A correlation study between step length, step frequency and the length of the leg

A study of running

Annica Kvick

Bachelor's programme in Exercise Biomedicine, 180 credits

Bachelor thesis in Exercise Biomedicine, 15 credits

Halmstad 2016-05-24
A correlation study between step length, step frequency and the length of the leg
A study of running

Annica Kvick

2016-05-24
Bachelor Thesis in Exercise Biomedicine, 15 credits
Halmstad University
School of Business, Engineering and Science
Thesis advisor: Lina Lundgren
Thesis examiner: Sofia Ryman Augustsson
Acknowledgement
I would like to thank my supervisor Lina Lundgren for her support and feedback throughout this work and my examiner Sofia Ryman Augustsson for the last and important feedback. I would also like to thank all my friends and family for your support and encouragement during this process. Without all of your support this bachelor thesis would have been a lot harder to complete. And last but not least, I want to thank my friend Malin Lindvert for all her help during data collection.
Abstract

Background: Running is one of the most popular branches of athletics. Running has several physiological benefits, such as a higher maximal oxygen consumption, increased muscle mass and reduced blood pressure. There have been plenty of discussions about what the most efficient running technique might be, should you use a short step length and a high step frequency or vice versa. It is generally known that you can increase your running speed by increasing your step frequency or your step length, and also both. However, maximal speed is achieved by increasing your step frequency rather than your step length. For endurance runners it is important to have a good running economy, because runners with a good running economy use less energy while running, and therefore require less oxygen than a runner with poor running economy. Previous research have not found any correlations between the length of the leg with step frequency or step length. Aim: The aim of this study was to examine whether there are any significant correlations between the length of the leg in relation to the step frequency or the step length while running in different speeds. Method: 15 trained males participated in this correlation study. All participants’ leg length were measured with a measuring tape. Three running trials, with the speeds of 12, 16 and 20 km/h were performed on a treadmill during 1 minute each. Between each trial the participants rested for 3 minutes. The trials were recorded with a video camera, and the participants individual step frequency, step length and heel or fore foot strike were collected. Persons coefficient of correlation test was used to analyze if there were any significant correlations between the length of the leg with step frequency and step length. Also a paired samples T test was performed to see if there was a significant increase between step frequency and step length with the speeds. Result: There were no significant correlations (p>0.05) found between the length of the leg and the step frequency or the length of the leg and step length in any of the different speeds. The paired samples t-test showed a significant (p<0.001) increase in step frequency and step length with the different speeds. Conclusion: In conclusion, according to the present study, there were no significant correlations found between the length of the leg with step frequency or step length, which is in consensus with previous research. Therefore, it is not advisable to predict an individual’s step length based on their leg length. There are various factors involved in determining a person’s step length and step frequency, and this study showed that running speed is one important factor. This information may be useful for runners and their coaches to apply, so they avoid making interventions involving alternations in the runners step length based on their body dimensions, such as leg length.
# Table of content

Introduction.........................................................................................................................1
Background............................................................................................................................1
  Running technique ............................................................................................................1
  Running economy and foot strike technique .................................................................3
Metabolic economy .............................................................................................................4
Energy systems ....................................................................................................................4
  Anaerob ............................................................................................................................5
  Anaerob ............................................................................................................................5
Physical aspects of running ...............................................................................................6
Aim .......................................................................................................................................8
  Research questions: .......................................................................................................8
Methods ..............................................................................................................................8
Participants.........................................................................................................................8
Study Design .......................................................................................................................8
  Testing procedures .......................................................................................................9
Data collection ...................................................................................................................9
  Statistical analyses ......................................................................................................10
  Ethical and social considerirations ..............................................................................10
Results ..............................................................................................................................11
  Relationship between variables ...............................................................................11
  Increasing running speed ............................................................................................15
Discussion .........................................................................................................................16
  Result discussion .........................................................................................................17
Method discussion ............................................................................................................18
  Participants ...................................................................................................................18
  Running procedure .....................................................................................................19
  Equipment and measurements ....................................................................................20
Conclusion ........................................................................................................................21
References ..........................................................................................................................22
Appendix ............................................................................................................................24
Introduction

Running is and has been for a long time, one of the most popular and fundamental disciplines of athletics. Running has several benefits, not only physiological benefits, but also psychological benefits (Warburton, Nicol & Bredin, 2006). Some physiological benefits of running and exercising are; higher maximal oxygen uptake (VO$_{2\text{max}}$), increased muscles mass, improved body composition and reduced blood pressure. Running can also improve your physiological well-being through reduced stress, anxiety and depression. Exercising regularly can also prevent diseases such as diabetes and cardiovascular diseases. (Warburton et al. 2006). However, running can also cause injuries and place muscle-skeletal stress on the body, if practiced in an inappropriate way (Elliott et al. 1979). There were many studies on running during the early 70s, nevertheless it seems to be less studies performed today that examine the importance of the leg length and step length. This is why it is important for more running studies to be done in modern time. With new technology and equipment, perhaps this will lead to new knowledge that will play an important role for the runners and their running economy. Because of this interest for running, the chosen topic for this thesis is to study the anthropometric parameter leg length, and its effect on step length and step frequency while running on a treadmill in different speeds.

Background

Running technique

There have been plenty of discussions about what the most efficient step length might be and what technique is more efficient than the other. Your running speed is determined by temporal and spatial variables, such as step frequency and step length. These variables all interact with each other to determine the running speed (Liberman, Warrener, Wang & Castillo, 2015). Endurance runners, who run further than 5000 meters, are sometimes advised to maintain a short step, and a higher step frequency, to make it as metabolically economic as possible (Liberman et al. 2015). In another study by Högberg, (1951a) it was found that the most economical step frequency (at the speed of 14 and 16 km/h) was 173 and 179 steps respectively per minute. There is still no consensus whether this step frequency is for everyone, or if people with different height and leg length should individually choose a step frequency suitable for themselves.
When running, the legs and feet absorb up to 6 times the body weight at each heel strike (Elliott and Blanksby, 1979). Therefore, it is of importance to have a step length that allows for high force absorption without excessive muscular effort. However, the concept of step length may be individually determined. Elliott et al. (1979) tested 10 female and 10 male runners in different speeds. The study showed mean values of the step lengths for the female runners in speeds such as 9, 13, 16 and 20 km/h at 0.93, 1.22, 1.44 and 1.60m respectively. For the males in the same speed their step lengths were calculated to 0.97, 1.30, 1.56 and 1.79m, whereas the mean step frequency for the males was calculated to 155.4, 162.6, 174 and 184.8 steps per minute. For the females the mean values of step frequency was 160.8, 172.8, 188.4 and 207.6 steps per minute (Elliott et al. 1979). Unless these differences are gender based due to running technique, they may be due to the general shorter leg lengths that females have.

A stride consists of right heel contact, left heel contact and then right heel contact again. A step is a part of a stride (left heel contact to right heel contact). Therefore, two steps will be one stride, also called one gait cycle. Stride/step length and stride/step frequency are the most commonly studied linear kinematic parameters (Hamill, Knutzen and Derrick, 2014), and the running speed is the result of the relationship between these. That is: running speed = stride/step length x stride/step rate. Generally, it is known that you can increase you running speed by increasing you step length or step frequency, and also both (Hamill et al. 2014). Maximal speed is generally achieved by increasing the step frequency rather than step length (Mercer, Vance, Hreljac & Hamill, 2002). The problem is though that the step length can only be lengthened by so much. There is a physical limit to how much a person can increase his or her step length. To run faster after that limit, the person needs to increase his or her step frequency instead (Hamill et al. 2014). Many studies have shown that in running, both step frequency and step length increase with increased speed. Nevertheless, this concept is not applicable in higher speeds above 25 km/h (Hamill et al. 2014). Up until 25 km/h the relationship between step length and step frequency is linear, but above this speed there will be a smaller incensement in step length and a greater incensement in step frequency instead (Hamill et al. 2014).

It is important to remember, that during high speed treadmill running, it may be advantageous to continue to increase the step length because the treadmill belt is moving beneath you while running. When running overground, the runner needs to propel himself or herself over the distance covered per step length. Therefore, it has been observed easier to increase step length
while running on a treadmill compared to running overground (Mercer et al. 2002). Previous research have studied the relationship between step length and the length of the leg. One of these studies report that the step length depended more on the leg drive at fast running speeds, more than the length of the leg (Högberg, 1951b). A further study by Högberg (1951a) showed that step length was dependent on the length of the lower leg up to a speed of 27 km/h. However, the role of the length of the lower leg in relation to step length will not be examined in this study. After the speed of 27 km/h was reached, the step frequency played a more important role in determining the step length while running (Högberg, 1951a). This finding agrees with the study of Hamill et al. (2014). If a runner would want to lengthen his step length he or she could do that in three different ways; by stretching the lower leg forward, by increasing the angle of the thigh in the sagittal plane or as mentioning before, with a more powerful legdrive (Högberg 1951a). When it comes to walking, the step length depends entirely on the length of the leg and suppleness in the hips, since when walking the back of the foot must remain on the ground until the front foot reaches the ground (Högberg, 1951b). It still needs to be done further studies on running to examine the importance of the running technique when it comes to step length and step frequency (Hamill et al. 2014).

Running economy and foot strike technique

When talking about running economy it can mean two different things. It can refer to the energy demand for a given speed of submaximal running. Runners with good running economy use less energy while running, and therefore less oxygen than runners with poor running economy. So with that being said, there is a strong correlation between running economy and distance running performance (Saunders, Pyne, Telford & Hawley, 2004). The other meaning of running economy can be related to biomechanics and the actual running technique, referring to aspects such as step length, step frequency and heel versus fore foot strike (Saunders et al. 2004). How an athlete prefers to run is individual, however they want as little energy as possible to be wasted on braking forces and excessive vertical oscillation (Saunders et al. 2004). Runner’s foot strikes can vary, and it may be hard to define and measure them. Daoud, Geissler, Wang, Saretsky, Daoud and Liberman, (2012) defined in their study two categories of strike types that are common for distance runners: rearfoot strikes (RFS), in which the heel contacts the ground first (heel–toe running) and forefoot strikes (FFS), in which the ball of the foot contacts the ground before the heel (toe–heel–toe running). The kind of strike pattern a runner use can depend on the speed they are running in, what kind of surface they run on and what kind of footwear the runner is using (Daoud et al.
2012). It is generally known that FFS gaits are more common at high speeds. Overall, the most common running technique is RFS. The RFS running technique have showed to cause twice as much stress injuries on the body, when measuring impact forces, compared to FFS (Daoud et al. 2012). That information is important for both runners and coaches to know about, so they can try to run as economical as possible and to avoid injuries (Daoud et al. 2012).

**Metabolic economy**

There seem to be a correlation between step length and the oxygen consumption. The longer step you are using the more energy it is going to cost (Högberg, 1951a). This plays an important role in determine your running economy. A measure of the energy cost in your body when running at a certain speed can be referred as the exercise economy (Baechle & Earle, 2008). When running, the running economy (metabolically) is important because athletes with a high exercise economy use less energy while exercising to maintain a certain running speed than a person with poorer exercise economy (Baechle et al. 2008). Several investigators have suggested that biomechanical parameters, such as step frequency and step length are connected to metabolic cost when running. The self-selected running speed is often affected by the metabolic cost per distance, by choosing a slower speed (Högberg, 1951a). As mentioned before, there seem to be a correlation between step length and the oxygen consumption. The longer steps you are using the more energy it is going to cost. This might have an impact on your running patterns, hence you want to run as metabolically economic as possible and therefor might choose a shorter step (Lussiana & Gindre, 2016). This information is important for runners to take into consideration when training.

**Energy systems**

The body has three basic energy systems: The phosphagen system (short and explosive), glycolysis system (glucose transfers to adenosine triphosphate (ATP)) and the oxidative energy system (primary source of ATP). The energy systems are usually referred to the anaerobic (do not require oxygen) energy system and aerobic (depend on oxygen) energy system (Baechle et al. 2008).
Anaerob

Anaerobic training involves high-intensity, intermittent exercise such as interval training, weight training and different plyometric (Baechle et al. 2008). The phosphagen system and the first phase of glycolysis are anaerobic mechanisms that occur in the sarcoplasm of a muscle cell (Baechle et al. 2008). To stress the anaerobic system and to be able to perform better you can for example train sprints and plyometric drills. The duration of these exercises, to stress the phosphagen system, should be under 10 seconds and needs complete recovery between the sets (5-7 minutes) (Baechle et al. 2008).

Instead of using oxygen to produce energy, the anaerobic system uses the first part of the glycolysis and the phosphagen system. The phosphagen system provides adenosine triphosphate (ATP) primarily for short-term, high-intensity activities such as sprinting. This energy system is active at the start of all exercises regardless of the intensity. Creatine kinase is being used to produce ATP by combining creatine phosphate (CP) and adenosine diphosphate (ADP) (Baechle et al. 2008). This system produces energy really fast but because of the low stores of CP it can only provide energy for a short amount of time. In the glycolysis, carbohydrates are broken down into ATP. The first steps in the glycolysis do not need oxygen to produce ATP. Depending on the rate of ATP resynthesizes pyruvate, which is the product of the first part in the glycolysis, can be converted into lactate or transported to the mitochondria (Baechle et al. 2008). The ATP resynthesis rate during the glycolysis is not as fast as with the phosphagen system. However, the capacity is much higher because of the larger supply of glycogen and glucose. It is called anaerobic glycolysis when the rate is high and pyruvate are then converted to lactate (Baechle et al. 2008).

Aerob

The kerbs cycle, electron transport (last phase of glycolysis) and the rest of the oxidative system are aerobic mechanisms that occur in the mitochondria of muscle cells and require oxygen (Beachle et al. 2008). When pyruvate is going into the mitochondria and in to the Krebs cycle, the ATP resynthesis rate is slower. But since it is slower it can occur for a longer time if the exercise intensity is low enough. And this process is called the aerobic glycolysis (Baechle et al. 2008). Hence if the energy must be transferred in a high rate, as in resistance training, pyruvate is converted into lactate. If the energy demand is not as high, and there is enough oxygen sufficient in the cell, pyruvate can be further oxidized in the mitochondria (Baechle et al. 2008).

For endurance runner who are active during a long period of time, they need to rely on the
long term aerobic energy system. If there is enough oxygen available to the working muscle, the body is going to use more of the aerobic (oxidative) pathways and therefore less of the anaerobic (phosphagen and glycolytic) pathways. It is only the aerobic energy system that can provide a large amount of ATP over time via Kerbs cycle and the electron transport system (Baechle et al. 2008). If the intensity is rather low, the aerobic energy system uses primarily carbohydrates and fats as substrates. Protein is usually metabolized if the exercise lasts longer than 90 minutes or if your body goes into starvation mode. When your body is at rest, approximately 70% of the ATP produced is from fat and 30% from carbohydrates (Baechle et al. 2008). During high intensity aerobic exercise almost all the energy required are coming from carbohydrates (Baechle et al. 2008). That’s why it is of most importance that endurance runners eat a lot of carbohydrates, to fill their storage of glycogen and make sure there is adequate supply available. After a long time of prolonged, submaximal, steady-state work, there is a gradual shift from carbohydrates back to fats and protein as energy substrates (Baechle et al. 2008). After a period of aerobic training, the energy delivered from fat increases while the amount of carbohydrates used decreases. A trained athlete can use a greater percentage of fat than a less trained person would use for the same workload (Baechle et al. 2008). Sprinting in a relatively high speed during 1 minute, as the participants for this study did, they will have to first rely on the fast and explosive energy system, the phospagen system. This energy system relies on the hydrolysis of ATP and breakdown of another high-energy phosphate molecule, creatine phosphate. However, this energy system is only reliable for about 15 seconds (Baechle et al. 2008). After that the glycolysis kicks in, which is when carbohydrates are broken down into pyruvate and then high-energy ATP. The glucose storage is only good for about 40 seconds. From here on you need to rely on the oxidative energy system (Baechle et al. 2008). This is why the participants in this study cannot rely on one energy system alone.

Physical aspects of running

A number of physiological and biomechanical factors appear to influence running economy. Among competitive elite runners, it is not enough to only have a good running economy. The competitive runners have to take into consideration the metabolic adaptions within the muscles such as increased mitochondria and oxidative enzymes, the ability to store and release elastic energy and the amount of type one and type two muscle fibres (Saunders et al. 2004). The composition of muscle fibres will affect the running economy. It is preferable to have a higher percentage of slow-twitched muscle fibres, also called type I muscle fibres to be
a good endurance runner (McArdle, Katch & Katch, 2010). Slow twitched muscle fibres have large and numerous mitochondria. Type I fibres are high fatigue resistant and ideal for prolonged aerobic physical activity, such as endurance running. Type I muscle fibres rely on oxidative metabolism (aerob). Muscle fibres type II (IIa and IIx) are also important for runners, as these fibres are fast twitch muscle fibres (McArdle et al. 2010). Type II muscle fibres have a high capability for electrochemical transmission of action potentials, and are therefore powerful and quick in their action. These qualities within the muscle fibres are important for runners to exhibit, when they have to do a fast sprint or run uphill (McArdle et al. 2010). The fast twitch muscle fibres rely on a short term glycolytic system for energy transfer. So these muscle fibres are dominated in anaerobic activity such as sprint and other forceful muscle actions (McArdle et al. 2010).

Another important factor, that must not be forgotten, is a high maximal oxygen uptake (VO$_{2max}$) in endurance running. There are several factors that affects VO$_{2max}$, including muscle capillary density, the amount of hemoglobin in the red blood cells, stroke volume and the muscle fiber type composition (Saunders et al. 2004). Another positive effect of endurance running is an increased change of functionality of the skeletal muscle mitochondria. This will permit runners to use less oxygen per mitochondria respiratory chain for a given submaximal running speed, which means that the running economy eventually will improve (Saunders et al. 2004). But not only that, also a smaller disturbance in homeostasis and a slower utilization of muscle glycogen in the working musculature will take place. This will all benefit the endurance runner and help in the journey to become a faster and a more economical runner (Saunders et al. 2004). Running technique, metabolic economy, running economy and physical aspects of running are all factors that affect the running performance. To be able to perform as good as possible you need to take all of these aspects into consideration.

Furthermore, there may be aspects of the body’s anthropometry that affect the running performance. What significance does the length of the leg have compared to the step frequency and the actual speed you are running in? There are few studies reporting on these aspects of running in modern time (after year 2000). Therefore, it would be of great relevance to further examine the relationship between leg length, step frequency and step length. Furthermore, the information about an individual’s step length, step frequency and the importance of the length of the leg is relevant for a runner coach to know about. It may also be important for competitive runners to know about the relationship between these variables
to be able to become the best runner as possible, and to be able to run as economic as possible and avoid injuries.

**Aim**
The aim of this study was to examine the role of the length of the leg in relation to the step frequency and the step length in males, while running in three different running speeds.

**Research questions**
1. Are there any significant correlations between the length of the leg, step frequency and the step length?
2. Are any potential correlations between the length of the leg, step frequency and step length consistent when the running speed increases?
3. How does the running speed affect the step length and step frequency?

**Methods**

**Participants**
In this study, 17 trained males were invited to participate, however only 15 trained males completed the study. The participants, with average (± SD) age 26 ± 6.04 years, height 181.7 ± 6.63 cm, leg length 87.3 ± 4.9 cm and weight 79.2 ± 8.7 kg, were recruited through a Facebook group that was created by the test leader for the purpose of this study. Participants were invited through friends and friends of friends. Inclusion criteria were a training volume of running at least 10 km/week, and that all participants should be familiar with running on a treadmill. The participants had to be injury free since 6 months. There were no demands on anthropometric homogeneity in the group, since the study required males with different leg length.

**Study Design**
This thesis was a cross sectional study. For the running tests a treadmill (Rodby, model 2500) was used, to ensure standardization in the running procedures and to make sure all participants were running at the same speed and under the same conditions. Each participant’s right leg length (from trochanter major to lateral malleolus) while standing up, was measured by the same test leader, with a measuring tape. The running speeds that the tests included were: 12, 16 and 20 km/h (Elliott et al. 1979). To collect the distance covered (d) after each
trial an equation was used (Eq.1.). The participants ran in their own running shoes with cushioning. The step frequency (SF) was measured with a pedometer (Andersson, STB 2.0). Using a pedometer or metronome has been validated for measuring step frequency according to Högberg, (1951a). To make sure the pedometer was accurate and did not result in the wrong values, the step frequency was also double checked by analysing the video from the trials (Högberg, 1951a). The pedometer measured 94 % of the steps. The running tests were recorded with a Panasonic SDR-S26 video camera. The camera was secured with a tripod and placed perpendicular to the plane of motion and 10 meter from the treadmill (Elliott et al. 1979). To estimate the participant step length (SL), the equation was used (Eq.2).

Eq. 1. \( \frac{\text{Speed}}{60} \times 1000 = \text{distance in meters} \).

Eq. 2. \( \frac{d}{\text{SF}} = \text{SL in meters} \).

Testing procedures

After the anthropometry measurements a standardized warmup took place. The warmup included walking on the treadmill in a speed of 6 km/h for about 4 minutes, and a successive speed increase to 8, 10 and 12 km/h during one minute each. After the warm up the participant rested for 3 minutes before the actual running test began (Damasceno, Duarte, Pasqua, Lima-Silva, MacIntosh and Bertuzzi, 2014).

The running test and warmup were performed on a treadmill. The running tests consisted of three trials. The trials were:

1. Level running with a speed of 12 km/h
2. Level running with a speed of 16 km/h.
3. Level running with a speed of 20 km/h.

The measurement started when the test speed was reached and continued for one minute. Between each trial the participant rested for three minutes. After the last trial, the participant cooled down by walking for two minutes at a self-selected pace.

Data collection

The step length was estimated by calculations (Eq.2) based on the participants running distance covered and step frequency on the different trials. The step frequency was recorded with a pedometer and afterwards controlled by analysing the video from the different trials. The values from step frequency and step length was plotted against the participant’s individual leg length. This was done to make it possible to compare the values to each other.
and see if there were any significant correlation between step length, step frequency and the length of the leg. Foot-strike patterns (heel- or front-foot strike) were also analysed to make sure this factor did not influence the result.

**Statistical analyses**

The collected data were first inserted into Microsoft Excel (2010). All statistical analyses were then done in Statistical Package for the Social Sciences (SPSS), version 20. A Shapiro-Wilks test has the ability to test for normality in groups smaller than 20, and therefore this was chosen to determine if the data were normal distributed or not. The data were normally distributed and therefore parametric tests were used. Pearson’s coefficient of correlation test was used to examine if there were any significant correlations between step length, step frequency and the length of the leg. A T test of paired samples were used to examine whether there were any differences between the different speeds regarding the variables step frequency and step length. The significance level for this study was set to be statistically significant if $p \leq 0.05$.

**Ethical and social considerations**

Ethical and social considerations were of great importance in this study since it involved humans and personal information. This study was performed according to the Helsinki declaration (World Medical Association, 2013). All these four following considerations were taken into account for this study;

1. The requirement of information (see appendix).

The test leader informed the participants about their role in the study and what the conditions for the participation was. All the participants were informed about their role in this study and participating was voluntary. All test participants had the right to cancel the participation at any time. The information included all the elements of the current investigation which could reasonably be expected to affect their willingness to participate. The test leader informed the participants about the risks and the benefits of the attendant. The participants were offered to ask any questions concerning the procedures (Thomas, Nelson, & Silverman, 2011).

2. The requirement of consent (see appendix).

The participants all had to sign a requirement of consent to be a part of this study. All the participants in this study were informed that they have the right to quit the participation without causing any negative consequences for the test leader. Those involved in the study have the right to determine independently for how long and under what conditions they
should participate (Thomas, Nelson, & Silverman, 2011).

3. Confidentially obligations

The participants were informed about their right to be anonymous in the study. Instead of using the participant’s name, every participant was given an ID number when collecting the data (Thomas, Nelson, & Silverman, 2011).

4. How to use personal information (requirement use)

Information about the individual participant, collected for research purpose, may not be used or loaned for commercial or other non-scientific purpose (Codex Vetenskapsrådet, 2010).

Individuals who might benefit from reading this study could be professional runners, coaches or just runners in general who want to improve their performance or minimize the injury risk.

Results

The result of this study are based on data from 15 participants, with average (±SD) age 26 ± 6,04 (21–44) years, height 181,7 ± 6,63 (173–194) cm, leg length 87,3 ± 4,9 (80–95) cm, weight 79,2 ± 8,7 (72–92) kg. Table 1 summarizes the descriptive mean and standard deviation values for the three running speeds recorded.

**Table 1. Descriptive mean and standard deviation values for step length and step frequency at three different running speeds. (N=15)**

<table>
<thead>
<tr>
<th></th>
<th>step length (meter)</th>
<th>step frequency (steps/minute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 km/h</td>
<td>1,22 ± 0,07</td>
<td>164,4 ± 9,3</td>
</tr>
<tr>
<td>16 km/h</td>
<td>1,47 ± 0,11</td>
<td>181,6 ± 14,4</td>
</tr>
<tr>
<td>20 km/h</td>
<td>1,67 ± 0,12</td>
<td>200,5 ± 14,4</td>
</tr>
</tbody>
</table>

Relationship between variables

According to Shapiro-Wilks test the data were normally distributed and therefore parametric tests was done. According to Pearson’s coefficient of correlation test there were no significant correlations found between the length of the leg and the step frequency or the length of the leg and the step length in any of the three running speeds. In Table 2 the values from the Pearson’s correlation tests are presented for each running speed, and all the variables are
plotted against each other and presented in figure 1 and 2. The paired samples T test showed a significant (p<0.001) increase for step frequency and step length with the different speeds. This is presented in figure 3 and 4.

**Table 2: Pearson’s coefficients of correlations (r), and statistical significance (p) between the length of the leg with step frequency and step length.**

(N = 15)

<table>
<thead>
<tr>
<th></th>
<th>12 km/h</th>
<th>16 km/h</th>
<th>20 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>(r) Step frequency</td>
<td>-.339</td>
<td>-.275</td>
<td>-.309</td>
</tr>
<tr>
<td>(p) Sig. (2-tailed)</td>
<td>.216</td>
<td>.321</td>
<td>.262</td>
</tr>
<tr>
<td>(r) Step length</td>
<td>.343</td>
<td>.298</td>
<td>.341</td>
</tr>
<tr>
<td>(p) Sig. (2-tailed)</td>
<td>.210</td>
<td>.280</td>
<td>.214</td>
</tr>
</tbody>
</table>
Figure 1. Step frequency in relation to leg length for each of the three running speeds (12, 16 and 20 km/h) and participants. (N=15)
Figure 2. Step length in relation to leg length for each of the three running speeds (12, 16 and 20 km/h) and participants. (N=15)
Increased running speed

Figure 3. Step frequency in relation to the different speeds (12, 16 and 20 km/h) (N=15)
Discussion

The results from this present study show that there were no significant correlations between either length of the leg with step frequency or the length of the leg with step length, in any of the three different speeds. This answers the first and the second research questions, which were related to possible correlations between these variables. The significance level for this study was set to be considered statistically significant at $p \leq 0.05$. The correlation was set to be considered small at values between $r = \pm 0.10$ to $0.29$, medium correlation with the range at $r = \pm 0.30$ to $0.49$ and large correlation with the range at $r = \pm 0.50$ to $1.0$ (Pallant, 2010). However, there were a significant increase in both step frequency and step length, when differences were analysed between running speeds. This result is graphically presented in figure 3 and 4, and answered research question three.
Result discussion

Previous research has not been able to show that there is a significant correlation between the length of the leg and a person’s step frequency or step length. Therefore, the general belief that the longer legs you have, the longer steps you are taking, is not evidence based hypothesis, at least not for running. The length of an individual’s step length in the speeds 12, 16 and 20 km/h is therefore based on other variables than the length of the leg, which has been supported also by authors (Cavandh & Kram, 1989). When it comes to walking on the other hand, the step length depends entirely on the length of the leg and suppleness in the hips, since when walking the back of the foot must remain on the ground until the front foot reaches the ground (Högberg, 1951b). This mean that the result of this present study is in line with previous research. Likewise, when it comes to the results from the relationship between step length, step frequency and the speed, where previous research has shown a significant increase between these variables and the speed, the results of this present study agreed (Hamill et al. 2014). From the paired samples T test we could see that both the step frequency and step length were higher at higher speed.

Other studies have showed that the step length depend more on the leg drive when you are running fast, rather than the actual length of the leg (Högberg, 1951). Previous research has also showed that a person’s chosen step length and step frequency are very individual. Usually an individual chooses subconsciously a particular combination of step frequency and step length. The combination a runner might choose can be influenced by many factors, such as the running speed, footwear, the kind of surface, muscle fibre composition, injuries and state of fatigue (Cavandh et al. 1989). Studies have showed that an increased step length usually is connected to an increased metabolic energy cost, and therefore not desirable, when a longer duration is required. Hence the step length is selected to minimize the energy cost while running (Cavandh et al. 1989). Based on these studies, it is not a revelation that there were no significant correlations found between the length of the leg and step length and step frequency in this present study. As mentioned earlier, there are so many variables that might affect the individuals chosen step length and step frequency, that it is difficult to predict beforehand (Cavandh et al. 1989). All the participants in this study were wearing shoes with cushioning, and no barefoot shoes were allowed. They all ran under the same circumstances, to make sure these variables did not affect the result. Thereby the result of this study is in line with the result of previous research.
Although the correlation between the length of the leg and step length was very low and not significant, it should be noted that all the correlations for these two variables were positive. Meaning that people with longer leg length tend to take longer steps, rather than opposite. Even so for the correlation between the length of the leg and step frequency, where all correlations were negative, hence the longer leg length the fewer steps your taking. Evidently this information cannot be used to make any predictions of an individual’s step length or step frequency. Furthermore, this information may be important for running coaches to know about, so that coaches do not attempt any interventions involving alternations in the runners step length based on their body dimensions alone (Cavandh et al. 1989).

Other studies that have examined the relationship between running speed and step length/ step frequency have come to the conclusion that there is a linear relationship up to a certain speed, where step length usually reaches a plateau. Thereby both step frequency and step length increases with speed up to speeds around 25 km/h (Hamill et al. 2014). In speeds faster than this, the relationship is no longer linear. This theory could not be tested in this study though, due to the safety issues in having participants run close to their maximal running speed. An individual’s step length can only be lengthened so much, until a physical limit is reached. When this occurs, you can only increase the speed by increasing step frequency (Hamill et al. 2014).

When looking at these results it is important to remember that running on a treadmill is not the same as running over ground, where the wind resistance will affect the performance. Furthermore, the technique of running on a treadmill is different to running over ground. The running economy on a treadmill is highly correlated to running economy over ground and therefore acceptable to use for standardization of the other factors (Saunders et al. 2004). The participants running style, when it comes to heel- versus front- foot strikes, were also noted to make sure that this was not a factor influencing the results. However, all the participant were heel strikers in this study, which rules out any questions of disturbances.

**Method discussion**

**Participants**

Inclusion criteria for this study were initially supposed to be trained runners who run at least 10 km per week, preferably including eight females and eight males. Because of the interest to see if the changes in variables were gender based. But due to low number of female participants suitable for the criteria of 10 km per week and able to run in high speeds, only
males were recruited for the study. The number of participants for this bachelor thesis were considered sufficient. However, a higher number of participants would be preferable, to be able to get a bigger data set and a more reliable result. There were no demands on anthropometric homogeneity in the group, since the study required males with different leg length. If all the participants had been similar in leg length it would not have been possible to correlate and see the effect of leg length, as was the purpose of this study. The leg length for the participants in this study had a minimum and a maximum value of 80-95 cm. This was quite a wide range (-15%) and allowed correlation of the effect of the longer or shorter leg lengths.

Running procedure
The running was performed on a treadmill located within the universities lab, to make sure they all ran in the same conditions and same speeds. The speed of the treadmill was controlled electronically from the control panel of the treadmill. To avoid errors that could have appeared if the running were performed outside, such as weather changes, the running procedure where chosen to be performed inside on a treadmill. However, it has been observed easier to increase step length while running on a treadmill compared to running overground (Mercer et al. 2002). Running on a treadmill also makes it easier to control the speed. The speeds chosen were based on the theory that the relationship between step frequency and step length are linear up to a certain speed (Hamill et al. 2014). Also higher speeds were necessary for this study to be able to study the effect of the length of the leg when it comes to determine the step length and the step frequency. Most studies based on step frequency and step length while running had speeds between 12-20 km/h (Elliott et al. 1979). As we know after this present study, and based on previous studies (Elliott et al. 1979; Hamill et al. 2014; Högberg, 1951a; Högberg, 1951b) the length of the leg does not play a major roll when it comes to determining the step frequency while running. There are various factors affecting an individual’s chosen step frequency and step length, as mentioned in the result discussion (Cavandh et al. 1989).

The participants ran for 1 minute on each speed, and rested for 3 minutes between each trial. The participants had to run in the particular speed for 1 whole minute so they had time to get into their normal step and get used to the speed (Damasceno et al. 2014). One minute was enough time to collect the data that was needed and to analyse strike patterns. The rest in between the trials was necessary so the participants had time to recover before the speed increased (Damasceno et al. 2014). The participants step frequency and step length, for this
study, were not supposed to be affected by fatigue. The test leader wanted to make sure the only manipulated variable was the speed, so in case the participant did not have enough recovery time in between each trial, it could have affected their running pattern. Fatigue can result in a shorter step and a lack of running technique (Cavandh et al. 1989). This is why each participant were given sufficient time to recovery.

There were verbal instructions and motivation given to the participants as they ran. This was to motivate them to finish the whole minute of running, as the last trials were tough to complete for some of the participants. Because all participants ran in the same speeds and for the same amount of time, it was not a question about how far they could run in distance, rather than just complete the whole minute of running. Therefore, the verbal motivation was assumed not to affect the study results, but to encourage them to complete the test.

**Equipment and measurements**

It is common to use a pedometer or an electric metronome to measure the participants step frequency in studies of running. It is a validated method for measuring step frequency according to Högberg, (1951a). A leg accelerometer or a speed profile have also been used in some studies, for example in a study made by Mercer et al. (2002) to measure the participants step frequency and speed. For this present study, a pedometer of the model Andersson, STB 2.0 was used. This particular model might not have a high reliability, but it is validated for measuring step frequency. Since the pedometer were not completely reliable (measured 94% of the steps), a camera was set up to record each running trial. The video from each running trial were analysed to ensure the step frequency measured was correct. This has also been done in other studies, to make sure the step frequency measured was correct (Elliott et al. 1979). The camera was placed 10 meters away from the treadmill, perpendicular to the plane of motion. This was done to provide an image of the runner that was large enough to ensure accurate identification of anatomical features and also negated both angular and linear distortion (Elliott et al. 1979). The video was also used to look for heal and front foot strikes, to make sure that these running technique didn’t influence the result. A source of error in this section could be the human factor. The fact that the test leader had to analyze the video afterword’s and count every single step to make sure the step frequency was right, that could have easily got mixed up and miscounted. But to make sure the right values were collected, it was necessary to also analyze the video. Based on the video the test leader could state that the pedometer was calculating only 94% of the steps.
The leg length was measured (from trochanter major to lateral malleolus while standing up) with a measuring tape by the same test leader. This may also have resulted in an error since it was difficult to locate trochanter major on some of the participants. This might have caused wrong measurements for the leg length. Perhaps measuring the leg length, using different measuring points would be preferable.

All participants ran in their own running shoes with cushioning. No barefoot shoes were allowed as that could have affected the individuals chosen combination of step frequency and step length, as has been shown by previous studies (Cavandh et al. 1989). None of the participants in this study were forefoot strikers, hence this factor did not influence the result. However, there could potentially be other factors related to running technique that may have affected the step frequency and step length of the participant.

There are various of methods to measure step length. In this study, the step length was calculated by taking the distance covered divided with the step frequency for each speed and participant. So the given step length is a mean value of the distance covered divided with the step frequency. It is better to take the average measurement over several steps, than to use an unsecure measure of one step, hence this method was better for this study. This might have given a slightly wrong value of the step length. If the step frequency were misleading it would influence the step length since the one is based on the other. However, this was also double checked with two independent measurements. Therefore this was the most effective way of getting a value of the step length, and also validated as a method based on Mercer et al., 2002.

Conclusion

In conclusion, according to the present study, there were no significant correlations between the length of the leg and the step frequency or the length of the leg and step length in any of the three different running speeds. The length of the leg does not determine an individual’s step length or step frequency. However, both step frequency and step length were higher when comparing them to a slower running speed. As previous authors have suggested, there are many other factors affecting an individual’s chosen combination of step length and step frequency, such as footwear, the running surface, muscle fibre composition, injuries and state of fatigue. This information is important for running coaches to know about so they do not attempt any interventions involving alternations in the runners step length based on their leg length. Further studies need to be done on the energy demand and running economy for a given step length or step frequency.
References


Högber, P. (1951a). How do stride length and stride frequency influence the energy-output during running?. *Arbeitsphysiologie, 14*(6), 437-441. doi: 10.1007/BF00934423

Högber, P. (1951b). Length of stride, stride frequency, flight period and maximum distance between the feet during running with different speeds. *Arbeitsphysiologie, 14*(6), 431-436. doi: 10.1007/BF00934422


Appendix

Information till deltagare

Hej!


Syftet med testerna är att undersöka några parametrar som påverkar steglängden vid löpning i olika hastigheter. Därefter studera korrelationen mellan benets längd, stegfrekvensen, steglängden och hastigheten du springer i.

Förfrågan om deltagande


Tillvägagångsätt

Studien kommer innehålla ett testtillfälle. Under detta tillfälle kommer du först få närmare information om de olika delarna som studien innehåller. Sedan kommer vi mäta din kroppslängd och benlängd. Därefter kommer du få genomgå en standardiserad uppvärmning på löparbandet, som kommer bestå utav 4 minuter gång på en hastighet av 6 km/h. Därefter kommer hastigheten successivt öka till 8, 10 och 12 km/h under en minut var.
uppvärmningen kommer du få vila i 3 minuter innan det riktiga löptestet börjar. (Löptestet kommer att ske med dina egna vanliga löparskor med dämpning, inga barfotaskor eller dylikt). Själva löparomgångar kommer gå till som så att du kommer få springa i tre olika omgångar (12, 16 och 19 km/h). Varje omgång har en annan hastighet och pågår under 1 minut. Mellan varje försök får du vila i 3 minuter. De tre olika omgångarna kommer i slumpmässig ordning. Efter alla tre omgångarna får du varva ner i 2 minuter på valfri hastighet. Löpartestet kommer att filmas med en höghastighetskamera på ett stativ. Stegfrekvensen kommer att beräknas med en stegräknare som du får bära under löpartestet.

Ditt deltagande i studien medför inga risker som inte förekommer under dina vanliga träningspass.

Frivilligt deltagande

Du som testperson har rätt att avbryta testet när som helst utan att ange orsak. Om så önskas kommer då redan insamlad data att förstöras.

Sekretess


Vänligen,

Annica Kvick

Ansvariga

Ansvariga för studien är:

Annica Kvick
Samtycke till deltagande i forskningsstudie

Nedan ger du ditt samtycke att delta i den studien som utvärderar korrelationen mellan steglängd, stegfrekvens och benets längd vid löpning i tre olika hastigheter. Läs igenom informationen noga och ge ditt medgivande genom att signera ditt namn nederst på sidan.

Jag medgiver att jag:

- Har tagit del av informationen kring studien förstår vad den innebär.
- Har fått ställa de frågor jag önskar och vet vem som är ansvarig huvudman om jag har fler frågor.
- Deltar frivilligt i studien och förstår varför jag har blivit tillfrågad.
- Vet att jag när som helst kan avbryta mitt deltagande i studien utan att ange orsak.

Jag intygar att jag har läst det informerade samtycket och tagit del av informationen kring studien. Jag förstår vad deltagande i studien innebär och ställer upp frivilligt.

Ort och datum___________________________________________________________

Namn______________________________________Underskrift________________________________
My name is Annica Kvick and I am 24 years old. This is the examination for my Bachelor's degree in Exercise Biomedicine.