

Chronic instability of the ankle: the functional effect of three different ankle orthoses

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The main function of the tested ankle orthoses is to stabilise the ankle, i.e. to limit ankle movements in the medio-lateral direction, without interfering with plantar or dorsiflexion. The current study investigated the influence of wearing three different ankle orthoses (new type: Push® Aequi ankle orthosis; of the shelf: Aircast® Standard and Malleoloc®) upon the movements of the foot and ankle in a population with chronic ankle instability. The tested orthoses have a different construction, offering support to the ankle in a different way. Push Aequi has a medial support structure whereas Aircast standard and Malleoloc both have a bilateral support structure.

The general design of the study was comparative. Three complementary evaluations were carried out.

In the functional evaluation of the orthoses, the influence upon the movements of foot and ankle during the stance phase in running was determined through quantitative motion analysis. At this occasion, subjects were also questioned how they perceived comfort and support offered by the orthoses. These "running tests" took place at the Laboratory of Kinesiology, Department of Movement and Sports Sciences, Medical Faculty, University of Ghent in Belgium.

The biomechanical evaluation relied upon the measurement of the effect of the different orthoses upon the stiffness of the ankle during an isolated dynamic eversion-inversion test. The latter was performed passively with an ankle loading device at TNO Institute of Industrial Technology Eindhoven in the Netherlands.

All the subjects were screened by a clinician in terms of ankle instability. 15 subjects took part at the biomechanical evaluation in TNO. Nine of them performed the running tests in Ghent.

Study 1:

Chronic instability of the ankle : the effect of three different ankle orthoses upon movements of the foot and ankle during the stance phase in running

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Introduction

Ankle orthoses are widely used, both in prevention and rehabilitation of ankle sprains. The beneficial effect of these

prophylactic ankle devices relies upon the restriction of the inversion/eversion movement. This concept is especially applicable to subjects with chronic unstable ankles, which is found more in people enrolling in sports. As running forms a basic activity in sports, the current study investigated the influence of wearing three different ankle orthoses (new type: Push® Aequi ankle orthosis; of the shelf: Aircast® Standard and Malleoloc®) upon the movements of the foot and ankle during the stance phase in running. A comparison was made with running without ankle orthoses. The following working hypotheses were formulated:

- ankle orthoses do not influence plantar or dorsiflexion,
- ankle orthoses limit the range of medio-lateral movements of the ankle,
- stiffening the ankle penalises the deceleration mechanism by initial subtalar eversion, leading to a more pronounced external impact force when wearing an orthoses.

Method

The movements of the right lower extremity of nine well trained male runners were filmed frontally (200 frames/s) and sagittally (50 frames/s) while running at 4.5 m/s over a Kistler force platform. Subjects were fully informed about the procedures and gave written consent. Apart from uni- or bilateral chronic ankle instability, all subjects were injury and pain free at the moment of testing. The diagnosis of the chronic instability of the ankle was confirmed by an authorised clinician through a clinical examination. During the running experiments, they were all wearing the same type of neutral shoes (Adidas® T-response®) and performed three trials in four conditions: Push® Aequi, Aircast® Standard, Malleoloc® and without orthoses.

Rearfoot kinematics were deduced from the frontal high speed video images following a procedure proposed by Edington (1990). Subtalar inversion and eversion was quantified by the rearfoot angle γ and pronation-supination by the achilles tendon angle β (see fig.1a and 1c). The latter were calculated from just before touch down of the foot until the end of midstance (about 60% of stance phase). Discrete numerical values at touch down (γ_0, β_0) and at maximal pronation (see fig 1b), were used for statistical comparison of the different conditions.

Plantar and dorsiflexion were quantified by the ankle angle, measured at the ventral side between the foot and the shank. Again, discrete numerical values at touch down and at a maximal value, were used for statistical comparison of the different conditions.

The first vertical impact force peak from the vertical ground reaction force was described by the maximal amplitude, the time of occurrence of the latter and by the average loading rate during impact. For a complete description of the running set up and data gathering see De Clercq, 1997. Differences between conditions (4) were tested with the GLM procedure taking the intra- (3) and intervariability (9) into account (4x3x9, level of significance $p < 0.05$, SPSS). A questionnaire, based upon a rating scale from 1 to 10, was used to evaluate how the subjects perceived support and comfort offered by the tested ankle orthoses during running. The comfort was rated in a zero to ten scale, in which a ten indicates the "same comfort as running without the orthoses" and in which zero describes "very uncomfortable". The support was rated in the same kind of zero to ten scale, where ten means "very high support" and zero "no support", just like wearing the running shoe without the orthoses.

Results and discussion

a. Impact force

Mean \pm Std. Deviation (n = 9)	No Orthoses	Malleoloc [®]	Push [®]	Aircast [®]	GLM
<u>Maximal Amplitude</u>					
F _{zi} (in N)	1750.5 \pm 289.2	1723.8 \pm 229.4	1781.1 \pm 320.9	1765.3 \pm 287.4	NS
F _{zi} (in body weight)	2.3 \pm 0.3	2.3 \pm 0.2	2.3 \pm 0.3	2.3 \pm 0.3	NS
<u>Time to Max. Amplitude</u>					
t _i (in ms)	30.7 \pm 4.3	30.0 \pm 3.6	30.3 \pm 3.7	31.4 \pm 2.8	NS
<u>Average Loading Rate</u>					
G _{zi} (in body weight/s)	74.9 \pm 16.5	76.7 \pm 14.0	75.9 \pm 17.3	73.2 \pm 12.4	NS

Table 1 : variables describing the first vertical impact force peak of the ground reaction force during running without orthoses and with orthoses (Malleoloc[®], Push[®] Aequi, Aircast[®] Standard); NS is not significantly different at $p < 0.05$.

No statistical differences between conditions were found in the variables describing the vertical impact force peak. Wearing an ankle orthoses did not alter the characteristics of the external impact force.

b. Ankle sagittal plane motion

Mean \pm Std. Deviation (n = 9)	No Orthoses	Malleoloc [®]	Push [®]	Aircast [®]	GLM
<u>Ankle Angle</u>					
Touch down angle (in deg)	82.3 \pm 5.0	84.5 \pm 5.0	83.6 \pm 4.5	83.4 \pm 4.0	NS
Maximal plantar flexion (in deg)	89.7 \pm 3.5	90.4 \pm 3.6	89.8 \pm 3.7	89.4 \pm 4.0	NS
Maximal dorsal flexion (in deg)	69.2 \pm 3.0	70.3 \pm 3.0	70.1 \pm 3.2	68.9 \pm 4.4	NS
Total range of movement (in deg)	20.5 \pm 2.8	20.1 \pm 2.6	19.7 \pm 2.9	20.5 \pm 3.6	NS

Table 2: variables describing dorsal and plantar flexion of the ankle during stance phase in running without orthoses and with orthoses (Malleoloc[®], Push[®] Aequi, Aircast[®] Standard); NS is not significantly different at $p < 0.05$.

The flexion-extension movement of the ankle joint in the sagittal plane was not influenced by wearing an orthoses. These results indicate that the natural gross running movement is not disturbed by wearing any of the tested ankle orthoses. The latter compares rather well with the average score of 6 in the perceived comfort rating by the subjects.

3). This is due to an interaction between conditions and subjects: subjects respond in a different way on the tested orthoses (see fig 2). One of the reasons could be inter-individual differences in ankle anatomy.

c. Ankle frontal plane motion

Mean \pm Std. Deviation (n = 9)	No Orthoses	Malleoloc [®]	Push [®]	Aircast [®]	GLM
<u>Rearfoot Angle γ</u> γ_0 (at touchdown, in deg)	9.1 \pm 4.9	6.9 \pm 4.1	7.0 \pm 3.6	5.7 \pm 3.6	p < 0.05
<u>Subtalar Eversion Velocity</u> $d\gamma_{\max}/dt$ (max. initial velocity, in deg/s)	-285.8 \pm 95.6	-250.2 \pm 70.7	-211.6 \pm 62.2	-182.4 \pm 55.8	p < 0.05
<u>Achilles Tendon Angle β</u> β_0 (at touchdown, in deg)	1.6 \pm 6.0	-1.6 \pm 5.4	-1.4 \pm 5.3	-2.3 \pm 4.5	p < 0.05
β_{\max} (at max. pronation, in deg)	-14.3 \pm 4.2	-14.2 \pm 4.3	-12.8 \pm 4.1	-11.8 \pm 4.3	p < 0.05
β_{range} (total pronation, in deg)	15.9 \pm 4.1	12.6 \pm 2.8	11.5 \pm 2.8	9.5 \pm 2.0	p < 0.05
$t\beta_{\max}$ (time of max., in % foot contact time)	47.5 \pm 11.7	45.3 \pm 12.5	52.1 \pm 10.1	53.0 \pm 6.8	p < 0.05

Table 3 : variables describing the frontal plane movements of the foot-ankle complex during stance phase in running without orthoses and with orthoses (Malleoloc[®], Push[®] Aequi, Aircast[®] Standard). Horizontal lines group homogeneous subsets (Tuckey post hoc).

Concerning the influence of the tested orthoses upon the medio-lateral movements of the foot and ankle during the stance phase, we will first make a comparison with running without an orthoses. In all cases wearing one of the orthoses, the foot touches the ground in a less inverted position (γ_0 reaches closer to zero) causing a less explicit subtalar eversion during the weight acceptance phase : the initial subtalar eversion velocity ($d\gamma_{\max}/dt$) is decreasing while wearing one of the orthoses. Looking at the end of mid-stance, the Push[®] Aequi and Aircast[®] are stabilising the ankle: maximal pronation (β_{\max}) is smaller. The total range of movement (β_{range}) is clearly limited by all orthoses. These elements correlate well with the average perceived support score of 7 on the rating scale.

Because of the mechanical construction of the orthoses, a restriction of the initial inversion towards a more aligned position ankle-lower leg, is not surprisingly. On the other hand, the Push[®] Aequi and Aircast[®] distinctly confine the subtalar eversion movement too, although this might not be the prime design feature.

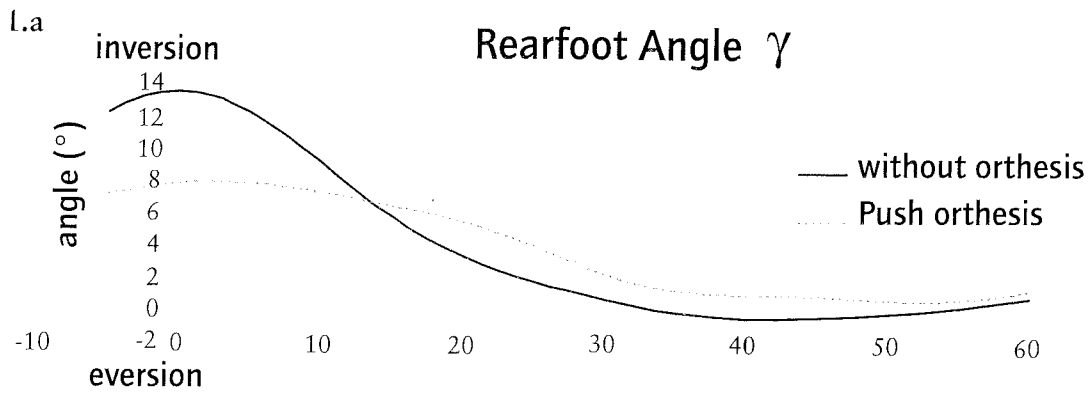
When comparing the three tested orthoses to each other, the picture is less clear, because no general trends can be observed (see the variation in homogeneous subsets in table

Conclusion

In runners with chronic instability of the ankle, wearing an ankle orthoses limits the ankle movements in the medio-lateral direction, without interfering with the natural running movement. It is difficult to rank the tested orthoses in terms of 'stability' because of inter-individual differences in the response. Therefore further research should consider the anatomical variation in foot-ankle morphology between subjects as a covariate.

References

- De Clercq, Ankle bracing in running: the effect of a Push[®] type medium ankle brace upon the movement of the foot and ankle during the stance phase. *Int. J. Sports Med.*, 18: 222-228, 1997
- C.J.Edington, E.C.Frederick,P.R.Cavanagh: Rearfoot motion in distance running. In Cavanagh P.R. (Ed): *Biomechanics of distance running*, Champaign, Illinois, 1990



1.b

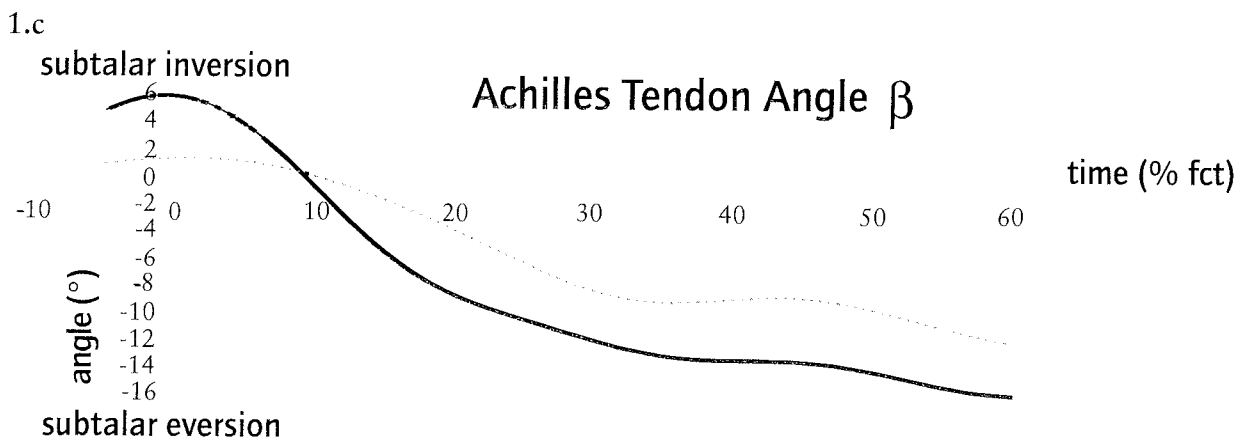
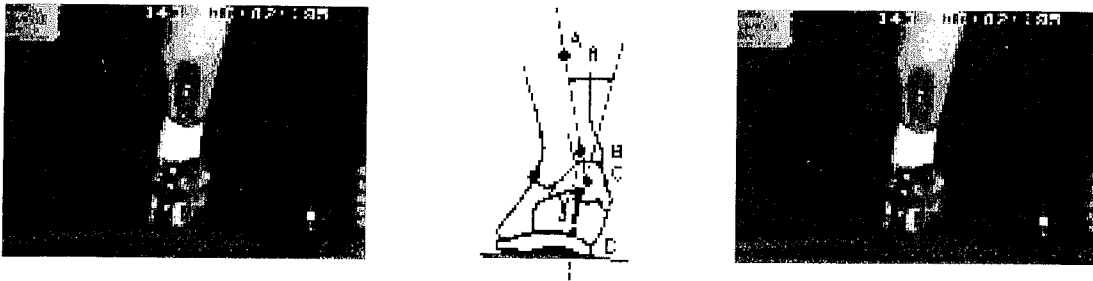


fig 1a. Temporal evolution for 1 trial of the rearfoot angle (γ); % fct = % of foot contact time, 0% = touch down, 60% = end of midstance.

fig 1b. Rear view (HS-video prints) at 0% and at maximal pronation ($\approx 50\%$).

fig 1c. Temporal evolution for 1 trial of the Achilles tendon angle (β); % fct = % of foot contact time, 0% = touch down, 60% = end of midstance.

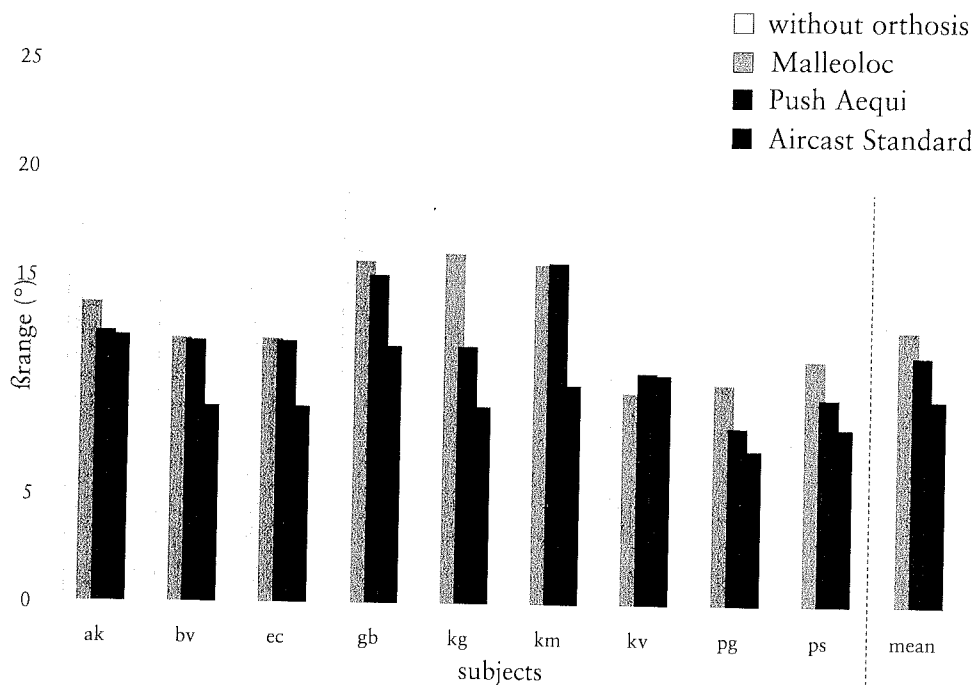


fig 2. Individuals range of pronation, in the four tested conditions, illustrating the subject dependent response.

Study 2

The effect of three different ankle orthoses upon the resistance against inversion and eversion in a passive dynamic test

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Method

The frontal plane ankle stiffness was measured in 15 subjects, with ankle instability, in four different conditions: without orthoses, or wearing the Push® Aequi, Aircast® Standard or Malleoloc®. This stiffness was quantified from the resistance of the ankle against a passive inversion and eversion movement at a low angular velocity (13.5 °/s). This was done with the so called "TNO ankle loading device". The linearized part of the moment/angle relationship revealed the total primary stiffness K_p , which can be separated in turn into a primary inversion stiffness K_p^I and a primary eversion stiffness K_p^E . The difference in the latter variables between the conditions without and with the ankle orthoses revealed the stiffening effect in a sound numerical way. The measurements were performed in two different anatomical positions: neutral foot position (0° flexion, 0° adduction) and a flexed position (10° flexion, 10° adduction). In all tests, the lower leg was axially loaded with 15 kg. For a complete description of the protocol see Verwaaijen, 1998.

Results and discussion

For the stiffness scores in all the tested conditions we refer to table 4 and 5.

As the detected differences between conditions go mostly in the same direction for the two tested foot positions, both scores were averaged.

Comparing the relative scores (primary stiffness with orthoses minus primary stiffness without):

- The rise in total primary stiffness is larger for Push Aequi, in comparison with Aircast and with Malleoloc; respectively + 0.34, + 0.29 and + 0.23 $Nm/^\circ$
- This is mainly due to the larger increase in primary inversion stiffness for the Push Aequi; respectively +0.38, + 0.28 and +0.22 $Nm/^\circ$.
- Concerning the rise in primary eversion stiffness, differentiation has to be made between the flexed foot position and the neutral foot position. During flexion, Push Aequi evokes a larger augmentation in resistance against eversion in comparison with Aircast and Malleoloc; respectively + 0.34, +0.30 and +0.25 $Nm/^\circ$ (See fig. 3). In the neutral foot position, the effect of Push Ortho and Aircast is not different, but the effect of the Malleoloc is lower.

The support concept of the Push Aequi relies upon a medial support structure and therefore it is not surprisingly that the increase in primary inversion stiffness is more prominent in comparison with the eversion stiffness. Nevertheless, wearing the Push Aequi results in an increase in primary eversion stiffness comparable to the Aircast.

C.Verwaaijen. Functionaliteit van drie enkelortheses: Push, Aircast en Malleoloc. TNO rapport MPO 98.1006/CV/ag, Eindhoven, 1998

General discussion of study 1 and 2

In a population characterised by chronic ankle instability, both studies clearly demonstrate that the tested ankle orthoses do what they are designed for: to stabilise the ankle in medio-lateral direction without interfering with the ankle mobility in the sagittal plane. Protection against excessive inversion and eversion is offered, but the gross natural running movement is not affected. This general conclusion from both the biomechanical and the functional test, is supported by the support and comfort perceived by the subjects when wearing the different orthoses.

In comparison with the Aircast and the Malleoloc, the Push Aequi evokes a more profound increase in primary ankle stiffness, mainly due to the increase in primary inversion stiffness, in the passive eversion/inversion test with the TNO ankle loading device.

Such a distinct difference cannot be detected in the functional running tests. This is due to the significant interaction effect between conditions (the tested orthoses) and subjects, meaning that subjects may respond in a different way to the three orthoses. This larger interindividual variation in the functional running test is not surprisingly because of the much more complex movement and loading pattern that occurs during the stance phase in running.

The passive eversion/inversion test has only one degree of freedom and occurs at a low angular velocity. During foot contact in running foot and ankle move in a complex three dimensional way (pronation/supination, dorsi/plantar flexion, adduction/abduction) and the loading (axial and shear forces) changes rapidly. And above all, both movement and loading will depend upon morphology and neuro-motor patterns, differing between individuals.

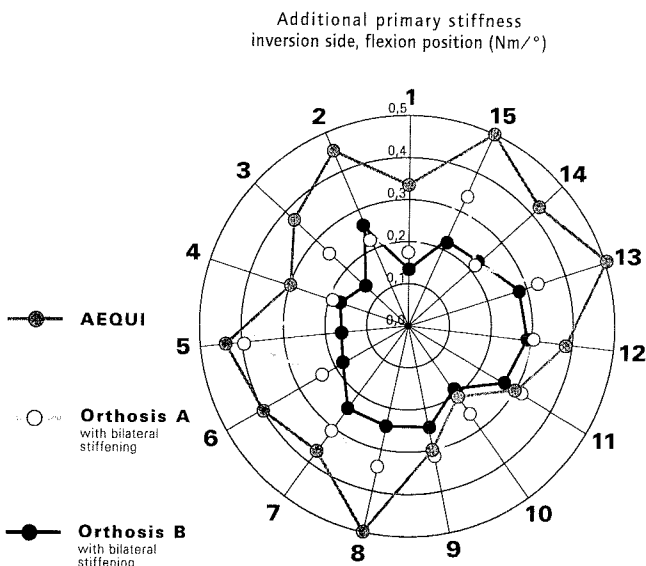


fig. 3. Additional primary stiffness of the 15 subjects Inversion side, flexion position (Nm/°)

		K _p		K _p ^I		K _p ^E	
		Mean	Std.	Mean	Std.	Mean	Std.
B0	neutral	0.307	0.056	0.287	0.048	0.401	0.074
	flexion	0.276	0.064	0.257	0.054	0.355	0.081
B1	neutral	0.637	0.096	0.658	0.106	0.689	0.105
	flexion	0.631	0.083	0.639	0.092	0.691	0.091
B2	neutral	0.598	0.070	0.580	0.078	0.687	0.087
	flexion	0.561	0.062	0.534	0.066	0.650	0.079
B3	neutral	0.534	0.084	0.507	0.069	0.638	0.109
	flexion	0.502	0.081	0.472	0.067	0.602	0.108
B1-B0	neutral	0.330	0.072	0.370	0.095	0.288	0.063
	flexion	0.355	0.068	0.382	0.086	0.336	0.067
B2-B0	neutral	0.291	0.064	0.293	0.077	0.286	0.069
	flexion	0.285	0.058	0.277	0.063	0.295	0.057
B3-B0	neutral	0.227	0.060	0.219	0.056	0.237	0.070
	flexion	0.226	0.058	0.215	0.045	0.248	0.071

Table 4: Primary stiffness scores (explanation see text) for the four tested conditions; B0 no orthoses, B1 Push Aequi, B2 Aircast, B3 Malleoloc

Parameter	Foot position	Hypothese	Confidence
K _p	neutral	B1-B0 larger than B2-B0	larger than 95%
		B1-B0 larger than B3-B0	larger than 99%
K _p	flexion	B1-B0 larger than B2-B0	larger than 99%
		B1-B0 larger than B3-B0	larger than 99%
K _p ^I	neutral	B1-B0 larger than B2-B0	larger than 99%
		B1-B0 larger than B3-B0	larger than 99%
K _p ^I	flexion	B1-B0 larger than B2-B0	larger than 99%
		B1-B0 larger than B3-B0	larger than 99%
K _p ^E	neutral	B1-B0 larger than B2-B0	no significant difference
		B1-B0 larger than B3-B0	larger than 99%
K _p ^E	flexion	B1-B0 larger than B2-B0	larger than 99%
		B1-B0 larger than B3-B0	larger than 99%

Table 5: statistical comparison of the increased primary stiffness for the three tested orthoses;