Improvement of Body Balance and Gait Stability by Means of the Hallufix® Foot Splint

Summary of a scientific study

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(Please note: The study is in the process for a scientific publication.)

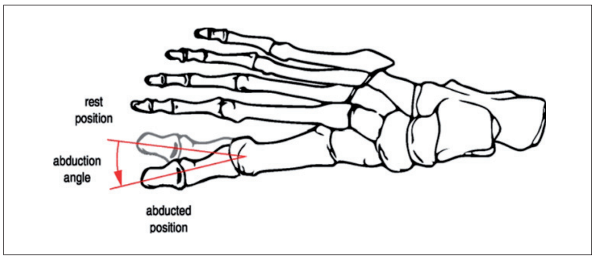
Study site:

Max Planck Institute for Human Cognitive and Brain Sciences, Munich, Germany

Study design:

Walking on a treadmill under three different conditions:

1. barefoot
2. with constrained toes (restriction, like in "stylish" shoes, without a heel)
3. with Hallufix® splints (correction of big toe angle towards "straight")



Measurements:

1. 3D measurement of the body in space (kinematics: posture & movement)
2. EMG measurement (muscle currents of the lower leg & the big toe abductor)

Method: general description

The tests were performed in the laboratory for sensomotoric coordination by Director Dr. Rafael Laboissière and the expert for "biomechanically optimised gait" physiotherapist Ralph Schleer, M. Sc. according to ethics standards of psychological research at the Max Planck Institute for Human Cognitive and Brain Sciences. The test persons walked on the treadmill while position and orientation of the body sections were measured with an optoelectronic device (Optotrak 3020, of Northern Digital Inc.). The electromyographic activity (EMG) of several selected muscles was also measured synchronously to the position data.

Test persons (height, weight and age are average values):

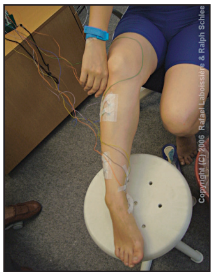
number:	n = 17	height: 1.74 m	weight: 74.9 kg	age: 26.4 years
female:	n = 8	height: 1.67 m	weight: 63.0 kg	age: 27.0 years
male:	n = 9	height: 1.80 m	weight: 78.4 kg	age: 25.7 years

The test persons are not ill but **healthy people**.

1. All test persons submitted a declaration of consent prior to the experiment and declared that they have not suffered and are not suffering from neurological or motoric ailments.
2. We kept only those test persons who had a hallux abduction angle of less than 19°; that is the threshold value of what is considered a pathological hallux valgus angle (Bonney & McNab 1952).

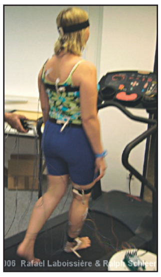
Execution:

Prior to setting the Optotrak marker and the EMG electrodes the test persons were made familiar with the treadmill. The practise session took five to ten minutes and at the end the test persons selected the velocity they felt most comfortable with. The test persons were instructed to look straight ahead and to avoid sidewards movements of the head that did not belong to walking. The sequence of the tested conditions was randomly distributed among the test persons.



EMG electrodes
muscle current

3D marker
movement recording



measurement

measurement of hallux
abduction angle (passive)

measurement of big toe
abduction angle (passive)

Results:

Large variation of the big toe abduction angle

The hallux abduction values varied considerably among the population with a **minimum value** of 1.62° and a **maximum value** of **15.90°**. Our **first conclusion** is that the abduction angle caused by the Hallufix® orthosis varies greatly among the test persons. Our **second conclusion** is that our male test persons have on average a lower abduction angle than the female ones. The total average of all test persons is 8.16°. The average value of the men is 7.33°, of the women 9.11°. The average value difference between the sexes is not significant ($t = 0.93$, p-value $= 0.37$) although it could point to the fact that women have a stronger adduced hallux because they wear tighter shoes than men. A more extensive and controlled study should be performed in order to check the hypothesis of different effects of the Hallufix® orthosis on a test person according to their sex.

Dynamic stability of the knee joint

The knee joint displayed an interesting effect in all conditions that can be related to gait stability. We calculated the average value of the integrated squared jerk for the knee joint of every test person and under every condition. The jerk is the third derivative of the position or – equivalent – the derivative of the acceleration (Flash & Hogan 1985). It has been demonstrated that **human movements** follow the **principle of "minimum jerk"** which is equivalent to **maximising the smoothness of movement** and a **minimising of energy input** (Hogan 1984). The average integrated squared jerk is defined as:

$$\frac{1}{T}\int_0^T dt|\dot{\mathrm{a}}|^2 \text{, wobei } \mathbf{a} = \ddot{\mathrm{x}}$$

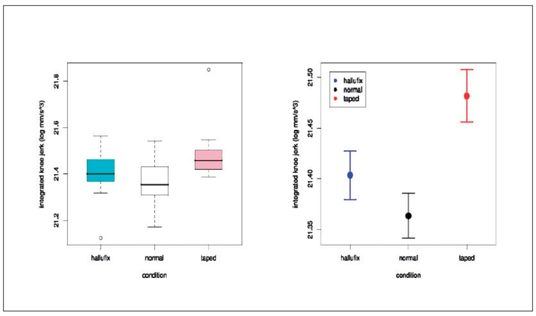


Fig. 25:
Left section: Distribution of the integrated knee-jerk in the three walking conditions (individual differences are eliminated).
Right section: Average values and standard error margins for the integrated knee-jerk in all conditions.

Cure advancements with the Hallufix® orthosis

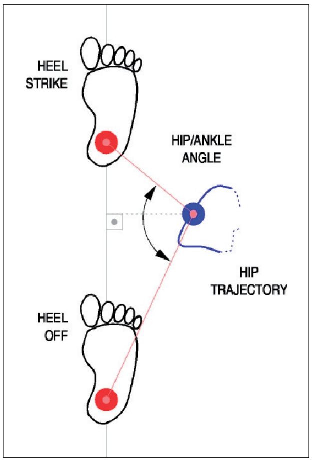


Fig 26:

Definition of the hip/heel angle as an indicator of gait stability. The figure displays the transversal plane. The positions of the right foot when touching down the heel (above) and lifting the heel (below) are indicated.

The positions of the heel during these two occurrences are marked by red dots. The trajectory of the hip during the heel contact phase is illustrated by the blue line. At every given moment the line connecting the hip and foot joint is vertical to the line connecting the heel positions while touching down and lifting the heel. The angle between the lines which connects the hip joint at this point with the heel touch down and lift positions is the variable under consideration in this study.

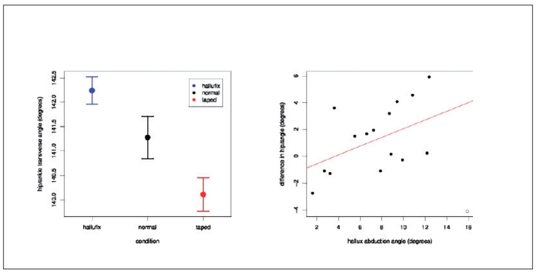


Fig 27:

Left section: Average value and standard error margins for the hip/foot joint angle in all walking conditions (individual differences eliminated)

Right section: Scatter diagram of the hallux abduction angle over the hip/foot joint angle. Die Regression line for the data with the exception of the test person at the lower right (open circle) is indicated by the red line.

The test described in the prior chapter refers to a dynamic aspect of the kinematics of the knee joint. We also checked if a change in the foot contact surface would have an effect on the kinematic pattern related to posture characteristics. We analyzed how the transversal position of the hip joint behaved with respect to the heel at the various conditions of the big toe angle.

The variable of interest is displayed in Fig. 26. It is calculated as the angle between two lines which connect the hip joint to the dots that denote the position of the heel during the occurrences "heel touches down" and "heel lifts up". The selected point in time of designating the position of the hip is that moment in which the line connecting the hip and the heel in the transversal plane is perpendicular to the line connecting the positions "heel touches down" and "heel lifts up".

The closer the hip joint is to the line "heel touches down"/"heel lifts up" the larger is the measured angle and the greater is the stability of the movement. The average values and the standard error margins for the hip/foot joint angle after removing the individual differences with p = 0.0047 (likelihood ratio = 10.69950, df = 2).

Since the fact that when the Hallufix® orthosis is used it has a pronounced effect on the position of the hip joint during the contact phase of the ipsilateral foot, it would be legitimate to ask if the change in the hallux abduction angle could be correlated to the change in the hip/foot joint angle on a basis of test person by test person. The results are displayed in Fig. 27 (right section). A Pearson's product/moment correlation test for these data display no significance (R = 0.113 p, p = 0.67). However, from the diagram it becomes apparent that one of the test persons (no. 13) is a true outlier. Interestingly enough he is the test person with the highest hallux abduction in the group. When this test person is removed from the correlation test the results are nearly significant, p = 0.065 (R = 0.471).

Changes in the EMG pattern of the muscle abductor halluxis longus (big toe abductor muscle)

There is **no systematic change** in the EMG patterns **in all conditions**. Although the variability among the test persons is quite high there are some mutual characteristics in the EMG patterns. **First of all**, almost all test persons display a peak for both conditions at the beginning of the gait cycle, between 0 and 20 %. It happens immediately after the occurrence touchdown of the foot and is probably associated with the requirement of bending the foot joint in order to stabilise the foot. For the same reason the toe flexor should be activated simultaneously and therefore the peak in EMG activity is caused by the abductor hallucis longus. Secondly, for most test persons there is a decline in EMG activity during the second half of the foot contact period. Some test persons show a relatively small activity bump around the event lifting up of the heel. Some test persons show multiple peaks and/or peaks within the balance period of the foot (the last 30 – 40 % of the cycle). The test persons (no. 8, no. 12 and no. 17) displayed an interesting pattern: all of these test persons display a peak in the normal condition around the event lifting up of the heel. This peak is considerably increased for test persons no. 8 and no. 12 and negligibly for test person no. 17 in the Hallufix® condition. (Since there are no systematic changes in all conditions, the diagrams and figures mentioned are not shown in this summary, but only the results and observations.)

Discussion:

Here is a summary of the major events of the study presented:

1. The constrained condition causes instability in the movement of the knee joint, illustrated by the significant increase in jerk when compared to the normal and Hallufix® condition. One could argue that this effect stems from the fact that the foot contact surface is decreased by binding the toes together. The value of the integrated jerk is slightly higher for the Hallufix® condition than the value for the normal condition, however the difference is probably not significant. Therefore our test results prove that an increased foot surface leads to an improved stability of the knee joint compared to the constrained condition. Our results do not prove that an increased foot surface improves the stability of the knee joint when compared to the normal condition. However, that could be due to the fact the Hallufix® condition was new to the test persons and that they did not have the time to adapt during the three-minute walking period. An interesting question for further analysis will be how the test persons adapt to the Hallufix® orthosis in the long term.
2. The Hallufix® condition significantly contributes to a shift of the hip joint towards the foot joint in the transversal plane during the heel-ground contact phase. That could indicate that the Hallufix® orthosis improves posture while walking by avoiding extreme sidewards motion of the pelvis as could be observed in the constrained condition. The leg axes are verticalised.
3. A certain correlation could be observed between the hallux abduction angle caused by the orthosis and the hip/foot joint angle which was measured. One of the test persons seems to be clearly an outlier. Without him we obtain a significant, howbeit weak, correlation. The larger the angle corrected by the Hallufix® splint the larger is the hip/foot joint angle, i. e. the larger is the correction of the course of the leg axis. Due to the weak significance we can only speak of a trend with this study. Further studies should be performed on this issue.
4. Comparing the EMG patterns for the various conditions no significant change was found that applied to all test persons. The EMG patterns of the test persons displayed a wide variation.

Results:

1. The jerk in the knee is significantly lower with the Hallufix® splint (large walking surface) than in the constrained condition (tight walking surface).
2. The hip is significantly closer above the heel with the Hallufix® splint (large walking surface) than in the constrained condition (tight walking surface) and in the normal condition (small walking surface).
3. Since the significance is low a trend is recognisable: The larger the angle corrected by the Hallufix® splint the larger the hip/foot joint angle.

Comments on the results:

Less jerk means:

- less stress for the joints and for movement,
- less loss of the trajectory,
- no constant correction and therefore
- less energy input in order to stabilise.

Gait is smoother, more guided, more secure and more stress-free
Every movement outside of the plane of the foot is a “waste” of energy and leads to an unsteady, asymmetrical and insecure gait.

Therefore the erection of the leg axis means:

- a verticalisation of movement,
- more symmetry in load (cartilage) and in movement (harmony),
- more stable, static and secure gait,
- less stopping and accelerating.

Gait flow is more economical, more stable, easier and “freer”, relieves the cartilage and is more harmonic.

The total balance of the body is improved!

Statement as conclusions to the results:

By wearing the Hallufix® splint **statics, dynamics and total balance** of the body are optimised, gait stability is improved – even for those who are not affected by hallux valgus. That leads to:

- **economy and freedom of movement**
- **with more movement security**
- **at more relief of the joint.**

About the author:

Ralph Schleer – conducting expert of this study
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sports therapist 1: psychosomatics, psychiatry, addiction
sports therapist 2: orthopaedics, traumatology, rheumatology, internal medicine