Running shoes effect on kinematics, muscle activity and comfort perception

Master Thesis

Anders Nielsen and Morten Kudsk

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Supervisor: Uwe G. Kersting
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Nielsen, Anders and Kudsk, Morten

Aalborg University, Sports Technology 4th semester

Purpose: (1) investigate if kinematics and muscle activation changes during running and (2) investigate how comfort and muscle activation correlates. **Method:** Ten subjects were recruited for the current study. Each subject ran five minutes in six different commercially available running shoes while wearing Xsens MVN Link sensors and EMG electrodes. Overall comfort assessment through questionnaire was done after each run. **Results:** A paired sample t-test with $\alpha = .05$ was conducted between the two shoes with the smallest and largest integrated EMG which showed a significant differences ($p = .028$). A Pearson correlation test with $\alpha = .05$ for the kinematics were conducted between the two shoes with smallest and largest integrated EMG. This showed significant correlations with overall strong coefficients in all ten parameters. To compare the overall comfort to the integrated EMG a Pearson correlation test was used. The correlation test showed that six out of ten subjects had a modest or strong correlation. **Conclusion:** There was a clear tendency towards that the kinematics did not change during running in different commercially available running shoes but the muscle activation did. Another tendency towards that a relationship between muscle activity and comfort perception exist.

1 Introduction

Recent studies have shown that the effect of shoe interventions or orthotics are likely subject specific (Nigg et al. 2003) (Nigg et al. 2015) (Nigg M 2001) and that individuals possess their own unique running style (Stacoff et al. 2000) (Stacoff et al. 2001). This is in contrast with the prescription of running shoes used in the last three decades, where running shoes has been prescribed to runners based upon their foot type (Enke, Laskowski & Thomsen 2009). This approach proposes that runners with pronated feet should wear motion control shoes and neutral shoes should be worn by runners with supinated feet (Schwellnus et al. 2006). However, a review by Richards et al. (2009) suggested that this method of choosing the appropriate footwear when running never had been proven to be beneficial.

A review by Nigg et al. (2015) suggested that the recommendation of a running shoe should be based on a new paradigm called “the preferred movement path”. This method suggests that a “good” running shoe allows the skeleton to move within its preferred path with the least amount of muscle activity (Nigg et al. 2015). A second concept proposed by Nigg et al. (2015) is “The comfort filter”. This concept suggests that runners should choose their running shoes based

Table 1: Anthropometric data of the subjects. The values are means with standard deviations in parentheses.

Subjects	Weight (kg)	Height (cm)	Age (years)	Dominant leg	Running speed (km/h)
10	77.1 (±4)	179.3 (± 4.8)	27.6 (± 5)	8 right and 2 left	10.1 (± 1.1)

on their own subject specific comfort. This suggestion implies that any runner can perceive which shoe allows for their individual movement patterns.

To the authors' knowledge, no studies have investigated the relationship between kinematics and muscle activation in different commercially available running shoes. A study by Luo et al. (2009) investigated how comfort perception related to VO_2 uptake which is a performance parameter. It is not known how comfort perception relates to muscle activation in commercially available running shoes. Therefore, there were two aims of this study; (1) investigate if kinematics and muscle activation changes during running with commercially available running shoes and (2) investigate how comfort and muscle activation correlate. The hypotheses tested in this study were:

H 1. No substantial kinematic differences are present in the path of movement, but muscle activation differs between shoes.

H 2. There is a negative correlation between muscle activation and comfort as subjects' will rate the shoe leading to lesser muscle activations higher in comfort.

2 Methods

2.1 Subjects

In this study ten recreational runners in the age of 23-39 years old were recruited as subjects (table 1). All were free from injury during the test and all practiced running a minimum of once per week. Subjects were given verbal information about the protocol and provided consent according to the institutional ethics regulations before the test.

2.2 Equipment

The shoes used in the current study were provided by Adidas (Adidas AG, Herzogenaurach, Germany) and Brooks (Brooks Running, Seattle, Washington, USA). These shoes included: Adidas Adipure (Adp), Adidas Adizero Primeknit 2.0 (Adz), Adidas Supernova Glide Boost (Glbo), Adidas Supernova Sequence Boost (Seq), Adidas Ultraboost (Ultra) and Brooks Adrenaline 15 (Br15). The shoes were size 8.5 and 9.5 UK and were developed for men except for the Adz which was a unisex shoe. It should be noted that the Brooks running shoe in size 9.5 was a Brooks Adrenaline 16. A control shoe was implemented which was a Nike (Nike, Inc., Beaverton, Oregon, USA) indoor soccer shoe with a minimalist midsole design.

For quantifying the kinematics, three Xsens MVN Link (Xsens Technologies B-V, Enschede, Netherlands) sensors (38x53x21 mm and 30 g) with integrated tri-axial accelerometers and gyroscopes were used. The use of accelerometers and gyroscopes has previously been found to be a valid method for analyzing running gait (Norris, Anderson & Kenny 2014) (Mayagoitia, Nene & Veltink 2002).

Surface electromyography (EMG) pre-gelled self-adhesive electrodes (AmbuNeuroline720, Ambu, Ballerup, Denmark) were used to quantify the muscle activation on the left lower extremity. The EMG system (Biovision, Wehrheim, Germany) was connected to a laptop through an input box. Ten muscles were included in the current study. The muscles included for the upper leg was; vastus medialis, vastus lateralis, biceps femoris, gluteus maximus and tensor fasciae latae. The lower leg muscles included; tibialis anterior, soleus, gastrocnemius medialis, gastrocnemius lateralis and peroneus longus. An electrode was placed on the left tibia for reference purpose. These muscles have been used in earlier studies when evaluating biomechanics during running (Nigg et al. 2003) (Tsuji et al. 2015) (Chumanov et al. 2012) (Castro et al. 2013).

All subjects received eight questionnaires during the test for addressing the comfort for each shoe. The questionnaire used was a 150 mm visual analogue scale (VAS) which was developed by Mündermann et al. (2002). The questionnaire consisted of nine questions about comfort with regard to; heel cushioning, forefoot cushioning, medio-lateral control, arch height, heel cup, shoe heel width, shoe forefoot width, shoe length and the overall comfort. The outer points of the VAS questionnaire were “not comfortable at all” (0 points) and “most comfortable condition imaginable” (15 points).

2.3 Test setup

In this study a laboratory setup at Aalborg University (Aalborg University, Aalborg, Denmark) a Woodway Pro XL treadmill (Woodway Inc., Wisconsin, USA) were used. The three Xsens sensors were placed on the left lower extremity; dorsal aspect of the foot beneath the shoe, the tibia just above the gastrocnemius and mid lateral side of the thigh. The sensors were fixed with straps according to Xsens standards (Xsens 1). The kinematic data were sampled with a frequency of 240 Hz. Placements of the EMG electrodes were done according to the SENIAM group (Seniam.org, Enschede, Netherlands). The EMG electrodes were attached with an approximate distance of 22 mm between electrode centers and secured with Fixomull stretch (BSN Medical, Hamborg, Germany). Prior to the EMG electrode placement the skin was shaved, polished with sandpaper and cleaned with alcohol to minimize skin impedance. The EMG data were acquired with a sampling frequency of 2000 Hz. A uniaxial accelerometer (Biovision ACC, Wehrheim, Germany) was placed on the left shoes’ heel-counter and recorded simultaneously with the EMG. The accelerometer was attached with tape.

2.4 Protocol

Upon arriving in the laboratory the subjects' anthropometrics were measured according to the Xsens manual (Xsens 2). Afterwards, their skin was prepared and the EMG electrodes and Xsens were attached (see section "2.3 Test setup"). The wires from the EMG electrodes and Xsens were contained by a close fitting sock during the test. Prior to the test, subjects were informed about the protocol and instructed in how to use the questionnaire. Subjects performed self-controlled warm-up on the treadmill in the control shoe (con1) for five minutes (test 1). This session also served as familiarization to the laboratory setup. During the warmup, the subjects found their self-selected speed that represented a normal training pace. The subjects could sustain this pace throughout the whole test without reaching fatigue. After the warmup the subjects answered the questionnaire. Afterwards, the subjects ran five minutes in each of the six shoes in a randomized order (test 2, test 3 etc.). A comfort assessment through the questionnaire was completed after each run. Lastly, the control shoe (con2) was repeated (test 8). The Xsens MVN Link was calibrated with each shoe change and a zero point reference was recorded. This was done to compensate for sensor placement deviations.

2.5 Data analysis

The data from both the Xsens and EMG were obtained between the 4th and 5th minute and processed in Matlab R2015b (Mathworks, Massachusetts, USA) and Microsoft Excel 2010 (Microsoft Corporation, Redmond, Washington, USA). Con1 and con2 were not included in the analysis with the other six shoes, but were only used for repeatability purposes.

Ten parameters were extracted for the kinematics which included; translational accelerations and angular velocities in the anterior-posterior direction for the thigh, tibia and foot and translational accelerations and angular velocities in the medio-lateral direction for the tibia and foot. The Xsens data were filtered with a 2nd order zero phase lag Butterworth low pass filter with a cutoff frequency at 18 Hz (Bhattacharya et al. 1980). The EMG data were filtered with a 2nd order zero phase lag Butterworth bandpass filter with cutoff frequencies at 10 Hz and 500 Hz. Afterwards, the data was full wave rectified followed by a 2nd order zero phase lag Butterworth low pass filter with a cutoff at 15 Hz.

Gait analyses were done in order to localize the touchdown during the one minute recording. A gait cycle was defined from touchdown to touchdown. The vertical accelerations for both the Xsens and uniaxial accelerometer were filtered with 60 Hz in order to perform gait analysis. The gait analysis method was adapted

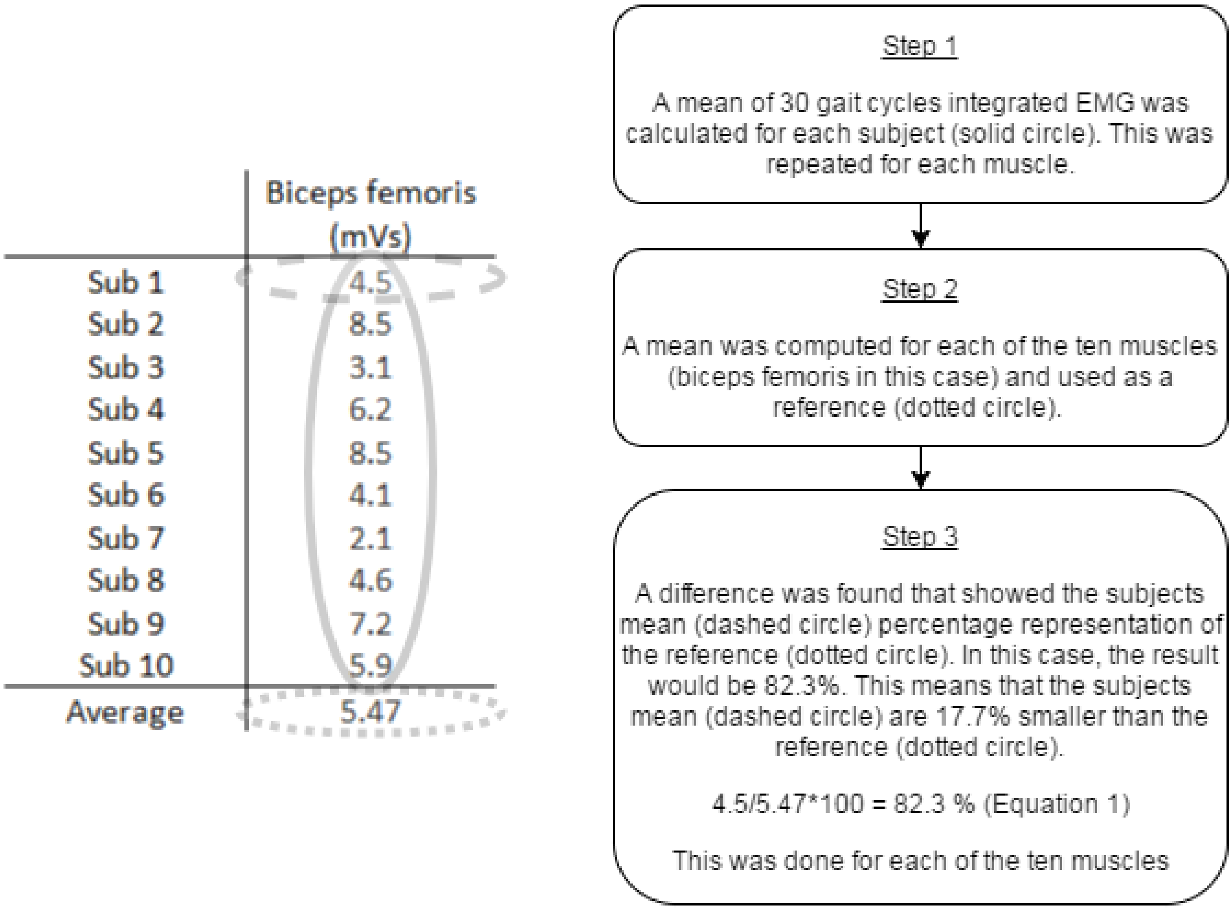

Figure 1 shows the progress of the EMG interpretation. The figure shows a flow diagram representing the three steps and a graphic view of random data.

from Oliveira et al. (2016). A tendency of decreasing EMG amplitude over time was found. To compensate for this tendency, the following method was developed. For EMG evaluation, the area under the curve was found by integrating each muscles EMG. Figure 1 represents test 2 with only one muscle shown (biceps femoris) for better overview. The shoes were not the same for each subject due to the randomized order. Figure 1 shows the calculation for subject 1 but the same method was applied for all the subjects. The numbers presented are random.

A mean was calculated from the ten (one for each muscle) percentage representations (step 3) which represented the shoe (IEMG) in test 2. Same approach was used for each test (test 3, test 4 etc.). This means a new reference was calculated for each muscle in each test. The same approach was used for test 1 (con1) and test 8 (con2).

2.5.1 Statistical analysis

For evaluating kinematics, the method from Luo et al (2009) was adapted where the best (highest comfort) and worst (lowest comfort) shoes were compared. In this study, the two shoes of interest were the two shoes with smallest and largest

IEMG respectively. A paired samples t-test with $\alpha=.05$ was conducted between the shoes with smallest and largest IEMG and between the con1 and con2 with regard to IEMG. A Pearson correlation test was applied between all kinematic parameters between the two shoes with the smallest and largest IEMG. Statistical significance in the Pearson correlation test was set at $\alpha=.05$. Furthermore, another Pearson correlation test was conducted between the IEMG and the overall comfort rating.

To interpret the correlation coefficient (r) a ranking from Taylor (1990) was used:

≤ 0.35 = weak

0.36 to 0.67 = modest

0.68 to 1.0 = strong

≥ 0.90 = very strong

3 Results

The t-test showed significant difference between the shoes with smallest and largest IEMG ($p=.028$).

The Adp and Ultra each had three subjects who had their largest IEMG whereas the Glbo and Br15 had two subjects each. Four subjects had their smallest IEMG in the Adz followed by the Glbo which had three subjects. Two subjects had their smallest IEMG in the Seq and one subject had his smallest IEMG in the Br15 (table 2).

The percentage increase between the shoes with the smallest IEMG and largest IEMG shoe showed that subjects 2, 4, 5, 6, 7 and 9 had an increase of 10 % or more. Subjects 1, 2, 8 and 10 had an increase between 5 % and 10 % between the shoes with smallest and largest IEMG (table 2).

The Pearson correlation test showed significant correlations in all kinematic parameters for all subjects. Three kinematic parameters between the shoes with the smallest and largest IEMG had a correlation coefficient lower than 0.68. The latter was the case in the angular velocity around the anterior-posterior direction of the foot for subject 3 ($r=0.53$) and 5 ($r=0.34$). This was also the case in the translational acceleration in the medio-lateral direction of the foot for subject 5 ($r=0.61$). The remaining 87 kinematic parameters showed strong correlation coefficients (figure 2).

The correlation coefficient between comfort rating and IEMG was negative for nine subjects (table 3). Strong correlations were seen for subject 3 ($r=-0.68$), subject 7 ($r=-0.72$), subject 9 ($r=-0.79$) and subject 10 ($r=-0.79$). A modest correlation was seen for subject 5 ($r=-0.48$) and subject 6 ($r=-0.52$) (table 3). Subject 4 was the only one with a positive correlation coefficient at 0.42.

When comparing the shoes with the smallest and largest IEMG, eight subjects' comfort increased when the IEMG decreased (figure 3). Four subjects rated the Adz to have highest overall comfort whereas three preferred the Seq.

Table 2 shows the IEMG. The order of the test is presented in the parenthesis after each percent. The blue and red values for each subject are the highest and lowest scores respectively. The gluteus maximus were excluded for subject 5 and 8 and vastus lateralis were excluded for subject 2, 4 and 9 due to signal loss.

	Con1 (%)	Con2 (%)	Adp (%)	Adz (%)	Br15 (%)	Glbo (%)	Seq (%)	Ultra (%)
Subject 1	75.8 (1)	75.9 (8)	75.5 (6)	78.3 (3)	76.8 (7)	**79.8 (2)**	**73.6 (4)**	74.6 (5)
Subject 2	97.6 (1)	107.6* (8)	94.7 (2)	**86.5 (4)**	91.8 (5)	99.1 (6)	94.4 (3)	**99.9 (7)**
Subject 3	139.6 (1)	146.6*(8)	**142.7 (6)**	133.6 (2)	139.8 (5)	**130.1 (4)**	139.3 (3)	141.4 (7)
Subject 4	113.8 (1)	107.7* (8)	**209 (4)**	128.8 (6)	126.2 (7)	130.5 (5)	**121.9 (2)**	129.8 (3)
Subject 5	143.9 (1)	123.6* (8)	**145.1 (2)**	**117.9 (4)**	130.3 (3)	131.8 (3)	138.8 (5)	136.7 (6)
Subject 6	85.8 (1)	78.3* (8)	83 (3)	**72.3 (4)**	78 (6)	**86.2 (2)**	81.3 (5)	79.2 (7)
Subject 7	88.2 (1)	86.5 (8)	84.2 (3)	78.5 (7)	**87 (2)**	**73.6 (4)**	80.4 (5)	77.3 (6)
Subject 8	73 (1)	65.8* (8)	67.2 (2)	68.3 (5)	**64.3 (4)**	67 (7)	68.4 (3)	**68.5 (6)**
Subject 9	97 (1)	117.1* (8)	110.6 (6)	107.8 (5)	101.8 (2)	**94.9 (4)**	100.8 (3)	**114.2 (7)**
Subject 10	87.8 (1)	93.4* (8)	91.1 (3)	**86.1 (4)**	**91.4 (5)**	88.1 (6)	90.1 (7)	91.3 (2)

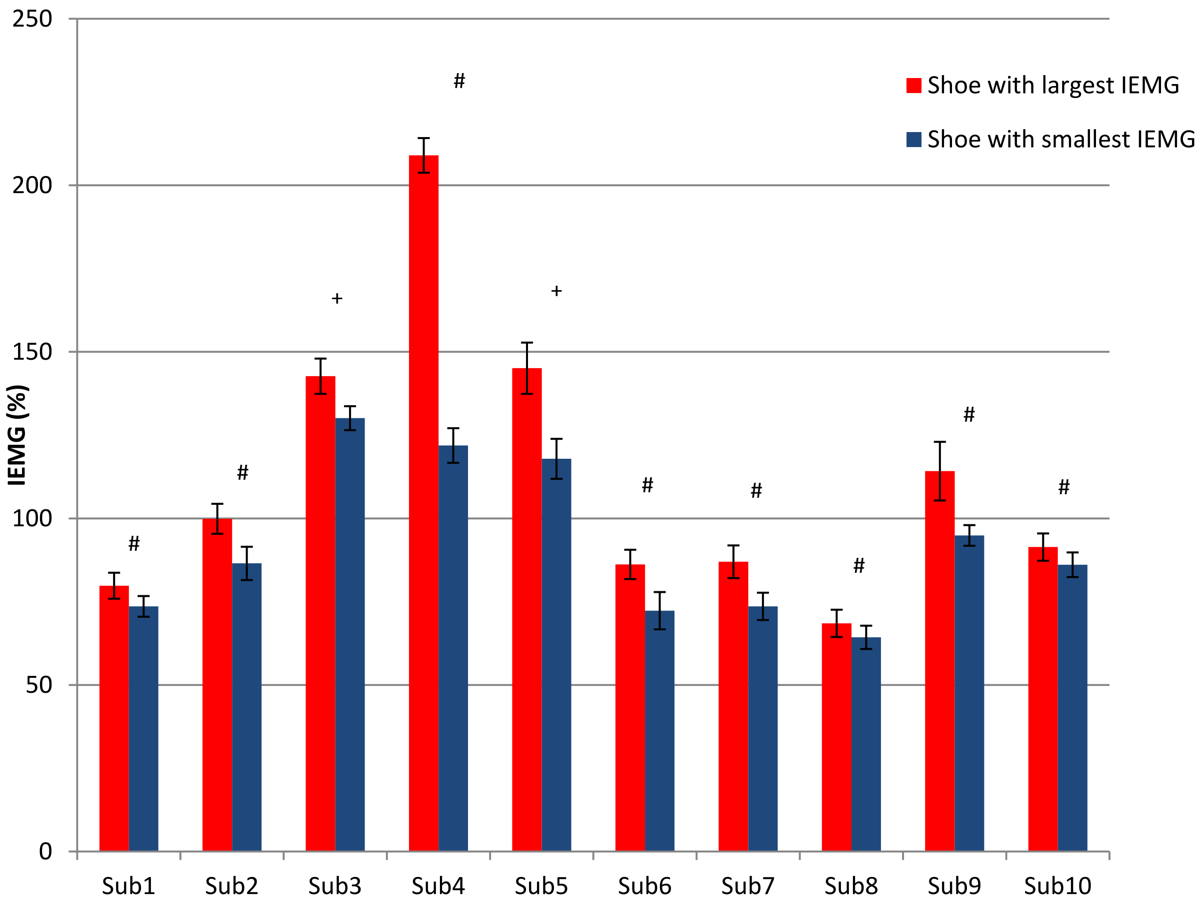

Figure 2 shows two shoes for each subject, the red is the shoe with largest IEMG and the blue is the one with smallest IEMG with standard deviations displayed. A (#) indicates that ten out of ten coefficients were above 0.68 with regard to kinematics. A (+) indicates that a minimum of eight out of ten coefficients were above 0.68 with regard to kinematics. For subject 1, the kinematics were excluded because of malfunction with the equipment.

Table 3 shows the correlation coefficient between overall comfort score and IEMG. Strong correlations are marked with (**) and modest correlations are marked with (*). The test order of the shoes is displayed in parenthesis after each comfort score. The blue and red values for each subject are the highest and lowest scores for each subject respectively.

	Con1	Con2	Adp	Adz	Br15	Glbo	Seq	Ultra	Correlation coefficient
Subject 1	3.1 (1)	5.7 (8)	**8.8 (6)**	9 (3)	9 (7)	10 (2)	9 (4)	**13 (5)**	-0.12
Subject 2	8.9 (1)	6.9 (8)	10.3 (2)	9.9 (4)	10 (5)	**6.7 (6)**	**13.3 (3)**	7.9 (7)	-0.33
Subject 3	4.7 (1)	4.5 (8)	6.3 (6)	**10.3 (2)**	8.8 (5)	8.9 (4)	9.1 (3)	**6.1 (7)**	-0.69**
Subject 4	13.3 (1)	3.6 (8)	13.2 (4)	**14.5 (6)**	1 (7)	14 (5)	3.9 (2)	**0.2 (3)**	0.42
Subject 5	10.5 (1)	10.8 (8)	**5 (2)**	13.5 (4)	9.1 (3)	12 (7)	**14.4 (5)**	13.3 (6)	-0.48*
Subject 6	6.9 (1)	9.7 (8)	**4.1 (3)**	**10.5 (4)**	10.2 (6)	9.2 (2)	8 (5)	9 (7)	-0.52*
Subject 7	4.2 (1)	6 (8)	**4.5 (3)**	4.6 (7)	6.5 (2)	**13.9 (4)**	6.2 (5)	10.7 (6)	-0.72**
Subject 8	4 (1)	4.7 (8)	**7.9 (2)**	8.9 (5)	10.1 (4)	11.1 (7)	**12.7 (3)**	8.5 (6)	-0.03
Subject 9	4.2 (1)	6.9 (8)	**5 (6)**	6.8 (5)	6.3 (2)	**11.7 (4)**	11.2 (3)	6.6 (7)	-0.79**
Subject 10	3.7 (1)	3.5 (8)	7.9 (3)	**10.6 (4)**	**6.5 (5)**	8.9 (6)	6 (7)	8.1 (2)	-0.79**

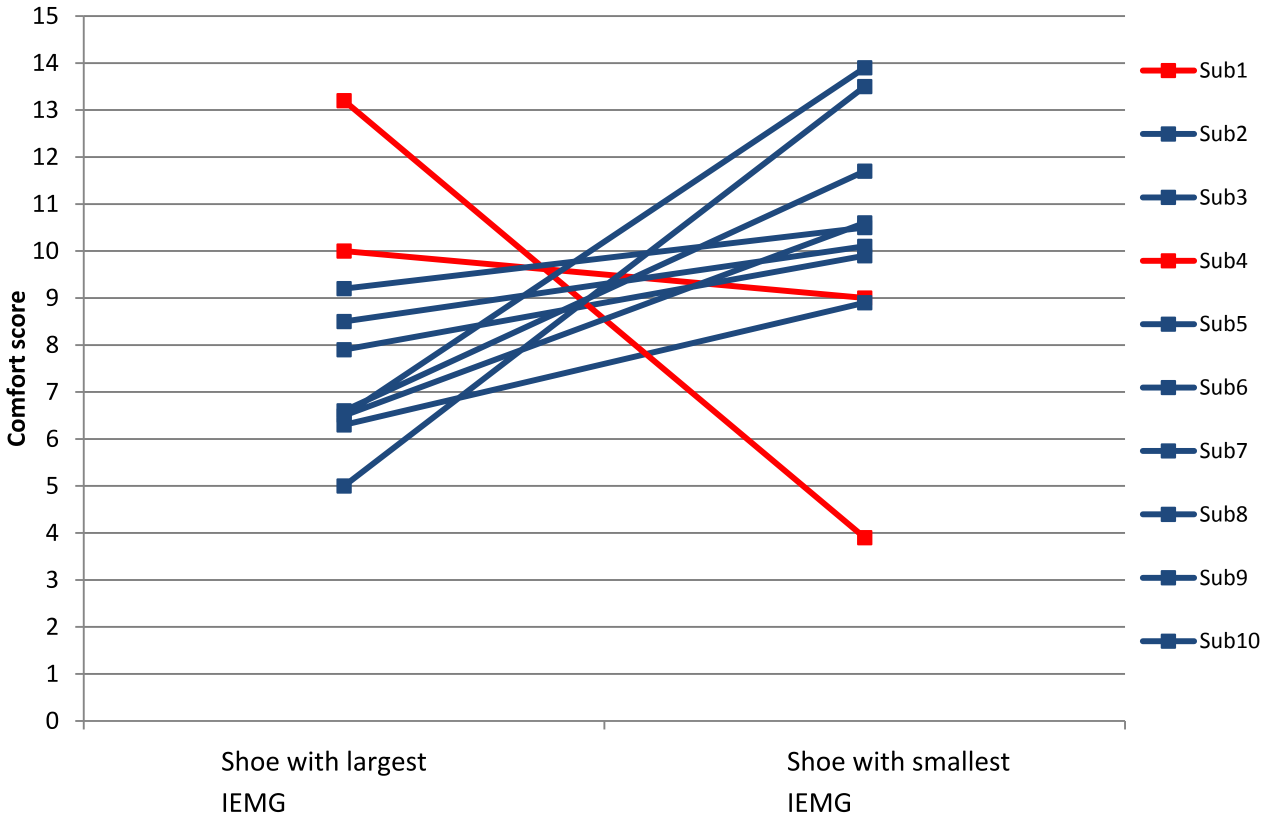

Figure 3 shows the difference in overall comfort between the shoes with the smallest IEMG and largest IEMG. The red color indicates that the comfort decreases when the IEMG decreases and the blue color indicate that the comfort increases when the IEMG decreases.

Furthermore, two subjects rated the Glbo to have highest overall comfort and one subject preferred the Ultra (table 3). Six out of ten subjects rated the Adp to have lowest overall comfort which was the highest incidence. The Ultra followed with two lowest overall comfort scores and Glbo and Seq with one each.

3.1 Control conditions result

No significant difference was found between con1 and con2 (p=1). Four subjects' IEMG decreased from con1 to con2 and the remaining six had an increase in their IEMG (table 2). The Pearson correlation test showed significant correlations between con1 and con2 in all kinematic parameters for all subjects. The kinematic correlation coefficients for the con1 and con2 showed that subject 5 (r=0.62) and subject 6 (r=0.63) had a modest correlation. This occurred in the angular velocity around the anterior-posterior direction in the foot. The remaining 88 kinematic parameters showed strong correlation coefficients.

Nine subjects had a difference between their overall comfort rating in con1 and con2 of three points or below. Additionally, four of the nine subjects' differences were below one point. Only one subject, subject 4, had a difference above three points as he rated the con1 to 13.3 points and con2 to 3.6 points, which gave a difference of 9.7 points (table 3).

4 Discussion

There were two purposes in the current study; (1) investigate if kinematics and muscle activation changes during running with commercially available running shoes and (2) investigate how comfort and muscle activation correlate. Significant difference was found for the shoes with the smallest and largest IEMG. Additionally, significant kinematic correlations with overall strong coefficients were found between the shoes with the smallest and largest IEMG. A tendency towards that when comfort increased the IEMG decreased was present. Furthermore, a negative correlation for nine subjects was found and six out of ten subjects had a modest or strong negative correlation coefficient.

4.1 Kinematics and IEMG relationship

In this study it was hypothesis that no substantial kinematic differences were present in the path of movement, but muscle activation differed between shoes. The results of this study showed that the muscle activation changed due to shoe intervention. This is in compliance with Wakeling et al. (2002) who found that insole interventions also caused changes in the muscle activation. Furthermore, the results of this study showed that the kinematic stayed the same which complies with Nigg et al. (2001), Nigg et al. (2003), Nigg et al. (2015). The relationship between the muscle activation and kinematics is in agreement with the hypothesis 1 of this study.

This study found significant kinematic correlations with overall strong coefficients in the foot, tibia and thigh between the shoes with smallest and largest IEMG. However, small visual changes in the range of movement were detected (figure 4). This is in agreement with Stacoff et al. (2000) and Stacoff et al. (2001) who also found small differences in the range of movement. In this study, the largest differences in the range of movement occurred in the angular velocity

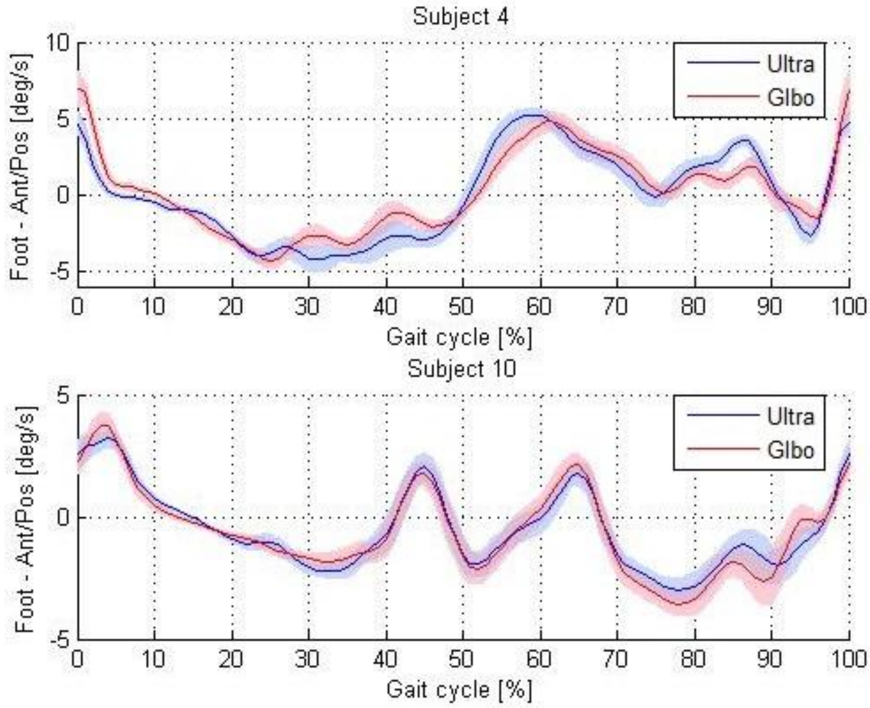

Figure 4: shows the kinematics for subject 4 (top) and subject 10 (bottom) in the Ultra (blue) and Glbo (red). The x-axis is percentage of the gait cycle and the y-axis is the angular velocity around the anterior-posterior direction. Neither of the subjects had their respectively smallest or largest IEMG in those two shoes.

around the anterior-posterior direction in the foot. The latter was seen in general for all subjects. According to Oliveira et al. (2016), the stance phase occurs from 0-35 % of a gait cycle and the remaining 65 % is the swing phase. If that method was adapted to the current study, a tendency towards that the difference in the range of movement general happened just before toe off and lasted until the touchdown. This suggests that the small changes do not occur in the actual stance phase but in the swing phase.

The small kinematic differences in the range of movement were nonsystematic and subject specific (Figure 4). When subjects were exposed to the same shoe conditions, the small differences were not similar and did not seem to occur simultaneously. This is in agreement with Nigg et al. (2001), Nigg et al. (2003), Nigg et al. (2015), Stacoff et al. (2000) and Stacoff et al. (2001) who also found subject specific and nonsystematic changes in the range of movement. The results of this study imply that the subject specific effects also are present in the muscle activation. This is based on subjects had different shoes where the IEMG was smallest and largest (table 2).

Stacoff et al. (2000) and Stacoff et al. (2001) showed that the changes in the kinematic varied between the measurements done on the bone level and shoe level. The differences were lower on bone level compared to the shoe level. The current study used Xsens MVN Link and placed the foot sensor inside the shoe on the dorsal aspect of the foot. This was done in order to measure the movement of the foot and not the shoe. This can be the reason why the current study found small differences similar to Stacoff et al. (2000) and Stacoff et al. (2001).

Furthermore, this study showed that the path of movement is not visually similar for each subject which can be seen in figure 4. This was the case for all subjects. These findings suggest that each subject possesses a unique running style, which is in compliance with Stacoff et al. (2000) and Stacoff et al. (2001).

The current study showed that not all subjects responded equally to the shoe interventions. Some subjects responded less than 10 % difference between the shoes with the smallest and largest IEMG. Meanwhile, other subjects responded up to 71.5 %. This indicates that some runners are responders to different commercially available running shoes and some are not.

4.2 Muscle activation and comfort relationship

The second hypothesis in the current study were that there was a negative correlation between muscle activation and comfort as subjects' rate the shoe leading to lesser muscle activations higher in comfort. The result of this study showed a tendency towards a relationship between muscle activity and overall comfort rating was present. This is based on table 3 and figure 3, where it can be seen that nine out of ten subjects had a negative correlation coefficient between IEMG and overall comfort rating. Although, the shoes with the smallest IEMG were not necessarily rated highest in regard to overall comfort. This indicates that runners do not necessarily pick the best shoe in regard to muscle activation. Still, subjects were able to differentiate between shoes with small and large IEMG with regard to perceived comfort (figure 3). However, only six out of ten subjects had a modest to strong negative correlation coefficient (table 3). Therefore, the relationship between muscle activation and comfort needs further research.

The shoes with the highest overall comfort were overall rated differently between subjects. This complies with Münderman et al. (2001) who showed that subjects had different comfort preferences. However, four subjects rated the Adz to be highest and no subjects rated the Adp and Br15 to be highest in the current study. To verify subject specific comfort preferences a larger sample is needed.

This potential connection between subjects' perceived comfort and performance is in compliance with Luo et al. (2009). They concluded that *"comfort has a significant influence on distance running. However, future work is needed to determine the underlying mechanism".* The current study proposes that it could be because of lower muscle activity.

4.3 Reliability

The test setup included a control condition which was implemented before and after the six shoes tested. This was done in order to test the reliability of the protocol.

The con1 and con2 kinematics were compared using a Pearson correlation which gave overall high correlation coefficients and was significant. Therefore, the kinematics is considered to be reliable for all subjects.

Luo et al. (2009) had an exclusion criterion for comfort assessment. If the difference in overall comfort score between the con1 and con2 exceeded half the difference between the lowest and highest comfort score, it was excluded. If that method was adapted to the current study, subject 1 and 4 would be excluded. It should be noted that subject 1 and 4 were also the only two who had an increase in their perceived comfort going from the shoes with smallest to the largest IEMG (figure 3).

No significant differences were found between con1 and con2 with regard to IEMG, although a small difference was seen. For seven subjects, the difference in IEMG between con1 and con2 was lower than the difference between the two shoes with the smallest and largest IEMG. However, this was not the case for subject 8 who had a difference between con1 and con2 on 9.86 % and a difference between the two shoes with the smallest and largest IEMG on 6.53 %. Two other subjects, subject 9 and 10, showed differences between the con1 and con2 to be similar to the differences between their shoes with smallest and largest IEMG (with differences of 0.38 % and 0.22 % respectively). Therefore, it can be discussed if it was the shoes that caused the difference for these three subjects.

5 Conclusion

The results showed a clear tendency towards that different commercially available running shoes did not change the kinematics but changes the muscle activation were present. However, further research is needed in order to say anything conclusively.

Another tendency towards that subjects' rated the shoe leading to lesser muscle activations higher in comfort was present. However, it cannot be concluded that there is a strong relationship between comfort and muscle activation. Further research is needed to conclude how a runner's comfort perception relates to muscle activation.

As described in the introduction, running shoes has previously been recommended based on kinematics. This study shows that this method for choosing a running shoe may not be appropriate and a new method should be developed. The authors propose that the new method should be based on measurements of muscle activity. The shoe which produces the overall lowest muscle activity should therefore be the most appropriate running shoe for that individual runner.

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