

Comprehensive testing of 10 different ankle braces Evaluation of passive and rapidly induced stability in subjects with chronic ankle instability

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Abstract

Objective. The aim of the present investigation was to test the stability of 10 different ankle braces under passive and rapidly induced loading conditions in a population suffering from chronic ankle instability in order to provide objective information to choose or recommend an appropriate model for specific needs. In addition, the relationship between passive and rapidly induced testing of the stabilizing effect against inversion was evaluated to identify if passive support characteristics of braces are reflected under rapidly induced conditions.

Design. An experimental in vivo study with a repeated-measures design was used.

Background. Ankle braces are commonly used for treatment, rehabilitation, and prevention of ankle injuries. A variety of products exists but there is few information available to assist clinicians, physiotherapists and coaches as well as consumers in choosing a brace on a basis of objective information. Furthermore, there is a lack of studies that provide data for both passively and rapidly induced movement of the ankle joint when using different ankle braces.

Methods. Twenty-four subjects with chronic ankle instability participated in the project. Passive ankle range of motion measurements were performed in a custom-built fixture and simulated inversion sprains were elicited on a tilting platform.

Results. The tested braces restrict range of motion significantly compared to the no-brace condition for both the passively and rapidly induced inversion and marked differences between braces were revealed. A close relationship between passive and rapidly induced test results for inversion was found.

Conclusions. Passive as well as rapidly induced stability tests provide a basis of objective information to describe the characteristics of different ankle braces. Combined results of passive and rapidly induced inversion as well as correlation between results demonstrate that passive support characteristics of braces are reflected under rapidly induced conditions but the amount of restriction is reduced. Therefore, caution should be taken when recommending braces for applications under dynamic circumstances only on the basis of passive support characteristics.

Relevance

A basis of information regarding the stability characteristics of different ankle braces under passive and rapidly induced conditions will help the clinician and consumer in choosing the most appropriate brace model for specific use. The results also provide more insights into factors that influence stability characteristics of ankle braces.

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1. Introduction

Injuries to the lateral ligaments of the ankle joint complex are among the most frequent injuries in sports and activities of daily living that mostly affect young

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physically active individuals [1,2]. For rehabilitation after injury or prevention of re-injuries a proprioceptive training program has been recommended throughout the literature [3–5]. Furthermore, ankle braces are commonly used for the treatment and rehabilitation of acute injuries and bracing is common practice among individuals with chronic ankle instability to prevent recurrent injuries. There is evidence that the use of braces in these subjects can reduce ankle sprains in high risk sporting activities like soccer or basketball [6]. Braces have to meet different requirements, e.g. in sports applications an optimal brace should ensure the necessary stability without limiting performance and also meet subjective demands like comfort or ease of application [7]. A wide variety of products are commercially available and consist of rigid or flexible materials in combination with special systems of straps. This diversity of products leads to a dissatisfactory situation for clinicians, physiotherapists and coaches to recommend or consumers to choose the most appropriate model for individual requirements on a basis of objective information.

Ankle sprains often occur in a combination of inversion, plantar flexion and internal rotation. Excessive motion in these directions should primarily be restricted by braces whereas the other directions may also be of importance [8]. In general, it has to be considered that stabilization against inversion is probably the major function of ankle braces [9].

Several studies have been performed in the past to evaluate the stabilizing effect of different ankle braces under passive [7,8,10,11] or rapidly induced conditions [12–14]. Passive condition refers to a situation where the ankle joint complex is moved passively in different directions in an unloaded situation (e.g. supine position). The advantage of this test is to obtain information of the stability characteristics in different directions, e.g. inversion–eversion, plantar–dorsiflexion. The disadvantage is that it is not a realistic representation of the potentially traumatizing situation, because of the lack of dynamics in the application of the torques and the neglected potential influence of the muscles that stabilize the ankle joint. Rapidly induced stability refers to a situation where subjects are subjected to a fast inversion event on a tilting platform simulating an ankle sprain. This method reflects a more realistic condition because the foot is loaded with bodyweight and the inversion instant is unknown to the subjects. The disadvantage of this test is that it is mainly limited to inversion. However, these two tests provide objective information about the stabilizing effects of various ankle braces either under laboratory or more realistic conditions. Results of both tests combined would provide even more valuable information for the evaluation of braces. However, braces have not been tested for stability with both test procedures and the relationship between passive and

rapidly induced conditions has not been investigated, yet. Most investigations focused only on few braces and differences between braces were not described so that no recommendations for the specific use of different braces are available. Furthermore, no subjects with recurrent ankle sprains were used. This is of special interest when focusing on prophylactic use of braces in sports because subjects with a history of ankle sprains may be expected to have different anatomical and/or functional preconditions and therefore, may react differently to test conditions compared to healthy subjects.

Therefore, the aim of the present investigation was to provide an overview of the characteristics of 10 different ankle braces that were tested for passive and rapidly induced stability in order to help clinicians, physiotherapists and coaches to recommend or consumers to choose the most appropriate model for individual requirements. It is of special interest to what extent different braces stabilize the ankle joint complex against passively induced inversion and eversion, plantar and dorsiflexion and internal and external rotation as well as against rapidly induced inversion movements on a tilting platform. In addition, correlation between passive and rapidly induced inversion and amount of restriction for both tests are of interest to understand relation between test conditions.

2. Methods

2.1. Subjects

Twenty-four subjects (15 females, 9 males) with chronic ankle instability participated in the project. Subjects who had endured an injury to the ankle joint complex within the last three months prior to testing were excluded from the study. Inclusion criteria were repeated ankle inversion sprains and a self-reported feeling of instability or giving way. Talar tilt and anterior drawer sign were not used as an inclusion criterion because of the variability of these parameters across subjects and the reported lack of correlation between mechanical and functional instability [15]. The method for testing rapidly induced stability was approved by the institution's human ethics committee and prior to participation all subjects were informed about the procedures and signed an informed consent form. At the beginning of the study all subjects were free of pain and 83% of them already had experiences with braces. Subjects with bilateral instability wore braces on the more seriously affected side or if there were no differences between legs the tested side was randomly selected. The level of sports activity was on average 7.3 (SD 4.7) h per week and the mean frequency of ankle sprains was 22.7 (SD 18.3) times per year (Table 1). Recurrent inversion was described by the subjects as follows: 92% felt a short

Table 1
Anthropometric and demographic data of the subjects ($n = 24$)

	Mean (SD)	Range
Age (years)	22.7 (2.7)	19–30
Weight (kg)	70.2 (12.3)	53–107
Height (cm)	176.4 (8.1)	165–194
Sex (male/female)	9/15	
Sports activity (h per week)	7.3 (4.7)	1.6–15
Frequency of ankle sprains (per year)	22.7 (18.3)	3–104
Experiences with braces (yes/no)	20/4	

pain, 83% had no or only little swelling, and 83% could return to normal business directly or after few minutes after inversion movement.

2.2. Braces

Ten commercially available ankle braces that are widely used in Germany were used in all subjects. Models were subdivided into three categories (rigid, semi-rigid and soft). The rigid category only consisted of the Caligamed® brace and was intended to serve as a reference model together with the condition without brace. The semi-rigid category included the Aircast®, Air Gel®, Air Brace®, Ligacast Anatomic® and Mal-

leoloc®. Soft braces were the Kalassy® and Kalassy S®, Fibulo Tape® and Dynastab® (Fig. 1). According to the brace manufacturers all semi-rigid and soft braces are intended to be used for prophylactic purposes in sports to prevent recurrent injuries.

2.3. Test procedures

Passive and rapidly induced stability were evaluated using different experimental set-ups. The two tests were performed on two occasions. A maximum of 3 h for passive stability and 2 h for rapidly induced stability were necessary to test all 10 braces and the condition without brace (a total of 11 conditions). The order of these testing conditions was randomized to minimize a potential influence of fatigue. The same shoe model was used in these investigations (model Cross Training XT, Nike Inc., USA). Brace application was practiced in specific training sessions prior to the start of the study to minimize mounting inconsistencies, and braces were applied to the subjects' leg by the same investigator according to the manufacturers' instructions.

To test reliability of both measuring systems the no-brace-condition was repeated at the end of the experimental session.












Code	Model	Picture of brace	Code	Model	Picture of brace	Code	Model	Picture of brace
no	No-brace condition		04	Air Brace® (Ruthner, Neckargemünd, GER)		08	Kalassy S® (NeaTec mbH, Neu-Ulm, GER),	
01	Caligamed® (Bauerfeind GmbH & Co. KG, Kempen, GER)		05	Ligacast Anatomic® (Thuasne GmbH & Co. KG, Burgwald, GER)		09	Fibulo Tape® (Sporlastic GmbH, Nürtingen, GER)	
02	Aircast® (Europa GmbH, Neubeuern, GER)		06	Malleoloc® (Bauerfeind GmbH & Co. KG, Kempen, GER)		10	Dynastab® (Thuasne GmbH & Co. KG, Burgwald, GER)	
03	Air Gel® (NeaTec mbH, Neu-Ulm, GER),		07	Kalassy® (NeaTec mbH, Neu-Ulm, GER),				

Fig. 1. Code and picture of tested braces (lateral view).

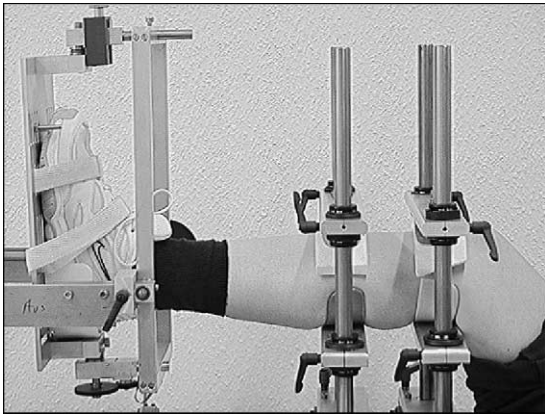


Fig. 2. Experimental apparatus to measure passive stability.

A custom-built device was used for testing the passive stability of the ankle joint complex in three planes with standardized torques. Subjects lay supine with the affected leg fixed in the apparatus, the foot placed on a foot plate in neutral position, and the shank fixed at two points (Fig. 2). Rotation axes for plantar/dorsiflexion, inversion/eversion and internal/external rotation were aligned with the intermalleolar axis, the long axis of the foot on the level of the cranio-posterior edge of the tuber calcanei and the longitudinal axis of the tibia, respectively. The same position was used for one subject when testing all braces. To determine individual torques, the leg was fixed without braces and rotated in each direction to the limits of comfort. The maximum torque for each direction was determined with a torque wrench and then used for all conditions. The rotational displacement was measured with potentiometers fixed to the axes. Five trials for each direction were measured and the individual means were calculated.

A custom-built trap door with a 30° tilting angle in the frontal plane was used to simulate lateral ankle

sprains and to test the rapidly induced stability of the braces. Subjects stood upright on the platform with the tested leg on the hinged trapdoor bearing most of the body weight. The axis of rotation of the trapdoor was just medial to the weight bearing foot and the other foot was placed only with the toes in contact to the fixed/stable part of the platform to maintain balance.

A customized goniometer was developed to measure the hindfoot inversion angle inside the shoe (Fig. 3, left). It consisted of a 2 mm thin, polished plastic cap that embraced the posterior part of the heel and was held in place by an elastic strap. At the upper posterior part of the heel cap, a u-shaped aluminum rod was fixed. A combination of a goniometer and a flexible bar was fixed with its rotation axis to the aluminum rod on the level of the cranio-posterior edge of the tuber calcanei. Finally, the flexible bar was attached to the lower leg. With this set-up, inversion movement of the hindfoot inside the shoe was transferred to the outside and the angle between calcaneus and lower leg was measured (Fig. 3, right).

Surface EMG signals were recorded for online monitoring purposes and the platform was released mechanically when only baseline EMG activity was observed. The time of release was unknown for the subjects and timing between trials was varied to prevent anticipation of the tilting event by the subjects. Each subject underwent at least 10 successful trials. Ten repeated trials per condition (each brace and no-brace) were recorded and for each trial maximum inversion angles were derived and averaged.

Test-retest reliability of the measuring systems for passive and rapidly induced stability for the condition without brace and correlation between passive and rapidly induced inversion was determined using Pearson's correlation coefficient R . Differences between braces and the no-brace condition were calculated using a repeated measures ANOVA with the α -level set to 5%.

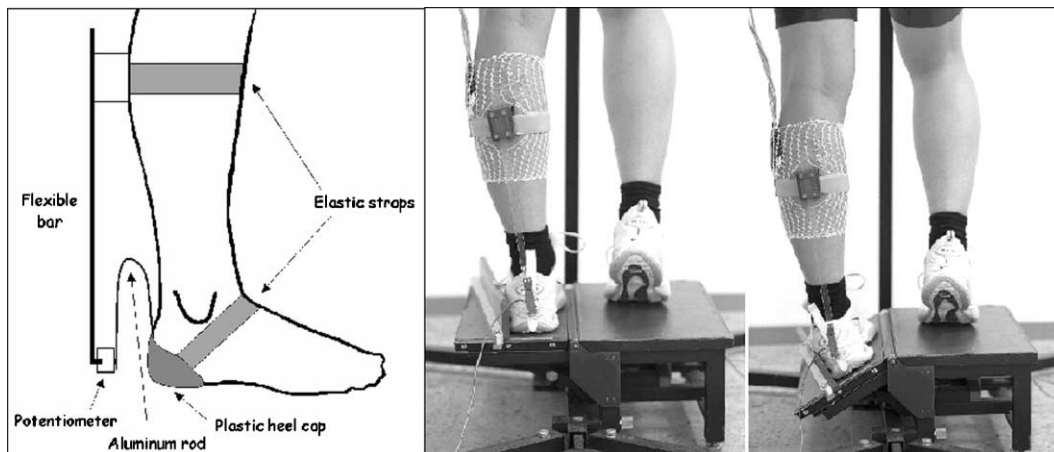


Fig. 3. Experimental apparatus to simulate inversion on a trap door (30° of tilting movement). Inversion angle inside the shoe was measured with a customized goniometer system. The condition without brace (no-brace condition) is presented.

The Scheffé post-hoc test was used for paired comparisons.

3. Results

A comparison between test and retest showed high correlation coefficients for the parameters of both measuring systems (Table 2).

In the no-brace condition the following mean angles for passive stability were determined: 39° (SD 9) inversion, 23° (SD 7) eversion, 43° (SD 5) plantar flexion, 25° (SD 2) dorsiflexion, 36° (SD 6) internal rotation and 37° (SD 6) external rotation. The corresponding mean torques were 6.7 Nm (SD 1.8) inversion, 8.1 Nm (SD 2.0) eversion, 7.2 Nm (SD 2.9) plantar flexion, 10.7 Nm (SD 3.5) dorsiflexion, 4.9 Nm (SD 1.9) internal rotation, and 6.1 Nm (SD 2.6) external rotation. To compare the different braces, the restriction of motion in relation to the no-brace condition was calculated for each direction (Table 3, Fig. 4).

All braces restricted the range of motion significantly in all directions compared to the no-brace condition. Furthermore, pronounced differences between braces were found (Table 4). The most distinct reduction in range of motion was obtained for inversion where the

most and least effective model showed passive restriction to 37% and 57% compared to the no-brace condition. Differences between the semi-rigid and soft braces were significant in nearly all cases, and therefore, a relatively clear distinction between semi-rigid and soft braces was possible. For eversion and plantar flexion, the rigid and the semi-rigid braces showed more stability than the soft braces but only some differences between these categories were significant. The rigid brace (01) showed a significantly higher stability compared to all other braces and the semi-rigid model (06) showed a reduced stability comparable to the soft braces. For dorsiflexion, internal and external rotation, the results are more consistent and only few significant differences between braces of all categories were found.

Under rapidly induced conditions, the maximum inversion angle without brace was 39° (SD 6), and to compare results to passive inversion, restriction of motion was also calculated in relation to the no-brace condition. All braces restricted maximum inversion significantly and restriction to 51% (SD 8) (model 02, 03) and 85% (SD 13) (model 07, 09) were reached for most and least effective models (Table 3). Focusing on the types of braces, models with stirrup design and stable/plastic reinforcements (models 02–05) restricted inversion more effectively than all other models. All differences between these braces and the remaining models were significant (Table 5).

A high correlation between passively induced and rapidly induced inversion ($R = 0.78$; $P = 0.0031$) was found. The amount of relative restriction for rapidly induced inversion decreased for all braces compared to passive inversion (Table 3).

4. Discussion

A comprehensive test of passive and rapidly induced stability in 10 different ankle braces was performed in a population suffering from chronic ankle instability. The

Table 2
Test–retest reliability (no-brace condition) for passive and rapidly induced stability tests

	Correlation coefficient <i>R</i>	<i>P</i> value
<i>Passive stability</i>		
Inversion (<i>n</i> = 17)	0.971	<0.0001
Eversion (<i>n</i> = 18)	0.967	<0.0001
Plantar flexion (<i>n</i> = 18)	0.982	<0.0001
Dorsiflexion (<i>n</i> = 18)	0.546	0.0178
Internal rotation (<i>n</i> = 15)	0.749	0.0008
External rotation (<i>n</i> = 18)	0.841	<0.0001
<i>Rapidly induced stability</i>		
Maximum inversion angle (<i>n</i> = 24)	0.817	<0.0001

Table 3
Passive and rapidly induced range of motion in % relative to condition without brace. The lower the value, the more effective the restriction. Code of braces: 01 = Caligamed®, 02 = Aircast®, 03 = Air Gel®, 04 = Air Brace®, 05 = Ligacast Anatomic®, 06 = Malleoloc®, 07 = Kalassy®, 08 = Kalassy S®, 09 = Fibulo Tape®, 10 = Dynastab®

% (SD)	No-brace	Rigid						Soft			
		01	02	03	04	05	06	07	08	09	10
<i>Passive</i>											
Inversion	100	38 (10)	40 (8)	37 (13)	44 (10)	38 (12)	54 (12)	54 (12)	57 (13)	56 (12)	47 (11)
Eversion	100	42 (10)	58 (9)	53 (18)	56 (12)	52 (12)	70 (10)	66 (12)	61 (13)	71 (10)	62 (11)
Plantar flexion	100	27 (13)	49 (9)	47 (14)	64 (8)	51 (11)	60 (8)	80 (8)	71 (10)	77 (9)	64 (10)
Dorsiflexion	100	66 (10)	52 (15)	50 (20)	48 (17)	51 (20)	58 (15)	60 (15)	52 (17)	72 (15)	44 (18)
Internal rotation	100	55 (22)	63 (18)	61 (18)	69 (19)	66 (14)	75 (13)	64 (20)	57 (17)	69 (19)	73 (17)
External rotation	100	81 (13)	83 (14)	79 (15)	81 (12)	77 (14)	86 (14)	85 (11)	87 (12)	87 (11)	85 (12)
<i>Rapidly induced</i>											
Inversion	100	77 (10)	51 (8)	51 (8)	54 (10)	56 (8)	69 (10)	85 (13)	79 (13)	85 (13)	74 (10)

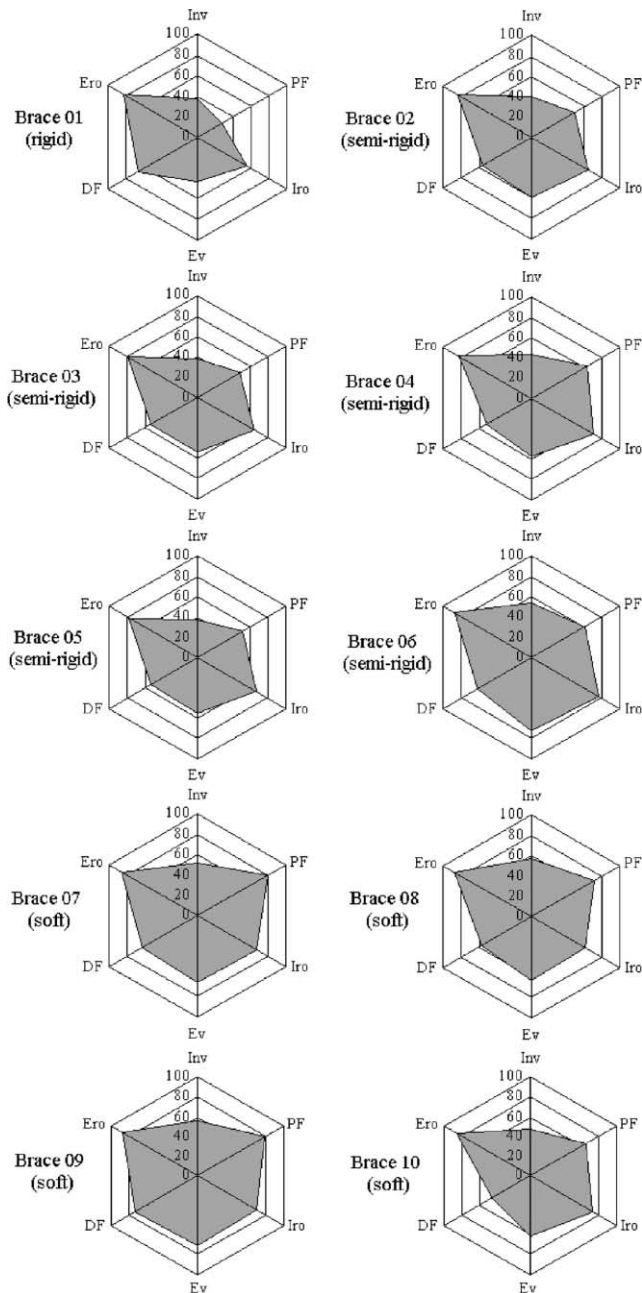


Fig. 4. Passive stability of each brace in six directions of motion. Inversion (Inv), eversion (Ev), plantar flexion (PF), dorsiflexion (DF), internal rotation (Iro) and external rotation (Ero) expressed as a percentage of the no-brace values. The size of the area in the spider web is smaller with a more pronounced stabilizing effect.

results of the present investigation identify large differences between braces and provide an objective basis to recommend or choose models for individual requirements. Combined testing of passive and rapidly induced inversion revealed important and new information about the characteristics of ankle braces.

Subjects with unstable ankle were used in this investigation because they have primarily problems with spraining their ankle and might react different to test

conditions compared to healthy subjects. This was found for a performance test when subjects with unstable ankle performed on average better with some brace models than without because they felt more stable and safe [16]. Furthermore, different results for inversion angles between unstable and healthy subjects to sudden inversion on a tilting platform might be likely because of differences in physiological parameters that are related to chronic ankle instability. Prolonged muscle reaction times of peroneus longus in restricting inversion was found in subjects with ankle instability [17].

Passive range of motion measurements without brace are comparable to values reported in the literature that were obtained with similar testing devices. Siegler et al. [8] reported mean angles in healthy subjects for in- and eversion of 34° and 26° , for plantar- and dorsiflexion of 37° and 26° and for internal- and external rotation of 25° and 33° with a similar testing apparatus and similar applied torques. These values are comparable to the ones in the present investigation especially when considering total range of motion in the three directions. Grimston et al. [18] reported values for 21–39 year old individuals of 21° and 17° in- and eversion, 48° and 26° for plantar- and dorsiflexion, and 40° and 36° of internal- and external rotation with a similar testing apparatus. Total range of motion for in- and eversion (38°) is less than reported in the present investigation (62°). This difference is probably due to the considerably lower torque (2 Nm) that was applied for both in- and eversion compared to average torques of 6.7 and 8.1 Nm in the present investigation. Bruns et al. [19] measured plantar- and dorsiflexion as well as internal- and external rotation in a cadaver experiment. The authors reported comparable ranges of motion for plantar–dorsiflexion (60°) but less movement for internal–external rotation (32°). The difference in internal- and external rotation is most likely due to the soft tissue and calf muscles impairing the fixation of the lower leg in the present in vivo investigation compared to an improved fixation of a cadaver leg in an in vitro experiment. However, range of motion measurements for in- and eversion as well as plantar- and dorsiflexion are comparable to values obtained in clinical examinations [20]. In consideration of the high test–retest reliability the present measuring device for passive stability provides reliable values.

Maximum angles under rapidly induced inversion conditions are also comparable to values reported in literature. Podzielnny and Hennig [14] reported mean angles of 38° for the no-brace condition using a tilting platform with a comparable inversion angle of 26° . Anderson et al. [13] measured maximum inversion angles of 27° for the no-brace condition using an inversion platform with a tilting angle of 22° . The lower maximum inversion angle was most likely due to the smaller tilting angle of the platform as compared to the present investigation. However, it is conceivable that a similar

Table 4

Significant differences between conditions (braces, no-brace) for in- and eversion, plantar- and dorsiflexion, internal and external rotation

			No-brace	Rigid	Semi-rigid						Soft			
				01	02	03	04	05	06	07	08	09	10	
<i>Inversion–eversion</i>														
				Inversion										
Eversion	Rigid	No-brace		***	***	***	***	***	***	***	***	***	***	
		01	***							***	***	***	***	*
		02	***	***						***	***	***	***	
		03	***							***	***	***	***	*
		04	***	***						***	*	***	***	
		05	***							***	***	***	***	*
	06	***	***	*	***	***	***							
	Soft	07	***	***		***	*	***						
		08	***	***										*
		09	***	***	**	***	***	***						*
10		***	***											
<i>Plantar flexion–dorsiflexion</i>														
				Plantar flexion										
Dorsi-flexion	Rigid	No-brace		***	***	***	***	***	***	***	***	***	***	
		01	***		***	***	***	***	***	***	***	***	***	
		02	***	*			***		**	***	***	***	***	
		03	***	**			***		***	***	***	***	***	
		04	***	***						***	***	***	***	
		05	***	**						***	***	***	***	
	06	***							***	***	***			
	Soft	07	***											***
		08	***	*										
		09	***		***	***	***	***	*	***	***			***
10		***	***					*	**	*	***			
<i>Internal rotation–external rotation</i>														
				Internal rotation										
External rotation	Rigid	No-brace		***	***	***	***	***	***	***	***	***	***	
		01	***						***				**	
		02	***											
		03	***											
		04	***											
		05	***											
	06	***									*			
	Soft	07	***											*
		08	***											
		09	***											
10		***												

*** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$.

inversion angle would have resulted when the tilting angle of the platform had been increased to 30°. In addition, high test–retest correlation coefficients underline the reliability of the customized goniometer system for measurements of hindfoot inversion inside the shoe.

In the present investigation, all braces significantly reduced passive range of motion compared to the no-brace condition. Inversion and eversion were restricted more effectively than plantar- and dorsiflexion followed

by internal and external rotation. This is in accordance with results of Shapiro et al. [10] and Bruns et al. [19] who tested various ankle braces in cadaver experiments. Both studies found significantly reduced range of motion for all directions between the condition without and with brace. Siegler et al. [8] compared the three-dimensional passive support characteristics of four ankle braces with a similar measuring device as in the presented study. Both lace-on and stirrup braces provided

Table 5
Significant differences between conditions (braces, no-brace) for maximum inversion in rapidly induced stability tests

		No-brace	Rigid					Semi-rigid				Soft				
			01	02	03	04	05	06	07	08	09	10				
<i>Maximum inversion</i>																
	No-brace															
Rigid	01	***														
Semi-rigid	02	***	***													
	03	***	***													
	04	***	***													
	05	***	***													
	06	***	*	***	***	***	***	***								
Soft	07	***		***	***	***	***	***	***	***						
	08	***		***	***	***	***	***	***	***						
	09	***		***	***	***	***	***	***	***						
	10	***		***	***	***	***	***			**			***		

*** = $P < 0.001$; ** = $P < 0.01$; * = $P < 0.05$.

significant limitation of motion compared to the no-brace condition. Alves et al. [7] and Hartsell and Spaulding [11] tested the passive support of ankle braces for inversion and eversion in a plantar flexed position. In both studies, restriction of motion was significant when wearing braces. Podzielnny and Hennig [14] tested four ankle braces under rapidly induced conditions on a tilting platform and found that all braces reduced inversion significantly compared to the condition without braces except for one soft bandage. Scheuffelen et al. [12] also reported a significant reduction of inversion when testing ankle braces on a tilting platform. Therefore, the results of the passive and the rapidly induced test of the present investigation are in accordance with the literature but provide a more comprehensive overview of various ankle braces. In addition, the above reported results were only valid for populations of healthy subjects, the results of the present investigation are valid for subjects with chronic ankle instability. This is important when focusing on prophylactic use of ankle braces to avoid recurrent ankle sprains.

Results of both test procedures may be related to categories and/or materials of braces. Models with stirrup design (02–05) appear to restrict inversion/eversion under passive and inversion under rapidly induced conditions significantly more effectively than all other braces. Surprisingly, the rigid brace did not provide the same stability as under passive conditions. The fixation of this brace to the lower leg with a strap system allowed too much relative movement between brace and shank leading to an increased inversion angle under rapidly induced conditions. For plantar flexion, soft braces allow significantly more movement than the other braces but there are also significant differences between some semi-rigid braces indicating the individual characteristics in spite of a similar design. For dorsiflexion, internal and external rotation results are more consistent and no differences between braces were relevant.

One major aspect of the present investigation was to focus on the relationship between passive and rapidly induced stability, and at this point it remains unclear whether the stabilizing effect of the braces under laboratory conditions is transferable to a more realistic situation when the foot–ankle complex is loaded with bodyweight. None of the investigations mentioned above have focused on both passively induced and rapidly induced stability. In the present study, a high correlation between passive and rapidly induced inversion was found and evaluation of rapidly induced stability showed that all braces restricted inversion significantly compared to the no-brace condition. The absolute inversion angle of 39° was the same for both tests but the amount of restriction decreased for the rapidly induced condition. For example, the soft brace (07) restricted passively induced inversion at the border of subjective tolerance to 54%, and rapidly induced inversion under bodyweight only to 85% compared to the no-brace situation (Table 3). These results indicate that differences between braces under passive conditions will be comparable to rapidly induced conditions but the amount of restriction for rapidly induced inversion is less than for passively induced inversion. Therefore, when recommending braces only on the basis of passive stabilizing characteristics it has to be considered that the amount of restriction is likely to be reduced for rapidly induced movements. It remains unclear if the results are transferable to other directions like eversion, plantar- and dorsiflexion, and internal–external rotation. Although the relationship between passive and rapidly induced stability for the other directions has not been tested in the present investigation it is likely that similar effects will occur for these directions because of the dynamics that result from loading with bodyweight. Therefore, the relationship between passive and rapidly induced conditions should be kept in mind when recommending braces for dynamic purposes on the basis of passive support characteristics.

With the results of the present study differences between braces can be well described and the model that stabilizes in directions that are necessary to counteract a known weakness can be found. One should keep in mind that stabilization against inversion is probably the major function of braces to avoid ankle sprains but limitations of motion in other directions are also very important [8,9]. Ankle sprains often occur in a combination of inversion, plantar flexion and internal rotation, and therefore, restriction of excessive plantar flexion and internal rotation may also be of great importance. Furthermore, it has to be considered that restriction of plantar flexion is important for the post-traumatic use of braces even though in sports, too much limitation of plantar- or dorsiflexion may impair performance. Injury prevention for the deltoid ligament requires limitation of eversion and external rotation.

To assist clinicians, physiotherapists and coaches to recommend as well as customers in choosing braces for individual requirements, the following recommendations according to Table 3 and Fig. 4 are made. At this point, it is important to recognize that recommendations focus on the test results made in this investigation.

- (i) If restriction of inversion under passive and rapidly induced conditions is the primary goal then semi-rigid braces with stirrup design (02–05) should be recommended. In addition to that, if restriction of plantar flexion and internal rotation is necessary, e.g. for early rehabilitation after injuries to the lateral ligaments, braces 02, 03, or 05 should be used. If a higher amount of plantar flexion is desirable then braces 04 and 10 (soft) should be appropriate.
- (ii) For pure restriction of eversion, braces 01–05 and 10 should be recommended.
- (iii) When using braces for prophylactic purposes in sports it has to be considered that braces should ensure the necessary stability without limiting performance. It was shown that no-brace except brace 01 limited performance in a short agility course with different movement tasks [16]. From that point of view semi-rigid models with stirrup design should be recommended. However, it has to be considered that the design of the stirrup braces may wear out shoes and is often not compatible to other equipment like shin guards in sports like soccer. Therefore, braces 06 and 10 should be appropriate for that purposes.
- (iv) If restriction of motion for inversion, eversion, plantar- and dorsiflexion without sport application and only for passively induced movements (post-traumatic circumstances, brace for bed rest) is the primary goal, then brace 01 should be appropriate.

In conclusion, all tested braces significantly restrict range of motion compared to the no-brace condition in passive and rapidly induced situations and results provide an objective basis for the selection of braces. Correlation between passive and rapidly induced results for inversion showed that passive support characteristics of braces are reflected under rapidly induced circumstances but the amount of restriction decreased, and therefore, caution should be taken when recommending braces for applications under dynamic circumstances only on the basis of passive support characteristics.

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