

Methods and Materials

Experimental Design

This study investigated the acute effects of stretching with or without vibration treatment on the strength and flexibility of the hamstring and quadriceps muscles. The study was a pretest, posttest, crossover, sham-controlled repeated measures design. The study design involved 2 independent variables: treatment (vibration or not vibration); test (pretest and posttest) with repeated measures (split height, knee flexion peak torque, knee extension peak torque). Figure 1 shows the design of the study. The sham treatment involved the same stretching as the experimental treatment, except that the vibration device was not turned on.

Subjects

Twenty-one male football team league members volunteered to participate in this study (age, 21.9 ± 1.8 years; body mass, 75.54 ± 7.3 kg; height, 178.7 ± 6.5 cm). To qualify for the experiment, each player had to be involved in regular training at an average of 6 hours per week. All participants were given an information sheet outlining the investigation and its potential risks. A signed consent form was obtained from each athlete before taking part. The University of Greenwich Ethics Committee approved the investigation.

Participants were randomly assigned to (vibration) or (no-vibration) group on their first testing day. They were tested twice on separate days with 1 week between the first and the second assessment. Those who were assigned to the vibration group for the first assessment had to perform the no-vibration trial on their second visit, and vice versa. All participants chose their dominant leg to be treated. They were requested to be fully hydrated and had their last meal at least 2 hours before the tests. All tests were performed in the same laboratory and at the same time of the day for each player to maintain similar arousal levels.

Table 1. Analysis of the within-subject variance.*

Assessment of flexibility	r	ICC (95% CI)	ANOVA of repeated measures: Mean square	F	p	η^2
No vibration						
Baseline	0.997	0.999 (0.999–0.999)	0.344	4.102	0.056	0.170
Posttreatment	0.995	0.997 (0.993–0.999)	0.504	3.276	0.085	0.141
Vibration						
Baseline	0.984	0.992 (0.980–0.997)	0.004	0.008	0.929	0.001
Posttreatment	0.999	0.999 (0.998–1)	0.034	0.945	0.343	0.045

*Statistical differences between the first and second flexibility assessment in each trial, for each group ($n = 2$) and treatment ($n = 2$). $p < 0.001$ for r and ICC. ICC = intraclass correlation coefficient; 95% CI = 95% confidence interval; ANOVA = analysis of variance.

Procedure

After the random assignment of treatments, a mark was penciled on the anterior superior

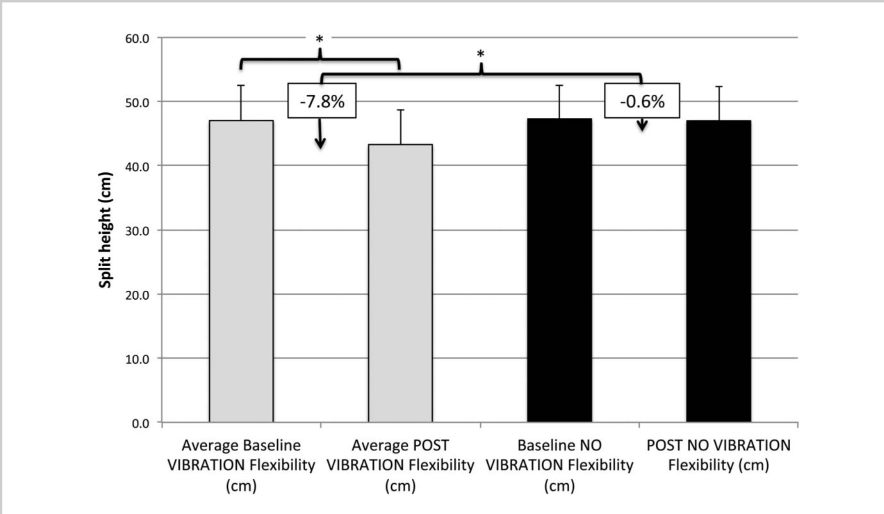

Figure 6. Pre- and postflexibility assessments with and without vibration (* $p \leq 0.05$).

were requested to keep their shoulders straight and facing forward, the toes of their front leg facing straight forward while lowering to the position until discomfort was felt (Figure 2). Two measurements of the height of the anterior superior iliac spine were obtained by the same investigator using a vertical meter stick. The mean of the 2 readings was calculated and used in further analyses. The lower the anterior superior iliac spine, the lower the split, and the better the performance.

The flexibility test is modified from the original forward split test used in the Talent Opportunity Program of USA Gymnastics (37) in women's gymnastics to reduce "cheating" in the split position. The modification included flexing the rear knee and setting it against a vertical block or mat. The ideal position for a forward split has the pelvis aligned perpendicularly to each leg so that flexion of the forward thigh and hyperextension of rear thigh occurs in the sagittal plane relative to the frontal plane of the pelvis (28). By placing the rear knee in flexion against the matted block, the gymnast is less likely to cheat in the forward split position by allowing his pelvis to turn toward the rear leg.

iliac spine of each player by palpation. The following chronological sequence of events outlines the conduct of the investigation.

Warm-up. A 5-minute standard warm-up was imposed including 2 minutes of cycling at 60 rpm against 2 kg resistance on a Monark ergometer (874e; Monark, Vansbro, Sweden). A prescribed stretching warm-up was also required before assessment. The stretches involved the hamstrings, quadriceps, gastrocnemius, and hip adductors. Each stretching position was held for 10 seconds.

Flexibility Assessment. The test consisted of adopting a forward split position with the rear leg flexed at the knee and the shank held vertically against a matted block. Athletes

Strength Assessment. The strength of the hip muscles was assessed using a Cybex Norm machine (Cybex International, Medway, MA, USA). Athletes performed 3 maximal knee flexion and extension efforts in a prone position as described

TABLE 2. Comparison between the 2 groups and 2 treatments using a 2- × 2-way ANOVA for repeated measures.*

Variable	Effect	F	df	*p*	η^2	Post hoc	*p*
Flexibility							
Flex	Tr × G	101.03	1.40	0.001	0.716	Tr_1: $g_2 > g_1$	0.030
	Tr	140.03	1.40	0.001	0.778	G_1: $Tr_1 > Tr_2$	0.001
	G	1.47	1.40	0.23	0.035	$Tr_1 > Tr_2$	0.001
Strength							
Hamstring	Tr × G	0.064	1.40	0.801	0.002		
	Tr	0.075	1.40	0.786	0.002		
	G	0.001	1.40	0.977	0.000		
Quadriceps	Tr × G	1.50	1.40	0.227	0.036		
	Tr	1.34	1.40	0.253	0.033		
	G	0.58	1.40	0.811	0.001		

*Treatment (Tr), group (G), vibration (1), no vibration (2). ANOVA = analysis of variance.

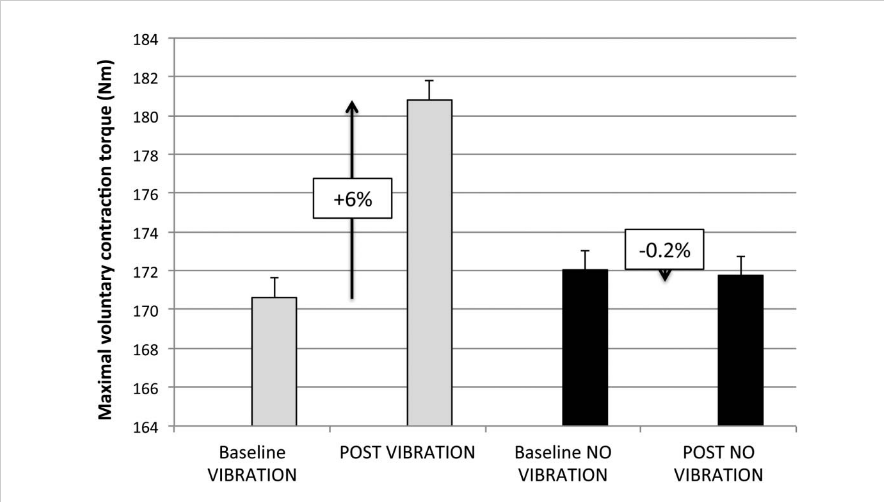

Figure 7. Pre- and postisokinetic strength assessments of the quadriceps with and without vibration.

in the manufacturer's manual. This test was chosen to place the participants in the most natural position and to avoid any closed chain actions while performing the exercise. The peak torque values were recorded by the Cybex software. The Cybex machine was adjusted to fit the player's appropriate position with isokinetic motion set at $60° \cdot s^{-1}$. The movement velocity was purposely slow to match the semiprofessional level of the participants. In addition, according to a similar previous study, the dynamometer's velocity did not affect the rate-of-force development (10). A belt was placed tightly around the player's hips to avoid involvement of other muscular groups while the arms were stretched and held along the sides (Figure 3). The same position was used in pretest and posttest.

Each player performed a pretest measurement for flexibility and strength (before any treatment), followed by either vibration or no-vibration stretching treatment and finishing by posttests replicating pretests.

Treatment. A Power Plate platform (MY5 Silver, Model 2011, Powerplate, Amsterdam, The Netherlands) was used for the vibration treatment. The experimental group performed the stretching series with the Power Plate turned on, whereas the control group treatment was the same except that the Power Plate was turned off. Figures 4 and 5 show the stretches the participants performed. Stretching the hamstrings required a flexed standing knee, the treatment leg was kept straight, toes upward, and upper body leaning forward until discomfort was achieved. The participants achieved a static stretching position, without bouncing, for 45 seconds at a frequency of 35 Hz and with vibratory amplitude of 2 mm. Stretching the quadriceps muscles required the leg to be placed rearward from the hip with the thigh muscles downward resting on the Power Plate and with a straight knee. The rear leg was placed such that the rear knee rested on the ground directly behind the athlete's forward leg, which was placed with the heel on the Power Plate (Figures 4 and 5). After the test was completed, all participants were allowed a 2-minute cool down using the cycle ergometer.

Statistical Analyses

Again, 21 participants performed 2 tests, separated by 1-week interval. The experimental treatment involved vibration and the control treatment did not. The participants acted as their own controls. All data were reported as mean and *SD*. As the sample size was below 40, a Shapiro-Wilk test and visual inspection of histograms and box plots were used to assess data distribution normality. The majority of the measurements demonstrated a normal distribution ($p \geq 0.05$). A Levene's test verified the equality of the variance in the samples ($p > 0.05$). A 2-way factorial analysis of variance with repeated measures was then applied to analyze the statistical differences between tests and treatment group results. When statistical differences were observed, a Sidak post hoc procedure was applied enabling pairwise comparisons between the treatments, tests, and the interaction between treatment and tests. Pearson correlation and intraclass correlation coefficient (ICC) were used to study the within-player reliability during the assessment of the flexibility. Pearson product-moment, zero-order correlation coefficients were also calculated to assess changes in flexibility and strength. Statistical significance was set at $p \leq 0.05$. All calculations and statistics were calculated using the software package SPSS, version 20 (SPSS, Inc., Chicago, IL, USA).

Results

The assessment of flexibility was internally consistent across trials (Table 1). Pearson correlation (r) and ICC analyses showed high values ($r \geq 0.98$; ICC ≥ 0.99). There were no statistical differences between both trials independently of the group and treatment ($p > 0.05$).

No statistically significant difference was found between the 2 trials when the pretests or the posttests, respectively, were compared ($p > 0.05$). Figure 6 shows improved flexibility when the vibration treatment was applied as compared with the control treatment ($p \leq 0.05$). Statistical comparisons are shown in Table 2.

The difference between pretreatment and posttreatment is designated as the "magnitude of change". The participants gained 7.8% in their range of motion when their lower

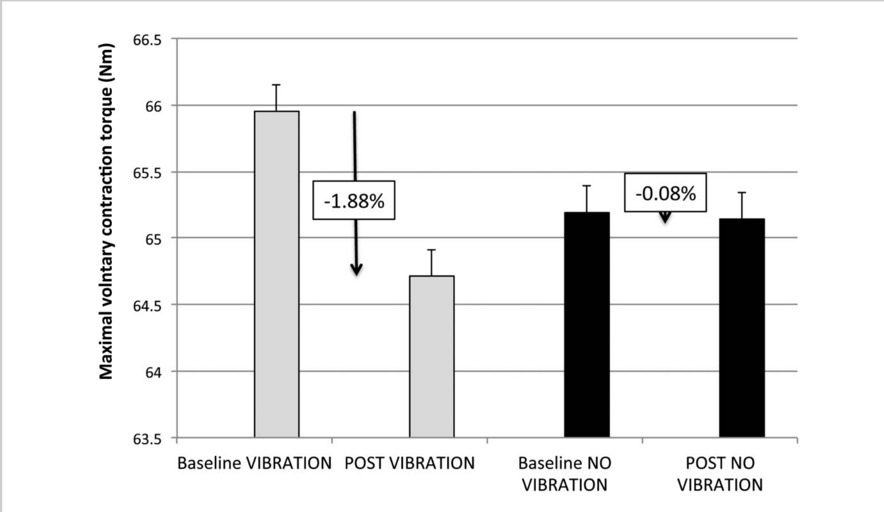

Figure 8. Pre- and postisokinetic strength assessments of the hamstring with and without vibration.

extremity muscles were vibrated. This magnitude of change was statistically different ($p = 0.001 < 0.05$) to the one calculated following the passive stretching, where the magnitude of change was only 0.6% (Figure 6).

Muscle strength was expressed by the isokinetic maximal voluntary contraction of the quadriceps and the hamstrings (Figure 7). No statistically significant difference was found when comparing the quadriceps torque values between pretest and posttest or between treatment conditions ($p > 0.05$; Table 2).

Similarly, knee flexion strength assessments did not reach a statistically significant differences when comparing pretest measurements with either posttest vibration or posttest no-vibration control treatment measurements ($p > 0.05$; Table 2, Figure 8).

This study did not support the premise that stretching resulted in a decline in maximal strength, as measured in knee flexion and extension using isokinetic machine. Pearson correlation analysis further supported this result by showing a nonstatistically significant correlation ($p > 0.05$; Table 2).

Discussion

This investigation is one of the few studies to focus on flexibility and its effect on isokinetic strength assessed by torque production of the knee muscles (10,29). The results showed a significant increase in hamstring and quadriceps flexibility following an acute treatment of local vibration when compared with passive stretching, as shown in Figure 6. This result confirmed an increasing number of recent studies that showed similar effects (11,19,22,25,33,35,37). Although slight differences exist between the experimental designs of these studies, the outcomes are consistent. A number of suggestions have been presented in an attempt to explain the underpinning physiological mechanisms. The following points highlight the likely mechanisms behind these effects:

- Inhibition/reduction of the stretch reflex. Bongiovanni and Hagbarth (4) suggested that vibration causes a stimulation of the spindle within the extrafusal fibers, which is unlike the potential mechanism within the intrafusal fibers. Bove et al. (5) have investigated the effect of vibration of the soleus and anterior tibialis muscles on the stretch reflex and short to medium latency reflex responses. The authors showed that medium latency reflexes were reduced more than the short latency reflex following different vibration frequencies (30 and 90 Hz). Their explanations were based on the presynaptic inhibition of group Ia afferent fibers (or a "busy line" phenomenon), which is created when both vibration and stretching nerve traffic occupy the same Ia pathways. Earlier in the 1980s, Claus et al. (8) have also suggested that the combination of vibration stimulus and strong stretching may result in the activation of the Golgi tendon organ through Ib pathways and resulting in autogenic inhibition of the vibrated muscle.
- Increase in blood flow and temperature: increases in heart rate, fluid volume, blood flow velocity, and blood pressure have been noted following vibration stimuli (21,30). These may account for an increased muscle temperature. Increased temperature has also been linked to increased muscle extensibility (12,15).

Other mechanisms have also been suggested but with less evidence and/or contradictory results, such as induced relaxation (6), pain threshold (27,35), and thixotoropy (2,18).

This study also aimed to investigate the effect of vibration-enhanced static stretching on the isokinetic strength of the hamstring and quadriceps muscles. The results here did not show statistically significant differences in strength following both types of acute stretching trials (Figures 7 and 8). Our investigation supports the results of Kinser et al. (22) also showing that vibration-enhanced static stretching did not show a postvibration stretching-induced decline in vertical jump ability, thus maintaining strength and power. Our data contrast with previous studies, such as that of Power et al. (29). The latter investigated whether acute static stretching affects isometric force, muscle activation, and jump power. They found that static stretches had reduced the maximal voluntary contraction torque of the quadriceps by 9.5%.

They also showed that torque remained statistically decreased by 10.4% over the 120 minutes following the trial. The 45-second static stretching applied in this study did not affect our footballers' maximal voluntary contraction torques in either muscle group. Figures 7 and 8 show nonstatistically significant percentages in the magnitude of change. A few methodological differences could explain the contrary findings. The duration of the treatment in our study was 2 times 45 seconds together for the hamstring and the quadriceps, whereas Power et al. treated their participants with 2 sets of 3 times 45 seconds separated by 15-second relaxation (total of 2 minutes and 30 seconds of treatment for each muscle separately). Total treatment time in the study of Power et al. required treatment of 3 muscles and thereby summed to almost 12 minutes. Longer exposure to static stretching may affect strength expression more profoundly than shorter duration exposures. We must also emphasize that the current study engaged a larger and more homogeneous sample when compared with Power et al.: 21 footballers regularly practicing a minimum of 6 hours per week and belong to only 1 league team vs. 12 university male students. Power et al. failed to provide any further details on their participants, which makes the comparison even more difficult. Strength assessment was also different between the studies. Power et al. have assessed isometric maximal voluntary contractions where the subjects were seated in a straight back chair with hips and knees at 90° with their leg secured in a modified boot apparatus, whereas our study used dynamic isokinetic maximal voluntary contractions where participants were laying on prone position.

Power et al. (29) showed an increased range of motion of 6% in 12 participants. Our footballers have increased their range of motion following static stretching by only 0.6% (Figure 6), which was nonsignificantly different and therefore did not confirm the findings of Power et al. Again, the way flexibility was assessed differs between the studies. Power et al. used the sit-and-reach test, which unfortunately would systematically involve the back and spine muscle resistance and thereby influence the overall results. To avoid this issue and based on the fact that the back and spine muscles were not treated, the current study has assessed the flexibility of the knee muscle using a split test.

Similar outcomes were reported by Costa et al. (10) who examined the acute effects of hip and calf stretching on hamstrings and quadriceps peak torque during maximal concentric isokinetic muscle contractions in women. The authors reported a 7.2% decrease in knee flexion peak torque, but no statistical change in quadriceps strength. Our results partially confirm that of Costa et al. with regard to the quadriceps strength but contrasts with hamstring torque reduction. Although physiological and anatomical differences between men and women could have contributed in the outcomes (such as, muscle mass and muscle stiffness), these have not been controlled in either study. However, we could refer to the stretching durations that was different between the 2 studies; our footballers have stretched for only 2 single stretches held for 45 seconds each (90 seconds in total), whereas female participants in Costa et al. performed a set of 30-second stretches repeated 4 times, with 20-second rest between repetitions (total stretch 120 seconds).

More studies are confirming that strength or power performances may be hindered if the power expressions are preceded by static stretching (3,14,23,26,38). Simic et al. (38) have shown in a meta-analysis that strength reduction may be observed with a minimum static stretch duration of 45 seconds. Isometric strength could be more pronounced than dynamic. The same authors added that this effect is not related to player's age, gender, or fitness level. Other authors attributed this decrease in performance to an increase in musculotendinous unit compliance, which in turn could lead to a decrease in the ability to store elastic energy tension during the development of eccentric movements (14,26).

Nevertheless, recent studies investigating the effect of vibration stretching on strength are not unanimous, with some showing positive effects (9,19,24) and others showing the opposite (17) or no effect (22). Herda et al. (17), for example, showed that peak torque of the plantar flexors decreased by 5% following 20 minutes of vibration treatment. Our study did not support this contention because hamstring torque was a nonstatistically significant reduction of only 1.9% after static vibration stretching (Figure 7). In contrast, the quadriceps increased torque, without reaching statistical significance, by 6% but without reaching a statistical significant level either.

It has been suggested that combination of vibration stimulus and stretching may activate the Golgi tendon organ and result in autogenic inhibition of the vibrated muscle and therefore enhances its passive viscoelastic characteristics (1). However, vibration effect on maximal voluntary contraction did not reach a consensus. The aim of this study was to compare the effects of acute vibration-enhanced static stretching or static stretching along on the strength and flexibility of the hamstrings and quadriceps muscles. The only statistically significant difference found was the increase in hamstring flexibility after vibration-enhanced static stretching when compared with passive stretching (−7.8% vs. −0.6%, respectively). No significant change was however noticed in the maximal voluntary contractions of the knee flexors and/or extensors following either treatment. More evidence-based reports are however showing the benefits of the vibration-enhanced static stretching on range of motion.

Practical Applications

The above findings may be helpful in field and clinical settings. We have noticed that several teams/athletes are currently applying vibration during a game halftime or break time in football and rugby. At this point of time and with only very few studies investigated the static vibration-induced stretching's effect on strength, a wise use of the vibration device should be considered to guarantee the subsequent performance. Our results showed that acute 90-second static vibration-induced stretching did not impair strength in either quadriceps or hamstring of football participants. There is evidence of increased flexibility using the device, however, coaches and scientists should bear in mind that there is significant growing evidence showing negative effect of static stretching on the subsequent performance.

The use of vibration-enhanced static stretching compared with classic field or clinical methods could provide beneficial effects, especially for general conditioning and rehabilitation. Previous studies have shown that participants have not only gained range of motion but have also saved time when using vibration-enhanced static stretching. The acute and chronic effects of this new technology on strength and power however still require further investigations before reaching a consensus.

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