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Analysis of movement in pace and *tölt* in the Icelandic horse

Gunnar Reynisson

Landbúnaðarháskóli Íslands
Agricultural University of Iceland

Faculty of Land and Animal Resources

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Main Supervisor: Ágúst Sigurðsson

Co-supervisor: Þorvaldur Kristjánsson

Agricultural University of Iceland

Faculty of Land and Animal Resources

Clarification of contribution

I hereby declare that the data accusition, analysis of the data and writing of the following thesis is my work, done with supervision of Dr. Ágúst Sigurðsson and Dr. Þorvaldur Kristjánsson.

Gunnar Reynisson

Abstract

The Icelandic horse is a gaited horse breed and in addition to walk, trot and gallop it has the ability to *tölt* and pace. These two gaits are from a biomechanical standpoint very similar and it is therefore not always easy to distinguish between them. The aim of this thesis was to objectively measure the major spatial and temporal variables that characterize the gaits *tölt* and pace. High quality horses were compared to low quality horses in *tölt* and pace and objective measurements of these gaits were compared to subjective assessments of judges. Simultaneous kinematic analysis and a subjective evaluation was carried out for pace and various speeds in *tölt*. Nineteen sound Icelandic horses in *tölt* and 49 horses in pace were evaluated and measured on a straight track. Each run was judged by two international certified judges and data was obtained with a high speed video camera (200 Hz) and inertial motion sensors. Footfall events were then determined and noted from the video footage. Attributes such as beat, stride length, stride frequency, speed, suspension and the ratio between stance phases of the frontlimbs and hindlimbs were analyzed and compared to subjectively scored data

Horses in high quality *tölt* (score ≥ 9) had a much higher range of speed, compared to horses in low quality *tölt* (score ≤ 7.5), 2.7 m/s – 9.14 m/s and 3.31 m/s – 6.23 m/s, respectively and a greater ability to increase stride length. Beat was measured as the time interval between the contact of ipsilateral limbs (lateral advanced placement: LAP) whereas 25% is a perfect four beat. The horses in high quality *tölt* also had a clearer four beat and moreover, kept the clear four beat throughout the speed range (Mean LAP = 24.8% ± 2.3%). Whereas the low quality *tölt* had a more lateral movement and became pacier with increased speed (Mean LAP 16.8% ± 2.9%). High quality *tölt* also had shorter stance durations of the front limbs compared to hindlimbs than low quality horses, especially in slow speeds. The data from the additional subjectively estimated scores for beat, stride length in high speed and speed capacity show a fairly high correlation with measured variables in *tölt*, but scores for stride length in slow *tölt* did not.

High quality pace (score ≥ 9) had a slightly higher average speed and stride length when compared with low quality pace (score ≤ 7.5). On the other hand there was no significant difference for LAP, LAL (lateral advanced lift off), stride frequency and suspension between the two groups. Suspension increased with speed and stride length, and had a negative correlation with LAP. On the other hand, LAP had not a significant correlation with increased speed. For LAP the mean value for the highest score for beat was 12.53% ±

2.41. There were only weak correlations between scores for beat and stride length and the measured variables. The correlation between scores for suspension and measured suspension was very low and non-significant in pace. Only scores for speed capacity had a high correlation with actual measured speed.

The results suggest that definition of *tölt* is clear and the Icelandic horse can *tölt* with a clear four beat at various speeds and according to the evaluation the judges can in most cases correctly evaluate the beat, but the accuracy could be improved. The results regarding pace suggest that there are some inconsistencies between the description of the gait and the objectively and subjectively attained results for beat and suspension. It also seems that the subjective evaluation of the beat and suspension has its limitations.

Keywords: Tölt, pace, horse, gait, video, analysis, subjective assessment.

Ágrip

Íslenski hesturinn er ganghestakyn og býr yfir tölti og skeiði ásamt grunngangtegundunum feti, brokki og stökki. Tölt og skeið eru mjög líkar gangtegundir og ekki alltaf auðvelt að greina á milli þeirra. Markmið þessarar rannsóknar var að mæla þær breytur sem helst einkenna þessar tvær gangtegundir og bera saman úrvals hross og lakari hross á tölti og skeiði. Einnig var markmið að bera saman huglægt mat a nokkrum eiginleikum gangtegundanna og mældum breytum. Nítján hestar á tölti og 49 hestar á skeiði voru notaðir í rannsóknina. Hestarnir voru mældir á beinni braut. Hver ferð var mæld með háhraðamyndavél (200 Hz) og hreyfinemum, samtímis var hver ferð dæmd af tveimur kynbótadómurum samkvæmt reglum um kynbótadóma, auk þess sem þeir gáfu einkunnir fyrir ákveðna þætti gangtegundarinnar sérstaklega. Gögn um hraða, niðursetningu og upptöku fóta voru greind út frá vídeó upptökum í tölvu og eiginleikar eins og hraði, taktur, skreflengd, skreftíðni, svif og hlutfall stöðutíma fram- og afturfóta voru mældir og bornir saman við huglægt mat.

Þegar hópar voru bornir saman kom í ljós að hágæða tölt (einkunn ≥ 9) hafði mun meira hraðabil (2.7-9.14 m/s) en lággæða tölt (einkunn ≤ 7.5) (3.31-6.23 m/s). Taktur var mældur sem sá tími sem líður á milli snertinga hliðstæðra fóta (LAP) þar sem 25% er fullkominn fjórtaktur. Hestar á hágæða tölti sýndu hreinni fjórtakt og héldu líka hreinum takti á öllu hraðabilinu (meðaltal LAP = 24.8% ± 2.3%). Hestar á lágæða tölti voru á skeiðbundnu tölti og urðu hliðstæðari með auknum hraða (meðaltal LAP 16.8% ± 2.9%). Hestar með hágæða tölt voru með styttri stöðutíma framfóta heldur en afturfóta, sérstaklega á hægu tölti. Við samanburð á huglægu mati og mældum breytum þá var marktæk fylgni á milli takts, skreflengdar á hröðu tölti og rýmis og mældra breyta á þessum eiginleikum. Ekki var hægt að greina marktæka fylgni á milli skreflengdar á hægu tölti og mældrar skreflengdar.

Þegar hestar á hágæða skeiði (einkunn ≥ 9) voru bornir saman við hesta á lággæða skeiði (einkunn ≤ 7.5) kom í ljós að það var hærri meðalhraði og skreflengd á hestum á hágæða skeiði. Hinsvegar reyndist ekki marktækur munur á milli hágæða og lággæða skeiðs fyrir mælingar á LAP, LAL (tími milli upptöku hliðstæðra fóta), skreftíðni og svifi. Mælingar sýndu að svif jókst með auknum hraða og skreflengd en hafði neikvæða fylgni við LAP. Hinsvegar hafði LAP ekki marktæka fylgni við hraða. Meðalgildi fyrir LAP á hæstu einkunn fyrir takt var 12.53 % ± 2.41. Fylgni á milli einkunna fyrir svif og mæld svifs var mjög lá og reyndist ekki marktæk. Það reyndist vera veik marktæk fylgni á milli einkunna fyrir takt og skreflengd og mældra breyta fyrir þessa þætti. Einungis einkunnir fyrir hraða og mælds hraða hafði háa fylgni.

Þessar niðurstöður benda til þess að skilgreining á tölti sé nokkuð skýr og að íslenski hesturinn geti tölt í hreinum fjórtakti á breiðu hraðabili. Huglæga matið var í góðu samræmi við mælingar og niðurstöður benda til að dómarar geti í flestum tilvikum metið takt á tölti nokkuð áreiðanlega, þó svo það mætti bæta nákvæmni. Niðurstöður fyrir skeið benda til þess að það sé misræmi milli skilgreiningu gangtegundarinnar og mældra og metinna breyta fyrir takt og svif. Einnig benda niðurstöður til þess að huglægt sjónmat á takti og svifi á skeiði sé takmarkað og bæta þurfi bæði skilgreiningu á þessum þáttum og nákvæmni við dóma.

Lykilorð: Tölt, skeið, hestur, gangtegundir, myndbandsupptökur, greining, huglægt mat.

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Abbreviations

DF	Duty factor: Duty factor is the percent of the total stride cycle which a given foot is on the ground.
DF avr	Average duty factor for all four limbs
DF front	Average duty factor for the forelimbs
DF hind	Average duty factor for the hindlimbs
DF ratio F/H	Duty factor ratio of DF front/DF hind. If the ratio is below zero the DF front is shorter than DF hind and if above 1 the DF front is higher than DF hind
Fzpeak	Peak vertical force of the stance duration
LAL (%)	Average lateral advanced lift off of the left and right side
LAL L	Lateral advanced lift off for the left ipsilateral limbs
LAL R	Lateral advanced lift off for the right ipsilateral limbs
LAP (%)	Average lateral advanced placement of the left and right side
LAP L:	Lateral advanced placement for the left ipsilateral limbs
LAP R:	Lateral advanced placement for the right ipsilateral limbs
Phase L	The time relationship within the stride between the cannon bone angle of the left hind and left front
Phase R	The time relationship within the stride between the cannon bone angle of the right hind and right front
Strfrq (Hz)	Stride frequency in strides per second
Strl (m)	Stride length in meters
Suspension L	Suspension phase after the horse pushes of with the left forelimb
Suspension R	Suspension phase after the horse pushes of the ground with the right forelimb
Suspension (%)	Combined total suspension of suspension L and suspension R in one stride.
Transverse suspension	When either both hindlimbs or forelimbs are in the air

1 Introduction

Was it pace or was it *tölt*? That's one of the most common reasons for discussions between observers, riders and judges at breeding field tests for the Icelandic horse. Based on footfall patterns both gaits are considered to have a lateral sequence of footfalls, where *tölt* should have an even four beat rhythm without suspension and pace more of a two beat rhythm and suspension (Clayton, 2004). In high speeds, it can be difficult to see if the horse shows a clear beat *tölt* without suspension or a pacey *tölt* with moments of suspension. Moreover, does the horse show a clear pace with good two beat and suspension or is the pace four beat with lack of suspension but excellent speed and movement. Therefore, it is of a great interest to evaluate the correlation between the official descriptions of the gaits and how the horse in fact is moving and how we perceive the movement.

At breeding field tests for Icelandic horses the gaits are assessed in a subjective and qualitative way with respect to e.g. beat, stride length and speed (FEIF, 2016a). The judges have to process the information that they receive and form a consensus decision on the quality of the gait. This decision is usually based on their background as horse person, education and previous experience. Although most judges have vast experience and are very good observers, this type of judging is always subjective and is prone to biases. The present judging standards are based on long experience but could be questioned partly due to limitations of the human eye and its ability to register fast movements and subtle variations in the gaits (Holmström, 1994). Scientific gait analysis on the other hand requires accurate quantitative data describing the movements and the associated forces. It is not an objective to dispute the validity of the current evaluation system. Rather to explore ways to improve the accuracy and precision of the current system.

2 Icelandic horse

The Icelandic horse is a naturally gaited riding horse. In addition to the basic gaits; walk, trot, canter and gallop; it has the two distinguishing gaits *tölt* and pace. Horses with *tölt* and pace in addition to the three basic gaits are called five-gaited, but some horses are not able to pace and they are called four-gaited horses. The Norse people that first inhabited the island approximately in the years 874-930 brought horses with them and it is believed that the horses were of different origin (Adalsteinsson, 1981). Since the settlement there has been no known import of horses and each horse that is exported from Iceland is not allowed back into the country. The Icelandic horse is the only horse breed in Iceland and is considered a pure bred horse (Adalsteinsson, 1981). Through mitochondrial DNA comparisons of the equine Y chromosome it is assumed that the Icelandic horse is closely related to the Shetland pony and the Nordland/Lynge horse and different breeds from the Middle East and Far East like the Mongolian horse (Bjørnstad, Gunby, & Røed, 2000). Recent studies on the horse's genome have linked gaitedness to a stop mutation in the *DMRT3* gene, the so called 'Gait keeper' mutation (Andersson et al., 2012). An examination of historic horse remains has tracked the *DMRT3* SNP to the medieval England between 850 AD and 900 (Wutke et al., 2016). The researchers genotyped ancient horses in Iceland from the 9th – 10th century and found that 10 out of 13 individuals had the *DMRT3* stop mutation. The author's hypothesized that the Norse people first encountered the ambling horse on the British Isles and transported them to Iceland. It is likely that the first horses imported to Iceland carried the 'Gait keeper' mutation and the early settlers selected for this trait (Wutke et al., 2016). Due to the fact of a small population and genetic isolation it is likely that the selection for the 'Gait keeper' mutation was enhanced by the founder effect (Wutke et al., 2016). The fact that Iceland is very mountainous and separated by deep fjords and difficult river crossings made it nearly impossible to build up a good road infrastructure. Therefore all the way from the settlement well into the twentieth century the horse was used not only as riding horse but also as a pack horse (Björnsson & Sveinsson, 2004).

The role of the Icelandic horse has changed through the years and today it is mainly a leisure horse as well as being used in various sport competitions. The horse is still used for work and transportation in some way, especially for farm work such as sheep gathering in the highlands (Björnsson & Sveinsson, 2004). Competition for the Icelandic horse is versatile, but mostly it involves gaited competition. Competitions vary from showing all five gaits or only four gaits ridden, in some there is only *tölt* ridden. There are also a number of different pace competitions and races, mainly in short distances ranging from 100m to 250m (FEIF, 2016).

2.1 Breeding goals

The main breeding goal focuses on a robust, healthy, fertile and durable horse. All color variations should be maintained within the breed. The Icelandic horse should be a versatile five-gaited horse with a functional and elegant conformation, a manageable temperament and willingness to perform (FEIF, 2016). A subjective scoring system for the evaluation of breeding horses was first elaborated in 1950 and since then there has been an emphasis on breeding a five gaited horse. The selection of horses is based on assessment of horses at breeding field tests for both conformation and performance. All information that is gathered at the breeding field tests are registered in the global database for the Icelandic horse; WorldFengur (www.worldfengur.com).

Breeding field tests for Icelandic horses include subjective scoring of 15 composite traits. These are eight conformation traits, which a have a combined weight of 40% in the total score and seven riding ability traits, which have a combined weight of 60% in the total score. These traits are evaluated by a panel of 2-3 certified breeding judges and are scored on a scale of 5.0 to 10.0. The assessment of the performance traits includes assessment of all gaits under rider on a straight dirt packed track. The test is performed in two separate assessments. In the first part of the assessment the horse is presented alone and can be ridden five times in each direction. In the second part, the horse is presented in a group of three horses, it can be ridden three times in each direction and the judges can raise the scores for the traits of riding ability if the horse improves its performance. Each gait is judged with respect to qualities such as correct beat, stride length, leg action, speed capacity and suppleness. A score is also given for general impression and spirit. All attributes that weigh into the scoring of the traits of riding ability are listed in Table 1. Additional information is provided by standardized comments on the assessment form that describe certain attributes of the traits. The judging scale and the breeding goal within each trait of conformation and riding ability are described in more detail in Icelandic Horse Breeding (FEIF, 2016).

Table 1. All attributes of the traits of riding ability that are assessed at breeding field tests for Icelandic horses and the weight of each trait in the total score (FEIF, 2016).

Trait	**Attributes**	**Weight (%)**
Walk	Beat, suppleness, energy and length of strides of the walk	4.0
Trot	Beat, suspension, movements, length of strides and speed capacity of the trot	7.5
Gallop	Beat, stretch, suspension and speed of the gallop	4.5
Canter	Beat, suspension, length of stride, suppleness	
Tölt	Beat, suppleness, length of strides, speed capacity and movements of the *tölt*	15
Slow *tölt*	Beat, suppleness, length of strides, movements	
Pace	Beat, security, movements, suspension and speed of the pace	10
Spirit	The willingness and disposition of the horse and how sensible and easy it is to handle	9.0
General impression	The elegance of the horse, head-carriage, raising of the neck and movements of the horse	10

2.2 The definition of the gaits

Gaits are generally classified on hand discrete patterns and timing of footfalls or the coordination of the movements of the four limbs (Clayton, 2004). All quadrupeds, horses included, can choose from various gaits. In nature, horses usually choose a gait dependent on how energy efficient it is at any given speed and the genetically determined gait repertoire of the breed (Budiansky, 1997). Each gait has a unique inter limb coordination of the legs or stride cycle. A stride is a complete cycle of limb movements and each stride cycle consists of its own inter limb coordination and stance and swing times of each leg (Hildebrand, 1965). The stance phase is the period of hoof contact with the ground. The swing phase is the period when the hoof has no contact with the ground as it swings forward until the next stance phase.

Usually gaits are categorized as running or walking gaits (Hildebrand, 1965). Duty factor (DF) is the first of the two key variables defined by Hildebrand (1965). Duty factor is a variable that measures the stance phase in relation to stride duration. Duty factors usually varies inversely with speed, as speed increases stride duration and stance phases shorten but on the other hand swing phases stay relatively constant (Back & Clayton, 2013). Walking gaits are without a suspension phase and where the stance time of the legs is over 50% of the stride cycle or DF>0.5. When DF is lower than 0.5 the gait is considered a running gait. Gaits are also divided into symmetrical gaits and asymmetrical gaits. In symmetrical gaits each forelimb and hindlimb are considered to be used equally on both sides. The second variable defined by Hildebrand (1965) is lateral advanced placement (LAP). This variable measures the percentage of stride interval that footfall of forelimb follows the hindlimb on the same side, and is used to measure and distinguish between the symmetrical gaits (Hildebrand, 1965). These two variables are often plotted on a diagram proposed by Hildebrand (1965) to show the continuum of symmetric gaits (Figure 1). When the gait is considered to be asymmetrical, the limbs move differently on each side of the horse and are unevenly spaced in time (Hildebrand, 1965). The most common asymmetrical gaits are canter and gallop, but there are also less common variations such as lope and transverse gallop. In non-gaited horses the symmetrical gaits are walk and trot. Most horse breeds are classified as non-gaited breeds where they only have walk, trot and canter/gallop. Gaited horses can show a variety of lateral sequenced gaits or ambling gaits, consequently the gait definitions are provided by the breeding association of each horse breed (Clayton, 2004). Commonly the gaits of gaited horses have regular or irregular four beat rhythms. Walk should have a regular rhythm with equal time intervals between footfalls; where the body is supported with two or three legs at each time. As the stride frequency or speed increases the stance phases shorten and the gait evolves to a more running gait. Some types of the ambling gait only evolve transverse suspension either of the front legs or the hind legs. Other evolves transverse suspension of both hind legs and front legs. When the transverse suspension occurs the body is only supported with one leg and either both front legs or both hind legs are in the air but not at the same time. Some horses evolve a full suspension where all for legs are airborne (Hildebrand, 1965).

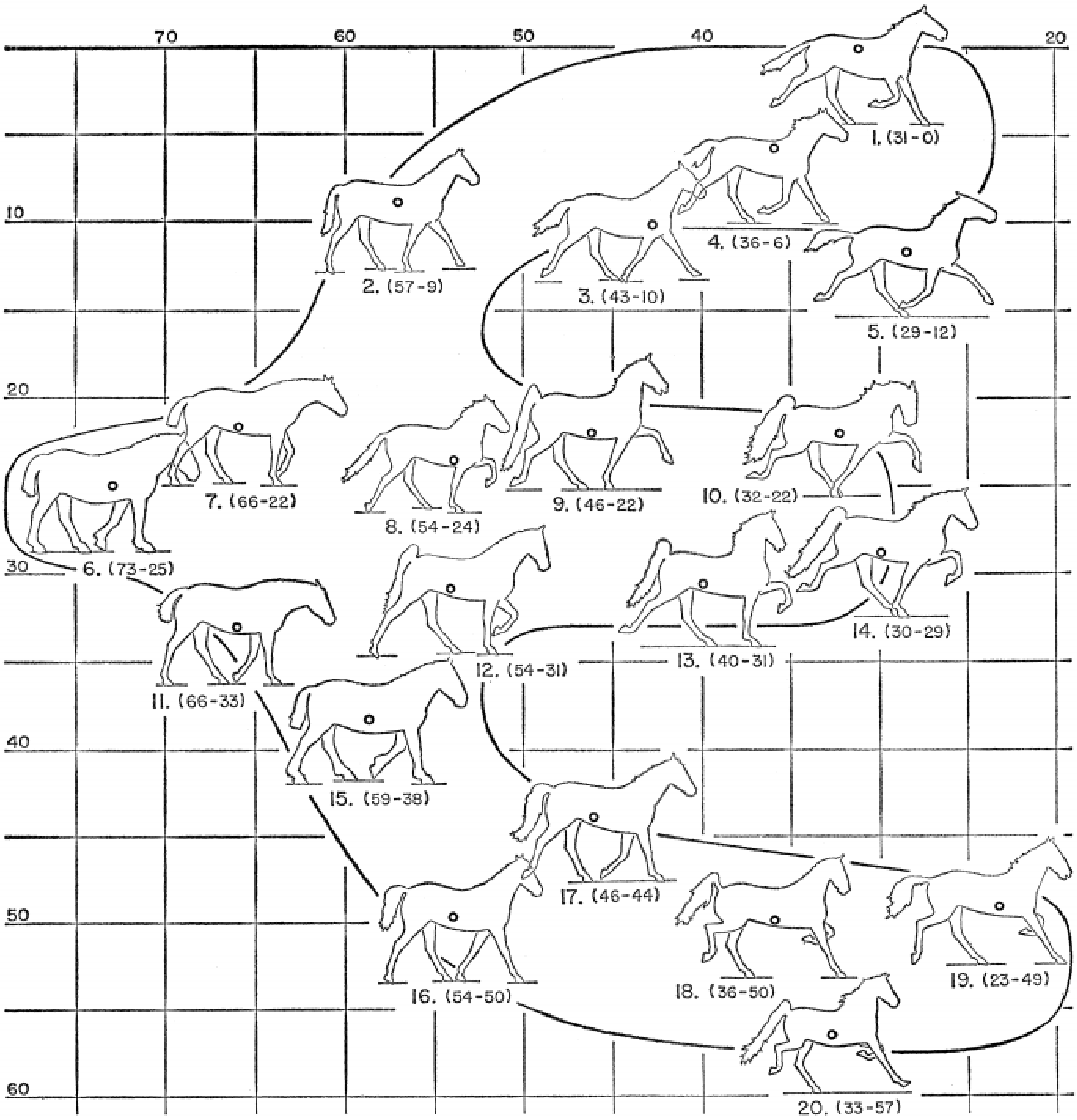

Figure 1. A Hildebrand diagram where symmetrical gaits are classified according to temporal characteristics (Hildebrand, 1965). Duty factor is on the x axis (first number in brackets) and LAP is on the y axis (second number in brackets). Both values are presented as a percentage of stride duration.

2.3 *Tölt*

Theodór Arnbjörnsson (1931) wrote one of the first descriptions of the gait *tölt*. He wrote that the gait should have four hoof beats with an even time interval between them, and no suspension. Moreover, he said that *tölt* lies between walk, pace and trot and can either be a pure *tölt*, a *pacetölt* or a *trotttölt*. According to the modern description, *tölt* is a symmetrical four-beat gait with lateral sequence of footfalls and eight phases. It is a gait without suspension. However, it has transverse suspension, both in front and hind and is therefore considered a running gait. The support phases during the *tölt* stride alternate between bipedal and unipedal support. The *tölt* is ridden at various speeds. The footfall sequence is as follows. When the right hind leg hits the ground the left foreleg should still be in contact. Next the right hind leg leaves the ground and there is a single support of the right hind leg. Next the right fore leg touches the ground and there is a lateral double support. As follows the right hind leg leaves the ground and a single support right front evolves. Then the left hind leg touches the ground and a diagonal double support evolves, and when the right front leg leaves the ground and there is a single support left hind until the left front leg touches the ground, then a lateral double support evolves. The left hind leg leaves the ground and the horse has a single support of the left fore leg until the right hind leg touches the ground then one stride cycle is completed (Figure 2). *Tölt* should follow a regular footfall pattern, where the forelimb should land about 25% of the stride cycle after the ipsilateral hindlimb (FEIF, 2016)

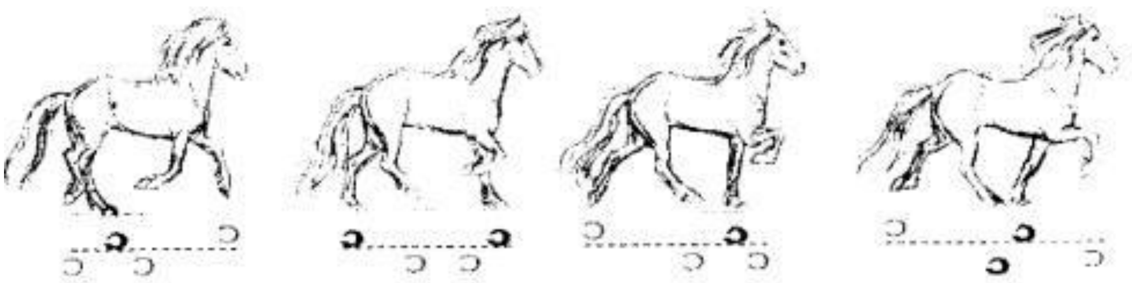

Figure 2. Stride pattern in *tölt* (Drawing by Pétur Behrens, FEIF 2016).

The official description of ideal movements and faults in *tölt* according to FEIF (FEIF, 2016):

Ideal movements in *tölt*

Characteristic of true *tölt* is suppleness and fluid movements. The horse should move in balance, with strong and active back and active hindquarters. The movements of the front part are light and free. The horse’s rhythm is a pure four-beat rhythm, which runs fluently through the horse.

Faults in *tölt*

A. Pacey *tölt*

In *tölt* it is undesirable if the interval between ground contacts of lateral limbs is too short. Then the correct four-beat rhythm is lost and the *tölt* resembles pace too much.

This is called pacey *tölt*. Then the *tölt* is said to have a lateral couplet, which is when the time interval between ground contacts of ipsilateral feet is shorter than 1/4 of the stride duration.

B. Trotty *tölt*

During *tölt* it is also undesirable if the interval between ground contacts of diagonal legs is too short. In this case the *tölt* has lost the purity of the four-beat and the *tölt* is too close to trot. Then the *tölt* is said to a have a diagonal couplet, that is, when the time interval between ground contacts of lateral feet is longer than 1/4.

C. Stiff *tölt*

The rhythm is a pure four-beat rhythm but the horse's body lacks suppleness. The back is inactive and stiff and the movements are not flowing through the body of the horse.

D. Irregular beat

It is a fault if the *tölt* has an irregular beat, for instance is more or less mixed with canter. The movements of the left and right sides of the horse are not symmetrical and there is not an even time interval between ground contacts of each four legs.

E. Tripedal support

At a very slow *tölt*, the half-suspension may disappear at the hind; then the horse supports itself on one front leg and both hind legs simultaneously (tripedal support). In this case the *tölt* is ridden more slowly than competition and breeding judgment requirements say and the gait is considered an interphase between walk and *tölt*.

2.3.1 Related research on *tölt*

There are a number of studies investigating footfall patterns in *tölt* and other symmetrical four beat gaits with lateral sequence of footfalls (Zips, 2000; Nicodemus & Clayton, 2003; Biknevicius, Mullineaux, & Clayton, 2004; Robilliard, Pfau, & Wilson, 2007; Starke, Robilliard, Weller, Wilson, & Pfau, 2009; Rumpler, Riha, Licka, Kotschwar, & Peham, 2010; Weishaupt, Waldern, Amport, Ramseier, & Wiestner, 2013). These gaits have been called running walks, the single foot (Hildebrand, 1965) or ambles. These gaits undergo a separate, non-overlapping aerial phases, with the feet striking the ground independently and have a lateral advanced placement (LAP) of approximately 25%, that is, the forelimb lands about 25% after the hind limb of the stride duration. For the *tölt* it is often referred to as clear beat *tölt* or true *tölt* when the LAP is 25% (Biknevicius et al., 2004). This can variate between horses and horse breeds and Hildebrand (1965) describes that the running walks should have a range between 19-31% LAP.

The lateral sequenced gaits of gaited horses can either have lateral couplets or diagonal couplets. A lateral couplet occurs when the ipsilateral feet are closely related in time or when the LAP is below 19% (Clayton, 2004; Hildebrand, 1965; Nicodemus & Clayton, 2003). This variation is most commonly called pacey or pacey *tölt* for the Icelandic horse. When the footfalls of the forelimb and the diagonal hindlimb are closely related in time (LAP > 31%) then the gait is considered to have diagonal couplets. In a study on kinematics of the *tölt* in the Icelandic horse, Zips (2000) showed that the Icelandic horse only shows true *tölt* at slow or medium speed. The majority of the horses used in her study showed lateral couplets (LAP at low speed 19.72%, 19.62% at medium speed and 18.19% at high speed) (Zips, 2000). Another study on the *tölting* ability of the Icelandic horse showed an average LAP of 29% and a clear tripedal support of 19% of the stride duration in slow speeds in *tölt* (Nicodemus & Clayton, 2003). Moreover, in a study made by Robilliard, et al. (2007) only 2/3 of the trials proved to be true *tölt*, the remaining trials showed either diagonal couplets or lateral couplets. Only true *tölt* were considered for the trial and the mean LAP for the true *tölt* in that trial was 25.7% for a speed range of 1.5 to 6.5 m/s.

In a study where the effect of the front hoof length on some kinetic and kinematic parameters in *tölt* showed a LAP of 17.7% for a standard shoeing and a LAP of 19.5% for long hooves (Weishaupt et al., 2013). This indicates a slight shift to more four beat with long hooves but may have negative implications for the health of the palmar structures of the distal foot (Weishaupt et al., 2013). Although the horses were adapted to the treadmill and riders confirmed that the horses were moving at appropriate speeds and in a manner equivalent to their normal gait, the treadmill situation, with its ground surface properties, might have influenced the gait pattern, increasing limb overlap and, therefore, the base of support for stability (Waldern, 2014).

Östlund (2011) measured 20 Icelandic horses with the Pegasus limb phasing system (see chapter 3.3.1). The ETB system measures the time-within the stride relationship between the four limbs, calculated through a continuous cross correlation between the cannon bone angle of the left hind (LH) and the other limbs, respectively. Note that the limb phasing does not measure foot on-foot off timings. Usually front- and hind limbs have different movement patterns and therefore the data will not show the same results as video analysis of foot-on foot of timings. For example, a two beat pace should have a time lag between the contact of left front (LF) 0%, right hind (RH) 50% and right front (RF) 50% in reference to the left hind

(LH) with foot on timing analysis. An analysis of a clean 4-beat walk or *tölt* should show results of, LF 25%, RH 50% and RF 75% in reference to the left hind (LH). A study with the ETB-Pegasus limb phasing system showed, for example, that ideal results for walk should be LF 32%, RH 49% and RF 81% in reference to the LH (ETB-Pegasus. 2011). The study also measured *tölt* and the mean stride duration was 550 ms with a stride length of 2.2 m at a mean speed of 4.35 m/s. The study also showed a limb phase of LF 29%, RH 51%, and RF 79% in respect to the LH (Östlund, 2011). Östlund (2011) also categorized a pacey *tölt* and a diagonal *tölt* and the limb phasing showed a mean LF phase in relation to LH of 22% for pacey *tölt* and 38% for trotty *tölt* (Östlund, 2011).

The *tölt* is often difficult to categorise within the traditional locomotion classification for quadrupeds based on criteria like DF and LAP. In trot and walk DF are very similar for the hindlimbs and forelimbs (Back & Clayton, 2013). But *tölt* may display both walking and running characteristics depending on speed as duty factors can be in the range of 0.41-0.66 (Starke et al., 2009). In a recent study by Waldern (2014) where some kinetic and kinematic variable were compared between *tölt* and trot in Icelandic horses, it was shown that the stride rate at *tölt* was higher than in trot at the same speed. In trot the mean DF were the same for the hindlimbs and forelimbs but in *tölt* the mean forelimb DF was shorter than the hindlimb DF, 0.47 and 0.51, respectively. This indicates running mechanics for the forelimbs and walking mechanics for the hindlimbs in *tölt*. Also when DF of individual limbs exceeds 0.50 overlaps occur and a period of tripedal overlap happens instead of single supports. Other studies have also recorded that in *tölt* the hindlimbs have higher DF than the forelimbs (Biknevicius et al., 2004; Robilliard et al., 2007; Starke et al., 2009). Moreover, at slower speeds, the DF of the hindlimbs exceeds 0.5 and they display double peaked vertical force profile expected for walking dynamics (Biknevicius et al., 2004). Waldern (2014) also noted that in *tölt* the forelimb maximum vertical ground reaction force (fz peak) was notably higher than in trot (+7.2%), the forelimb transverse suspension was twice as long and there was less limb compression and shorter ground contact times in *tölt* than in trot. Even though the horses stepped further under the center of gravity in *tölt* than trot there was no shift of impulse to the hindlimbs and no evidence of increased collection could be confirmed. Weishaupt et al. (2014) observed that 85% of the strides showed a two hindlimb/one forelimb tripedal support at speeds of 3.28 m/s, and 45% at speeds of 3.9 m/s but on the other hand no suspension phases at these speeds. A study on the influence of the effect of rider weight and additional weight in Icelandic horses on stride parameters responses in tölt, showed that riders weight can influence some of the stride parameters. The results howed that stride length became shorter and more frequent with added weight. Duty factor and bipedal support increased with increased body weight ratio, whereas unipedal support decreased. Lateral advanced timing of limb placement and liftoff and height of front leg action were not affected by bodyweight ratio (Gunnarsson, Stefánsdóttir, Jansson, & Roepstorff, 2017).

There has been debates on how fast can the Icelandic horse tölt without evolving suspension and getting to pacey, Zips (2000) recoments that suspension of up to 10% should be allowed in faster tölt. Theoretically speaking to attain a suspension in true *tölt* with LAP of 25%, a DF of 0.25 or lower is required, but when the footfall pattern deviates from 25%, suspension will occur at DF greater than 0.25 (Hildebrand, 1965). In the study made by Zips (2000) the horses showed only true *tölt* at slow and medium speeds; 2.8 m/s and 3.6 m/s respectively, but at higher speeds (4.4 m/s) the horses showed more of a four-beat pace with a mean suspension of 10.52% of the stride duration (Zips, 2000).

2.4 Pace

Gaited horses have a variation of lateral movements. Pace is a lateral sequenced gait and can be ridden in various speeds. In Iceland, pace is traditionally ridden in high speeds for short periods, variant from 60-80 m on the long sides on an oval track to 100-250 m on a straight racetrack or a breeding track. According to the modern gait description, pace is a symmetrical, two beat lateral gait with a moment of suspension. The footfall sequence is left hind – left front – suspension – right hind – right front – suspension (Figure 3). It is one of the front legs that propel the horse into suspension before the diagonal hind leg lands. The hooves on the same side land almost simultaneously. At high speed in pace the footfalls of the lateral limbs become dissociated with contact of the hindlimb preceding the ipsilateral frontlimb. Pace is still considered a two-beat gait since the divergence from synchronous movements of lateral legs is not noticeable (FEIF, 2016).

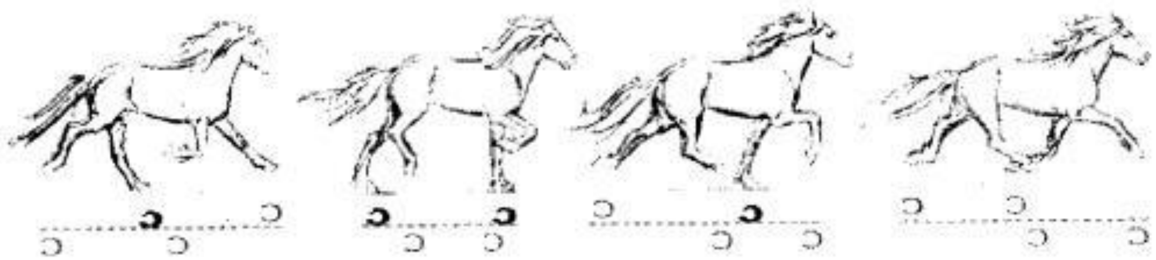

Figure 3. Stride pattern in pace (Drawing by Pétur Behrens. FEIF, 2016)

The official description of ideal movements and faults in pace according to FEIF are as follows (FEIF 2016):

Ideal movements in pace

Pace should only be executed as flying pace: Secure, effortless and impressive with long strides with good period of suspension and excellent speed. Pace is an energetic gait ridden at high speed, where the horse lengthens its strides. During pace the horse should lift its back and extend the head and neck forward. In the suspension phase lateral front and hind legs are stretched far forward and the opposite legs are stretched far backward. Pace is considered pure if the moment of suspension is clearly visible and the divergence from synchronous movements of lateral legs is not noticeable.

Faults in pace

A. Four-beat pace

The so-called four-beat pace is undesirable. Pace is four-beat if the dissociation of lateral limbs becomes visible and time interval between ground contacts of lateral limbs becomes too long. With increased four-beat rhythm the horse's suspension phase becomes shorter.

B. Stiff pace

It is also undesirable if the pace is stiff and with too much lateral movement. The movement goes too much to the sides of the horse and it is unable to proceed fast enough. If the horse´s center of gravity moves too forwards the front leg hits the ground before the ipsilateral hind leg and the horse switches to disunited canter. This change of gaits is referred to as jumping out of gait.

C. Irregular pace

It is a fault if the pace has an irregular beat and the horse is repeatedly losing its balance and jumping into gallop and then taking the pace again. This is often associated with too high neck-carriage, too much four-beat in the pace and the horse taking a few strides of gallop in between.

2.4.1 Related research on Pace

Although the horse's gaits have been studied very extensively there are very few scientific studies on pace or other symmetrical two beat racing gaits with suspension (Boehart et al., 2012; Hildebrand, 1965; Wilson, Neal, Howard, & Groenendyk, 1988a; Wilson, Neal, Howard, & Groenendyk, 1988b). Usually pace is considered a two-beat gait, were the lateral limbs move synchronously and each lateral stance phase is followed by period of suspension (Wilson et al., 1988a). Slow motion studies have shown that ground contact of the hind hoof precedes that of the front hoof (Wilson et al., 1988a). The lateral limbs are dissociated both at lift off and when they contact the ground and the lateral dissociation increases with speed (Clayton, 2004). Standardbred pacers have been studied under race conditions and 7% dissociation was measured at racing speed. The pacing speed was between 9.1 and 16.0 m/s, with a stride length of 4.5 - 6.28 m and stride duration of 448 - 465 ms. (Wilson, et al., 1988b). As a result, Wilson et al. (1988b) concluded that the pacing speed is primarily increased as a result of increase in stride length with minimal change in stride frequency. High order finishing pacers appear to have longer stride length and greater lateral advanced placement, than low order finishers. High order pacers also exhibited greater ranges of limb motion than did low order finishers (Wilson, et al., 1988b).

Pace racing in Iceland are of a shorter duration than harness pace racing, and range from 100m to 250m. The Icelandic record for 100 m pace race with a flying start is recorded at 7.18 s which amounts to an average speed of 13.9 m/s (FEIF, 2016). Scientific studies have measured Icelandic horses at racing speeds of 8.0-10.5 m, and stride duration between 386 ms and 490 ms (Boehart et al., 2012; Robilliard et al., 2007). No scientific records exist on measurements on lateral advanced placement (LAP) in relation to suspension times for the Icelandic horse in pace. Östlund (2011) measured a few horses in pace with the Pegasus limb system (see chapter 3.3.1). The average speed was 8.1 m/s with stride length of 3.47 m, and stride duration of 430 ms. Limb phasing system recorded an average limb phase of 18% for the left side and a 10% for the right side. Both Östlund (2011) and Robilliard et al. (2007) found that pace deviates most from left-right symmetry and had a greater variation in forelimb-hindlimb ratios among symmetrical gaits. Robilliard et al. (2007) hypothesized that in pace handedness is more apparent than in other gaits because of the great speed and that the horse has to push of into suspension phase in a very high frequency.

2.5 Effect of the *DMRT3* mutation on gaiting ability

There has been a long-standing debate over why some horses show alternate gaits and some do not. The most common theory is that certain conformational traits determine why for example some Icelandic horses are five-gaited and some are four-gaited. A recent study on the horse's genome has shed some light on the matter and shown a remarkable association between the *DMRT3* nonsense mutation and gaitedness in horse breeds (Andersson et al., 2012). The study concludes that *DMRT3_Ser301STOP* is a causative mutation affecting the pattern of locomotion in horses. Through genotyping of many different gaited horse breeds around the world it was concluded that the allele is in a very high frequency in gaited horses as well as harness racing breeds. The horse phenotype indicates that DMRT3 neurons not only have a critical role for left/right coordination but also for coordinating the movement of the fore- and hind legs. The DMRT3 neurons are present in the horse spinal cord and develop the connection of left-right phasing during locomotion and selection of different motor patterns and gait coordination (Anderson et al., 2012). It seems that the mutation has a favorable effect on the ability to perform lateral gaits and to run fast at trot and pace. It has also been confirmed that homozygosity (AA) for the mutation is required for pacing ability and has positive effect on the *tölting* ability and speed, beat and suppleness in *tölt* (Kristjansson et al., 2014). The results also indicate that the AA genotype reinforces the coordination of ipsilateral limbs and has a negative effect on the coordination of diagonal limbs (Kristjansson et al., 2014). Horses with the CA genotype had on the other hand significantly higher scores for the basic gaits; walk, trot, and gallop (Kristjansson et al., 2014). Although the AA genotype is required for pacing ability, all AA horses do not have the ability to pace. A high proportion of four gaited horses are AA horses (Kristjansson et al., 2014). It is likely that a combination of genetic, environmental and conformational factors discriminate between AA horses that are four gaited and five gaited. It has been shown that the ideal body format for *tölt* is in some aspects different from the ideal one for pace. Good pace horses tend to have a longer body frame, shorter front pasterns and longer and more inclined pelvis than four-gaited horses (Kristjansson et al., 2014).

2.6 Research technique

There are many ways to study and measure equine gaits. Which technique is used is dependent on the data. Kinematic studies rely on determination of stride events to define movement and stride cycles. Kinetic data describe the internal and external forces behind the movements such as ground reaction forces (Barrey, 1999; Biknevicius et al., 2004; Clayton, 2004). Kinematic analysis quantifies different features of the horses gait such as temporal, linear and angular data. Temporal data rely on foot off and foot on timings of the stride events to allow a comparison of locomotors parameters within and across horses (Clayton, 2004). To define the stride events data such as stance times, swing times, duty factor and limb coordination patterns such as lateral advanced placement of the hindlimb to the forelimb, footfall timings have to be quantified. Footfall timings can be established in different ways, with 2D Video analysis, force plates, 3D optical motions capture or via accelerometer sensors which are either hoof mounted or mounted on the distal limb of the horse (Back & Clayton, 2013).

Each technique has its advantages and disadvantages. Some require sensors or markers that are mounted on the horse and can influence the movement or gait. Techniques like force plate measurements and 3D optical motion capture are also limited to a small capture area and even indoor area or a specialized treadmill (Barrey, 1999; Back & Clayton, 2013). The advantages are that they are more accurate and it is easier to standardize the environment, speed and track surface. But they are not always suitable when the horse should be measured outside or even in a competition environment due to venue restrictions. The most common method today involves optical motion capture, which may be accomplished by using passive markers, active markers or no marker. Some systems offer the automatic digitization of reflective markers, while others are video systems that offer simple visual appraisal, which is time consuming, but can be useful for competition environment or when auto-digitizing systems have difficulties differentiating between markers that are temporarily obscured (Back & Clayton, 2013).

Most commonly, for two-dimensional studies, only one camera is used. The camera is stationary and precisely oriented with axis perpendicular to the field of the path of the horse. With this method it is possible to measure angular and linear data as well as the temporal data but is limited to a very small field of view. To be able to analyze large number of strides and to produce a representative mean value for temporal events and overcome the small field of view panning the camera can be used. With this method the data set is limited to temporal data only (Back & Clayton, 2013). A standard camcorder in Europe in the PAL format records in the frame rate of 25 frames/s and with adequate software each frame can be de-interlaced into two successive fields sequentially giving a sampling rate of 50 fields/s. This can be enough for analyzing temporal stride variables in walk or in slow trot or *tölt* but in faster gaits higher sampling rates are preferable (Back & Clayton, 2013). There are many high-speed video cameras on the market that are capable of very high frame rates ranging from 120-20.000 frames per second. These cameras require very good lighting and usually offer only a few seconds of recording time but are more accurate due to the higher sampling rates. The appropriate sampling rate for measuring the duration of an event is determined according to the sampling theorem. This states that the sampling rate should be at least double and preferably four or five times higher than the frequency of the event of interest. This means if the stance duration is 100 ms an accurate measurement requires a sampling rate of at least 40-50 frames per second (Clayton, 2004).

2.7 Aims

The main objective of this thesis was to compare objectively measured parameters and traditional categorical scoring of the gaits *tölt* and pace. Moreover, the objective was to examine the variability within and relationship between parameters such as beat, stride length, speed and suspension in these two gaits.

The specific aims were to:

- Measure the gaits *tölt* and pace with video analysis and the Pegasus system which uses gyroscope techniques
- Compare groups of high quality and low quality horses in *tölt*
- Compare groups of high quality and low quality horses in pace
- Assess the relationship objectively measured and subjectively scored attributes of *tölt* and pace.

3 Materials and methods

3.1 Horses, riders and tack

A total of 68 horses were haphazardly selected in Iceland in the year 2012, of which 19 horses were studied in *tölt* and 49 horses were studied in pace. The age of the horses ranged from 6 to 21 years (mean 9 years ± 3.1). The horses had various background, training and purpose of usage, some were trained for leisure, some for competition and others had a competition background and used as leisure or school horses. The horses were judged to be free of lameness through an observational examination from rider and researcher. The horses were shod according to standard shoeing principles and standard regulation from FEIF (2016). Each horse was ridden by its trainer or competition rider. Each rider chose his own tack that fitted the horse best. All of the horses in the *tölt* group and 25 horses in the pace group was fitted with four synchronized ETB limb phasing sensors (40 gr). ETB-Pegasus Limb Phasing (ETB-Pegasus, 2011) is a system measuring movements of the horse (see chapter 3.3.1). Each sensor was placed on the cannon bone (lateral metacarpus/-tarsus) of all four limbs and was held in place by standard bandage (80 gr).

3.2 Experimental design

The horses were filmed and judged and sensor data was collected for all of them. In the *tölt* group the riders performed a usual warm up in walk, trot and *tölt* for approximately 15-20 min. The horses were ridden on a 100m straight track and the area of filming was 40m in the middle of the track. The track was a packed dirt surface where all hooves could be seen clearly. Each horse was ridden in slow tempo *tölt*, medium tempo *tölt* and fast tempo *tölt*. Each tempo was ridden two times or six runs in total. Not all horses were able to show two runs in fast speed *tölt*, in conclusion there were 111 runs for the data set in *tölt*.

In the pace group the riders performed a usual warm up in walk, trot and *tölt* for approximately 15-20 min. The horses were ridden on a straight track, 80-150m, and the area of filming was 40m in the middle of the track. Each horse had 1-2 runs in pace depending on the horse and situation. In total 25 of the 70 runs in pace was measured with the Pegasus system. Some of the horses were filmed in competition and therefore it was not possible to fit them with the ETB-Pegasus Limb Phasing system.

A panel of two certified breeding judges reaches a consensus on the subjective scoring of the gaits on a scale of 5.0 to 10.0 for each run according to FEIF, 2016. Additional information was assessed by standardized scoring cards that described certain attributes of the gait on the scale of 1-5, where 1 is the lowest mark and 5 is the highest mark. The attributes in *tölt* were: *Stride length*, where one means *tölt* with short strides and a high stride frequency and five is for *tölt* with excellent stride length; *speed capacity*, where the score of one is for poor speed capacity and the highest score of five is for excellent speed capacity; *beat*, where the score of one is for an obvious deviation from a clear four beat (could be either pacey or trotty *tölt*) and five is for a perfect four beat; s*uppleness*, where the score of one is for stiff *tölt* and the score of five is for excellent suppleness; *movement*, (the evaluation of leg movements of the front legs),where the score of one is for very low leg movements and the score of five is for very high movements. The attributes in pace were: *Stride length*, where score of one means a pace with short strides and a very high stride frequency and score of five is for excellent stride length; *speed capacity*, where one is for slow pace and the score of five is for excellent speed; *beat*, where one is for a very four beated pace and the score of five is for excellent two beat pace where the divergence from synchronous movements of lateral legs is not noticeable; *suspension* phase of the gait, where one is for very little or barely noticeable suspension phase and the score five is for excellent and clear moments of suspension.

3.3 Data acquisition and analysis

The horses were filmed with a digital camera (Panasonic Lumix DMC-FZ200) placed perpendicular to the horse's plane of travel in a distance of 10 m. The camera followed the horse through the track that allowed for recording of at least 10 full strides of the gait. The digital footage was analyzed frame-by-frame at 200 Hz using Kinovea open source video analyzing software (Kinovea, Version 0.8.14, 2014). In all cycles chosen for analysis, the horse was travelling at an even and steady speed through the track. Frames on point of entry and leaving the 40 m test track were marked from video footage to calculate the speed for each run. After that each stride cycle was cropped beginning and ending at touchdown for the same hindlimb. Temporal stride variables were calculated from timing limb placement and liftoff of each foot and expressed as mean percentage of stride duration, as described in the literature (Nicodemus and Clayton, 2003; Clayton, 2004). The frame numbers of ground contact and lift-off for each limb of the horse was determined for 10 consecutive stride cycles in each run. The frame of which heel on was detected was considered as ground contact or when the hoof was almost touching the ground and a flexion of the metacarpophalangeal and proximal interphalangeal joint was detected in the next frame. The frame for lift off was considered as toe off or the frame were the hoof was at 90° angle to the ground and in the next frame after that the toe was clearly off the ground (Clayton, 2004). The frame numbers from the video footage for each stride cycle were entered in a spreadsheet to calculate speed, stride frequency and stride length. The frame numbers of limb contacts and lift off were used to calculate the following stride variables, which were expressed as a percentage of the stride duration:

Stance and swing times for each limb of the horse

LAP L: Lateral advanced placement for the left ipsilateral limbs

LAP R: Lateral advanced placement for the right ipsilateral limbs

LAP: Average lateral advanced placement of the left and right side

LAL L: Lateral advanced lift off for the left ipsilateral limbs

LAL R: Lateral advanced lift off for the right ipsilateral limbs

LAL: Average lateral advanced lift off of the left and right side

DF front: Average duty factor for the forelimbs

DF hind: Average duty factor for the hindlimbs

DF avr: Average duty factor for all four limbs

DF ratio F/H: Duty factor ratio of DF front/DF hind. If the ratio is below zero the DF front is shorter than DF hind and if above 1 the DF front is higher than DF hind

Suspension L: Suspension phase after the horse pushes of with the left forelimb

Suspension R: Suspension phase after the horse pushes of the ground with the right forelimb

Suspension total: Combined total suspension of suspension L and suspension R in one stride.

In total 111 runs or 1110 strides were analyzed for 19 horses in *tölt*, and 70 runs or 700 strides for 49 horses in pace. One horse showed 3 pace runs, 21 horses showed 2 pace runs and 26 horses showed 1 pace run. The average values of each run or 10 consecutive stride cycles were calculated. To be able to compare high quality *tölt* and pace to low quality *tölt* or pace the data set was divided into groups depending on the score they received. The group of high quality horses in *tölt* had a score of 9.0 or higher (average score: 9.12) and the group of low quality horses in *tölt* had a score of 7.5 or lower (average score: 6.26). The group of high quality horses in pace had a score of 9.0 or higher (average score: 9.10) and the group of low quality horses in pace had a score of 7.5 or lower (average score: 6.83). For the comparison of high quality *tölt* and low quality *tölt*, runs with scores between 8.0 and 8.5 were excluded, in total 88 runs were used for the comparisons. For the comparison of high quality pace and low quality pace, runs with scores between 8.0 and 8.5 were excluded, in total 26 runs were used for the comparisons.

3.3.1 Pegasus Limb Phasing system

ETB-Pegasus Limb Phasing (ETB-Pegasus, 2011) is a system measuring movements of the horse. The system consists of four synchronized sensor monitors (IMS) fitted on each cannon bone of the horse. Each sensor (IMS) includes three orthogonal 1200 deg/s gyroscopes. Anti-aliasing filters with a cut-off frequency of 50 Hz and output at 102.4 Hz processed data outputs. Each IMS was factory set to within 1 part per million (1 ppm = 3.6 ms/h) of a reference time traceable to national standard. IMS units were time synchronized at the start of each horse's trials by a simultaneous pulse sent to the respective units (Poseidon software version 4.0, ETB Pegasus). Using the synchronized time pulse information, the segment angles were matched in time. Based on the assumption that each limb displayed a similar cyclic motion, a correlation approach was used to determine the relationships between the respective limbs. The sensors measure the angles of the cannon bones and the limb phasing is not equivalent to the hoof beat of the gait. The system also includes a GPS (Global Positioning Sensor) sensor that is fitted on the rider. For each trial the system measures the number of strides and the distance traveled. Stride length and speed are measured for each stride. The temporal shift between the limb cycles could be calculated using the maximal correlation coefficient between waveforms. The system usually refers to the left hind limb (LH), i.e. this is set to 0%. If the gait is symmetric the right hind limb (RH) is then assumed to be at 50%, i.e. to come exactly after half of the stride cycle. A protocol and timestamp was made on a separate laptop in an excel spreadsheet for the start and end of each run. Later the timestamp was compared to the laptop with the Poseidon software to identify the beginning and end of each measurement. This approach made it possible to find and isolate the recording of the ETB system within the 40m measuring track and later compare them with the digital video recordings.

3.4 Statistical analysis

Statistical analysis of the data was mostly performed with SAS package (SAS Institute Inc., 2015). Descriptive data were expressed as mean, standard deviation (SD), minimum value (min), maximum value (max) and coefficient of variation (CV).

To evaluate the effect of speed and group (High-quality tölt vs. Low quality tölt) on gait parameters in tölt, Mixed Effects Models for repeated measures (PROC MIXED; SAS Institute Inc., Cary, NC, 27513, USA) was applied. The dependent variables were the following parameters in tölt: stride length, stride frequency, LAL and LAP. The independent variables were: speed (continuous variable) and group and the interaction term group*speed. Each horse was measured six times at different speeds and therefore the horse was modeled as a random factor in the regression model. The analysis of the PROC MIXED did not show an effect of the random factor horse in the data set for pace. Therefore, PROC GLM in SAS was used to evaluate the effect of speed and group on gait parameters in pace. The effect of speed, group and interaction term group*speed on stride length, stride frequency, LAP and LAL was analyzed in pace. Visual inspection of residual plots did not reveal any obvious deviations from homoscedasticity or normality. This method compares the lines by testing whether their slopes and intercepts are significantly different. Values of $p < 0.05$ indicated a significant difference in the slopes or intercepts.

The Pearson product-moment correlation coefficient (PROC CORR) was used to evaluate the relationship between each of the measured parameters. A Student´s t-test was used to ascertain if parameters differed significantly between high-class and low-class horses in tölt and pace. Pearson correlation coefficient was used to evaluate the relationship between objectively given scores and the measured parameters. A Kruskal-Wallis non-parametric analysis of variance was conducted to determine if there was a significant difference between measured parameters for different scores. Dunn´s test was used as a post hoc test, analyzing pair wise differences between the scores. Kruskal-Wallis and Dunn´s test were performed using GraphPad Prism version 7.00 (GraphPad Software, Inc., San Diego, CA, USA).

4 Results

4.1 Tölt

4.1.1 Measured temporal and spatial variables

The *tölt* was ridden at speeds ranging from 2.7 m/s to 9.14 m/s with a stride length between 1.67m and 3.87m and a stride frequency between 1.62 Hz and 2.42 Hz. The data was also divided into two groups: group 1 comprised horses with high quality *tölt* (scores 9.0 or higher) and group 2 comprised horses with low quality *tölt* (scores 7.5 or lower). In table 2 the mean values for each group and variable are shown. A two sample T test was made to test if there was a significant difference between the groups for measured temporal-spatial variables (Table 2).

Table 2. Temporal-spatial variables of *tölt* in Icelandic horses. Data is devided into groups of high quality (score ≥ 9.0) and low quality (score ≤ 7.5) *tölt*. Overal means ± standard deviations, minimum value, maximum value and coefficiant of variation.

	Group1 High quality *tölt* (N=39)					Group2 Low quality *tölt* (N=48)				
Variable	Mean	SD	Min	Max	CV	Mean	SD	Min	Max	CV
Speed m/s	5.81	1.69	2.70	9.14	29.09	4.89***	0.88	3.31	6.23	17.93
Strfrq (Hz)	2.08	0.19	1.62	2.42	9.28	2.00*	0.10	1.77	2.20	5.08
Strl (m)	2.74	0.60	1.67	3.87	21.72	2.44*	0.34	1.80	3.01	14.08
DF ratio F/H	0.83	0.04	0.75	0.91	5.12	0.89***	0.04	0.78	0.96	4.31
LAL (%)	17.60	3.55	9.59	24.05	20.19	11.99***	2.20	5.91	18.43	18.33
LAP (%)	24.81	2.26	20.30	30.12	9.13	16.81***	2.85	9.90	23.40	16.97

N: number of runs; Speed: Average speed; Strfrq: stride frequency in strides per second; Strl: stride length; DF ratio F/H: ratio between duty factor front / duty factor hind; LAL: lateral advanced liftoff; LAP: lateral advanced placement.
Levels of significance between mean values of groups: *$p < 0.05$; ***$p < 0.001$.

A Pearson correlation analysis of the data showed a positive correlation between speed and stride length, $r = 0.96$, $p < 0.001$. A mixed model was applied to test for differences of slope and intercept between low quality *tölt* and high quality *tölt*. Here subject horse was a random factor and speed and groups treated as fixed factor. The type 3 test of fixed effects showed that speed had a significant effect on stride length ($p < 0.001$), but group did not ($p = 0.887$). And furthermore there was not a significant interaction between group and speed ($p = 0.117$). This indicates that there is not a significant difference in the intercept and slope of the regression lines for speed and stride length between groups. Fixed factor group and interaction group * speed were therefore removed from the model and the regression for speed and stride length is; stride length (m) = 0.639 + speed (m/s) * 0.365, r^2 = 0.92, p < 0.001 (Figure 4).

The same approach was used for determining the relationship between speed and stride frequency. Pearson correlation analysis of the data showed a positive correlation between speed and stride frequency, r = 0.92, p < 0.001. The type 3 test of fixed effects showed that speed had a significant effect on stride frequency (p < 0.001) but group did not (p = 0.681). The interaction between group and speed was also not significant (p = 0.594). This also indicates there is not a significant difference in the intercept and slope of the regression lines for speed and stride frequency between groups. The regression model for speed and stride frequency is; stride frequency (Hz) = 1.510 + speed (m/s) * 0.100, r^2 = 0.82, p < 0.001 (Figure 4).

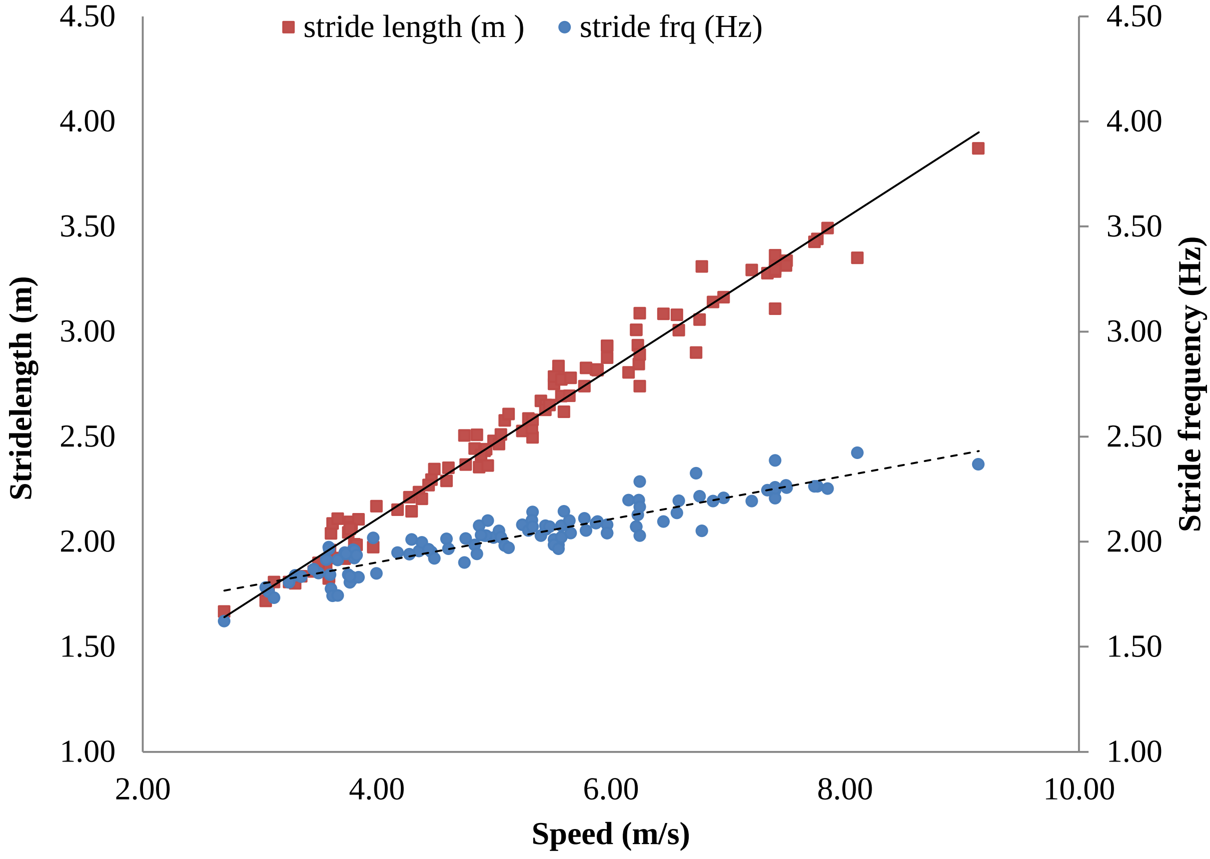

Figure 4. Stride length (m) and stride frequency (Hz) plotted against speed in *tölt*. A linear scaling relationship was found for stride length (solid line) and stride frequency (dashed line) (N = 111).

An analysis was made on how many horses show tripedal supports above 2% of stride duration in *tölt*. The analysis showed that seven horses showed tripedal support (two hindlimbs and one forelimb) at slow speeds (Table 3).

Table 3. Results for seven horses that showed tripedal support above 2% of stride duration. Mean values ± standard deviations, minimum and maximum values for the duration of tripedal support, DF ratio and speed.

	Mean	SD	Min	Max
Tripedal support (%)	3.92	1.26	2.25	6.07
DF ratio F/H	0.824	0.053	0.753	0.890
Speed (m/s)	3.421	0.384	2.697	3.799

Tripedal support, Duration of two hindlimbs one forelimb support; DF ratio F/H, ratio between duty factor front / duty factor hind; Speed, average speed.

An analysis of suspension phase in *tölt* revealed that no horse showed a suspension phase in all strides on both sides in *tölt*, only three horses showed a partial suspension phase above 1% of average stride duration. One horse showed suspension of 1.42% at the speed of 7.41 m/s and a value for LAP of 16.74%. The second horse had a suspension of 2.47% at a speed of 5.05 m/s and a value for LAP of 12.68%. The third horse showed a suspension phase of 1.22% at a speed of 7.41 m/s, a value for LAP of 23.78%.

A further comparison between high quality and low quality *tölt* was performed at different levels of speed. After a visual inspection of the data the limit for category 1 (S 1) slow speed was set at speed < 4.4 m/s and category 2 (S 2) fast tempo *tölt*, the limit was set at speed > 5.8 m/s (Table 4). The value for DF ratio is significantly lower for high quality *tölt* at both speed categories. The values for LAL are slightly higher for high quality *tölt* in slow speeds but in high speeds there is a significantly greater dissociation of the ipsilateral limbs than low quality *tölt*. There was a significant difference between the two groups for LAP (Table 4). The values for LAP are significantly higher for high quality *tölt* at both speed categories than low quality *tölt.* The values for LAP for the high speed *tölt* in high quality *tölt* are slightly higher but not significantly compared to slow speed *tölt* (Table 4).

A Pearson correlation analysis did not reveal a significant correlation between LAP and speed, $r = 0.125$, $p = 0.193$. A further analysis made with proc mixed analysis where LAP was a dependent variable, group and speed fixed effect and horse was treated as random factor. The mixed model type 3 test showed a significant fixed effect of speed ($p = 0.005$) and the effect of the interaction between speed and group was also significant ($p = 0.003$). Solution for fixed effects with a intercept of LAP = 24.77% show for low quality *tölt* (group2) a negative effect of speed on LAP, with a slope of -1.385, $p < 0.001$ but high quality *tölt* (group 1) has an estimated slope of 0.053, $p < 0.001$. This indicates that LAP decreases with increased speed for low quality *tölt* but speed has very small influence on LAP for high quality *tölt*. A mixed model where LAL was a dependent variable and group and speed were treated as a fixed effects and horse as a random effect revealed no significant fixed effect of speed and group ($p = 0.123$, $p = 0.601$ respectively) but the interaction between group and speed was significant ($p < 0.001$). Solution for fixed effects with an intercept of LAL = 10.0% did not show a significant effect on LAL with increased speed for low quality *tölt* ($p = 0.591$). But high quality *tölt* has an estimated slope of 1.391, $p < 0.001$. This indicates that low quality *tölt* does not increase LAL with speed but high quality *tölt* increases LAL with increased speed.

Table 4. Means ± standard deviations of temporal-spatial variables in *tölt* for the two groups. High quality (score ≥ 9.0) and low quality (score ≤ 7.5) and two speed categories.

	S1(speed < 4.4 m/s)				S2 (speed > 5.8 m/s)			
	Group 1 High qualiy (N=10)		Group 2 Low quality (N=15)		Group 1 High qualiy (N=21)		Group 2 Low quality (N=10)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Speed (m/s)	3.53	0.43	3.82[a]	0.27	7.18[b]	0.71	6.03[a,b]	0.17
Strfrq (Hz)	1.83	0.10	1.89[a]	0.08	2.23[b]	0.10	2.09[a,b]	0.05
Strl(m)	1.92	0.15	2.02[a]	0.12	3.22[b]	0.24	2.89[a,b]	0.09
DF ratio F/H	0.77	0.02	0.87[a]	0.04	0.85[b]	0.03	0.90[a]	0.02
LAL (%)	13.18	2.64	11.77	2.93	19.97[b]	2.10	11.80[a]	0.90
LAP (%)	24.48	1.94	18.21[a]	3.56	25.48	2.50	15.99[a]	1.39

Speed; average speed; Strfrq: stride frequency in strides per second; Strl: stride length; DF ratio F/H: ratio between duty factor front / duty factor hind; LAL: lateral advanced liftoff; LAP: lateral advanced placement.

[a] Significant difference ($p < 0.05$) between groups

[b] Significant difference ($p < 0.05$) between speeds and groups

4.1.2 Correlation between measured variables and subjective assessments in *tölt*

The subjective scores from the judges of speed capacity, beat and stride length were related to corresponding measured variables. For each score the median for each of the measured variable was calculated and a Pearson correlation was calculated to evaluate the correlation factor between the scores and a measured variable. A Kruskal-Wallis H test showed that there was a statistically significant difference for LAP between the five scores ($\chi^2(4) = 71.495$, $p < 0.001$). The post hoc test showed a significant difference between all scores ($p < 0.001$) exept between score 4 and score 5 ($p = 0.53$). There was a strong positive correlation between the scores and measured beat (LAP), N = 111, $r = 0.75$, $p < 0.001$. If the data marked as trotty (N=10) is excluded, the correlation factor is, N = 101, $r = 0.81$, $p < 0.001$. The results without data marked as trotty are shown in a pox plot in figure 5.

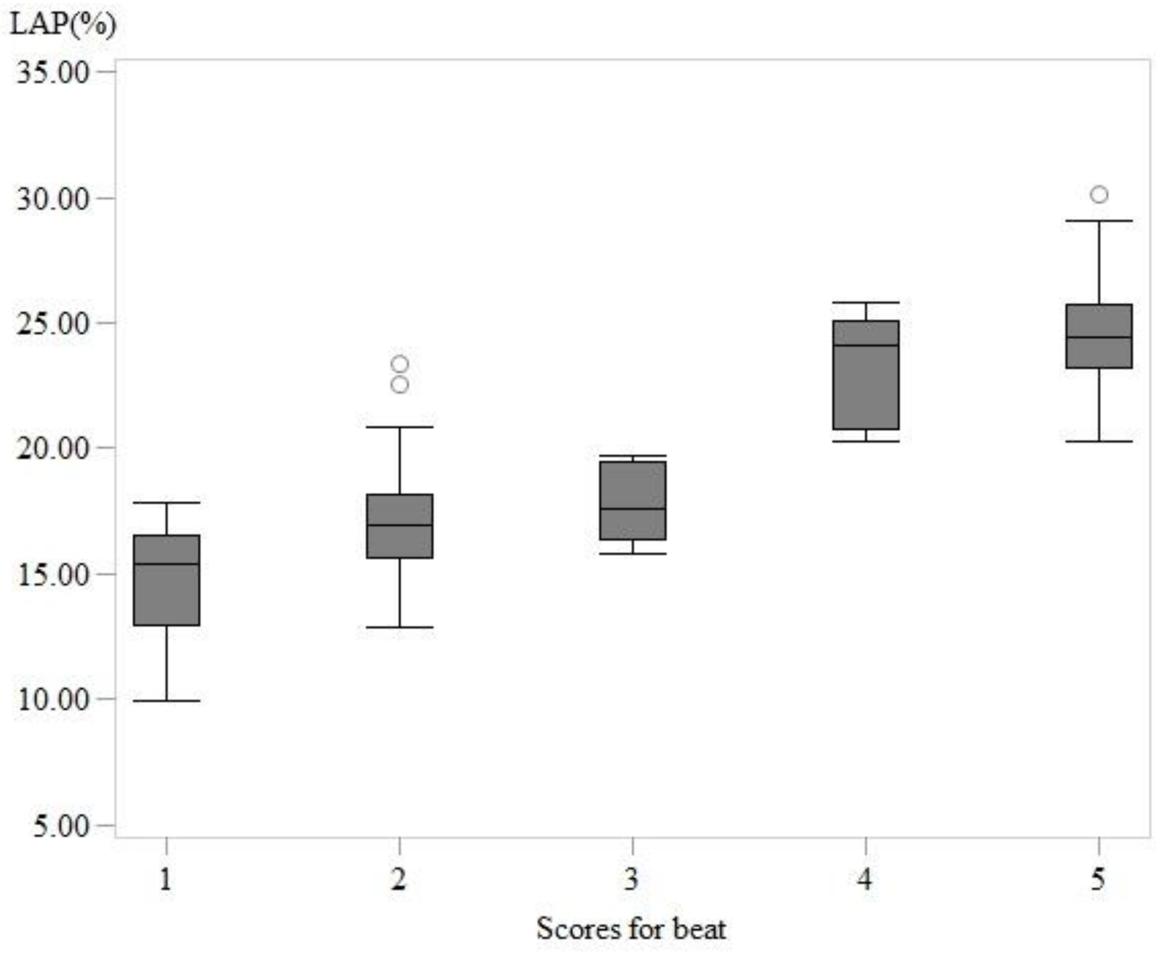

Figure 5. Median for LAP (%) is shown for each score for beat in *tölt*. Bottom and top of boxes show the 25th (first quartile) and 75th (third quartile) percentiles, respectively. Whiskers show maximum and minimum, except when outliers are present. Outliers are shown as hollow dots and are 1.5 times below the first quartile and 1.5 times above the third quartile, respectively.

For the evaluation of the correlation between measured speed and scored speed capacity the two runs for each horse that was marked as high speed *tölt* was analyzed (N = 35). Pearson correlation between measured speed and objectively evaluated speed capacity was, $r = 0.760$, $p < 0.001$. A Kruskal-Wallis H test showed that there was a statistically significant difference for speed between the five scores (χ^2 (4) = 24.54, $p < 0.001$). The post hoc test showed no significant difference between 4 and 5 ($p = 0.73$) and no significant difference between 1, 2 and 3 ($p = 0.14$) but scores 4 and 5 were significantly higher than 1, 2 and 3 (Figure 6).

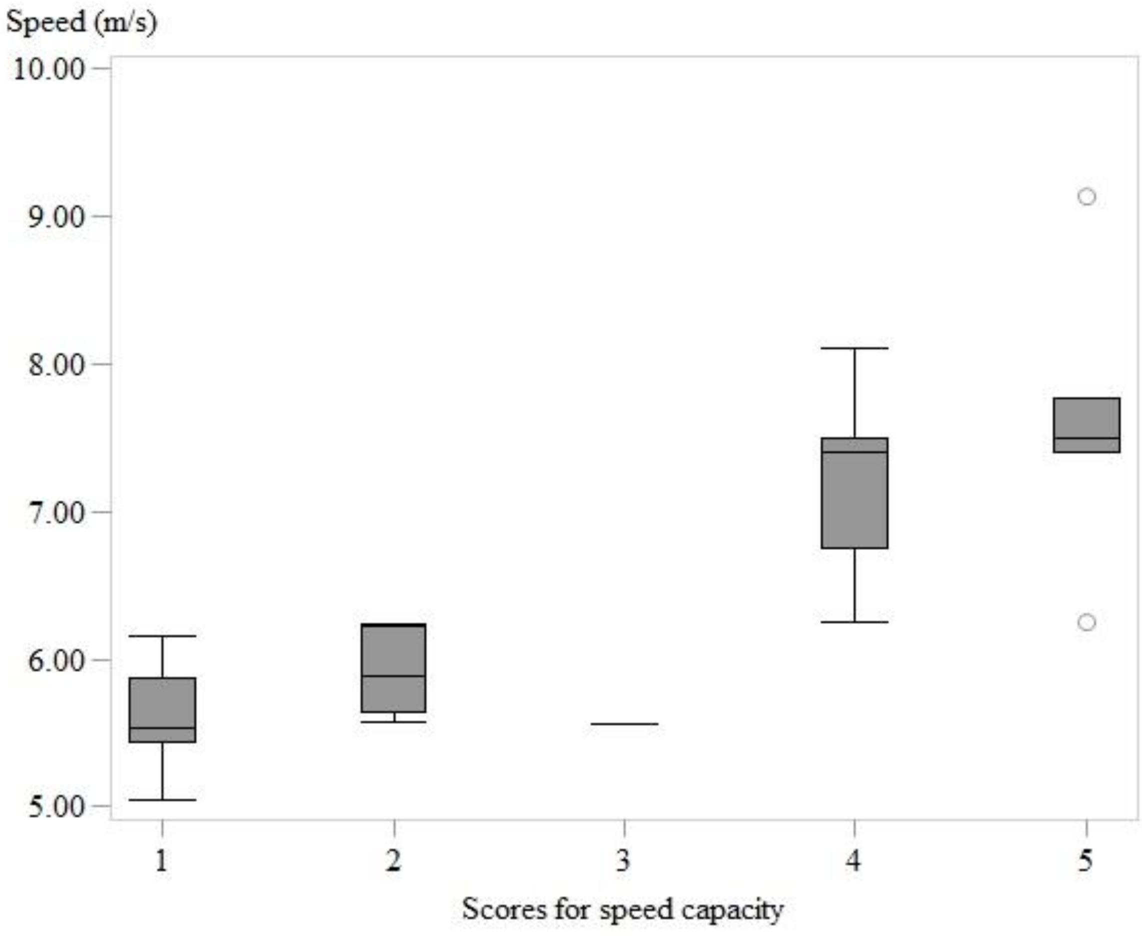

Figure 6. Median speed (m/s) is shown for each score for speed capacity in *tölt*. Bottom and top of boxes show the 25th (first quartile) and 75th (third quartile) percentiles, respectively. Whiskers show maximum and minimum, except when outliers are present. Outliers are shown as hollow dots and are 1.5 times below the first quartile and 1.5 times above the third quartile, respectively.

For the evaluation of the relationship between measured stride length and scores for stride length, the data set was divided into two groups, fast *tölt* and slow *tölt*. The two runs marked as slow *tölt* were analyzed (N = 36) (Figure 7). A Kruskal-Wallis H test showed that there was not a statistically significant difference for stride length between the five scores ($\chi^2(4) = 1.493$, $p = 0.828$) in slow *tölt*. The Pearson correlation between measured stride length and objectively evaluated stride length was negative but non-significant, $r = -0.157$, $p = 0.542$.

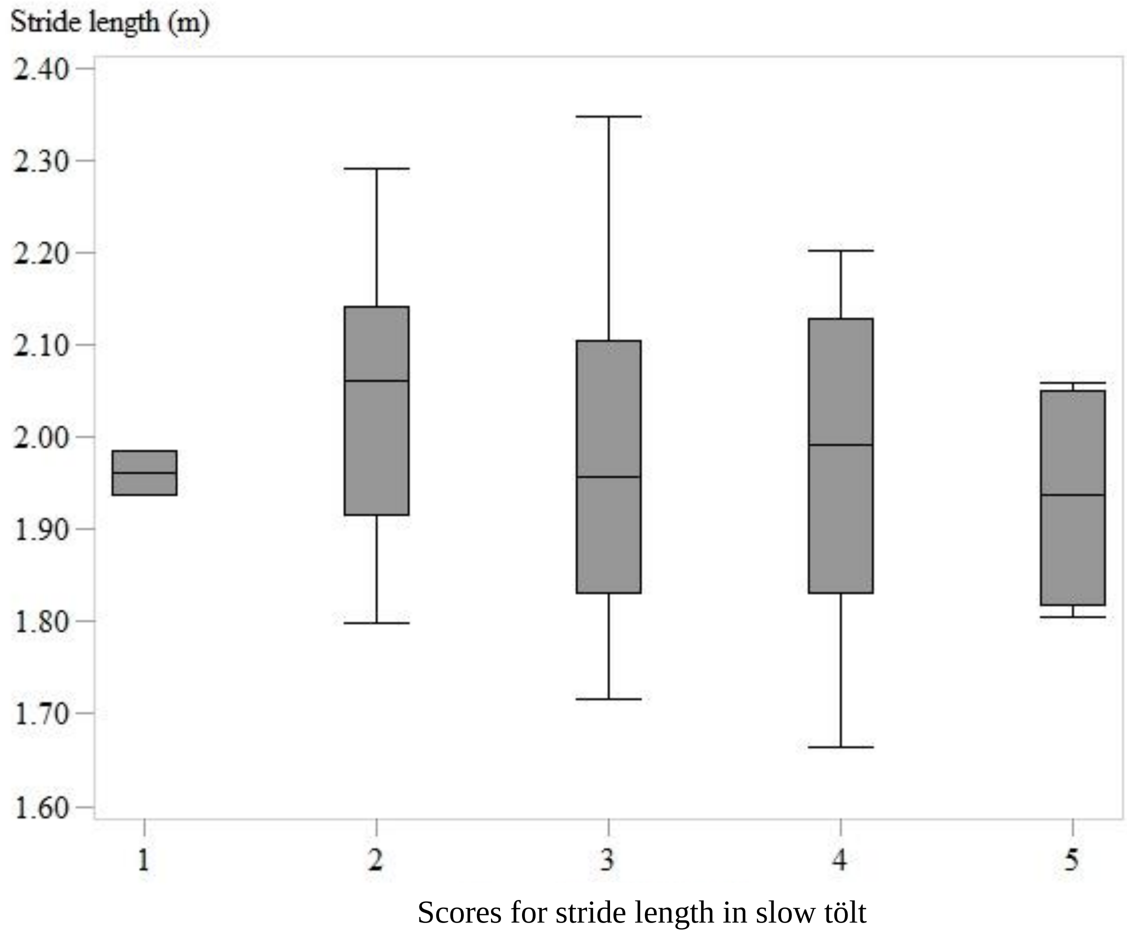

Figure 7. Median stride length (m) is shown for each score for stride length in **slow *tölt***. Bottom and top of boxes show 25th (first quartile) and 75th (third quartile) percentiles, respectively. Whiskers show maximum and minimum, except when outliers are present. Outliers are shown as hollow dots and are 1.5 times below the first quartile and 1.5 times above the third quartile, respectively.

For the evaluation of stride length in fast *tölt* the two runs marked as fast *tölt* were analyzed (Figure 8). A Kruskal-Wallis H test showed that there was a statistically significant difference for stride length in high speed *tölt* between the five scores (χ^2 (3) = 19.606, $p < 0.001$). The results for the post hoc test for *tölt* at high speeds showed that there is no significant difference between scores 2 and 3 ($p = 0.093$) and no significant difference between score 4 and 5 ($p = 0.73$). Scores 2 and 3 are significantly lower than scores 4 and 5 ($p < 0.05$). There was a strong positive correlation between the measured stride length and objectively evaluated stride length, $r = 0.74$, $p < 0.001$.

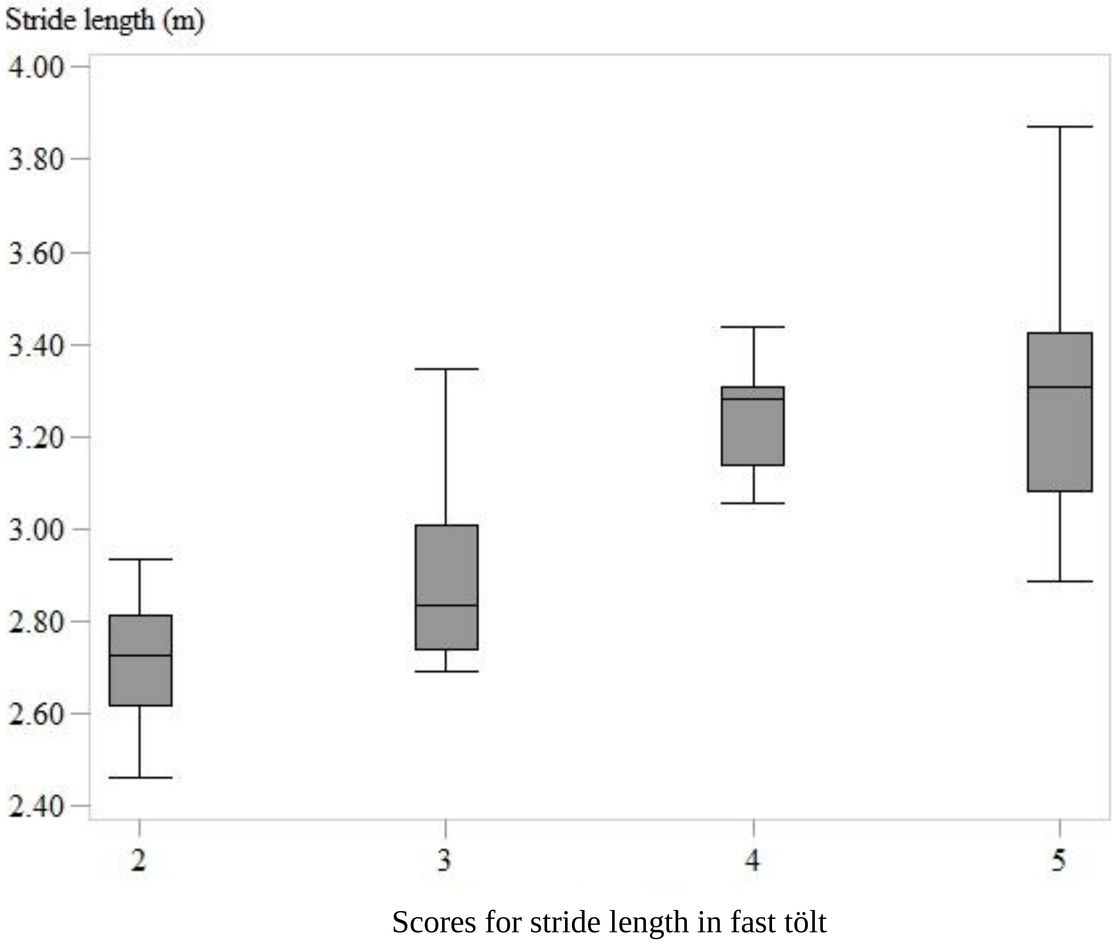

Figure 8. Median stride length (m) is shown for each score for stride length in **fast *tölt***. Bottom and top of boxes show the 25th (first quartile) and 75th (third quartile) percentiles, respectively. Whiskers show maximum and minimum, except when outliers are present. Outliers are shown as hollow dots and are 1.5 times below the first quartile and 1.5 times above the third quartile, respectively.

Correlations between each measured variable and the overall score and all additional subjectively evaluated scores were calculated and are shown in Table 5. All of the measurements are positively correlated with the scores except DF ratio F/H which has a negative correlation with each of the scores.

Table 5 Correlations between measured variables and subjectively evaluated attributes of the gait and total score

	All *tölt* runs, N = 111				Fast *tölt*, N = 35	
	Total score	Suppleness	Movement	Beat	Speed capacity	Stride length
LAP (%)	.82***	.79***	.78***	.75***	.79***	.72***
LAL (%)	.73***	.69***	.66***	.69***	.66***	.61***
DF ratio F/H	-.58***	-.55***	-.60***	-.58***	-.58***	-.58***
Strl (m)	.30***	.19*	.29*	.12	.76***	.74***
Speed (m/s)	.32***	.21*	.29*	.15	.76***	.66***

Levels of significance between mean values of groups: *$p < 0.05$; ***$p < 0.001$.

4.1.3 Comparison of methods

In total 111 runs were measured with both Pegasus and video analysis. And 35 runs were measured with the GPS tracking system. The mean values for Phase L, Phase R, LAP R and LAP L are listed in table 6.

Table 6. Mean, standard deviation, minimum and maximum value and coefficient of variation for the results from ETB Pegasus system (Phase R and Phase L) and video analysis (LAP R and LAP L) are shown in this table.

	N	Mean	SD	Min	Max	CV
Phase R	111	29.48	4.05	20.21	37.74	13.73
Phase L	111	29.28	3.95	19.61	37.74	13.50
LAP R (%)	111	21.30	5.00	10.80	32.50	23.58
LAP L (%)	111	21.50	4.90	9.00	31.90	22.91

Phase R: the time-within the stride relationship between the cannon bone angle of the right hind and right front; Phase L: the time-within the stride relationship between the cannon bone angle of the left hind and left front; LAP R: lateral advanced placement of the right ipsilateral pair of limbs; LAP L: lateral advanced placement of the left ipsilateral pair of limbs.

Pearson Correlation Coefficients were calculated between LAP R and Phase R and showed a strong correlation, $r = 0.818$, $p < 0.001$. The results also showed a strong correlation between

LAP L and Phase L, $r = 0.793$, $p < 0.001$. The correlation between measured speed with video analysis and speed plotted with GPS for Pegasus limb phasing system correlated strongly, $r = 0.997$, $p < 0.001$. There was also a strong correlation between the two measuring techniques on stride length and stride frequency or $r = 0.991$ and $r = 0.981$, respectively ($p < 0.001$).

4.2 Pace

4.2.1 Measured temporal and spatial variables

Stride data from 70 pace runs was collected. For each run a mean from 10 consecutive strides was calculated. The standard parameters with mean, min, max, SD and CV are listed in table 7. The values for DF hind were significantly higher than DF front ($p < 0.001$). The average DF ratio was 0.88 ± 0.03, and did not correlate with speed. The variables LAP and LAL also had a strong positive correlation, $r = 0.927$, $p < 0.001$. In general the parameters for LAP, LAL and suspension had the most variation (Table 7).

Table 7 Temporal-spatial variables of pace in Icelandic horses. Overal means ± standard deviations, minimum value, maximum value and coefficiant of variation.

	Mean	SD	Min	Max	CV
Speed (m/s)	11.18	0.66	9.45	12.31	5.9
Strfrq (Hz)	2.66	0.11	2.38	2.92	4.22
Strl (m)	4.23	0.21	3.62	4.79	4.71
DF hind	0.32	0.01	0.29	0.35	3.91
DF front	0.28	0.01	0.25	0.31	4.58
Dfratio (F/H)	0.88	0.03	0.80	0.95	3.31
LAP (%)	14.61	3.28	6.95	23.3	22.46
LAL (%)	21.08	5.63	8.07	36.95	26.71
Suspension (%)	15.88	6.45	0.78	29.68	40.59

Speed: average speed; Strfrq: stride frequency in strides per second; Strl: stride length; DF hind: duty factor hind limbs; DF front: duty factor forelimbs; DF ratio F/H: ratio between duty factor front / duty factor hind; LAL: lateral advanced liftoff; LAP: lateral advanced placement; Suspension: average suspension phase.

The PROC GLM analysis showed no statistically significant effect of speed or group on LAP and LAL ($p > 0.05$). There was a strong and significant correlation between speed and stride length, $r = 0.685$, $p < 0.001$ and speed and stride frequency, $r = 0.602$, $p < 0.001$. A linear regression model for stride length was calculated for the entire data set (Stride length = 1.92 + speed * 0.210, $p < 0.001$, $r^2 = 0.462$). The linear regression model for stride frequency and speed is (Stride frequency = 1.512 + speed * 0.102, $p < 0.001$, $r^2 = 0.36$) (Figure 9).

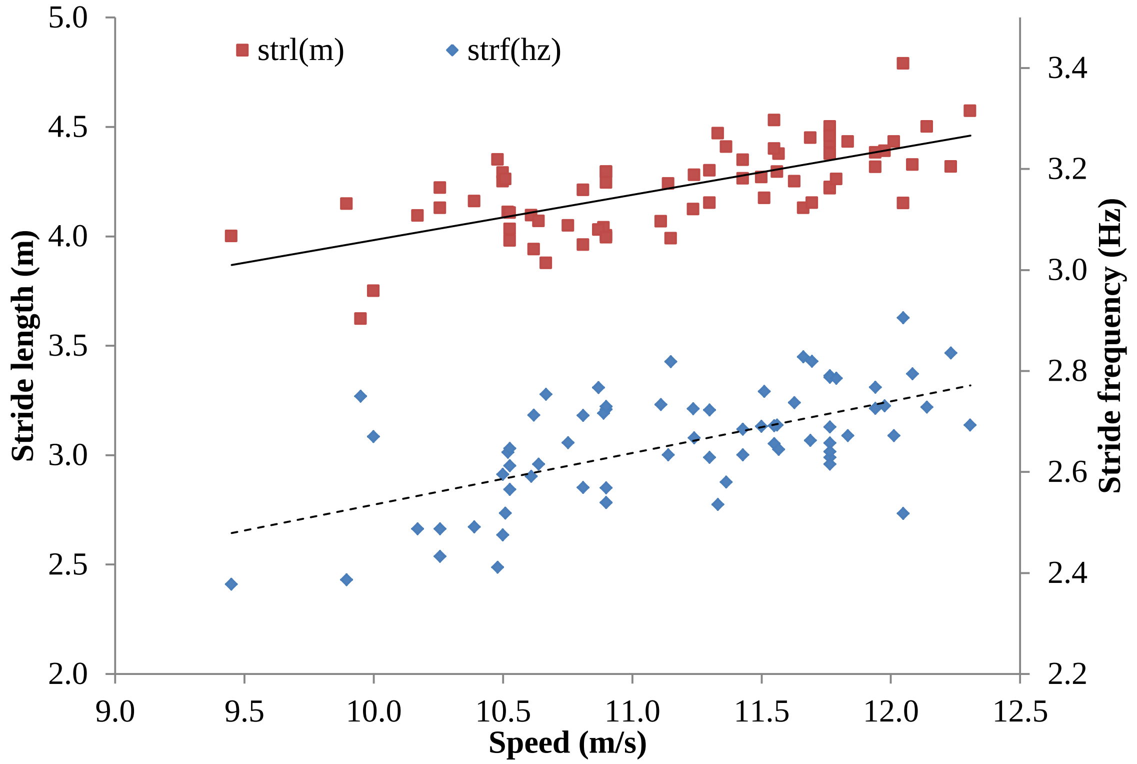

Figure 9. Stride length (m) and stride frequency (Hz) plotted against speed in pace. A linear scaling relationship was found for stride length (solid line) and stride frequency (dashed line) (N =70).

The Pearson correlation test revealed that it was a negative non-significant correlation between LAP and speed, r = -0.1334, p = 0.269. There was a strong positive correlation between suspension and stride length, r = 0.509, $p < 0.001$. But a weak positive correlation between suspension and speed, r = 0.326, p = 0.006. No significant correlation was found between suspension and stride frequency, r = 0.096, p = 0.434. A strong negative correlation was between LAP and suspension, r = -0.928, $p < 0.001$ (Figure 10).

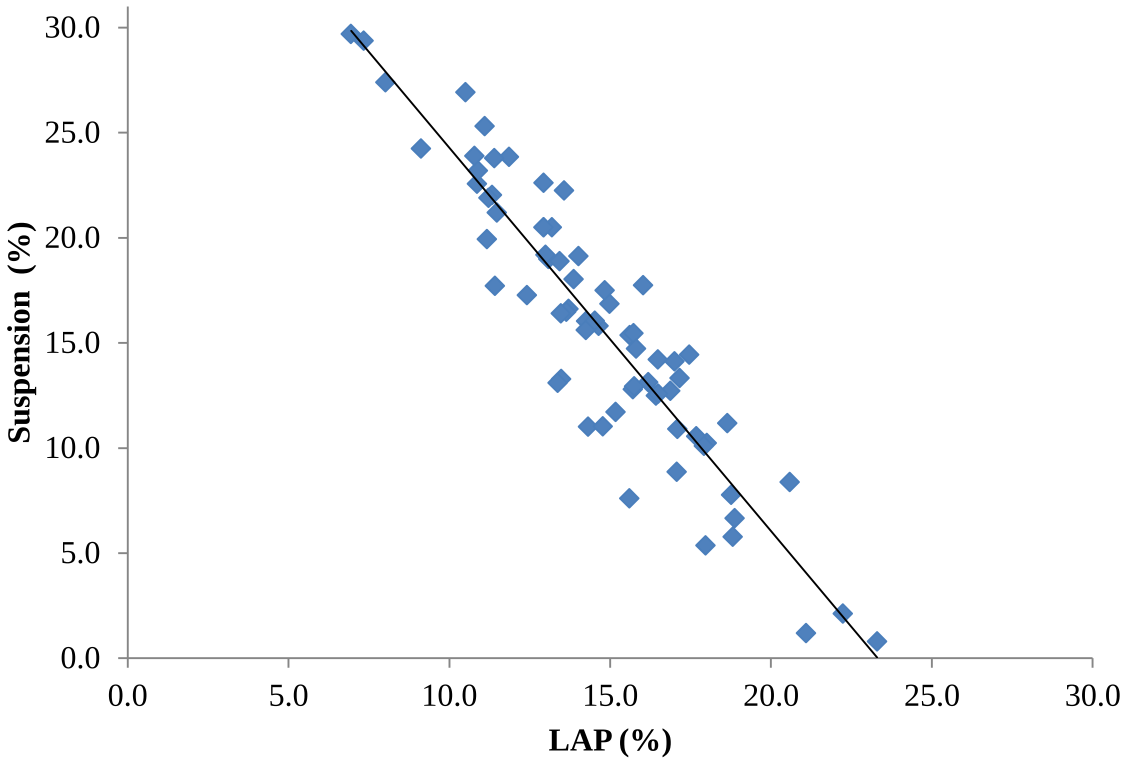

Figure 10. Total suspension calculated as a percentage of each stride plotted against lateral advanced placement calculated as a percentage of each stride (LAP%) in pace, (N = 70).

The data set was divided in two groups; group 1 is high quality pacers with a score of 9 or higher, group 2 is low quality pace with a score of 7.5 or lower. A two sample T-test was calculated for significant levels between the two groups. The standard parameters with mean, min, max, SD and CV are listed with significant levels in table 8. High quality pace had a slightly higher speed and stride length than low quality pace. There was no significant difference for LAP and LAL between groups, low quality pace had a much greater variance than high quality pace (Table 8). High quality pace had a slightly more suspension than low quality pace but it was not significant. Low quality pace had a much greater variance compared to high quality pace (Table 8).

Table 8. Temporal-spatial variables for pace in Icelandic horses. Data is devided into groups of low quality (score ≤ 7.5) and high quality (score ≥ 9.0) pace. Overal means ± standard deviations, minimum value, maximum value and coefficent of variation

	Group 1 High quality pace (N=17)					Group 2 Low quality pace (N=9)				
	Mean	SD	Min	Max	CV	Mean	SD	Min	Max	CV
Speed (m/s)	11.63	0.41	10.48	12.31	3.52	10.68***	0.64	9.45	11.79	6.00
Strfrq (Hz)	2.69	0.11	2.41	2.90	4.23	2.60	0.12	2.38	2.79	4.77
Strl (m)	4.33	0.12	4.15	4.57	2.73	4.13***	0.14	3.96	4.28	3.30
DF hind	0.31	0.01	0.29	0.33	3.47	0.32	0.01	0.30	0.34	4.25
Dfratio F/H	0.86	0.02	0.82	0.90	2.49	0.89*	0.03	0.84	0.93	3.13
LAP (%)	14.36	2.50	10.86	18.88	17.43	14.69	5.33	6.95	23.30	36.32
LAL (%)	20.14	4.04	13.38	27.00	20.08	22.04	9.18	8.07	36.95	41.67
Suspension (%)	18.09	4.92	6.65	25.30	27.22	15.02	9.95	0.78	29.68	66.22

Speed: average speed; Strfrq: stride frequency in strides per second; Strl: stride length; DF hind: duty factor hind limbs; DF front: duty factor forelimbs; DF ratio F/H: ratio between duty factor front / duty factor hind; LAL: lateral advanced; LAP: Lateral advanced placement; Suspension: average suspension phase.

Levels of significance: *$p < 0.05$; ***$p < 0.001$.

4.2.2 Correlation between measured variables and subjective assessments in pace

Additional information was assessed by standardized scoring cards that describe certain attributes of the gait on the scale from 1-5 for the attributes: speed, beat, suspension and stride length. For each score category the mean was calculated and a Pearson correlation was calculated to evaluate the correlation factors between the marks on the scoring card and a measured variable. The correlation between score for beat and LAP was weak but highly significant, r = -0.313, p = 0.008. A Kruskal-Wallis H test showed that there was a statistically significant difference for LAP between the five scores (χ^2 (4) = 8.330, p = 0.005). Score 1 had only two values and was excluded from the test. A post hoc test showed that there was a significant difference between all the scores, except score 2 and score 5 (p = 0.46) and score 3 and 4 (p = 0.76) (Figure 11).

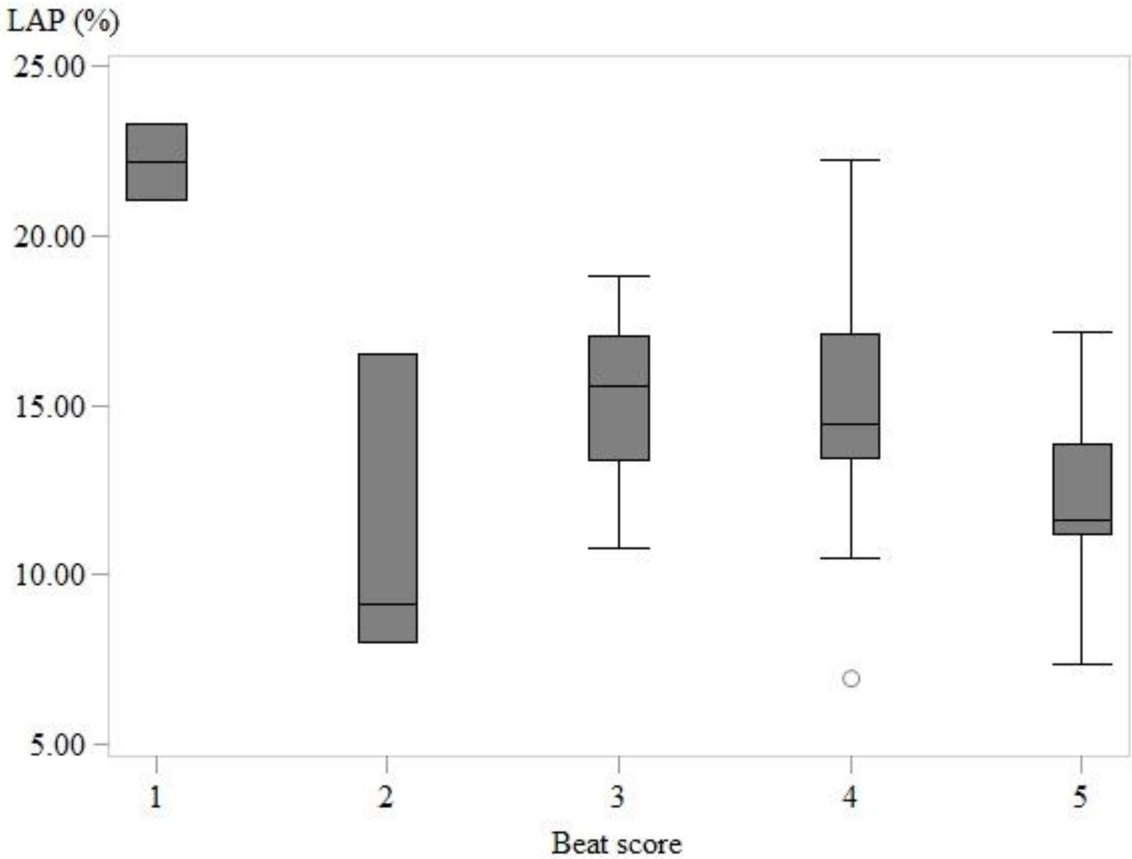

Figure 11 Median LAP (%) is shown for each score for beat in pace. Bottom and top of boxes show 25th (first quartile) and 75th (third quartile) percentiles, respectively. Whiskers show maximum and minimum, except when outliers are present. Outliers are shown as hollow dots and are 1.5 times below the first quartile and 1.5 times above the third quartile, respectively.

The overall average suspension of each run was also compared to the score given for suspension. There was a weak positive but not significant correlation between the two variables, r = 0.249, p = 0.088. A Kruskal-Wallis H test showed that there was not a statistically significant difference for suspension between the four scores (χ^2 (3) = 2.610, p = 0.45). Score one had only two values and was excluded from the test but was significantly lower than the other scores (Figure 12).

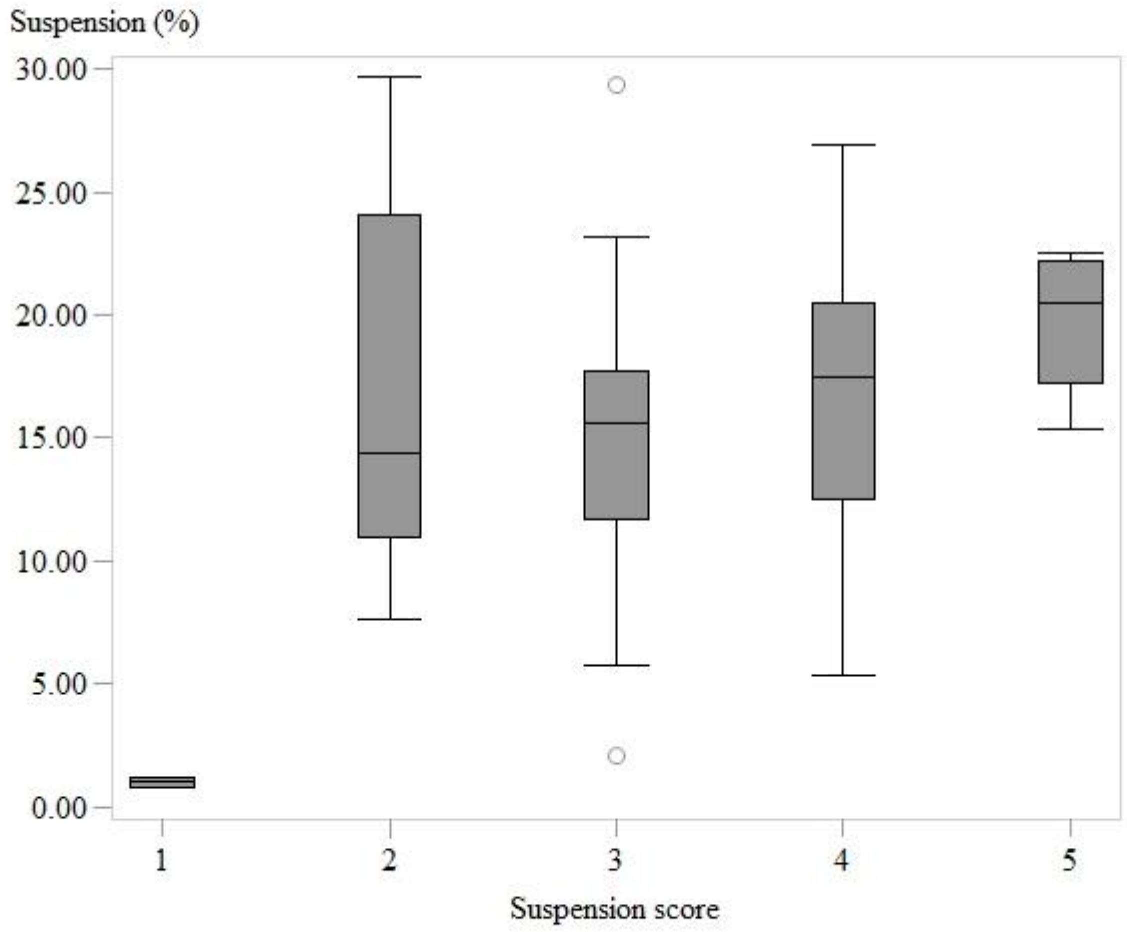

Figure 12. Median suspension (%) is shown for each score for suspension in pace. Bottom and top of boxes show 25th (first quartile) and 75th (third quartile) percentiles, respectively. Whiskers show maximum and minimum, except when outliers are present. Outliers are shown as hollow dots and are 1.5 times below the first quartile and 1.5 times above the third quartile, respectively.

The judges were asked to score the horses for speed capacity for each run. These scores were then compared to the actual speed. There was a high significant positive correlation between the scores and measured speed, $r = 0.622$, $p < 0.001$. A Kruskal-Wallis H test showed that there was a statistically significant difference for speed between the five scores (χ^2 (3) = 26.23, $p < 0.001$). There was a significant difference between the means of all scores ($p < 0.05$) except between scores 2 and 3 ($p = 0.078$) (Figure 13).

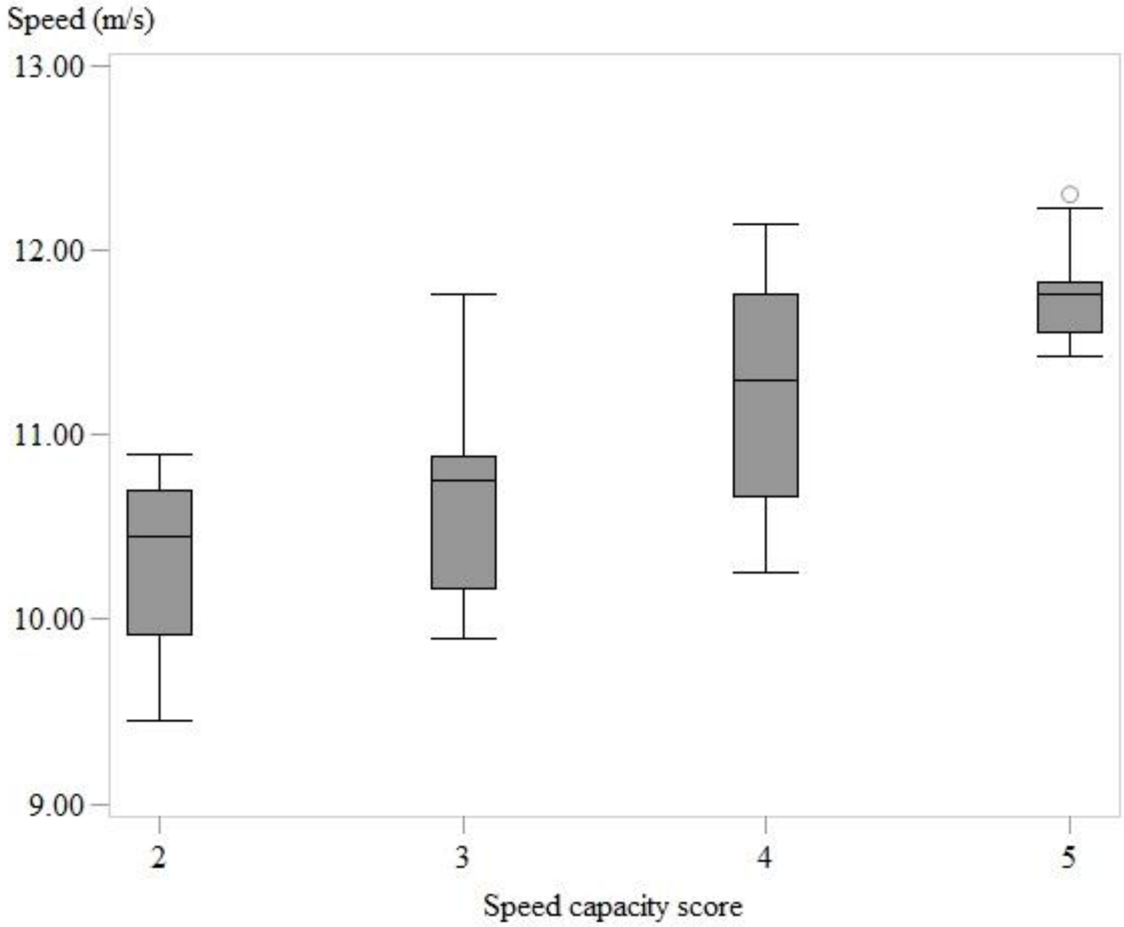

Figure 13. Median speed (m/s) is shown for each score for speed capacity in pace. Bottom and top of boxes show 25th (first quartile) and 75th (third quartile) percentiles, respectively. Whiskers show maximum and minimum, except when outliers are present. Outliers are shown as hollow dots and are 1.5 times below the first quartile and 1.5 times above the third quartile, respectively.

Stride length is also one of the attributes which the judges were asked to objectively evaluate. These scores were then compared to the actual stride length of the horse and there was a significant positive correlation, $r = 0.385$, $p < 0.001$. A Kruskal-Wallis H test showed that there was a statistically significant difference for stride length between the five scores ($\chi^2(3) = 11.023$, $p < 0.016$). According to the post hoc test there was only a significant difference between the scores 2 and 5 ($p = 0.013$) (Figure 14).

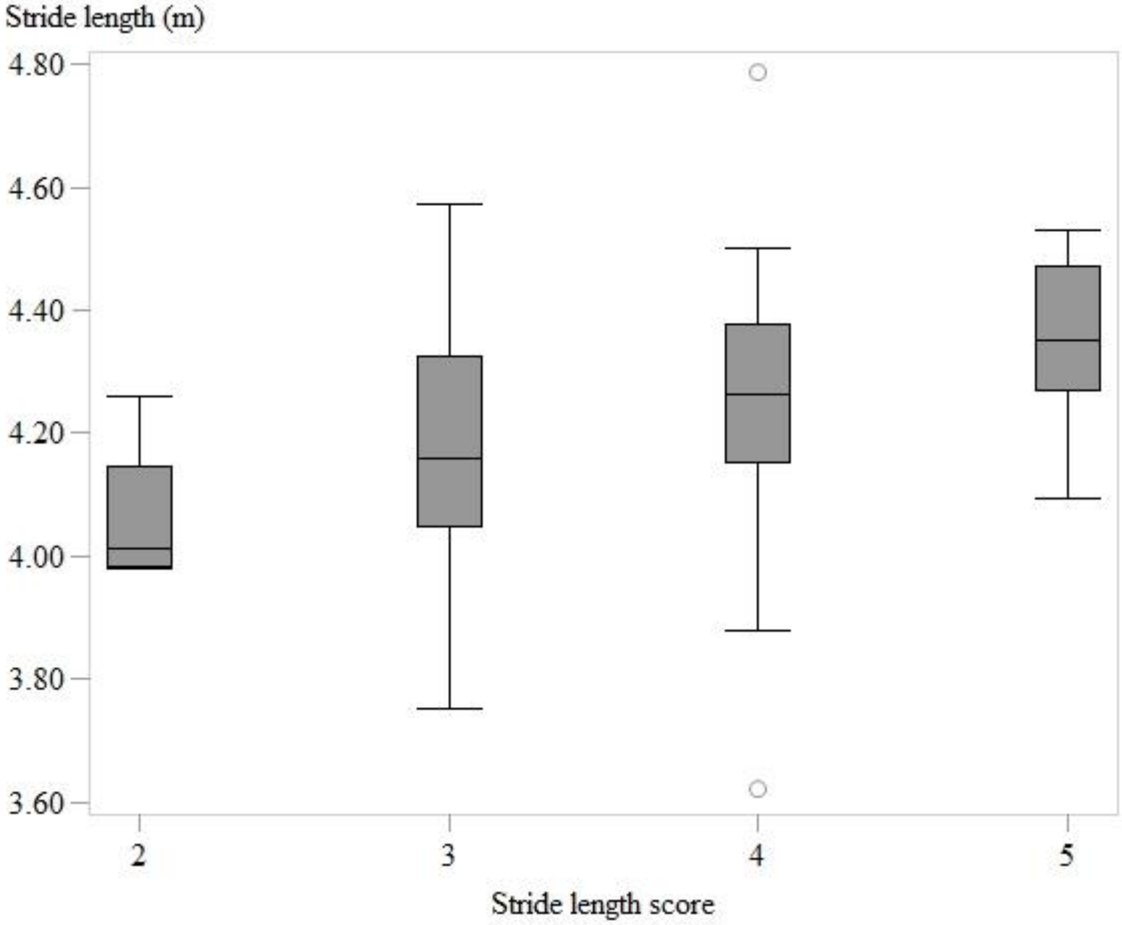

Figure 14. Median stride length (m) is shown for each score for stride length in pace. Bottom and top of boxes show 25th (first quartile) and 75th (third quartile) percentiles, respectively. Whiskers show maximum and minimum, except when outliers are present. Outliers are shown as hollow dots and are 1.5 times below the first quartile and 1.5 times above the third quartile, respectively.

Correlations between total score, individually scored attributes and measured variables were calculated. The results show that speed and stride length have the strongest correlation with the total score (Table 9). The score for speed capacity has the strongest correlation with speed and stride frequency. It is to notice that the correlation between the given score for suspension has a stronger correlation with speed and stride length than the actual measured time of suspension (Table 9). The given score for movement has also the strongest correlation with speed and stride frequency. Table 9 shows that the correlation between the score for beat has a stronger correlation with suspension than LAP.

Table 9 Correlations between measured variables and subjectively evaluated attributes of pace and total score (N =70).

	Total score	Speed capacity	Beat	Movement	Suspension	Stride length
Speed(m/s)	.46***	.62***	.21*	-.41***	.37*	.12
Strfrq(hz)	.22	.47***	.01	-.39*	.12	-.21
Strl(m)	.36*	.40*	.23	-.16	.32*	.39*
Lap (%)	-.13	-.14	-.31*	.27*	-.14	-.09
DFratio	-.21	-.02	.12	-.08	-.08	-.13
Suspension(%)	.26*	.29*	.40*	-.28*	.25*	.23

Levels of significance between mean values of groups: *p < 0.05; ***p < 0.001.

4.2.3 Comparison of methods

In total 25 runs were measured with both Pegasus and video analysis. The mean values for phaseL, phaseR, LAP R and LAP L are listed in table 10 along with standard deviation, minimun, maximu, CV, skewness and kurtosis. The distribution of the measurements did not deviate significantly from zero skewness and kurtosis, exept PhaseR (skewness = -0.81) and Phase L (kurtosis = -0,9).

Table 10. Means ±standard deviation, minimum and maximum value and coefficient of variation for the results from ETB Pegasus system (Phase R and Phase L) and video analysis (LAP R and LAP L) at pace are shown in this table.

Variable	N	Mean	SD	Min	Max	CV
Phase R (%)	25	15.15	6.62	2.28	24.91	43.67
Phase L (%)	25	18.29	3.81	11.27	23.96	20.84
LAP R (%)	25	12.13	4.07	3.61	18.64	33.56
LAP L (%)	25	14.32	3.11	8.09	22.40	21.75

Phase R: The time-within the stride relationship between the cannon bone angle of the right hind and right front; Phase L: The time-within the stride relationship between the cannon bone angle of the left hind and left front; LAP R: Lateral advanced placement of the right ipsilateral pair of limbs; LAP L: Lateral advanced placement of the left ipsilateral pair of limbs.

Pearson Correlation Coefficients were calculated between LAP R and phase R and showed a moderatly strong correlation, $r = 0.633$, $p < 0.001$ and a weak correlation between LAP L and phase L, $r = 0.406$, $p = 0.044$. The correlation between measured speed with video analysis and speed plotted with GPS for Pegasus limb phasing system correlated strongly, $r = 0.973$, $p < 0.001$. There was also a strong correlation between the two measuring techniques on stride length and stride frequency, $r = 0.801$ and $r = 0.852$ respectively ($p < 0.001$).

5 Discussion

This is the first study to measure and compare the results of different qualities in both *tölt* and pace in Icelandic horses. The horses in the study were selected with respect to their quality and the aim was to have representatives of both low quality and high quality *tölt* and pace for comparison and documentation of the variability within the gaits. Although the researcher tried to choose horses of different qualities it is a possibility that the results do not represent the complete variation within the population. Furthermore, it would have been better to have a bigger sample for the analysis.

5.1 Measuring techniques

Two measuring techniques were used for comparison in this study. ETB Pegasus limb phasing system, which uses gyroscope techniques to measure how synchronal the legs move and GPS system for speed measurements and a video analysis, which measures foot on and foot events and calculates time intervals between the contact and liftoff of all four limbs. Both techniques correlated very well for data on speed, stride frequency and stride length. There was a strong correlation between the values for Phase and LAP, which indicates that the data could be comparable for the estimation of beat. The mean value for the ETB system showed a higher value for phase (~+8%) than the video analysis for LAP, and this is in agreement with the results shown in the instructions made by Pegasus (ETB, 2011). The results for the mean phase for *tölt* are also nearly the same as in the study made by Östlund (2011) 29% and 29.3% respectively (Table 6). The data for pace show a much lower correlation factor between the two techniques and some signs of asymmetry. According to this measurements pace shows more deviation in the synchronization of the limbs on the right and left side (Table 10). Robilliard et al., 2007 and Östlund, 2011 also found that pace deviates most among symmetrical gaits.

5.2 Tölt

This study investigated the spatial and temporal variations within the *tölt* of the Icelandic horse. Based on the footing sequence and relative timing of the different phases of the stride, the *tölt* shows a great variation both in speed, stride length and stride frequency and are similar to previously published values for *tölt* (Zips, 2000; Nicodemus & Clayton, 2003; Biknevicius et al., 2004). Although in this study there is a much greater variation in speed than in previously published research on *tölt*. This study could not report a quadratic relationship between speed and stride frequency as reported in other studies (Clayton 2003; Biknevicius et al., 2004). But a visual inspection of the data shows that speed in *tölt* increases as a result of an increase in stride length and stride frequency up to speeds of approximately 6.5-7 m/s. After that the horses only increase stride frequency marginally and to reach higher speeds they have to increase stride length (Figure 4). The reason could be that that with more data in higher speeds in tölt it could be possible to report a quadratic fit between speed and stride frequency. When the data set is divided into groups depending on the score given there are certain differences between the two groups for some of the variables. The horses with high class *tölt* (group 1) have a significant higher speed range compared to horses with low class *tölt* (group 2) ranging from 2.7 to 9.14 m/s and 3.31 to 6.23 m/s respectively. There is no significant difference in stride length in low to medium speed between the groups but group 1 has the capacity to lengthen the strides more than group 2 at high speeds and can therefore reach higher speeds in *tölt*.

The data showed a significant difference in DF ratio between the two groups. This is not a large difference but at slower speed *tölt* there is a larger difference between high class and low class *tölt*, DFratio is 0.77 and 0.87 respectively (Table 4). This correlates with the findings of Gunnarsson et al. (2017), Waldern (2014) and Biknevicius et al. (2004) but they showed that Icelandic horses have shorter relative stance durations of the forelimbs compared to the hindlimbs in tölt, which leads to higher peak vertical forces and the hindlimbs have longer relative stance durations. As seen in the description of the gait *tölt*, a tripedal support is seen as a fault in the gait. But as the DF ratio lowers it is unevoitable that a tripedal support evolves at slower speeds in *tölt.* In this study seven horses showed tripedal support at slow speeds as also the majority of horses in the study made by Biknevicius et al. (2004). This also shows that high class horses in *tölt* have more pushing power in the frontlimbs, which is depicted by a longer stance durations of the hind limbs compared to stance durations of the forelimb and a longer forelimb transverse suspension. This indicates that these horses are lighter in the front and have more leg movement. Gunnarsson et al. (2017) showed that DF increases with increased weight of the rider, which is to expect that the horse is more earthbound with short time increase weight. On the other hand the study showed no changes in LAP and frontlimb movement (Gunnarsson et al., 2017), it would have been interesting to see how and if the DF ratio changes with increased bodyweight.

The two variables that depict how synchronal the ipsilateral limbs move are LAL and LAP. When the whole data set is analyzed *tölt* shows a great variation in LAP and LAL. In slow *tölt* there is no significant difference between high class and low class *tölt* with respect to LAL. But at high speed, ipsilateral legs are more dissociated in the group of high class *tölt* compared to low class *tölt*. The dissociation of the ipsilateral limbs at lift off was the same for the two groups at slow speeds, but at touch down high class *tölt* had a higher LAP than low class *tölt*. When the horses in high class group increase speed they maintained a four beat *tölt* and the dissociation on the point of lift off was higher whereas in low class *tölt* there was a more lateral movement both on touch down and lift off (Table 4). Only three horses showed an average suspension over 1% of stride duration, two of them were very lateral or pacey and one had some moments of irregular canter in between the *tölt* strides.

The correlation factors between measured variables and the total score in *tölt* were the highest for LAP and LAL of all measured variables (Table 5). The additional scores for the attribute beat show that there is a strong correlation between the objective score for beat and the measured value for beat. For example, the score 5 which should have been a perfect score for beat had a mean value of 24.7% ±2.2% and the range was from 20.3% to 30.1%. The average LAP for high class horses (group1) was 24.8% and shows that in general this study is in an agreement with the official description of the gait (FEIF, 2016). This is also in agreement with Hildebrand (1966), but he stated that a running walk, in this case *tölt,* should have a LAP of about 25% and in the range of 19%-31%.

The scores for stride length have no significant correlation to the measured stride length for slow speed *tölt* but when the stride length in fast speed *tölt* was looked at especially there was a significant positive correlation. The stride length is depended on speed and to accurately evaluate the stride length, speed must be standardized. There was also not a significant difference between the slope of the linear regression model for high class *tölt* and low class *tölt*. There were some horses that deviate from the slope and have higher or lower stride frequency than the average. One reason could be that the judges scores were more influenced by the general impression, form, leg movements and suppleness rather than the actual stride length. There are many factors that could influence stride length such as track surface, weights on the legs, height of the horse, and a recent study has also shown that a short time increase in weight of the rider results in shorter strides and higher stride frequency (Gunnarsson, et al. 2017). These factors were not taken into account in this study. The aim was moreover to measure and compare the scores with measurements and not to analyze all the influencing factors.

Speed capacity is one of the important attributes for *tölt* in Icelandic horse. The scores for speed capacity on the scale 1 to 5, showed a strong positive correlation with measured speed. The data further revealed that there was no difference between score 4 and score 5 and the scores 1 to 3 were significantly lower than 4 and 5. Here it is likely that the judges also take in account balance and the beat of the horse and when the horse varies from clear beat they do not give that horse good score for speed capacity.

5.3 Pace

This study measured the Icelandic horse in full speed pace, the aim was to describe the different gait mechanics and understand the movement of the horse in pace better. The official description of pace is that the gait should be two-beated with excellent suspension (FEIF, 2016) but the gait can become somewhat four-beated at high speed (FEIF, 2016; Hildebrand, 1965). In the present study, there was a large range in the values for beat and suspension in pace to be observed, and surprisingly no statistical difference between high class pace and low class pace for LAP and suspension was found. But low class pace had a much greater variation in beat than high class pace and that could point to more irregularity in the gait. There was only a significant difference between the groups in speed and DFratio where high class pace had a higher average speed and a lower DF ratio than low class pace (Table 8). This means that the high class pacers had more capability to extend stride length and stride frequency, and had more pushing power in the front. Wilson et al., (1988b) found that a 22% increase in speed resulted in 35% increase in LAP; in this study there was no significant correlation between LAP and speed and just a very weak correlation between suspension and speed. The reason for the different results could be that the horses in Wilsons study were harness racing horses and had a much lower LAP and the distances of the race much longer than of the horses in this study. On the other hand there was a very strong negative correlation between suspension and LAP ($r = -0.93$, $p < 0.001$). That shows that the more four-beated the pace is, the less suspension it has. In general it seems more difficult to accurately evaluate some attributes of the gait in pace than in *tölt*. There was no significant difference between high quality pace and low quality pace for LAP and suspension. The correlation between the score for beat and the value for LAP is very low, $r = -0.313$, $p = 0.008$. And the range for the perfect score for beat is very high; the value for LAP lies between 7.34% and 17.16%, with a mean value of 12.5%. But in contrast the values for the medium score of 3 is 10.79% and 18.82% and there is no significant difference between score 3 and score 4 and between score 2 and score 5 for example. The same pattern was to be seen for the scores for suspension in pace. There was a weak positive but non-significant correlation between the score for suspension and the measurements for suspension and there was also no significant difference between the individual scores. The score for speed capacity had a strong correlation with measured speed and there was a significant difference between all the scores. The evaluation for stride length had also a significant correlation with measured stride length. Speed and stride length has the highest correlation with the total score and score for suspension had a higher correlation with speed than measured suspension (Table 9). The results suggest that the assessment of speed and stride length correlates fairly well with measured speed and stride length, but the assessment of beat and suspension could be improved. The results also indicate that speed and stride length are valued the most in the breeding evaluation for pace and the emphasis on beat and suspension is lower.

5.4 Future research

These measurements of footfall events show that pace and *tölt* are in some cases a very similar gaits and often difficult to evaluate the subtle differences. There are a number of factors that can influence the balance of the horse and the gait. Therefore, it would be interesting to investigate and measure some of these effects on the characteristics of the gaits. First of all it would be interesting to measure how the form and elevation of head and neck influences beat and suspension in pace. In the same way it would be interesting to measure the influence of weights on the hoof and track surface on the beat in *tölt* and pace. It would also be of interest to explore other options of developing methods that can display the results faster and accurate for more practical use. Such as for instance using audio measurements to measure stride frequency and beat of the gait. Such methods could also help with the education and training of judges to improve accuracy and precision.

6 Conclusions

The results of the comparison of measuring techniques suggest that ETB system could be suitable to analyze slower gaits such as walk, trot and *tölt*, and for measurements of synchronism of movement, stride length and stride frequency. Video analysis captures the moment of foot placing and is therefore a better choice when comparing judges score for the beat of *tölt* and pace. Furthermore the results of this study show that there are measurable differences between high class and low class horses in *tölt* and pace. This study confirms that high class *tölt* can maintain a clear four-beat gait without suspension in the range 2.7 – 9.15 m/s were as the low class *tölt* tend to get more pacey or irregular with increased speed. Pace has great variation in beat, suspension and stride frequency within the population and within the group of high quality pace horses. The results also show that pace is never a clear two beat gait, and always has a certain amount of dissociation of lateral limbs. The fact that the gait is ridden at high speeds with a very high stride frequency makes it very difficult to evaluate beat and suspension.

There is a great deal of subtle variations in the gaits and often the limitations of the perception can be deceptive. Although the judges are fairly accurate in evaluating beat in *tölt* the precision could be improved. On the other hand both accuracy and precision could be improved in evaluating pace.

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