Kinematics of Ankle Taping after a Training Session

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- biomechanics
- ankle injuries
- 3D photogrammetry

Abstract

This study aimed to test the effectiveness of ankle taping on the limitation of forced supination during a change of direction, as well as the losses of effectiveness after a 30-minute training session. Fifteen young men with no ankle injury volunteered for the study. The static and dynamic ranges of movement (ROM) were measured before and after a training session. The dynamic measurements were recorded using high-speed 3D photogrammetry. The differences between static and dynamic measures of ankle supination and plantar flexion were significant. The losses of effectiveness during supination and ankle plantar flexion restriction were 42.3% and 47.6%, respectively. Ankle taping was effective in restricting the maximal static ROMs before a training session, but the effectiveness decreased after 30 min of training. The present study shows the necessity of performing dynamic ROM analysis of sports techniques involved in the ankle sprain mechanism in order to determine the degree of tape restriction after a training session, because there were differences between static and dynamic ankle ROMs. The lack of effects on the restriction of the dynamic plantar flexion would bring into question the necessity of ankle taping in subjects without previous injuries.

Introduction

Ankle sprains caused by inversion are common in team sports, where fast and sharp changes of direction are performed. In basketball, handball, soccer and volleyball, ankle sprains represent from 60 to 90% of the injuries, and the 75% of the athletes affected have relapses that can force them to give up their competitive practice [4,11, 18,21,24]. The main mechanism of injury is the forced inversion of the ankle, caused by the subject's landing on another player's feet, or during a feint [4,24]. The probability of suffering an injury could be related to individual characteristics such as anthropometrical variables [17,19] and foot morphology [17,28]. Body size, expressed as height, weight, or the relationship between them (body mass index, BMI), has been reported to affect the incidence of lower limb injury in several studies [1,15,20]. The subjects with greater body sizes would suffer a proportional increase in the forces that joint structures and ligaments must resist. On the other hand, several studies have reported a relation between foot morphology and injury. Subjects with high arches have been found to have greater incidence of overuse injuries compared with those with low arches [28]. One of the most utilized methods for the ankle sprain prevention is the functional taping. However, despite its effectiveness in the limitation of the ankle's ROM (range of movement) [2,5,6,9, 13,23,26,27], its effect on the ROMs during the specific sports techniques involved in the mechanism of injury is not clear, because most of the studies on the mechanical effects of ankle taping have used static tests for the measurement of ROM. The effectiveness of taping decreases during the exercise because of the tape loosening and the loss of tape adherence to skin [3,7,8,10, 12,14,16]. In addition, the majority of the studies have not controlled the quantity and quality of the intervention on the subjects, because they were carried out during training sessions or actual competitions, where each player performs different tasks and has different periods of intervention depending on the game position. In this way, we believe that it is important to design experimental protocols that reproduce the same tasks and periods of training in all subjects.

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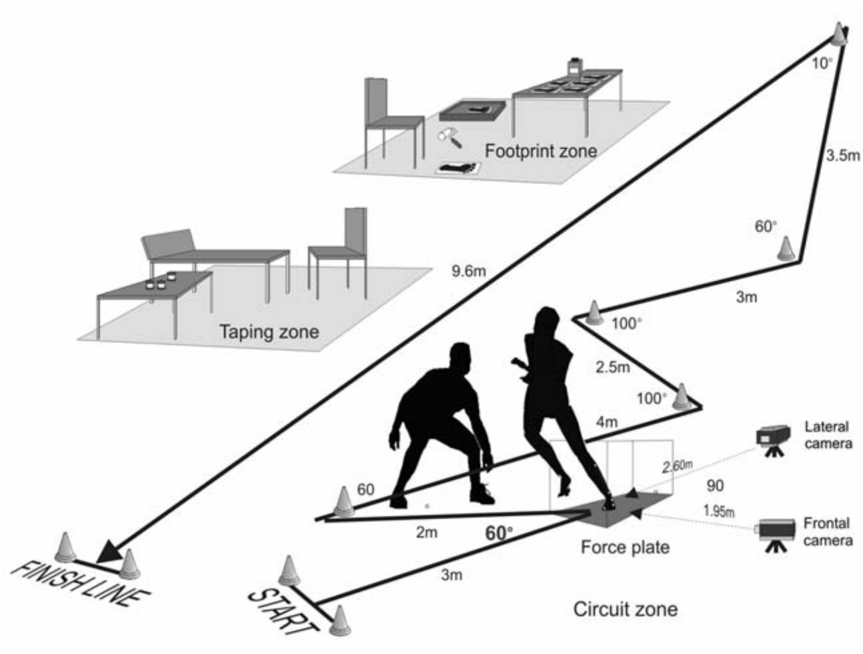

Fig. 1 Distribution of registering systems.

The present study aimed to test the effectiveness of ankle taping on the limitation of forced supination during a change of direction, as well as the losses of effectiveness after a 30-minute training session. A secondary purpose was to analyze the influence of subject's individual characteristics on the tape restriction and the loss of effectiveness to find out the individual requirements for taping replacement. It was hypothesized that there would be a significant decrease in the ankle taping effectiveness after the training session and that this decrease would be influenced by the subjects' individual characteristics.

Methods

Fifteen active and healthy young men, physical education students, with no ankle injury or with full recovery from previous injuries (more than three years), volunteered for the study after providing written informed consent, and the study protocol was approved by the Institutional Research Ethics Board of the University of León (Spain). All of them carried out the same protocol, with three different situations:

- Without taping, before a training session.
- With new tape, before the training.
- With worn tape, after training.

Testing

The experimental design was as follows:

(1) The footprint was registered during bilateral stance by carefully applying photograph developer on each subject's foot sole with a paintbrush. Then the subjects had to put their foot on a photographic paper placed at the ground level, with great care, and finally, the paper was immersed in a fixer solution. With this technique we can obtain high-quality permanent pictures of the footprint without special equipment.

(2) The subjects performed a 10-min warm-up, with 5 min of active joint mobilization and stretching, and 5 min performing several trials in the agility course growing intensity in each rehearsal (**Fig. 1**).

(3) Static ROM measurements were recorded using manual goniometry following the protocol of Root et al. [25]: supination, pronation, plantar flexion and dorsiflexion.

(4) The subjects performed an agility course with six changes of direction and a total length of 26.7 m (**Fig. 1**). The first change of direction was recorded and analyzed using high speed 3D photogrammetry. The placement of a player in a defensive position at the first change of direction allowed maximal performance intensity, in a more similar way to the competitive situation.

(5) An inelastic tape Leuko Sportstape Premium (Beiersdorf Australia Ltd., North Ride, Australia) was applied to the subject's right ankle by an experienced sports physician. The taping procedure did not include a pre-tape, and was designed to limit ankle plantar flexion and supination. Two adhesive anchors were applied to the skin under the gastrocnemius heads. The inferior adhesive anchor was applied over the metatarsal head. Three strips with a "U" shape were fixed on the leg anchor, passing over the lateral and medial malleolus, and the calcaneus. Three additional strips with "C" shape from the Achilles tendon insertion to the metatarsal anchor were also fixed. Finally, six active strips that limited ankle supination, and 13 to 17 strip locks, depending on the size of the lower limb, were utilized.

(6) New static ROM measurements were carried out on the taped ankle before exercise.

(7) The subjects performed the agility course again in order to test the dynamic ROM with the ankle taping.

(8) The subjects performed a 30-min training session. It was directed and supervised by a researcher and included exercises that focused mainly on the ankle muscles with identical periods of intervention in all subjects. The training session was performed without stops between the different tasks, and at the same pace for all the participants. Therefore, all the subjects carried out the same number of jumps and changes of direction. The training session was as follows:

- Five-min jogging at a 140 – 150 bpm heart rate.
- Five-min running with changes of direction of 100° each 2 m, marked on the floor.

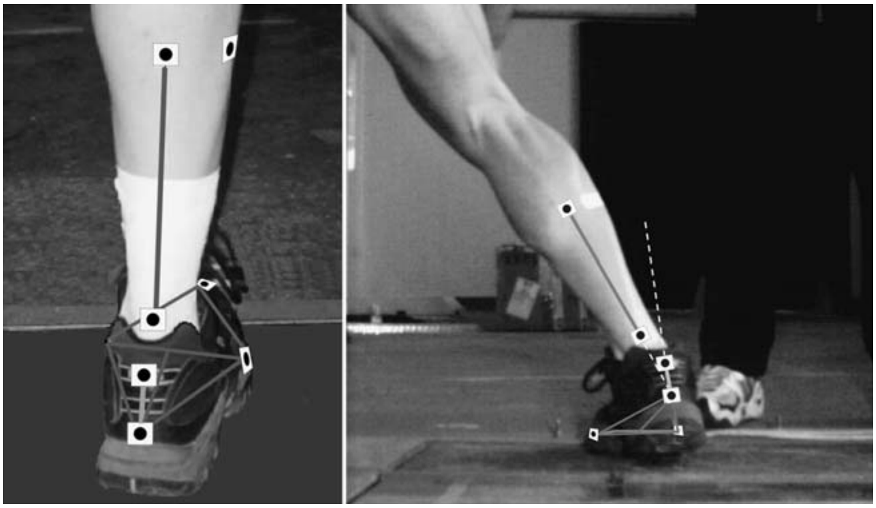

Fig. 2 Markers position and segment model design of the 3D video analysis.

- Five-min performing four-step approach runs and maximal vertical jumps.
- Five-min running combined with sharp changes of direction. The lines of the volleyball court were utilized to perform two short and submaximal runs of 18, 12, 9 and 6 m.
- Five-min jogging (130 – 140 bmp).
- Five-min stretching of the lower limb muscles.

(9) A new static ROM measurement was carried out on the taped ankle after exercise in order to test the loss of restriction of the ankle taping.
(10) The subjects performed the agility course again in order to test the dynamic ROM with the used ankle taping.
(11) Taping was removed, and new static ROM measurements were made.

Data analysis

The footprint was analyzed by the following equation: *(Fw-Mw) × 100/Fw*, where *Fw* is the width of the weight bearing area of the forefoot and *Mw* is the width of the weight bearing area of the midfoot. This ratio was defined as arch index. The foot categories established from it where *pes cavus* (high arched feet) (arch index ≥ 60%), neutral (arch index from 40 to 59.9%) and flat feet (low arched feet) (arch index < 40%).

The ROM measurements during the feint were recorded by two fixed and synchronized high-speed video cameras, Kodak Motion Corder Analyzer SR-500 (Kodak, San Diego, CA, USA), at 125 Hz, and a shutter speed of 1/500 s. The cameras were placed at an angle of 90° in rear and lateral positions (at 1.95 m and 2.60 m, respectively). Spotlights illuminated the experimental space from behind the cameras. A cubic calibration frame with eight points of known locations was used to calibrate the movement space. Before the testing session, the calibration frame was placed in the movement space, so that all points were visible from both camera views, and then recorded for a brief period. Care was taken not to alter the cameras in any way after the calibration frame had been recorded. The kinematic analysis was performed with the software Kinescan v. 8.2 (IBV, Valencia, Spain). A segment model was designed, with eight points and nine links using adhesive markers: upper leg (middle position over the gastrocnemius heads and the corresponding lateral reference), lower leg (over the Achilles tendon), upper calcaneus (assumed position of the upper edge of the calcaneus under the shoe), lower calcaneus (assumed position of the lower edge of the calcaneus under the shoe), and the assumed position of the first metatarsal, the fifth metatarsal and the toe cap (**Fig. 2**). Manual digitalization and 3D reconstruction (Direct Linear Transformation, DLT algorithm) were carried out with the same software. The best of three trials (the one with shortest time to complete the course) was selected, recorded and digitized for each camera view from the start to the finish of the contact. Where the view of a marker was obscured or was obviously unrepresentative of the joint center, its position was visually estimated. For each trial, the two sets of digitized coordinates of the selected body landmarks were combined using the DLT algorithm, and the corresponding three-dimensional coordinates determined. To minimize the effect of digitizing and other random errors, each dimension (x, y, and z) of each digitized point was smoothed using splines of 5^{TH} order.

Ankle kinematics were analyzed, and the variables related to the ROMs (expressed in degrees), from which initial restriction, final restriction and the loss of effectiveness (the difference between initial and final ROM restrictions) were assessed (**Fig. 3**; **Table 3**). The static and dynamic ROM values were defined as the difference between the anatomical position and the maximum ROM of each ankle position. Kinematic variables were correlated with the individual characteristics of body weight, standing height, body mass index (BMIs = weight/height^2) and foot typology.

The statistical analysis was performed using the software Statistica for Windows v. 4.5 (StatSoft Inc., Tulsa, OK, USA). Normality tests were applied to the data using the Shapiro-Wilk's W test. As most of the variables were not normally distributed, nonparametric tests were used in the analysis. Wilcoxon matched pairs test was used to assess ROM differences among the three situations (without taping before the training session, with taping before, with taping after). Relationships between variables were tested using Spearman's rank correlations. The $p < 0.05$ criterion was used for establishing statistical significance. The minimal number of subjects required with a power of 0.8 and a level of significance α of 0.95 was calculated to be 14, considering differences between dynamic supination on the braking phase in the not taped condition and in the taped condition before training.

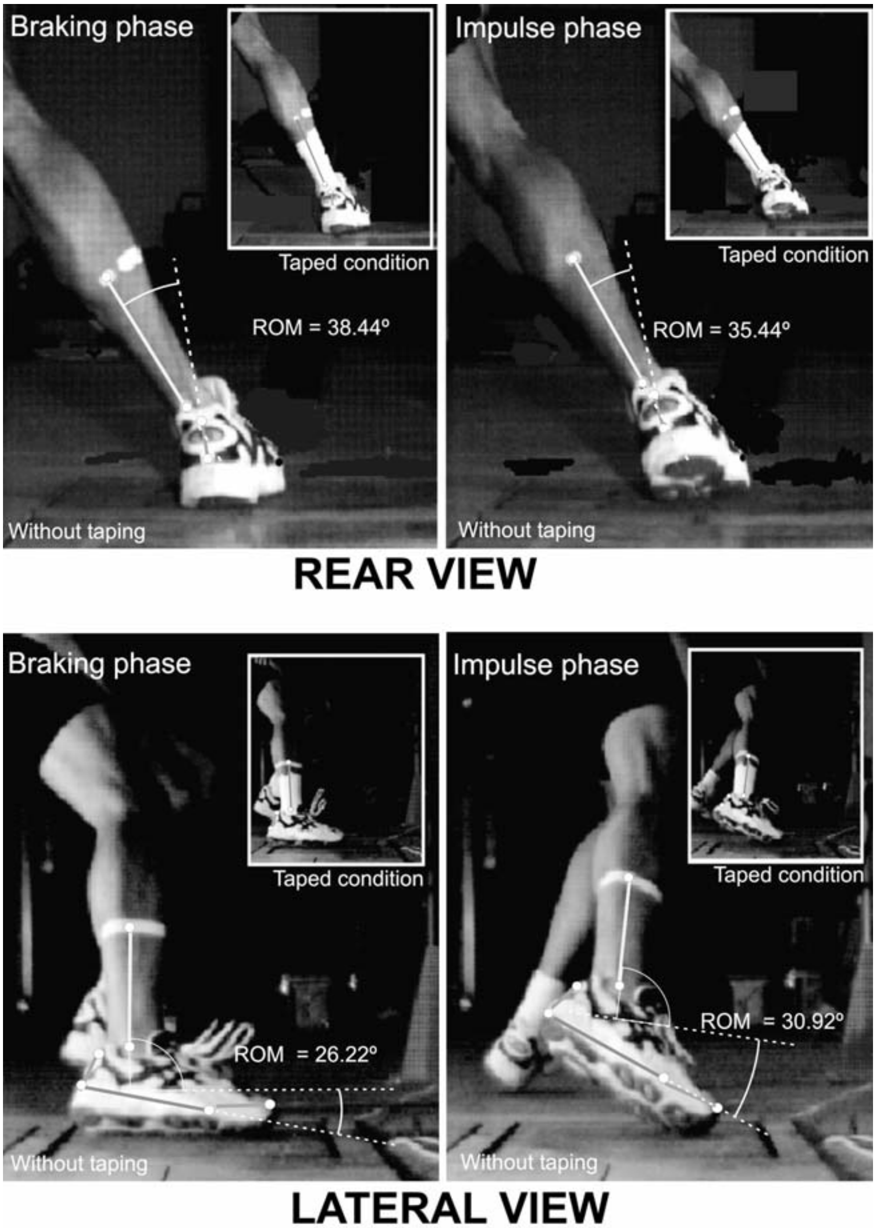

Fig. 3 Recorded ROMs during the feint. ROM: range of movement.

Table 1 Mean (± SD) static and dynamic ranges of motion during the feint

Condition	Movement	Static/dynamic braking phase	Static/dynamic impulse phase
Not taped	supination (°)	28.3 (6.3)/38.4 (4.9)**	28.3 (6.3)/35.4 (7.7)*
	plantar flexion (°)	64.7 (6.6)/26.2 (5.9)***	64.7 (6.6)/30.9 (10.9)***
Taped-pre	supination (°)	10.1 (5.4)/33.2 (5.6) ***	10.1 (5.4)/31.9 (5.5)***
	plantar flexion (°)	26.5 (8.0)/25.5 (4.7)	26.5 (8.0)/27.3 (5.6)
Taped-post	supination (°)	19.1 (5.8)/35.4 (7.4)***	19.1 (5.8)/34.2 (7.9)***
	plantar flexion (°)	44.7 (11.3)/25.8 (7.6)**	44.7 (11.3)/30.0 (10.1)*

Taped-pre: taped condition before the training session; taped-post: taped condition after the training session; * static vs. dynamic condition, $p < 0.05$; ** static vs. dynamic condition, $p < 0.01$; *** static vs. dynamic condition, $p < 0.001$

Results

Differences between dynamic and static ROMs

Static supinations were significantly lower than the dynamic ones (without taping: 28.3° vs. 38.4°, $p < 0.01$; with taping before the training: 10.1° vs. 33.2°, $p < 0.001$; with taping after: 19.1° vs. 35.4°, $p < 0.001$. Static vs. dynamic situations, respectively), while the plantar flexion ROMs in the static situations were greater than those measured in the dynamic ones (without taping: 64.7° vs. 26.2°, $p < 0.001$; with taping after training: 44.7° vs. 25.8°, $p < 0.01$. Static vs. dynamic situations, respectively), except for those recorded during the ankle plantar flexion with new

Table 2 Mean (± SD) static ranges of motion during the three situations

Static variables	Not taped ROM (°)	Taped-pre ROM (°)	Taped-post ROM (°)	Not taped vs. taped-pre (%)	Not taped vs. taped-post (%)	Taped-pre vs. taped-post (%)
Supination	28.3 (6.3)	10.1 (5.4)	19.1 (5.8)	– 64.45***	– 32.69***	49.29***
Pronation	14.7 (3.5)	6.0 (3.3)	10.1 (2.6)	– 59.27***	– 31.23***	47.31*
Plantar flexion	64.7 (6.6)	26.5 (8.0)	44.7 (11.3)	– 59.07***	– 30.93**	47.64***
Dorsiflexion	19.6 (5.9)	9.9 (6.8)	14.6 (6.6)	– 49.64***	– 25.51*	48.61***

ROM: range of movement; taped-pre: taped condition before the training session; taped-post: taped condition after the training session; * significant differences between means, $p < 0.05$; ** significant differences between means, $p < 0.01$; *** significant differences between means, $p < 0.001$

Table 3 Mean (± SD) dynamic ranges of motion during the feint

Dynamic variables	Not taped ROM (°)	Taped-pre ROM (°)	Taped-post ROM (°)	Not taped vs. taped-pre (%)	Not taped vs. taped-post (%)	Taped-pre vs. taped-post (%)
Sup during braking phase ROM	38.4 (4.8)	33.2 (5.6)	35.4 (7.4)	– 13.5**	– 7.9	41.9
Sup during impulse phase ROM	35.4 (7.7)	31.9 (5.5)	34.2 (7.8)	– 9.9	– 3.6	63.6
PF during braking Phase ROM	26.2 (5.9)	25.5 (4.7)	25.8 (7.6)	– 2.7	– 1.6	40.0
PF during impulse phase ROM	30.9 (10.9)	27.3 (5.6)	30.0 (10.1)	– 11.8	– 3.0	10.0

ROM: range of movement; taped-pre: taped condition before the training session; taped-post: taped condition after the training session; sup: supination; PF: plantar flexion; * significant differences between means, $p < 0.05$; ** significant differences between means, $p < 0.01$

tape, which had similar values (26.5° vs. 25.5°, not significant) (**Table 1**).

Taping restriction effectiveness

Table 2 shows significant static ROM restriction values in the four tests. The mean restriction with new tape was 58.1%. The supination and plantar flexion were restricted by 64.5% ($p < 0.001$) and 49.6% ($p < 0.001$), respectively. **Table 3** shows the dynamic ROM restriction values, quite lower than the static ones. There was only a significant restriction of 13.5% ($p < 0.01$) in the supination during the braking phase.

Loss of range-limiting effectiveness

Table 2 shows the loss of range-limiting effectiveness observed in the static measurements after the training session, which were significant in all the movements, but lower during the pronation. The losses of effectiveness during supination and ankle plantar flexion restriction were 49.3% and 47.6% ($p < 0.001$), respectively. As shown in **Table 3**, the losses of dynamic ROM restriction effectiveness during the feint were not significant in either movement studied.

Influence of individual characteristics on the taping restriction effectiveness and the loss of range-limiting effectiveness

Related to the anthropometric characteristics, on the one hand, there were significant correlations between the body weight and the losses of ROM restriction on the static pronation ($r = 0.519$; $p < 0.05$) and on the dynamic forefoot torsion ($r = 0.564$; $p < 0.05$); on the other hand, the height had positive correlations with the losses of ROM restriction on dynamic plantar flexion during the braking phase ($r = 0.595$; $p < 0.05$). Related to foot dimensions and typology, there were also significant correlations between the forefoot width and the loss of restriction on dynamic plantar flexion on the braking phase ($r = 0.737$; $p < 0.01$). Furthermore, the arch index correlated significantly with the loss of restriction in the dynamic supination ($r = 0.619$; $p < 0.01$) and dynamic plantar flexion ($r = 0.636$; $p < 0.05$) during the braking phase.

Discussion

Most of the studies that compared tape restriction before and after a training session have utilized static ROM measurements. In the present study, dynamic ROM measurements were carried out during maximal and specific movements, starting from the hypothesis that dynamic ROM measurements during sport specific tasks are better than the static ones for determining the optimal degree of tape restriction. The observed differences between static and dynamic measures of ankle supination and plantar flexion were significant (**Table 1**). The static supinations were significantly lower than the dynamic ones. Two possible reasons can explain this finding: the first is that the dynamic supination during the feint was mixed with a slight plantar flexion, so the supination ROM was greater. The second is the short length of the levers in the subtalar joint, which makes it difficult to apply great force during the manual goniometry to get the maximal ROM. Nevertheless, during the feint, the ankle joint was withstanding forces greater than body weight which could lead this supination to greater values. On the other hand, the static plantar flexions were greater than the dynamic ones, because the plantar flexion ROM is not fully utilized during the feint. However, the differences between the static and the dynamic plantar flexion were minor with tape restriction, probably due to the lack of proportion between the ankle plantar flexion ROMs with taping during the feint and those found during the static measurements without taping. Therefore, it seems that such a great restriction in a movement without maximal ROMs is not necessary. Hence, static ROM measurements could not be accurate enough to determine the degree of tape restriction, because they can be very different from those measured during a specific sport technique. The point of reference for the measurement of the actual restrictions should be the dynamic ROM during the sport movements involved in the injury mechanism. Moreover, static measurements only give information about kinematics of "pure movements", and sports techniques are combinations of them, thus further studies are needed to clarify this issue.

The mean static restriction with new taping in the four measured movements was 58%. The percentages of static ROM restrictions in ankle supination and plantar flexion were 64% and 59%, respectively, both ankle positions related to the ankle sprain mechanism. However, the dynamic ROM restrictions during the feint were lower than those measured in the static condition (**Table 3**), especially after the training session, thus the ankle taping only had significant effects in the supination when it was new. Our findings are not in agreement with those reported in previous studies [5], because worn ankle taping seemed not to cause considerable restriction on healthy subjects. It would bring into question the utility of ankle taping in subjects without previous injuries or deficits in ankle proprioception [22].

There were significant losses of effectiveness of the ankle taping in all the static measurements after training (**Table 2**) as it has been reported in previous studies [3,8,10,12,14,16,24,26], although these losses were smaller during the pronation movement because it was hardly used during the training session. Nonetheless, the restriction after the training session was significant, so the ankle taping had not lost all its effectiveness. There were no significant losses of restriction effectiveness during the feint.

There was a significant correlation between the loss of restriction during ankle pronation and body weight after the training session, that is, the subjects with greater body weight underwent less ankle pronation restriction. The most interesting correlation from the point of view of injury prevention was found between the subjects' height and the loss of effectiveness during plantar flexion in the braking phase, because it is one of the movements that we tried to restrict. The longer levers at the ankle joint observed in these subjects could let us apply high forces against taping restriction during dorsiflexion movement. In this sense, the degree of restriction can be modified during the taping preparation, by tightening or reinforcing the tape on the anterior part of the ankle during the sports activity.

The subjects with high arches were associated with a lower taping restriction during the supination and plantar flexion in the braking phase, both movements involved in the injury mechanism. In this sense, the subjects with high arches could have an increased risk of injury, because they underwent greater losses of effectiveness during the movements involved in the mechanism of ankle sprain, therefore, it would be advisable to substitute or reinforce their ankle taping more frequently than in other athletes.

The main limitation of the present study is that the wearing of shoes could distort the actual measurement of the ROMs during the dynamic task. This fact could have led to an overestimation of the ROM measurements between the shank and the foot, because the markers had to be placed on the shoe. Therefore, further studies on ankle taping kinematics during dynamic tasks should improve the present approach.

In conclusion, the present study shows the necessity to perform dynamic ROM analysis of sports techniques involved in the ankle sprains mechanism, to determine the degree of tape restriction after a training session, because there are differences between static and dynamic ankle ROMs.

Ankle taping was effective in restricting the maximal static ROM of the ankle before a training session, but the effectiveness decreased after 30 min of training. Nonetheless, there were only significant dynamic ROM restrictions in the ankle supination during the braking phase, and no losses of dynamic restriction after training. This fact and the lack of effects on the restriction of the dynamic plantar flexion would bring into question the necessity of ankle taping in subjects without previous injuries.

Finally, the subjects with greater body weights, heights and BMIs underwent higher losses of effectiveness than the others during the ankle supination and plantar flexion. Furthermore, there was a relationship between the subjects with high arches and higher losses of effectiveness in the restriction of supination and plantar flexion. Thus anthropometrical characteristics and the foot type should be taken into consideration in the taping preparation and the subsequent reinforcement.

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