GÖTEBORGS UNIVERSITET
INST FÖR KOST- OCH IDROTTSVETENSKAP

Barefoot running vs shod running

A comparison in lower leg muscle activity

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Sammanfattning

Sedan människan avvek från schimpanserna har hon sprungit. På den tiden var syftet med löpning att hitta föda. Idag fyller löpning ett mer rekreationellt syfte. De senaste åren har löpning fått ett uppsving. Med det har även en önskan att gå tillbaka till rötterna genom barfotalöpning, uttryckts av många. Beskrivningar om barfotalöpningens alla fördelar basuneras ut i media, men forskningen håller inte alltid med. Det finns i dagens läge ingen forskning som pekar på att barfotalöpning alltid skulle vara bättre än löpning i skor. Syftet i denna studie var därför att jämföra skillnader i muskelaktivitet i underbensmuskulaturen vid barfotalöpning och löpning i skor på två olika hastigheter. Hypotesen var att det inte finns någon signifikant skillnad. Sju friska deltagare som alla sprang på framfoten, fick springa på ett löpband med EMG-elektroder på fyra utvalda muskler (S, GL, GM, samt AT). Envägs beroende ANOVA-beräkning utfördes i SPSS för att testa signifikans. Resultaten visar inte någon skillnad i muskelaktivitet mellan löpning barfota och i skor. Det var dock signifikant högre muskelaktivitet (p<.05) i två muskler (GL och S) under löpning i skor på 14 km/h jämfört med 10 km/h. En möjlig anledning till att ingen skillnad upptäcktes mellan löpning barfota och i skor kan vara att deltagarna sprang i icke-standardiserade skor. Några rekommendationer om hur löpning ska tränas på bästa sätt kan ej ges eftersom inga skillnader hittades, men framtida forskning kan dra nytta av erfarenheter från denna studie för fortsatt forskning inom området.

Preface

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1. Introduction

Since the divergence from the chimpanzees, man has been running long distances. It has possibly been a key factor in the evolution of man. Due to natural selection, features like tendon springs, narrow waist, short forearms, shock absorption and thermoregulation, evolved. In the open grasslands, ancestors of man relied on their evolved features of endurance running to scavenge or hunt down their prey. "Today, endurance running is primarily a form of exercise and recreation, but its roots may be as ancient as the origin of the human genus, and its demands a major contributing factor to the human body form." (Bramble & Lieberman, 2004, p. 351).

Running has also been mentioned in the myths and legends of ancient civilizations, such as Greece and Egypt. Professional messengers ran between cities carrying news of importance. In the year of 490 BC the Persians attacked the Greek city of Marathon. The courier Pheidippides ran from Marathon to Sparta (240 km) in call for aid. When the battle was won Pheidippides ran to Athens (40 km) with the news of the victory, but he died delivering the message according to ancient Greek storyteller Herodotus (Christensen et al., 2009).

In the 1960 Olympic Games, an Ethiopian barefoot runner named Abebe Bikila won the Marathon gold with a time of 2:15:16. This set the marathon world record, and is considered a respectable time to this day. This was probably one of the first accounts in modern times of someone winning a major competition while running completely without shoes. Zola Budd is another barefoot runner that won recognition by setting a world record at 5000 m in 1985, finishing at 15:01:83.

Those impressive achievements could have laid groundwork for the rising interest in barefoot activities today. Along with rising trends in all physical activities overall, running has boomed over the past decade. An example of this is GöteborgsVarvet half marathon. In 2006, approximately 36 000 runners had signed up for the race. By 2012, this number had increased to almost 63 000, an increase comparable with the running boom in the eighties (Göteborgsvarvet 2012).

Running is the third most popular physical activity in Sweden, after walking and resistance training (RF, 2010). Despite its popularity, research has yet to determine the optimum way to improve running ability. In fact, there are many considerations to be made. Should one focus on injury prevention, or improvement in VO2max? Maybe running efficiency is the most important aspect to consider? Likely, all of these and more are factors involved in improving running ability. The question then becomes 'what is the best way to improve in all of these different areas, and by extension, improving running ability?'.

This is a question that many have sought to answer. One recent trend is the interest in barefoot running. There are many voices on the Internet that believe it may be more beneficial to run barefoot than the standard practice of running in cushioned shoes (Barefootrunner, 2012). Manufacturers of barefoot sports shoes currently state that wearing their shoes will stimulate and strengthen muscles in the feet and lower legs, improving general foot health and reducing the risk of injury. Further statements are that barefoot shoes will improve range of motion in ankles, feet and toes, and stimulate neural function important to balance and agility. The shoes would even help you to unleash your optimal running stride.

2. Background

The muscles chosen in this study are the three muscles of the posterior superficial compartment of the lower leg (Triceps Surae), and one muscle of the anterior compartment of the lower leg, TA (Tibialis Anterior). The Triceps Surae is divided into three single muscles - S (Soleus), GL (Gastrocnemius lateralis) and GM (Gastrocnemius medialis) - that all have their insertion at the Achilles tendon (Benhke, 2008). The function of those three muscles is plantar flexion of the foot and flexion of the knee. The function of TA is, along with other muscles, dorsi flexion of the foot (Wirhed, 2007).

While running, a stretch force is loaded upon the calf musculature and the Achilles tendon. The force is of an eccentric nature and it is followed by a concentric counter force that springs the leg in the opposite direction. That reflex is called the SSC (stretch shortening cycle) (Komi, 2003). The SSC is more abundant in forefoot running than in heel strike running, because it starts earlier in the gait cycle. In forefoot running the SSC starts when the ball of the foot strikes the ground, and ends when the toes roll off the ground. In heel strike running the SSC starts when the whole foot is in contact with the ground, and ends when the toes roll off the ground (Lieberman et al., 2010).

There are a number of studies that have compared barefoot running with shod running. In a paper from 2009, the author states that there is indirect evidence that barefoot training strengthens both large and small muscles crossing the ankle joint (Nigg, 2009). This raises the question of what else there is to the barefoot condition that can be advantageous compared to the shod condition. From an injury prevention perspective, it may prove beneficial to run barefoot rather than in shoes. Believed to be a fact by some, this has yet to be proven by research (Nigg, 2009). However, evidence exists on the aspect of energy expenditure while running, where the barefoot condition shows significantly lower values in energy consumption compared to the shod condition (Hanson, 2009). According to a literature review regarding the claims and controversies of barefoot running, evidence neither supports nor rejects the thesis that performance is improved or that injuries are reduced by training barefoot (Jenkins & Cauthon, 2011).

Some other researchers have looked at biomechanical factors such as calcaneal and tibial movements (Stacoff et al., 2000) or ways to reduce tibial rotation by wearing athletic running shoes (Fukano et al., 2009), and ground collision forces between habitually shod or barefoot runners (Lieberman et al., 2010). One study looked at the muscle activity of barefoot and shod gait in diabetic neurophatics (Sacco et al., 2010). Although, there is very few articles that concern muscle activity discrepancies in barefoot and shod runners.

Stockton and Dyson (1998) did, among other things, examine the muscle activity in a number of muscles in barefoot and shod running.

By the lack of research made on the comparison of muscle activity between barefoot and shod running, this study was conducted to expand the knowledge in this area.

The purpose of this study is to compare muscle activity between two conditions: running barefoot and running in conventional running shoes, at two different speeds. The hypothesis was that there would not be any significant difference in muscle activity between barefoot running and shod running.

2.1 Research questions

1. Is there a difference in muscle activity in the TA, S, GL and GM when running in traditional shoes compared to running barefoot?
2. Will an increased running speed result in a higher muscle activity?
3. If yes, is this true for all the muscles, or will the different lower leg muscles react differently depending on the condition?

2.2 Definitions

The definitions of the running techniques (forefoot running, midfoot running and heel strike running) are our own, as we were unable to find a definition of these terms in any of the scientific literature, and since there doesn't seem to be a universal definition of them. We were also unable to find a definition of muscle activity in commonly cited studies (Ludewig & Cook, 2000; Nilsson et al.,1985), and therefore we chose to make our own definition of this as well, based on Noraxon's description of surface EMG (electromyography).

Forefoot running: The ball of the foot is the first part of the foot that touches the ground while running.

Midfoot running: Most of the foot touches the ground at approximately the same time during running.

Heel strike running: The heel is the first part of the foot that touches the ground during running.

Barefoot running: Running without shoes, minimalistic barefoot-like shoes or socks.

Muscle activity: The microvolt level electrical signals of a muscle fiber contracting. (http://www.noraxon.com/semg/whatissemg.php3)

3. Method

3.1 Design

This is an explorative study of a cross-sectional design. EMG electrodes were placed on four different muscles, S, GL, GM and TA, in order to measure muscle activity. Measurements were taken at two different paces, 10 km/h and 14 km/h. Tests were performed on a treadmill (Rodby RL2500E). Three reflective markers were placed on the foot. One was placed at the heel, one on the lateral anklebone and one at the middle of the forefoot. The latter one was used to determine when the foot was in contact with the ground. The other two markers were placed to get visual feedback in the QTM (Qualisys Track Manager) software.

3.2 Subjects

Eight subjects expressed interest in participating in the study. However, one dropped out prior to testing due to his child being ill. Seven adult volunteers that fulfilled all the inclusion criteria participated in this study (age = 30.7 yr ± 8.5, length = 173.1 cm ± 11.2, weight = 67.6 kg ± 14). Three were elite competitive runners, another three were skilled recreational runners and one was a novice recreational runner. Popular Internet forums for runners (i.e. jogg.se and funbeat.se), and personal contacts were utilized in order to find participants. The criteria for participation in the study was a minimum average running dosage of 10 km per week over the last year, and participants had to feel comfortable running at 14 km/h for at least five minutes. The participants had to be healthy, free of injury and between the ages of 18 and 45. They had to have some experience running barefoot or in minimalistic running shoes. Participants were required not to run with a heel strike technique.

3.3 Ethical considerations

Information that was given to the test subjects before they decided to take part in the study involved the following: Participation in the study is completely voluntary and the test subjects are free to end their participation at any time without stating a reason why. They were given information about the risk of participating in the study and that they did so at their own risk. Risks involving falling of the treadmill or straining muscles.

Before the test procedure, safety information was given to the participants. Information regarding the increasing speeds, verbal communication between test leaders and test subject, and how to stop the treadmill if any problem occurred. Tests were scheduled so that only one participant at a time was in the laboratory. Only the test leaders were able to see the results of the tests. The collected data was coded and the results can therefore not be traced back to a specific participant (Vetenskapsrådet, 2002).

3.4 Overview of EMG

Electromyography, or EMG, is a method for receiving and observing electrical signals of the muscle membranes. EMG was invented in the 1940s, but wider use of the method started with a study that successfully measured the shoulder musculature in the mid-1940s. Soon after, in the mid-1950s a study of how the erector spinae musculature reacts when the torso leaning forward was conducted (Cram, 2003).

With the use of EMG, activity of a muscle can be measured and studied in order to determine functionality in different body maneuvers. EMG can be used in many different ways, but always with the purpose of looking into the muscle to see its functionality.

Some examples of the usage of EMG are rehabilitation, medical research, sport science and ergonomics. There are two different kinds of EMG set-ups used to measure muscle activity in the extremities. There is the fine wire type where a needle inserts the electrodes into the deeper musculature, where a regular skin surface electrode type that has been used in this study cannot reach. The disposable skin surface electrodes are hygienic and easy to handle. (Noraxon Inc, 2005)

Before using EMG, some basic aspects must be taken into consideration. Recommendations founded by the SENIAM group, is to be followed. For example, knowing where to place the electrodes is essential to get valid and reliable results. Even the slightest change in the replacement of the electrodes can affect the signal in a negative way (Cram, 2003).

3.5 Procedure

Upon arrival, participants were weighed and measured, and given information about their participation in the study, and the procedure. Participants brought their own running shoes. They were asked to bring their most cushioned, built up and supportive running shoes. After shaving and cleaning each area with alcohol (if needed), electrodes were attached to the skin, as recommended by the ABC of EMG (Noraxon Inc, 2005, p.14). EMG electrodes were placed in pairs, adjacent to each other, on each of the four muscles according to SENIAM recommendations (Seniam, 2008). EMG DTPs (direct transmission probe) with a built-in grounding plate were placed on the closest bone area from each electrode pair (Noraxon Inc, 2005, p.17).

Reflective markers were placed on the outside of the anklebone, the back of the heel (or on the shoe, in case of the shod condition) and on top of the foot above the ball of the foot (or the equivalent location on the shoe). Before the shod running tests, the shoes had to be prepared by making sure that any reflective surface on the shoe was covered up by tape, so that they could not interfere with the tracking of the markers.
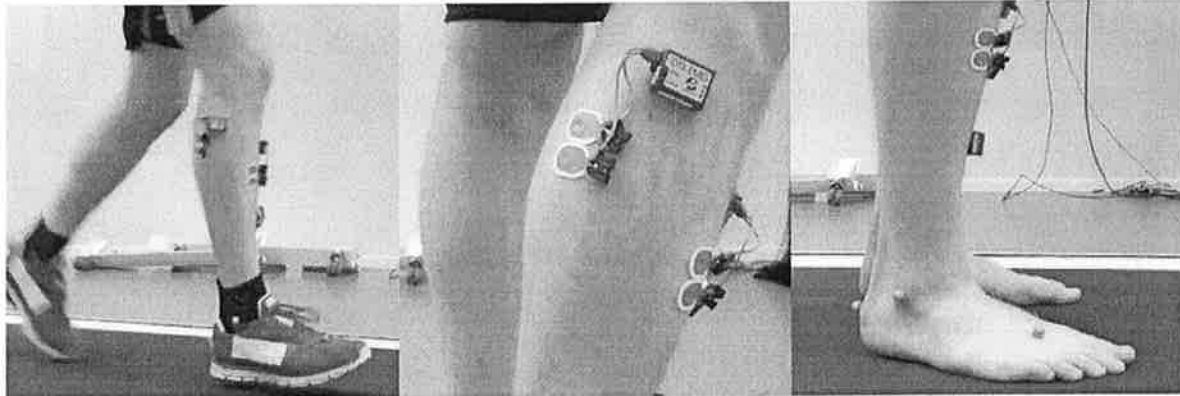
Figure 1. EMG electrode, DTP and reflective marker placements.

After a short warm up on the treadmill (no more than five minutes) in a pace chosen by the participant, testing could begin. During the trials, an EMG DTP sometimes fell off while a participant was on the treadmill. It occurred once in almost every testing session (one subject performing each of the four tests), sometimes twice. The test was aborted when this happened, in order to properly reattach the device.

Recording of the data started when the subject felt comfortable running at the given velocity (10- or 14 km/h). A metronome was used to standardize the step frequency at 180 strides per minute. The total time of data collection was 10 seconds for each circumstance (shoes at 10- and 14 km/h and barefoot at 10- and 14 km/h respectively). Between the circumstances, velocity (on the treadmill) was increased progressively when the test subject said it was okay to do so.

QTM software was used to collect the data from the EMG electrodes and the reflective markers. In order to keep track of which marker was which, they were given descriptive names. The same was done for the data streams from the EMG electrodes. The muscle activity of each muscle during the 10-second timeframe, and the marker positions were measured. Either 14 or 15 steps were recorded during that period, depending on the timing of the first step, and how accurately the test subjects were able to follow the beats of the metronome. After each recording, the data was monitored to make sure that there had been no interference with the tracking of the markers, and that all the data had been recorded successfully. The raw data was then exported in .c3d (a file format used by MyoResearch XP) format for analysis.

3.6 Instruments

Data was collected in the KHP-laboratory (Kunskapscentrum för Hälsa och Prestationsutveckling) at the University of Gothenburg. The software program used in the collection of the data was Qualisys Track Manager Version 2.6 (build 682) (Qualisys Motion Capture Systems, Gothenburg, Sweden). MyoResearch XP Master Edition, Version 1.07.01 (Noraxon U.S.A. Inc., Scottsdale, Arizona) was used to process the raw data. Motion capture

was handled by a total of 16 cameras (eight Oqus 3+ and eight Oqus 4) with a chosen capture frequency of 500 Hz. SPSS V20,0 was used in the statistical analysis.

A stationary high definition video camera was used to film the runner's foot strike on the treadmill and was synced with the recordings of the Qualisys motion capture system. The treadmill used in the trials was a Rodby RL2500E, with a Speed deviation of $\pm$ 1,8 % (Rodby Innovation AB, Vänge, Sweden). EMG electrode surface area was 15 mm^2. The metronome used was an online free metronome that was able to do 180 beats per minute (http://a.bestmetronome.com/).

3.7 Data analysis

Analysis and processing of the raw EMG data was done in MyoResearch XP. After each of the .c3d files were imported, the EMG signals were processed through rectification and smoothing (Noraxon Inc, 2005, p.26-27). Rectification means that all negative amplitudes are converted to positive amplitudes, and is recommended by the ABC of EMG (Noraxon Inc, 2005, p.26) when quantitative amplitude analysis is the target, as is the case in this study. Smoothing was also performed, with the algorithm set as mean, and the window to 50 ms (these are settings in MyoResearch XP). This should help reduce the steep EMG amplitude spikes (Noraxon Inc, 2005, p.27). The effects of these steps on the EMG curve and data are illustrated with figures 1 and 2 in Appendix I.

Test subjects were filmed from the side during the data collection. This film was used to determine whether the participants were running with a heel striking technique, or not.

Markers were placed systematically - based on the z-axis position of the toe marker - to make sure only the intended part of the step (when the foot was in contact with the ground) was analyzed further. Displayed in Figure 2 (Appendix I) is an example of where the markers would be placed in this case, though for visibility reasons only two markers were placed in the image, instead of the ~30 that were used in the study. The interval shown between the two blue markers displays when the foot is in contact with the ground. It is the part of the step where the Toe marker is closest to the ground.

Analysis was done, using the standard amplitude template (in MyoResearch XP) and making sure that the correct marker intervals were selected. The results of the analysis were exported to an excel file for easy processing. Statistical analysis of the data was then performed using one-way repeated measures ANOVA in SPSS 20, in order to compare the differences within subjects.

4. Results

Analysis of the video footage confirmed that all seven participants were in fact using a midfoot or forefoot running technique. Since none of them used a heel striking technique in any of the tests, the data from all the participants was included in the study.

The results for mean muscle activity of the different conditions, and the comparison between them, are presented in tables 1 and 2. A comparison between, running at the different speeds is shown in Table 1, and the comparison between the shod and barefoot conditions is presented in Table 2.

Table 1. Comparison of muscle activity at different running speeds

| Muscle | Condition | Muscle activity, μV (mean, S.D.) | | Difference in % |
		10 km/h	14 km/h	
Tibialis Anterior	Shoes	77,9 ± 58,6	104,7 ± 69	26%
Tibialis Anterior	Barefoot	93,5± 89,7	144,5 ± 162,9	35%
Soleus	Shoes	201,5 ± 104,9	286,1 ± 143,1	30%*
Soleus	Barefoot	149,8 ± 72,5	222,8 ± 154,2	33%**
Gastroc. Lat.	Shoes	147,4 ± 61,3	196,4 ± 84,7	25%*
Gastroc. Lat.	Barefoot	139,2 ± 44,8	174,5 ± 80	20%**
Gastroc. Med.	Shoes	233,5 ± 128,2	363,3 ± 306	36%
Gastroc. Med.	Barefoot	224,5 ± 132,5	251,6 ± 167,7	11%

* $P \leq 0.05$
** $P \leq 0.08$

When examining the data from the TA electrodes, the results demonstrated that there was no significant difference in the TA muscle activity between running at the speeds of 10 km/h and 14 km/h for either condition ($p<.05$). However, there was a significantly higher muscle activity in the S when running in shoes at 14 km/h compared to 10 km/h ($p<.05$). For the barefoot condition the results show a trend that there may be an increase in muscle activity at the higher speed, however it is not statistically significant ($p=.076$).

Muscle activity in the GL while running in shoes at 14 km/h was significantly higher than at 10 km/h ($p<.05$). While the same cannot be said for the barefoot condition, there is a strong trend

that there may be a difference in muscle activity between the speeds for this muscle as well (p=.068). In the GM there is no significant difference for either condition when running at the two different speeds (p<.05).

Table 2. Comparison between the shod and barefoot conditions

| Muscle | Speed | Muscle activity, μV (mean, S.D.) | | Difference in % |
		Shoes	Barefoot	
Tibialis Anterior	10km/h	77,9 ± 58,6	93,5 ± 89,7	17%
Tibialis Anterior	14km/h	104,7 ± 69	144,5 ± 162,9	28%
Soleus	10km/h	201,5 ± 104,9	149,8 ± 72,5	-35%
Soleus	14km/h	286,1 ± 143,1	222,8 ± 154,2	-28%
Gastroc. Lat.	10km/h	147,4 ± 61,3	139,2 ± 44,8	-6 %
Gastroc. Lat.	14km/h	196,4 ± 84,7	174,5 ± 80	-11%
Gastroc. Med.	10km/h	233,5 ± 128,2	224,5 ± 132,5	-4%
Gastroc. Med.	14km/h	363,3 ± 306	251,6 ± 167,7	-44%

There was no significant difference in results when comparing the shod condition with the barefoot condition for any of the four muscles examined (p<.05).

All the data tested significant in Mauchly's test of sphericity. This means that there was a relatively large standard deviation in the results, and this is also evident when looking at tables 1 and 2. Therefore, sphericity could not be assumed. The Greenhouse-Geisser (1959), and the Huynh-Feldt (1976) corrections were used to test for significance of data, and those are the results presented in Table 1 and Table 2.

5. Discussion

With running getting increasingly more popular, topics such as running technique and what to wear (or not to wear) receive more attention than ever. Advances in electronic media in the past decade have also contributed to a large scale debate being possible, where anyone can state their opinion. Statements are made; however, few of them are based on modern research. The community of runners seems to be divided into groups. On one side we have those who wear shoes because they believe it is the best way to run and stay injury free. On the opposite side we have those who believe we should run like the primeval man, because it is the natural way to run. In between we have those who wear shoes because they are told to do so by retailers and social lobbying. The problem is the deficiency of facts backed up by proper research. If this information is produced, people will be able to make informed decisions based on the facts available to them.

The findings of our research show a lack of significant results in comparison of the shod and barefoot conditions. This may have been caused by a number of aspects. Since the variance of data was so great, despite the differences in mean muscle activity, the results were not statistically significant. The low number of participants is one reason for the lack of any significant findings. With only seven test subjects, there is likely no normal distribution of data, and therefore it is possible that individual differences is what caused the variance of data.

Another reason may be the shoes used in the trials. Shoe models varied from kind of minimalistic (i.e. Saucony ProGrid Kinvara), to more sturdy (i.e. Adidas Adizero Aegis 2) ones. If the shoes would have been standardized to a certain model, the results may have been different.

Results of the TA showed no significant difference between the two speeds for either condition. This was because of the large variance in data. Some subjects showed a slight decrease in muscle activity at 14 km/h, while others showed an increase. There was also an extreme outlier, which affected the variance greatly. It is possible that there is an increase in TA muscle activity when running faster, both in shoes and barefoot, however we were unable to detect it.

The only significant results found in the study were in the S and GL muscles, in the shod condition, between 10 km/h and 14 km/h. It is quite logical that these two muscles would need to exert more force to make the body move further with each step, as the frequency was the same at both speeds. So the result is in itself unsurprising. As for the barefoot condition, the results were not significant; however they did indicate a strong trend towards the same result. Likely, this would have been significant with a larger number of participants.

A possible reason for the smaller variance in this case compared to the other muscles is likely that in all the participants showed a larger activity at the higher speeds. For most other

parameters we looked at, there were some participants that showed an increase in muscle activity, and some that showed a decrease between conditions. The lack of previous research on possible increases in muscle activity at higher running speeds is easily explained, since this could seem obvious; at least for some of the muscles like the S, GM and GL. This was not the main purpose of this study, but simply something we realized that we had data on and therefore could compare as well. It was interesting that these two muscles showed a significant difference, while the other two did not even show a trend. So perhaps there was some merit in looking at this aspect as well.

Since there is no other research in this particular area, it is unclear why GM did not show any significant results when the other head of the muscle, GL, did. When looking at the data in detail, the cause of the larger standard deviation in the GM data seems to be that some participants showed a higher activity at the higher speed, while some showed a lower activity. There was also yet another of the extreme outliers, increasing the variance by a lot.

The hypothesis that there will be no significant difference in muscle activity between the shod and barefoot conditions turned out to be true, in this case. While we thought that there is a difference in muscle activity between the two conditions, we did not expect to find it statistically significant due to the small number of participants. Ideally, this type of study would be conducted on a greater number of participants. However, due to very limited resources available to conduct this study, a compromise had to be made and only a few participants could be tested.

In the background we mentioned that Stockton and Dyson (1998) had compared the muscle activity between the shod and barefoot conditions. While they state that they did, they failed to properly report any findings in this regard. In the report, they just state that there was a difference, without providing any data to support this claim. And they do not mention the results being significant. Therefore, we cannot assume that they have found anything in their study. Another aspect that would make a direct comparison difficult is that they did not consider that running technique may have an impact on the results. It is conceivable that any results they may have gathered are due to a transition from a heel strike running technique while running in shoes, to a forefoot running technique while running barefoot.

Sadly, that was the only study we found that made a comparison between the shod and barefoot conditions in running, looking at lower leg muscle activity. It would have been interesting to compare the results of this study to theirs, if it had been properly reported and/or conducted.

To perform the specific tests made in this study, the use of EMG was necessary. However, we were not that experienced in the use of EMG prior to the study. This may have led to some aspects being overlooked. For instance, we were not aware of the MVC (maximal voluntary contraction) procedure, used to get a reference value of specific muscles in EMG measurements. Had we known about it, however, it would still not have been viable to use it. Having the test

subjects perform an MVC would have proven very time consuming, as it is not a simple matter to do an MVC-test.

According to the ABC of EMG instruction booklet (Noraxon inc, 2005, p.30), there are many ways to validate test data by use of MVC. Every muscle must be individually tested, preferably with rigid resistance done by straps, human aid or isometric training machines. It is of absolute importance that the muscle contraction is performed correctly to ensure that the maximal EMG peak of the specific muscle is measured. Further reading on the subject revealed, however, that performing an MVC is mostly used when electrodes need to be removed in-between measures. Since we only compared results within subjects, this was likely not an issue. We cannot tell if the results of this research would have been different if MVC-tests were performed.

Barefoot runners tend to utilise a forefoot/midfoot striking technique while running. Shod runners on the other hand, especially when running in heavily cushioned shoes with a large built up heel, often run with a heel striking technique. According to the research done by Lieberman et al. (2010), these two running techniques may differ in collision forces. Further, Mansour Eslami et al. (2007) have found that forefoot adduction/abduction and rearfoot eversion/inversion coupling motion patterns were significantly different between barefoot running and shod running.

These findings lead to the conclusion that running technique may have a significant impact on different mechanics during running. This means that there could be an effect on muscle activity as well. Therefore, in order to isolate the differences between the two conditions, a forefoot/midfoot striking technique was chosen as criteria for participation in the study. This should make it more likely that any results from the study are due to a difference between the shod and barefoot conditions, and not a difference in running technique between the conditions. If these considerations were not made, a heel strike technique may have resulted in greater activity in the TA and less in the calf musculature due to a greater dorsi flexion of the foot.

During the testing session, the EMG DTP sometimes fell off, going into the fourth and final test per participant (shoes at 14 km/h or barefoot at 14 km/h). The problem was with the adhesive tape that failed when the speed increased. It is unclear if the abort and re-initiation of the tests had an influence on the outcome of the results, but such a thing may explain some of the large standard deviations in the data.

Criteria for participation in the study were quite extensive. There are two main reasons for this. First, we wanted to make sure that any risk of injury for the test subjects was minimal. Since barefoot running is quite different from shod running, we wanted the participants to have some experience in this before entry in the study. The other reason was that a group of experienced runners should have developed more efficient running mechanics, which are very similar from step to step. They would also need to be able to handle the speed of 14 km/h without making any major adjustments to their running technique. This should help in getting as valid data as possible.

Due to the extensive inclusion criteria and low participation, the results found in this study are not fit for making general assumptions about the whole population. However, the results may

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provide future research with a direction marker for what to expect, when dealing with EMG and low participation.

As aspiring strength and conditioning coaches we cannot directly apply the results of this study in our future profession. What we were hoping to find was a difference between shod and barefoot running, to be able to give training recommendations to future clients. We can, however, use the experience gained working on this project and share it with colleagues and researchers who look to continue the research. It is also possible that we may continue the research ourselves in the future.

5.1 Suggestions for future research

Future research on muscle activity has to include a greater number of test subjects to get a greater power. To find a more distinct difference in muscle activity, running velocities may be adjusted, for example 10 km/h and possibly over 15 km/h. Another field to examine is muscle activity in further muscles, such as the Hamstrings, Gluteus, and Quadriceps or Peroneus longus. It could also be of interest to test for differences in muscle activity in different muscles in the feet. However, it may prove difficult to do since a shoe would be blocking electrode placements in the shod condition. There may be ways around this in the future, though.

One key aspect for finding significant results may be to standardize the shoes to wear by the test subjects. Maybe even add more shoe types to expand the research, including minimalistic barefoot-like shoes as well as heavily supported and cushioned shoes. In the data analysis, other parts of the stride can be compared to see if there are any other significant results.

Another interesting area for future research could be to find out how much of the percentage of a muscle's maximal muscle activity is engaged during running for each of the four different conditions. To do this, one could repeat the same type of tests as in this study, preferably with more participants, and having them perform an MVC prior to the testing. The data could then be compared.

5.2 Conclusion

This study does little to help further the question of how to train in order to improve running ability. Since the results we found significant were unrelated to that topic, and there were no significant differences in the comparison between shod and barefoot running, we can provide no training recommendations for runners. Hopefully the experience gained by this study can be used to aid future studies in finding answers to this question.

5.3 Conflict of interest statement

This study has not benefited from any sort of funding, and there is no conflict of interest.

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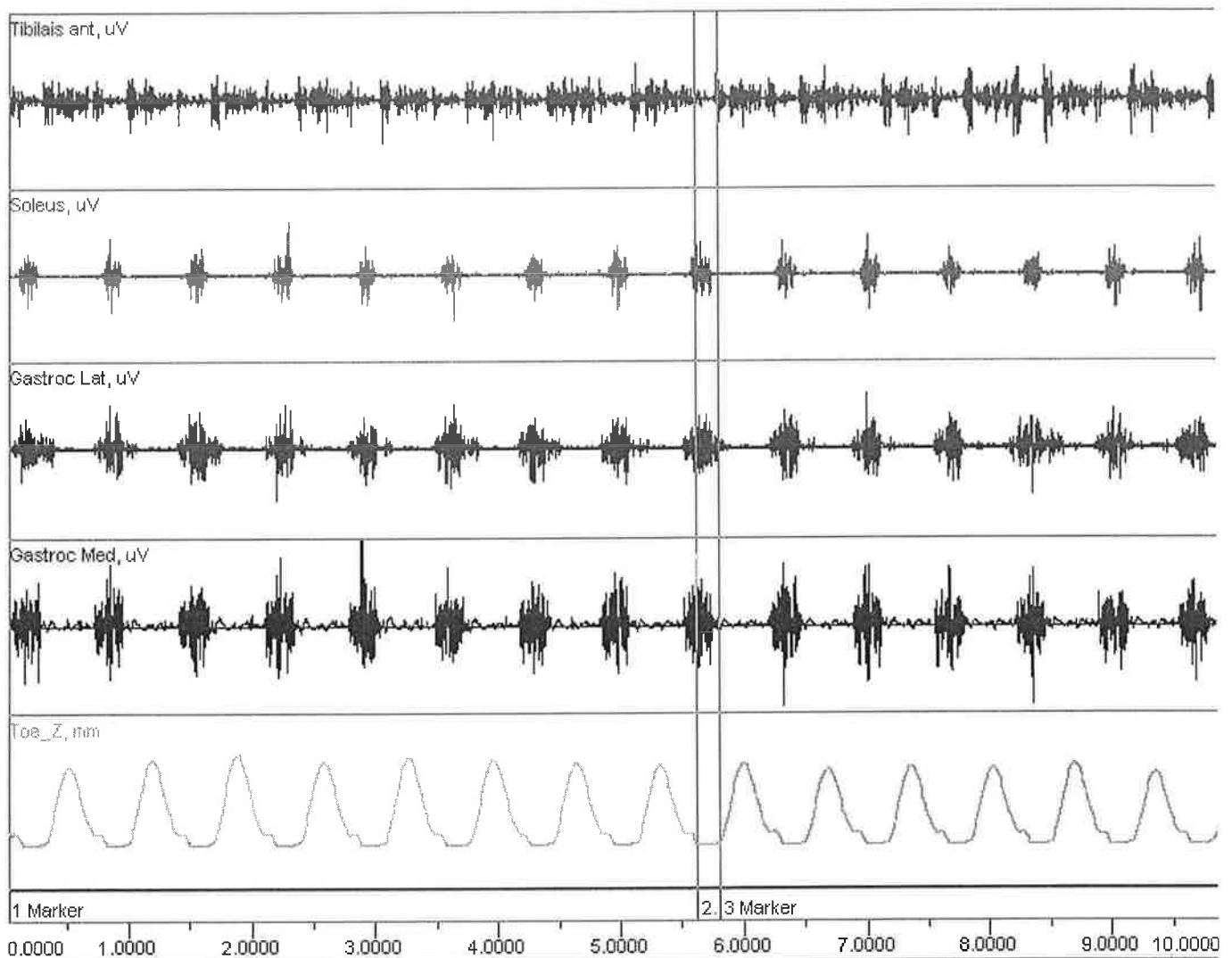
7. Appendix I

Figure 1. An example of a measured 10 second recording (*before* rectification and smoothing), displayed in MyoResearch XP, showing the muscle activity for each of the four lower leg muscles, and the Z-axis of the toe marker (Toe_Z). Also shown is an example of the contact phase periods, marked by two blue vertical markers (2 and 3).
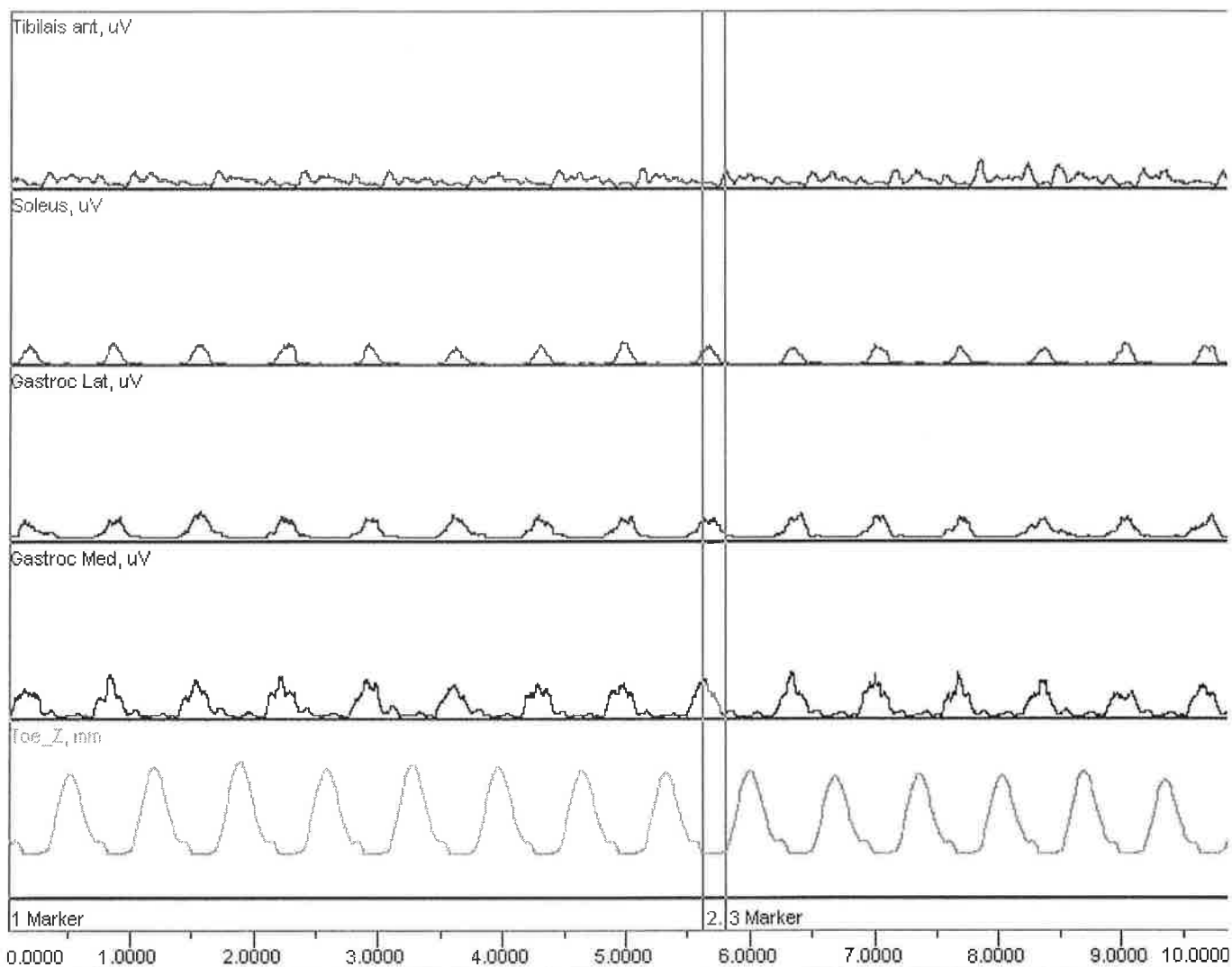
Figure 2. An example of a measured 10 second period (*after* rectification and smoothing), displayed in MyoResearch XP, showing the muscle activity for each of the four lower leg muscles, and the Z-axis of the toe marker (Toe_Z). Also shown is an example of the contact phase periods, marked by two blue vertical markers (2 and 3).