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Running shoes effect on kinematics, muscle activity and comfort perception

Worksheets

Anders Nielsen and Morten Kudsk

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Supervisor: Uwe G. Kersting
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Paradigms

"The preferred movement path"

A review by Nigg et al. (2015) suggested that the choosing of a running shoe should be based on a new paradigm called "the preferred movement path" instead of the method used in the last three decades (Enke, Laskowski & Thomsen 2009). "The preferred movement path" paradigm is based upon the actual movement of the skeleton exposed to shoe or insole interventions. Stacoff et al. (2000) and Stacoff et al. (2001) have shown that such intervention have a small and nonsystematic change of the tibia and the calcaneus during running. These studies indicate that the primary change of the calcaneus and the tibia appeared in the range of movement but not in the path of movement. However, some running shoes aim at altering the subject-specific movement path of the skeleton, which will result in change of the muscle activation due to the muscles trying to ensure the skeleton's preferred movement path. This change in muscle activation has been proven by Wakeling et al. (2002) who showed that the muscle activation changes, due to insole interventions, in a subject-specific manner. Therefore, "the preferred movement path" paradigm suggests that the choosing of running shoes should be the shoe that allows the skeleton to move within its preferred path with the least amount of muscle activity (Nigg et al. 2015).

"The comfort filter"

"The comfort filter" is another paradigm suggested by Nigg et al. (2015), for choosing the most appropriated footwear when running. This paradigm suggests that runners should choose their running shoes based on their own subject-specific comfort. All runners have different associations to what comfort is, which has been shown by Mündermann et al. (2001), who tested the comfort of six different insoles. The results showed that the frequency of the most comfortable insoles was a proximally the same for five of the six insoles, which suggests that runner's rate comfort differently based on their own subject-specific comfort filter.

Xsens MVN Link

In this study Xsens MVN Link has been used as a wearable motion capture system to quantify the kinematic of each subject's running style. The Xsens MVN Link consists of 17 wired MTx sensors (38x53x21 mm and 30 g), placed on the feet, lower legs, upper legs, shoulders, upper arms, lower arms, hands and the head (Roetenberg, Luinge & Slycke 2013). However, in this study only the left lower extremity sensors have been used (figure 1). The MTx sensor consists of a 3D MEMS accelerometer, 3D MEMS gyroscope and a 3D magnetometer (Roetenberg, Luinge & Slycke 2013).

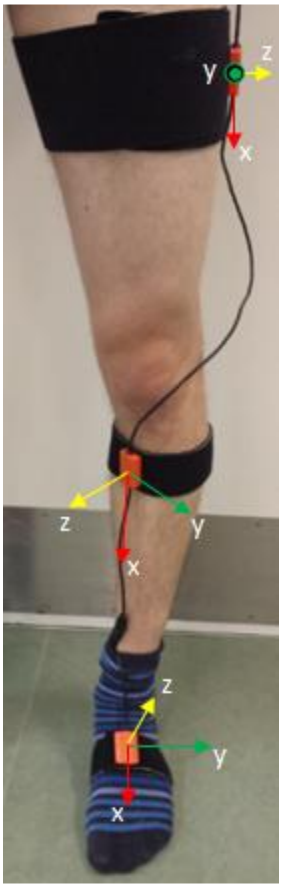

Figure 1 shows the placement of the Xsens MVN Link sensors on the left leg, where red is the x-direction, green is the y-direction and yellow is z-direction. During the tests the sensors were placed beneath the straps.

Before using the Xsens MVN Link, a calibration needs to take place (Roetenberg, Luinge & Slycke 2013). The calibration consists of a anthropometrics data of the subject including; height, foot size, arm span, ankle height, hip height, hip width, knee height, shoulder width, shoe sole height. Afterwards a calibration of the system were done, where the subject need to assume a certain position (Neutral position). Once the calibration has taken place, the Xsens MVN Link is fully functional and ready for recording.

MEMS Accelerometer

A MEMES accelerometer is a devices that measures accelerations in 3 dimensions; x-, y- and z-direction. Most MEMS accelerometer is based upon a displacement of a known mass as a result of change in acceleration of a simple mass spring system. Therefore, two physical principles are used to measure acceleration; Newton's second law (equation 1) and hook's law (equation2) (Lab#7.).

Equation 1: $\boldsymbol{F = m * a}$

Equation 2: $\boldsymbol{F = k * x}$

Where *F* is the force, m is the known mass, *a* is the acceleration, *k* is the spring stiffness and *x* is the displacement of the known mass. When the mass undergoes acceleration it will result in a displacement of the known mass. This displacement is then used to calculate the magnitude of the acceleration (equation 3).

Equation 3: $\boldsymbol{a = \frac{k*x}{m}}$

MEMS Gyroscopes

A MEMS gyroscope is based upon the Coriolis effect. The Coriolis effect is seen when a known object moves in a rotating frame of reference with a certain velocity. The force acting on this object is called Coriolis force (equation 4). This force is proportional to the rotation velocity of the frame of reference and the direction is perpendicular to the direction of the rotation in the reference frame (Renaut 2013).

Equation 4: $\boldsymbol{F = 2m * (v * \Omega)}$

Where *F* is the force, *m* is the known mass, *v* is the velocity of the mass and *Ω* is the angular velocity. The angular velocity can then be calculated once the force has been measured.

EMG

EMG is a method for detecting myoelectric signals within the muscles. This was used in the current study for analyzing the muscles activation pattern during running using Ambu (Ambu, Ballerup, Denmark). EMG has been used in medical research, rehabilitation, ergonomic and sports science. EMG helps to analyze muscular performance, which is in this case how the muscles react on different running shoes (Konrad 2006).

During running the depolarization and repolarization process in a muscle is what an EMG signal measures. In other words it measures the action potential at the end of the motor endplats on the motor unit (Konrad 2006).

Different factors can influence the EMG signal such as; tissue type, tissue thickness, physiological changes and temperature. (Konrad 2006)

Other muscles close to the sensor placement can also affect the EMG signal. This is due to that a sensor can accidental detect a neighboring muscles signal. This is called "cross talk" and usually does not exceed 10-15 % of the overall signal if present at all. External noise, meaning a noisy electrical environment which comes from external electrical devices, can also be a factor that influences the EMG signal. The EMG baseline can be affected by possible noise that the hardware makes. (Konrad 2006)

To ensure high quality of an EMG signal, skin preparation and electrode positioning should be made with caution. A simple alcohol cleaning may be sufficient for a slow or static movement, whereas if a more dynamic movement is planned, such as running, a thorough preparation is needed. (Konrad 2006)

Electrodes

The electrodes (model Ambu Neuroline 720) used in the current study were surface electrodes. Surface electrodes are placed on the skin and detect only surface muscles, which is a limitation. The benefits of using surface electrodes, are that they are easy and quick to handle and hygienic is not a problem. Compared to other types of electrodes, the wet-gel electrodes have the best skin impedance values. (Konrad 2006)

If deeper muscles are investigated, the use of fine wire electrodes is preferred. These sensors are inserted with a needle into the muscles and connected to a steel spring adapter. (Konrad 2006)

Running shoes

A running shoe has five major components: outersole, midsole, board lasting, heel-counter and upper (Figure 2). During running, the outersole of a shoe is in direct contact with the ground during every stance phase. Its main function is to provide good traction. The durability of the outersole (figure 2) should be good, meaning it should not wear down, especially at the heel. (Noakes 2003)
The shoes midsole absorb the shock forces during landing when running. Depending on which material is used, a certain amount of energy is returned with every deformation of the midsole. (Noakes 2003)
Materials like expanded thermoplastic polyurethane pellets (TPU) and ethylene vinyl acetate (EVA) are used as midsoles in today's commercial running shoes. These midsoles alter the softness and affect the energy return of a shoe (Worobets et al. 2014) (figure 2).
A board last is used to separate the midsole with the upper and can be used to alter the stiffness of the shoe. The heel counter on a shoe is a firm structure which surrounds the heel, in order to make the foot stabile inside the shoe (figure 2). The upper surrounds and covers the foot. (Noakes 2003)

Figure 2 shows a running shoe with the five major components

The six different shoes used in this study are different. The Adidas Ultraboost (Ultra), Adidas Supernova Sequence (Seq) and Adidas Supernova Glide Boost (Glbo) all have TPU midsoles, whereas the Adidas Adipure 360.3 (Adp) and Adidas Adizero Primeknit 2.0 (Adz) have EVA midsoles (Adidas). According to Brooks, their Adrenaline 15 (Br15) uses a midsole of non-newtonian as midsole (Brooks). These different midsoles are some of the components that affect the properties of the shoes, such as cushioning, bending and torsion (table 1).
The six different shoes are characterized differently, meaning Adidas characterize the Ultra and Glbo as neutral shoe, the Seq as a stabile shoe and the Adp as a training shoe (Adidas). The Adz was not characterized. Brooks characterize their Br15 as a cushioning shoe with high support (Brooks). The shoes

have different mechanical properties which were assessed (the left shoe in all cases) by undertaking mechanical tests that took place at Adidas' headquarter in Herzogenaurach, Germany (table 1).

Table 1 shows the different properties of the six different shoes tested.

Model	Weight	Midfoot bending	Energy loss midfoot	Forefoot bending	Energy loss forefoot	Rearfoot cushioning	Energy loss Rearfoot	Forefoot cushioning	Energy loss Forefoot	Torsion inversion	Torsion eversion
Adp	225.30 g	36 Nmm	46 %	15 Nmm	33 %	239 Nmm 218 Nmm	36 %	166 Nmm 439 Nmm	34 %	2.46 Nm	2.15 Nm
Adz	230.70 g	45 Nmm	46 %	25 Nmm	34%	176 Nmm 146 Nmm	39 %	167 Nmm 297 Nmm	31 %	2.89 Nm	3.71 Nm
Seq	298.90 g	47 Nmm	47 %	21 Nmm	31 %	112 Nmm 173 Nmm	31 %	120 Nmm 233 Nmm	30 %	3.24 Nm	2.90 Nm
Glbo	310.30 g	30 Nmm	38 %	16 Nmm	32 %	82 Nmm 174 Nmm	27 %	102 Nmm 266 Nmm	28 %	1.52 Nm	2.70 Nm
Ultra	294.1 g	21 Nmm	33 %	9 Nmm	31 %	62 Nmm 103 Nmm	24 %	102 Nmm 257 Nmm	24 %	1.80 Nm	1.72 Nm
Br15	320.80 g	56 Nmm	51 %	29 Nmm	39 %	118 Nmm 158 Nmm	41 %	180 /mm 274 Nmm	35 %	3.82 Nm	3.98 Nm

Comfort

In this study comfort is being quantified to evaluating each shoe tested for each subject.

Comfort is suggested to be an important aspect for shoe manufacturing (Che, Nigg & de Koning 1994) (Hoerzer et al. 2015). However, comfort can be difficult to define (Che, Nigg & de Koning 1994) because everyone has their own opinion on what comfort is (Mündermann et al. 2002). Therefore, comfort cannot just be categorized as the softest or with the most shock damping effect. Comfort is also difficult to quantify because individuals tend to compare the comfort of a shoe with other shoes they have worn in the past. This compromises the reliability due to the fact that different runners do not have the same basis for evaluating different shoes, since they have not worn the same shoes in the past (Mündermann et al. 2002). This is one reason why a reliable method for measuring comfort not has been developed yet. However, Mündermann et al. (2002) suggested that comfort should be measured with the use of a visual analogue scales (VAS) like the ones used for measuring pain (Borg scale). Mündermann et al. (2002) uses the same VAS as the one that have been used in this current study (figure 3). Mündermann et al. (2002) also suggests that the implementation of a control condition could improve the reliability of comfort measures. They implemented a control condition between each tested condition to insure the subjects had the same basis for evaluating the upcoming test condition. It was also done to evaluate if the ratings of the control condition where the same for each time to insure higher reliability. Other studies use different method to ensure high reliability.

Luo et al. (2009) uses a different method to ensure high reliability. They rate one shoe condition, there has been randomly chosen, twice. If the two ratings of the same shoe condition not were similar the subject was discarded from the investigation.

The Method used in this project is a combination of the two method presented. As mentioned the same VAS used by Mündermann et al. (2002) was also used in this study. In this study a control condition was also implemented. However, the control condition was not implemented between each shoe tested. Instead the control shoe was implemented as the first shoe tested and the last shoe tested. The reliability will then be tested with the same method as Luo et al. (2009), where the control shoe will be the ones rated twice.

Heel Cushioning

Not comfortable at all — Most comfortable condition imaginable

Heel cup fit

Not comfortable at all — Most comfortable condition imaginable

Forefoot Cushioning

Not comfortable at all — Most comfortable condition imaginable

Shoe heel width

Not comfortable at all — Most comfortable condition imaginable

Medio-lateral control

Not comfortable at all — Most comfortable condition imaginable

Shoe forefoot width

Not comfortable at all — Most comfortable condition imaginable

Arch height

Not comfortable at all — Most comfortable condition imaginable

Shoe lenght

Not comfortable at all — Most comfortable condition imaginable

Overall comfort

Not comfortable at all — Most comfortable condition imaginable

Figure 3 shows the questionnaire for comfort assessment. The questionnaire was obtained from Mündermann et al (2002)

Setup

The test setup used in this study is seen in figure 4. It is seen that the close fitting sock is surrounding the Xsens MVN Link sensors (black straps) and the EMG electrodes, with the wires coming out beneath his shorts. The subject is standing on the treadmill and is about to start the testing procedure.

Figure 4 shows a subject in the test setup.

Results

The results of the kinematics for all shoes tested, including the control condition, for each subject is presented in this section, along with the correlation coefficient between the shoe with the highest EMG impulse and the shoe with the lowest EMG impulse.

Kinematik

Subject 2

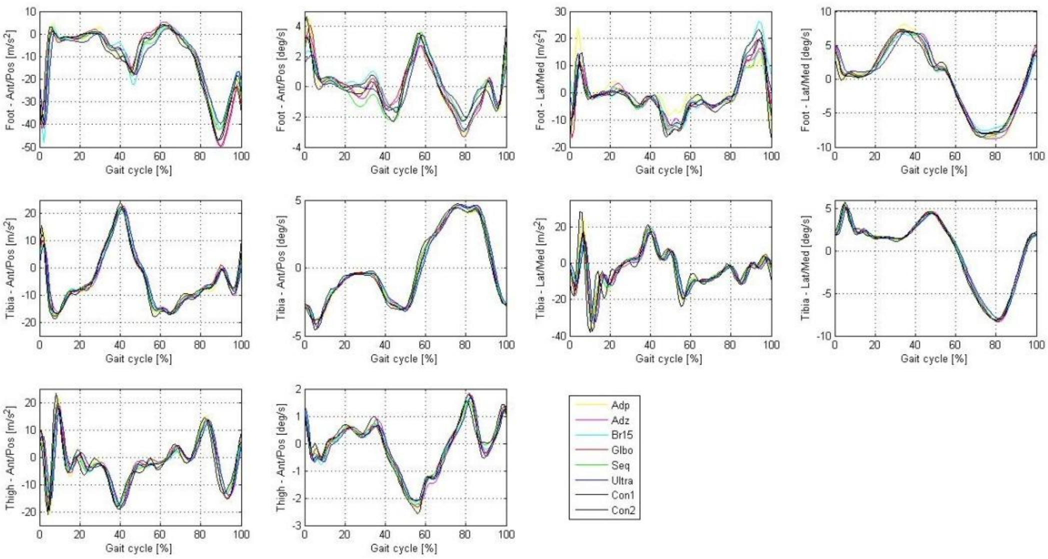

Figure 5 shows the path of movement for all shoes tested including the control condition. The color coding are: Adp(yellow), Adz(purple), Br15(cyan), Glbo(red), Seq(green), Ultra(blue), Con1(black) and Con2(black)

Table 2 shows the kinematic correlation coefficients between the shoe with the highest and lowest EMG impulse. The correlation coefficients for con1 vs. con2 are also displayed. Significant differences are marked with a (*).

Kinematics parameter	Correlation coefficient Adz vs. Ultra	Correlation coefficient Con1 vs. Con2
Foot		
Acc. Ant/Post	0.93	0.95
Ang. Vel. Ant/Post	0.80	0.86
Acc. Lat/med	0.90	0.90
Ang. Vel. Lat/Med	0.99	0.98
Tibia		
Acc. Ant/Post	0.97	0.96
Ang. Vel. Ant/Post	0.99	0.98
Acc. Lat/med	0.89	0.74
Ang. Vel. Lat/Med	0.99	0.99
Thigh		
Acc. Ant/Post	0.90	0.85
Ang. Vel. Ant/Post	0.94	0.92

Subject 3

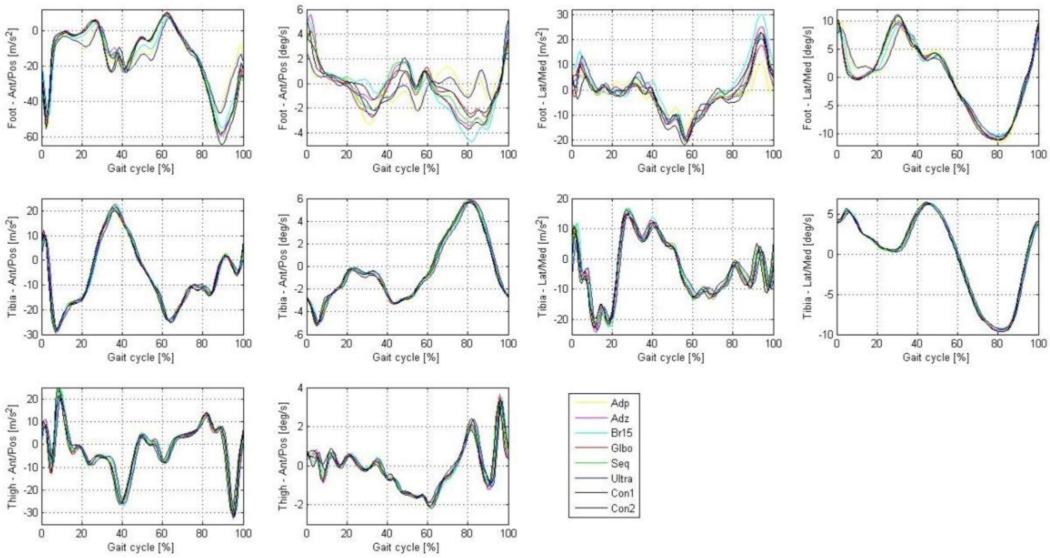

Figure 6 shows the path of movement for all shoes tested including the control condition. The color coding are: Adp(yellow), Adz(purple), Br15(cyan), Glbo(red), Seq(green), Ultra(blue), Con1(black) and Con2(black)

Table 3 shows the kinematic correlation coefficients between the shoe with the highest and lowest EMG impulse. The correlation coefficients for con1 vs. con2 are also displayed. Significant differences are marked with a (*).

Kinematics parameter	Correlation coefficient Glbo vs. Adp	Correlation coefficient Con1 vs. Con2
Foot		
Acc. Ant/Post	0.90	0.98
Ang. Vel. Ant/Post	0.53	0.85
Acc. Lat/med	0.87	0.93
Ang. Vel. Lat/Med	0.97	0.99
Tibia		
Acc. Ant/Post	0.99	0.99
Ang. Vel. Ant/Post	0.99	0.99
Acc. Lat/med	0.95	0.93
Ang. Vel. Lat/Med	1	1
Thigh		
Acc. Ant/Post	0.95	0.93
Ang. Vel. Ant/Post	0.94	0.89

Subject 4

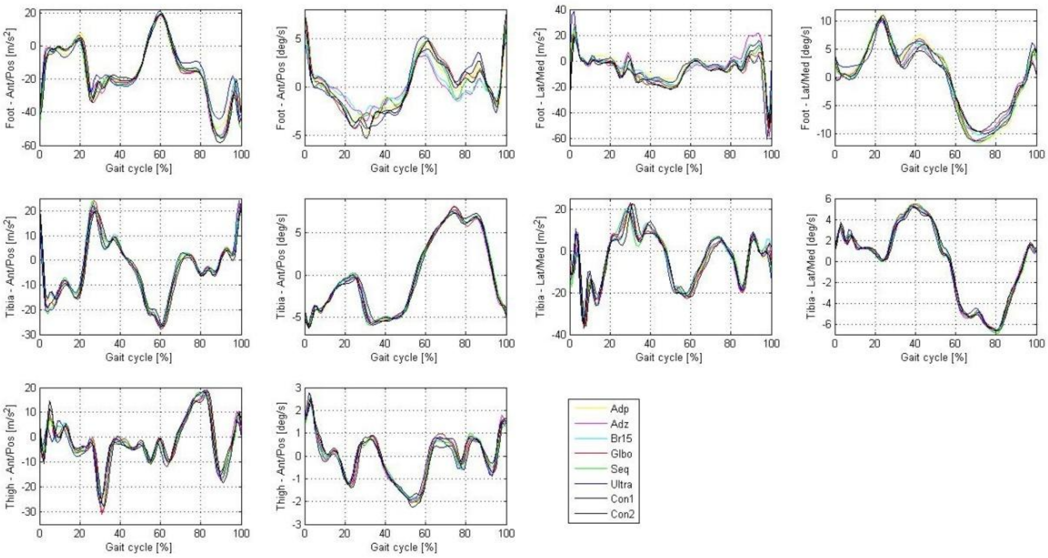

Figure 7 shows the path of movement for all shoes tested including the control condition. The color coding are: Adp(yellow), Adz(purple), Br15(cyan), Glbo(red), Seq(green), Ultra(blue), Con1(black) and Con2(black)

Table 4 shows the kinematic correlation coefficients between the shoe with the highest and lowest EMG impulse. The correlation coefficients for con1 vs. con2 are also displayed. Significant differences are marked with a (*).

Kinematics parameter	Correlation coefficient Seq vs. Adp	Correlation coefficient Con1 vs. Con2
Foot		
Acc. Ant/Post	0.94	0.95
Ang. Vel. Ant/Post	0.91	0.95
Acc. Lat/med	0.79	0.90
Ang. Vel. Lat/Med	0.99	0.98
Tibia		
Acc. Ant/Post	0.95	0.96
Ang. Vel. Ant/Post	0.99	0.99
Acc. Lat/med	0.90	0.89
Ang. Vel. Lat/Med	0.99	0.99
Thigh		
Acc. Ant/Post	0.89	0.88
Ang. Vel. Ant/Post	0.93	0.91

Subject 5

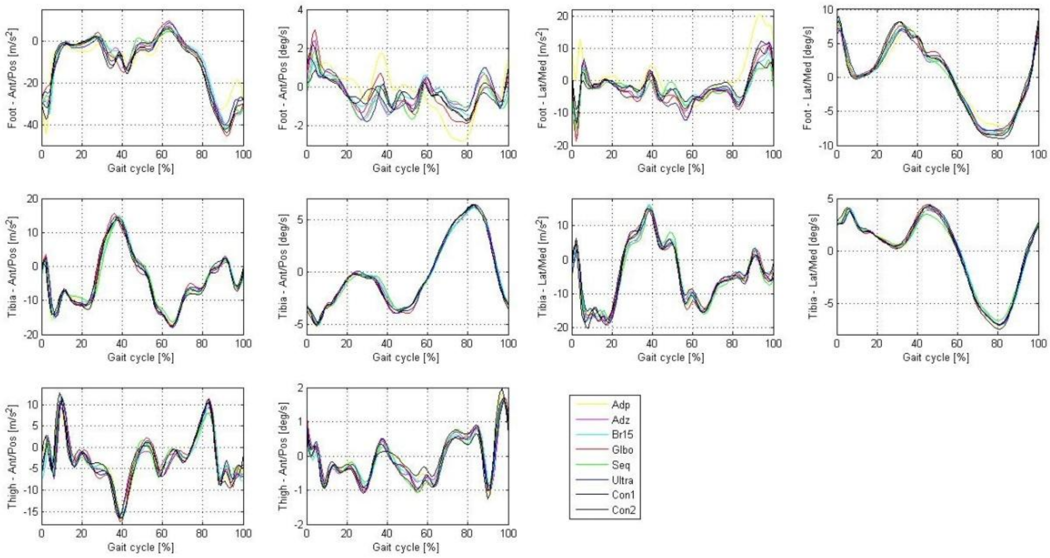

Figure 8 shows the path of movement for all shoes tested including the control condition. The color coding are: Adp(yellow), Adz(purple), Br15(cyan), Glbo(red), Seq(green), Ultra(blue), Con1(black) and Con2(black)

Table 5 shows the kinematic correlation coefficients between the shoe with the highest and lowest EMG impulse. The correlation coefficients for con1 vs. con2 are also displayed. Significant differences are marked with a (*).

Kinematics parameter	Correlation coefficient Adz vs. Adp	Correlation coefficient Con1 vs. Con2
Foot		
Acc. Ant/Post	0.89	0.96
Ang. Vel. Ant/Post	0.34	0.62
Acc. Lat/med	0.61	0.81
Ang. Vel. Lat/Med	0.99	0.99
Tibia		
Acc. Ant/Post	0.96	0.96
Ang. Vel. Ant/Post	0.99	0.99
Acc. Lat/med	0.95	0.94
Ang. Vel. Lat/Med	0.99	0.99
Thigh		
Acc. Ant/Post	0.84	0.85
Ang. Vel. Ant/Post	0.84	0.83

Subject 6

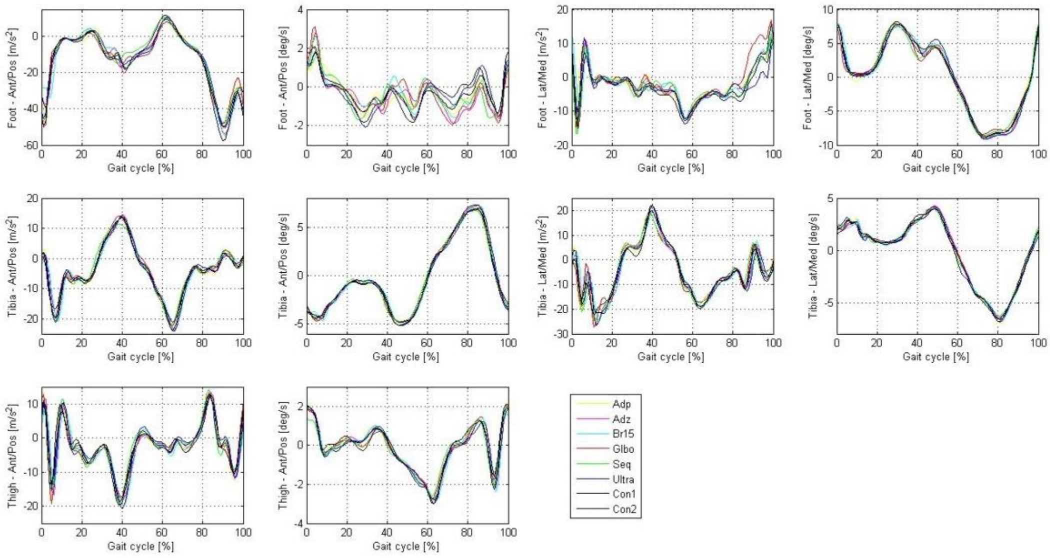

Figure 9 shows the path of movement for all shoes tested including the control condition. The color coding are: Adp(yellow), Adz(purple), Br15(cyan), Glbo(red), Seq(green), Ultra(blue), Con1(black) and Con2(black)

Table 6 shows the kinematic correlation coefficients between the shoe with the highest and lowest EMG impulse. The correlation coefficients for con1 vs. con2 are also displayed. Significant differences are marked with a (*).

Kinematics parameter	Correlation coefficient Adz vs. Glbo	Correlation coefficient Con1 vs. Con2
Foot		
Acc. Ant/Post	0.93	0.95
Ang. Vel. Ant/Post	0.70	0.63
Acc. Lat/med	0.81	0.80
Ang. Vel. Lat/Med	0.98	0.99
Tibia		
Acc. Ant/Post	0.95	0.95
Ang. Vel. Ant/Post	0.99	0.99
Acc. Lat/med	0.89	0.92
Ang. Vel. Lat/Med	0.98	0.99
Thigh		
Acc. Ant/Post	0.81	0.80
Ang. Vel. Ant/Post	0.89	0.90

Subject 7

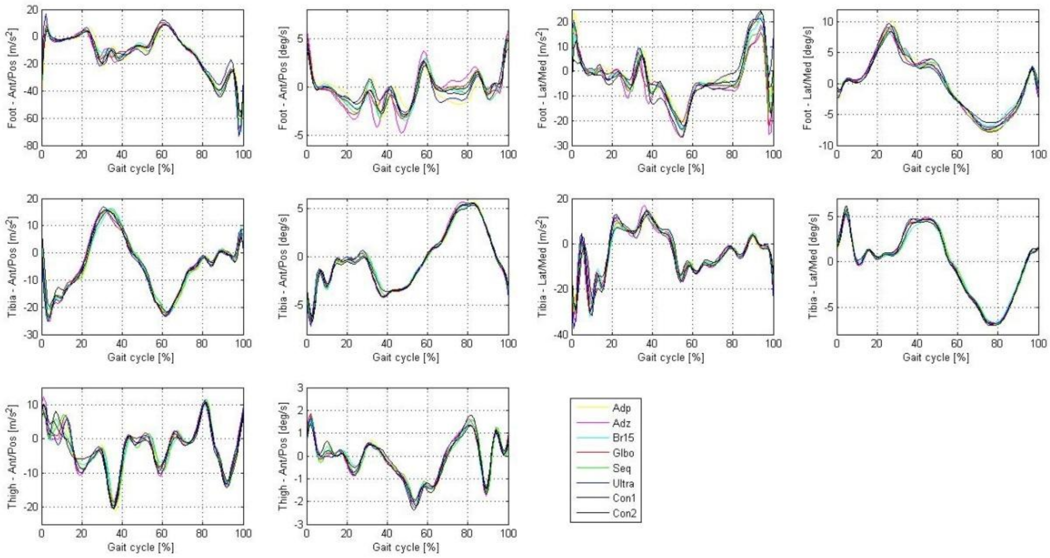

Figure 10 shows the path of movement for all shoes tested including the control condition. The color coding are: Adp(yellow), Adz(purple), Br15(cyan), Glbo(red), Seq(green), Ultra(blue), Con1(black) and Con2(black)

Table 7 shows the kinematic correlation coefficients between the shoe with the highest and lowest EMG impulse. The correlation coefficients for con1 vs. con2 are also displayed. Significant differences are marked with a (*).

Kinematics parameter	Correlation coefficient Glbo vs. Br15	Correlation coefficient Con1 vs. Con2
Foot		
Acc. Ant/Post	0.95	0.98
Ang. Vel. Ant/Post	0.89	0.87
Acc. Lat/med	0.87	0.93
Ang. Vel. Lat/Med	0.98	0.99
Tibia		
Acc. Ant/Post	0.97	0.97
Ang. Vel. Ant/Post	0.98	0.99
Acc. Lat/med	0.92	0.91
Ang. Vel. Lat/Med	0.99	0.99
Thigh		
Acc. Ant/Post	0.85	0.88
Ang. Vel. Ant/Post	0.90	0.93

Subject 8

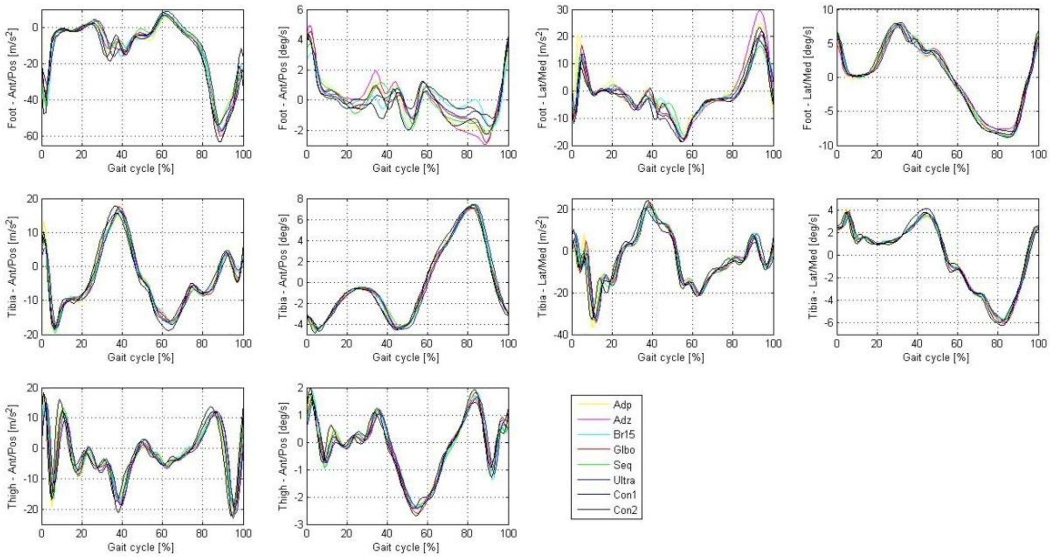

Figure 11 shows the path of movement for all shoes tested including the control condition. The color coding are: Adp(yellow), Adz(purple), Br15(cyan), Glbo(red), Seq(green), Ultra(blue), Con1(black) and Con2(black)

Table 8 shows the kinematic correlation coefficients between the shoe with the highest and lowest EMG impulse. The correlation coefficients for con1 vs. con2 are also displayed. Significant differences are marked with a (*).

Kinematics parameter	Correlation coefficient Br15 vs. Ultra	Correlation coefficient Con1 vs. Con2
Foot		
Acc. Ant/Post	0.94	0.95
Ang. Vel. Ant/Post	0.75	0.73
Acc. Lat/med	0.90	0.92
Ang. Vel. Lat/Med	0.98	0.99
Tibia		
Acc. Ant/Post	0.97	0.97
Ang. Vel. Ant/Post	0.99	0.99
Acc. Lat/med	0.94	0.93
Ang. Vel. Lat/Med	0.99	0.99
Thigh		
Acc. Ant/Post	0.87	0.87
Ang. Vel. Ant/Post	0.94	0.94

Subject 9

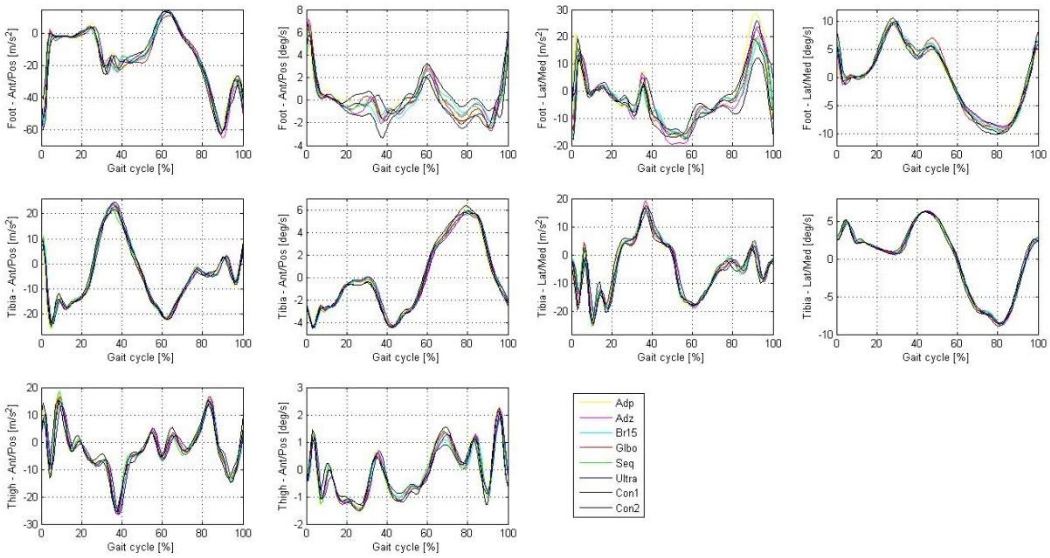

Figure 12 shows the path of movement for all shoes tested including the control condition. The color coding are: Adp(yellow), Adz(purple), Br15(cyan), Glbo(red), Seq(green), Ultra(blue), Con1(black) and Con2(black)

Table 9 shows the kinematic correlation coefficients between the shoe with the highest and lowest EMG impulse. The correlation coefficients for con1 vs. con2 are also displayed. Significant differences are marked with a (*).

Kinematics parameter	Correlation coefficient Glbo vs. Ultra	Correlation coefficient Con1 vs. Con2
Foot		
Acc. Ant/Post	0.97	0.96
Ang. Vel. Ant/Post	0.90	0.69
Acc. Lat/med	0.92	0.82
Ang. Vel. Lat/Med	0.99	0.98
Tibia		
Acc. Ant/Post	0.98	0.98
Ang. Vel. Ant/Post	0.99	0.99
Acc. Lat/med	0.94	0.94
Ang. Vel. Lat/Med	1	0.99
Thigh		
Acc. Ant/Post	0.91	0.91
Ang. Vel. Ant/Post	0.93	0.91

Subject 10

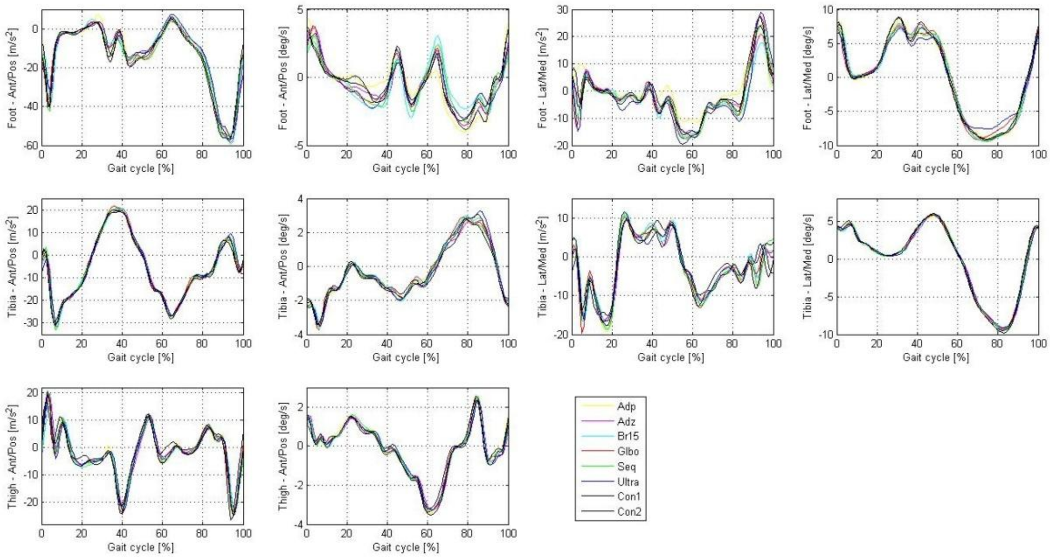

Figure 13 shows the path of movement for all shoes tested including the control condition. The color coding are: Adp(yellow), Adz(purple), Br15(cyan), Glbo(red), Seq(green), Ultra(blue), Con1(black) and Con2(black)

Table 10 shows the kinematic correlation coefficients between the shoe with the highest and lowest EMG impulse. The correlation coefficients for con1 vs. con2 are also displayed. Significant differences are marked with a (*).

Kinematics parameter	Correlation coefficient Adz vs. Br15	Correlation coefficient Con1 vs. Con2
Foot		
Acc. Ant/Post	0.94	0.96
Ang. Vel. Ant/Post	0.80	0.87
Acc. Lat/med	0.88	0.92
Ang. Vel. Lat/Med	0.99	0.99
Tibia		
Acc. Ant/Post	0.97	0.98
Ang. Vel. Ant/Post	0.96	0.96
Acc. Lat/med	0.89	0.84
Ang. Vel. Lat/Med	0.99	0.99
Thigh		
Acc. Ant/Post	0.85	0.87
Ang. Vel. Ant/Post	0.94	0.95

Reference

Adidas, AG. *, Adidas homepage* [Homepage of Adidas], [Online]. Available: Adidas.com [2016, 5/31].

Brooks, Running. *, Brooks running homepage* [Homepage of Brooksrunning], [Online]. Available: Brooksrunning.com [2016, 5/31].

Che, H., Nigg, B.M. & de Koning, J. 1994, "Relationship between plantar pressure distribution under the foot and insole comfort", *Clinical Biomechanics,* vol. 9, no. 6, pp. 335-341.

Enke, R.C., Laskowski, E.R. & Thomsen, K.M. 2009, "Running Shoe Selection Criteria Among Adolescent Cross-Country Runners", *PM&R,* vol. 1, no. 9, pp. 816-819.

Hoerzer, S., Trudeau, M.B., Edwards, B. & Nigg, B. 2015, "How reliable are subjective footwear comfort assessments?", *Footwear Science,* vol. 7, pp. 106-107.

Konrad, P. 2006, *The ABC of EMG,* 1.4th edn, Noraxon INC.

Lab#7. *Assessing MEMS accelerometers performance*.

Luo, G., Stergiou, P., Worobets, J., Nigg, B. & Stefanyshyn, D. 2009, "Improved footwear comfort reduces oxygen consumption during running", *Footwear Science,* vol. 1, no. 1, pp. 25-29.

Mündermann, A., Nigg, B.M., Stefanyshyn, D.J. & Humble, R.N. 2002, "Development of a reliable method to assess footwear comfort during running", *Gait & posture,* vol. 16, no. 1, pp. 38-45.

Mundermann, A., Stefanyshyn, D.J. & Nigg, B.M. 2001, "Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors.(Statistical Data Included)", *Medicine and science in sports and exercise,* vol. 33, no. 11, pp. 1939.

Nigg, B.M., Baltich, J., Hoerzer, S. & Enders, H. 2015, "Running shoes and running injuries: mythbusting and a proposal for two new paradigms: 'preferred movement path' and 'comfort filter'", *British journal of sports medicine,* vol. 49, no. 20, pp. 1290.

Noakes, T.D. 2003, *Lore of running,* 4. ed. edn, Champaign, Ill. : Human Kinetics.

Stacoff, A., Reinschmidt, C., Nigg, B.M., van, d.B., Lundberg, A., Denoth, J. & Stüssi, E. 2000, "Effects of foot orthoses on skeletal motion during running", *Clinical Biomechanics,* vol. 15, no. 1, pp. 54-64.

Stacoff, A., Reinschmidt, C., Nigg M, B., Bogert, A., Lundberg, A., Denoth, J. & Stüssi, E.:. 2001, "Effects of shoe sole contruction on skeletal motion during running", *Medicine & Science in Sports & Exercise,* , pp. 311.

Renaut, F. 2013, *MEMS inertial sensors technology*, Studies on mechatronics.

Roetenberg, D., Luinge, H. & Slycke, P. 2013, "Xsens MVN: Full 6DOF human motion tracking using miniature inertial sensors", *Xsens Technologies,* vol. April 3, pp. 1.

Wakeling, J.M., Pascual, S.A. & Nigg, B.M. 2002, "Altering muscle activity in the lower extremities by running with different shoes", *Medicine and science in sports and exercise,* vol. 34, no. 9, pp. 1529-1532.

Worobets, J., Wannop, J.W., Tomaras, E. & Stefanyshyn, D. 2014, "Softer and more resilient running shoe cushioning properties enhance running economy", *Footwear Science,* vol. 6, no. 3, pp. 147-153.