UNIVERSIDADE DE LISBOA

FACULDADE DE MEDICINA VETERINÁRIA

SHORT-TERM EFFECTS OF UNDERWATER TREADMILL THERAPY ON GROUND REACTION FORCES OF CANINE ORTHOPAEDIC PATIENTS

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EFEITOS A CURTO-PRAZO DE HIDROTERAPIA EM PASSADEIRA AQUÁTICA NAS FORÇAS DE REAÇÃO AO SOLO DE CANÍDEOS COM PATOLOGIA ORTOPÉDICA

Resumo

Esta dissertação teve como objetivo estudar o efeito de uma sessão de terapia em passadeira aquática (UWT) nas forças de reação ao solo de cães com claudicação de origem ortopédica, localizada em um ou ambos membros do mesmo par, através de análise de movimento. Foram pré-avaliados 14 cães que apresentavam condições ortopédicas apendiculares, e já submetidos a UWT anteriormente. Os 9 candidatos selecionados foram separados em dois grupos: o Grupo A incluiu cães com claudicação dos membros torácicos e o Grupo B indivíduos com claudicação dos membros pélvicos. Realizou-se análise de movimento com placa de pressão para determinar os valores base das forças de reação ao solo. Depois de terem completado uma sessão de UWT, os animais foram novamente submetidos a análise de movimento para determinar os valores pós-sessão. Mediu-se o pico e impulso das forças verticais (PFz e IFz), duração da fase de estação (SPD), área de contacto do membro (PCA), e comprimento da passada. A correlação entre o comprimento da passada e a altura do garrote foi avaliada usando os dados de todos os participantes. A simetria dos membros contralaterais foi calculada através de um índice de simetria (SI) para os parâmetros PFz, IFz, SPD e PCA (SIPFz, SIIFz, SISPD and SIPCA). Cães com um valor de SIPFz e SIIFz inferior a 3% foram considerados não claudicantes e excluídos. Todos os participantes apresentaram valores de claudicação nos membros pélvicos, independentemente do diagnóstico. Os valores pré e pós-UWT foram avaliados com o teste t de student para amostras emparelhadas. Não se observaram alterações significativas em nenhum dos parâmetros. No entanto, no Grupo A os valores pré e pós-UWT do comprimentos da passada, e do SIPFz e SIIFz nos membros torácicos demonstraram uma forte correlação positiva, o que também se verificou nos valores do comprimento da passada, velocidade média, SIPFz dos membros pélvicos e SIPCA dos membros torácicos no Grupo B. No Grupo B, observou-se uma diminuição geral no SIPFz dos membros pélvicos. Em ambos grupos, o valor médio de SIPCA aumentou nos membros torácicos e diminuiu nos pélvicos. O valor médio do comprimento da passada aumentou em 6 cães, e manteve-se inalterado em 2. A correlação exponencial entre o comprimento da passada e a altura do garrote apresentou um valor de R = 0.78. Após UWT, 1 dos 9 participantes passou a ser considerado não claudicante. Investigação adicional é necessária para determinar os efeitos a curto prazo da UWT nos parâmetros temporo-espaciais e pressão ao solo em cães com claudicação de origem ortopédica.

Palavras-Chave: Cães, ensaio clínico, análise de movimento, claudicação de origem ortopédica, terapia em passadeira aquática

SHORT-TERM EFFECTS OF UNDERWATER TREADMILL THERAPY ON GROUND REACTION FORCES OF CANINE ORTHOPAEDIC PATIENTS

Abstract

This dissertation aimed to use kinetic gait analysis to study the effects of an underwater treadmill therapy (UWT) session on ground reaction forces of dogs with lameness caused by an orthopaedic condition, located in one or both contralateral limbs of a pair. Fourteen client-owned dogs presenting appendicular orthopaedic conditions were recruited. All dogs had previously undergone UWT. The nine selected candidates were divided into two groups: Group A comprised dogs diagnosed with an orthopaedic condition in the forelimbs, and Group B individuals diagnosed with orthopaedic conditions in the hindlimbs. Pressure plate gait analysis was performed to determine ground reaction forces baseline data of all individuals. Afterwards, the dogs completed an UWT session, and gait analysis was repeated to determine post-session values. Peak and impulse of vertical forces (PFz and IFz), stance phase duration (SPD), paw pressure contact area (PCA), and step length were measured. A correlation between step length and withers height was assessed using the collective data of all participants. Contralateral limb pair symmetry was calculated using a symmetry index (SI) for the parameters PFz, IFz, SPD and PCA (SIPFz, SIIFz, SISPD and SIPCA, respectively). Non-lame dogs were excluded, using a SI cut-off value of <3% for PFz and IFz between contralateral limbs. All participants presented baseline hindlimb lameness, regardless of their diagnosis. Before and after measurements were evaluated using a paired student t-test. No statistically significant alterations were observed in any of the parameters. However, baseline and post-session values showed a strong positive correlation in Group A step length and forelimb SIPFz and SIIFz, as well as in Group B step length, mean velocity, hindlimb SIPFz and forelimb SIPCA. In Group B, post-UWT measurements showed an overall decrease in hindlimb SIPFz. In both groups, mean SIPCA increased in the forelimbs and decreased in the hindlimbs. Mean step length increased in 6 dogs and remained equal in 2 dogs. Step length and withers height exponential correlation presented a R value of 0.78. After UWT, 1 out of the 9 participants was considered nonlame. Further research is required to determine the short-term effects of UWT in temporospatial and pressure gait parameters of dogs with orthopaedic lameness.

Keywords: Dog, clinical trial, gait analysis, orthopaedic lameness, underwater treadmill therapy

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°C – Degrees Celsius
ρ – Density
%TF – Percentage of total force
BCS – Body condition score
cm – Centimeter
EMS – Electrical muscle stimulation
ESWT – Extracorporeal shockwave therapy
GRF – Ground reaction force
IFz – Vertical impulse
LLLT – Low level laser therapy
m/s – Meter per second
Kg – Kilogram
NSAID – Non-steroidal anti-inflammatory drug
PCA – Pressure contact area
PFz – Peak vertical force
Ppm – Parts per million
SD – Standard deviation
SG – Specific gravity
SI – Symmetry index
SPD – Stance phase duration
TF – Total force
TENS – Transcutaneous electrical nerve stimulation
US – Therapeutic ultrasound
UWT – Underwater treadmill therapy

1. TRAINEESHIP REPORT

As part of the Integrated Masters Degree in Veterinary Medicine from the Faculty of Veterinary Medicine of the University of Lisbon I completed a 4-month training between the 26th of February of 2015 and the 30th of June of 2015, in an approximate total of 680 hours, in the section for Physical Therapy and Rehabilitation, headed by Dr Barbara Bockstahler (DVM, PD, DECVSMR (Small Animals), DACVSMR (Canine), FTA, CCRP, EBVS® European Specialist in Veterinary Sports Medicine and Rehabilitation) at the Clinic for Small Animal Surgery and Ophthalmology, University of Veterinary Medicine (Vetmeduni), Vienna, Austria. Throughout the training, I acquired skills concerning physical therapy case diagnosis and planning, resourcing from referral reports, anamnesis and complementary exams, which included MRI scan, CT scan, X-ray and motion analysis using a pressure plate and a camera.

I had the opportunity to assist to and train physical examination, mainly within the neurologic and orthopaedic disciplines, comprising a significant number of geriatric and postoperative patients. Additionally, I partook in therapy planning, involving the devices and exercises, according to each case and its progression throughout sessions. I learned to work with the various tools in the department, which I operated daily.

Figure 1 – Treadmill Runner 1™ (Theravet®), equipped with a sling suspension system.

On-site rehabilitative equipment included two underwater treadmills (treadmill 1: Keiper™ model, Water Walker® brand; treadmill 2: custom-built, no brand), and a land treadmill with an adjustable sling suspension system (Runner 1™, Theravet®) (Figure 1). Other therapeutic on-site gears were a low level laser therapy (LLLT) device with Multiwave Locked System® (Mphi VET™ model, ASAlaser®), two different models of electrical stimulators which provided electrotherapy in the form of transcutaneous electrical nerve stimulation (TENS) and electrical muscle stimulation (EMS) (AmpliMove synchro™, Knop®; PT-2010-N™, S+B medVET®), a therapeutic ultrasound (US) apparatus (Vetri-combi™, Physiomed®) and an extracorporeal shockwave therapy (ESWT) device (Swiss DolorClast VET™, EMS®) (Figure 2). The department was also equipped with a nuclear magnetic resonance therapy machine (ProVet Station™, MBST®). However, it was not operated during the traineeship period, as it was mostly used for research purposes.

Additional tools were available to complement therapy, namely, therapy balls and rolls, balance boards, vertical weave poles, cavalletti rails, elastic bands, hot and cold packs, and vests and flotation equipment for aquatic therapy. Assistive devices for ambulation such as carts, slings, harnesses, boots, and joint protectors were available for pet owners to borrow and purchase. Contacts for reliable manufacturers of veterinary custom-made carts, orthoses, and prostheses were provided as well.

Figure 2 – Examples of used devices. Top left: LLLT device Mphi VET™ (ASAlaser®) with protective goggles for the operator and patient; top right: electrotherapy device AmpliMove synchro™ (Knop®); bottom left: ESWT device Swiss DolorClast VET™ (EMS®); bottom right: US device Vetri-combi™ (Physiomed®).

The Physical Therapy and Rehabilitation department provided the Surgery, Internal Medicine, and Intensive Care units with ambulatory physical therapy treatment for the inpatients, where I practised post-operatory and critical care handling. Also, I studied and trained massage techniques, and assisted in shockwave therapy, neural therapy, and acupuncture sessions. With the tutoring of Dr Marion Mucha (DVM, CCRP, CVA, CVPP) I learned basic principles of neural and acupuncture therapies, mostly regarding pain and stress management, as well as acupuncture needle handling. During the traineeship period, I attended a webinar lectured by Dr Mila Speciani (DVM, EBW, GP Cert WVA&CPM) from

ASAVET®, concerning biological and therapeutic effects of general laser therapy, its modalities and applications, and the Multiwave Locked System®.

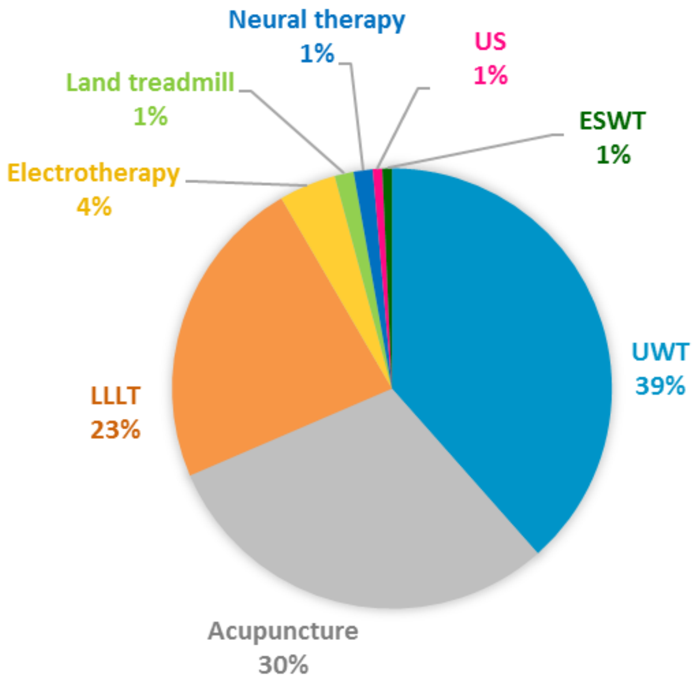
Although not numbered for this dissertation, the main objectives for patients to attend the Physical Therapy and Rehabilitation Department were for pain management, muscular reinforcement, weight loss, and neurologic rehabilitation. These usually followed surgery, trauma (car accidents, falling off windows, balconies and stairs), or were part of a degenerative joint disease management program. Surgical patients were accompanied together with a surgeon, and physical therapy was practised alongside conservative treatment, before and after surgery, as needed, adjusted to each case. Besides traditional acupuncture, a form of permanent acupuncture with gold bead implantation was used in surgery. It was mainly aimed at musculoskeletal conditions with chronic pain and/or inflammation, such as degenerative joint disease and osteochondritis.

In cases regarding severe pain management, Gabapentin was the elected drug to provide analgesia, and it was on occasion complemented with nonsteroidal anti-inflammatory drug (NSAID) therapy, as needed. Patients with neurologic disorders affecting micturition were administered Terazosin regularly, to prevent urostasis and subsequent urinary tract infection. A minor component of outpatients came from other hospitals and clinics as referrals. These were usually referred due to the specialised equipment the department provided, and to get a second opinion.

The overall number of patients observed during the traineeship period consisted of 139 dogs and 4 cats, comprising a total of 143 patients. From this group, one healthy dog attended the department for exercising purposes, as physical conditioning for rescue dog training. All the remaining animals presented a clinical condition background.

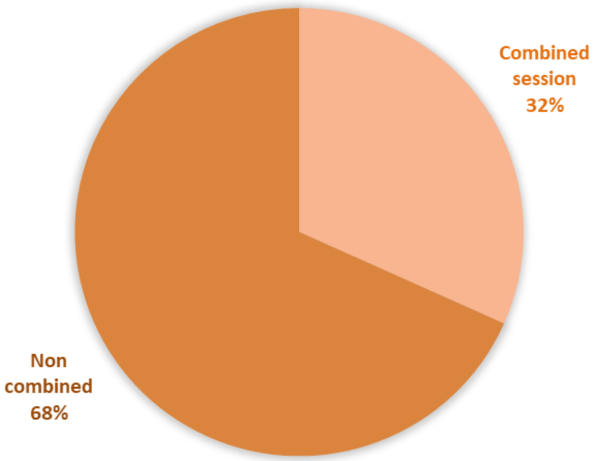
As shown in Graph 1, underwater treadmill therapy (UWT) was the most commonly practiced modality (n=55, dogs=54, cats=1). However, this graphic depicts only the main modality for each session, as most cases included a combination of two or more therapeutic modalities (Graph 2).

Graph 1 – Frequency of the main modality used for each patient, in percentage (n=143). LLLT– low level laser therapy; US– therapeutic ultrasound therapy; ESWT– extracorporeal shockwave therapy; UWT– underwater treadmill therapy.

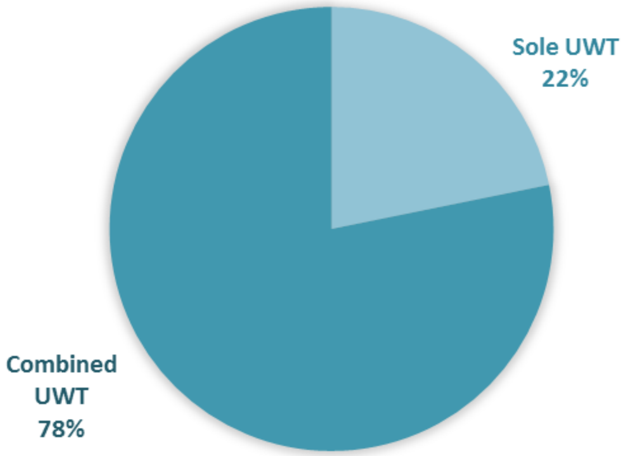


It is currently widely accepted that a rehabilitation program including a combination of different therapeutic modalities works synergistically in generating a better outcome when compared to using a single modality (Bockstahler 2004; Millis et al. 2004; Robertson 2013; Monk 2016). During the course of this study, UWT was more frequently used in combination with other modalities than it was as a single modality (Graph 3).

Graph 2 – Distribution of sessions using one therapeutic modality or a combination of two to three modalities.

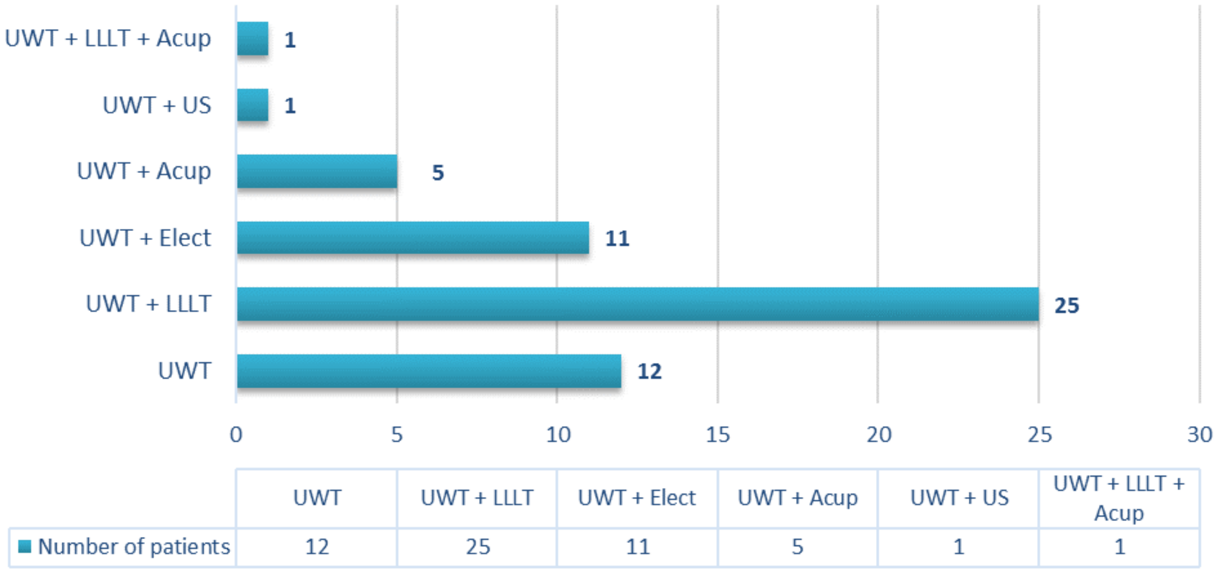


Graph 3 – Distribution of sessions according to whether UWT therapy was performed alone or combined with other modalities.



As seen in Graph 4, UWT was routinely the first phase of the session and would either be followed by laser therapy or electrotherapy (usually TENS). It was common practice to massage the patients at the end of the session, for 10 to 20 minutes, depending on the intensity of the exercise, presence of pain or an increase in muscular tension. A warm-up massage prior to UWT was also performed on geriatric individuals and on patients with considerable muscular soreness or tension.

Graph 4 – Number of patients according to the different combinations of UWT with other modalities. UWT– underwater treadmill therapy; LLLT– low level laser therapy; Acup – acupuncture; US– therapeutic ultrasound; Elect – electrotherapy.



	UWT	UWT + LLLT	UWT + Elect	UWT + Acup	UWT + US	UWT + LLLT + Acup
■ Number of patients	12	25	11	5	1	1

At the time of the traineeship, veterinary chiropractic was becoming increasingly popular in Vienna, particularly in dogs and horses. Many dogs that were on a physical therapy program also attended private chiropractors; some regularly once a week, others solely when the owners noticed muscular discomfort or postural abnormalities.

Considering the cat patients observed during the traineeship (n=4), laser therapy and acupuncture were the most frequent treatment choices (n=3), and one cat performed underwater therapy (Figure 3). Both massage and passive range of motion were fairly accepted therapy complements.

Figure 3 – Cat during an UWT session.

Patients attended the department typically twice a week, usually with a minimum two-day interval between sessions. During the traineeship period, only two dogs did three sessions weekly. Depending on the patient's condition, its improvement, and owner's compliance, sessions would become progressively less frequent, up to one session monthly or total therapy cease. However, some cases, mainly associated with palsy and unsuccessful post-hemilaminectomy recovery, were kept on lifelong therapy to maximise the chances of better living quality.

Being the physical therapy team part of the research Movement Science Group, I also had the opportunity to assist to a project's results briefing. It regarded the conception of an apparatus (Vienna Equine Surface Tester – "The BALL") designed to measure the mechanical properties of surfaces and floors, and its potential on future research on the racing horse health and performance, which was meanwhile published (Schramel and Peham 2016) [1].

On March I wrote an Animal Use Protocol with the guidance of Dr Bockstahler, which was later presented to the University's Ethics and Animal Welfare Committee, to obtain approval for the use of patients to represent the population sample for this dissertation.

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[1] Schramel J and Peham C. 2016. Vorrichtung zur Bestimmung der mechanischen Eigenschaften von Oberflächen und Böden und Verfahren zum Betrieb der Vorrichtung.

2. LITERATURE REVIEW

2.1. AQUATIC PHYSICAL THERAPY

According to Geytenbeek (2008), the concept of aquatic physical therapy applies to the exercise of physical therapy in a water medium, with the goal of rehabilitating or achieving a particular physical conditioning objective. Hydrotherapy is a broader concept, which comprises all types of water-based therapy performed by a variety of professional specialities, including balneotherapy, spa therapy, whirlpool, colonic irrigation, Kneipp therapy, and hydrokinesiotherapy.

Exercising in an aqueous environment is physically different from doing the same in land. In water, there are additional resistance forces involved in locomotion, and the body is subjected to buoyant and extra pressure forces. Therefore, land exercises cannot be identically mimicked in water, and to do so would imply not using the assets of exercising in water (Millis et al. 2004; Monk 2016).

To develop an efficient aquatic therapy program, it is essential first to acknowledge several intrinsic properties of water, as well as principles that apply to the immersion and movement in the water. (Lindley and Watson 2010; NARCH 2015).

2.1.1. Basic properties of water

2.1.1.1. Fluid mechanics

a. Density and specific gravity

The density (ρ) of a substance is the quantity of mass existing per unit of volume. It is mathematically defined as the division of mass by volume. For a heterogeneous body (p.e., a mammal), the considered density is the average of all its body components (OpenStax 2017; Ling et al. 2018).

In aquatic physical therapy, the average density of a body is what fundamentally determines whether it floats or sinks in water. To determine such, a ratio is calculated that compares the density of a substance (an animal, in this case) with the density of a reference substance (water, in this case). This ratio is referred to as specific gravity (SG), also known as relative density (Monk 2016; OpenStax 2017; Ling et al. 2018).

Pure water has a SG of 1.0 at 4.00 °C, where water is at its maximum density, and it is considered the standard reference substance (Table 1). Besides temperature, density (and therefore SG) also varies with pressure and the presence of dissolved substances (OpenStax 2017; Ling et al. 2018).

Table 1 – Specific gravity values of water and several main body tissues at atmospheric pressure. A fat SG of 0.96 means it's 0.04 less dense than water. Muscle and bone SG of 1.06 and 2.0 means it's 1.06 and 2 times denser than water, respectively. *Varies from area to area, due to differences in its dissolved substances. **Varies with salinity content and temperature. (Adapted from Kerth 2013; Walker 2015; Monk and Goff 2016; Ling et al. 2018).

Substance/tissue	Specific gravity
Pure water at 4 °C	1.0
Pure water at 20 °C	0.998
Tap water at 20 °C	0.998*
Seawater	1.020-1.030**
Fat	0.8-0.96
Skeletal muscle	1-1.06
Bone	1.5-2.0

The variations in water SG are negligible when applied to aquatic physical therapy practice. Hence, a SG value of 1 is standardly used to refer to pool[2] and tap water.

If the SG of a body is lower than 1, it will float on water; if higher than 1, it will sink (Millis et al. 2004; Lindley and Watson, 2010). If SG is exactly 1, the body will remain suspended at its present depth (OpenStax 2017). This phenomenon is further discussed in the buoyancy topic below.

The SG also determines the degree of immersion of a body in water (Figures 4 and 5). If a body has a SG of 0.8, 80% of it will be submerged in water, while the remaining 20% will sit above the water surface (Monk 2016). An individual's SG is influenced by its body condition. As such, the effects of SG on aquatic therapy are:

- Animals with higher body condition score (BCS) float more easily in the water;
- Lean or heavily muscled animals tend to sink, and thus need to make more effort to move in the water. They may require additional assistance or flotation equipment;
- Animals with osteoporosis will have a lower bone SG and, consequently, tend to float more easily. (Bockstahler et al. 2004; Mikail 2006; Monk 2016).

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[2] Pool water has a standard chlorine content of 0.001% to 0.003% in veterinary aquatic therapy practices, so it's considered to have a SG similar to tap water (NARCH 2015).

Figures 4 (left) and 5 (right) – Comparison of dogs with different average SG. The dog in figure 4 is deeper immersed in water, compared to the dog in figure 5.
https://www.needpix.com/photo/download/1522834/nature-animals-pets-dogs-browndog-dachshund-wienerdog-swimming-bluewater
https://www.sciencenewsforstudents.org/article/dissecting-dog-paddle

b. Buoyancy

Buoyancy is the upward force of the water on an immersed or floating body. It is experienced as a thrust of the body towards water surface (Bockstahler et al. 2004; Mikail 2006). According to Archimedes' principle, the value of the buoyancy of a body equals the weight of the water it displaces. In its turn, the weight of water displaced depends on the SG of the body. The buoyant force is always present on any body in water, whether it floats or not. (OpenStax 2017; Ling et al. 2018).

In aquatic physical therapy, buoyancy substantially reduces the weight the animal must carry (Bockstahler et al. 2004). The interaction between weight-bearing and water depth in dogs was assessed by Levine et al. in 2002 (Table 2).

Table 2 – Percentage of weight-bearing of dogs standing at different water depths. Comparing to normal weight-bearing on land, the results obtained showed the higher the water level, the less weight-bearing occurs (Levine et al. 2002). Additional investigation in various breeds and sizes of dogs is needed, as well as the study of variations on weight-bearing during ambulation (Monk 2016).

Immersion depth	Weight-bearing (%)
Tarsus	91
Stifle	85
Hip	38

Since ambulatory limitations are typically due to an inability to support weight normally during a full gait cycle, animals may show improved ambulation when load-bearing is reduced. (Shmalberg 2018).

The implications of buoyancy and reduced weight-bearing on animal patients are:

- Unloading of painful joints by raising the water level above these (Bockstahler et al. 2004; Lindley and Watson 2010; Steiss 2010);
- Allowing ambulation when land-based exercise is contraindicated (Jackson et al. 2002). It includes starting ambulation earlier in recovery, for example in intervertebral disc protrusions and postoperative rehabilitation following cruciate ligament repair;
- Provide a milder transition to land-based exercise, post-surgery or injury (Shmalberg 2018);
- Rehabilitation of muscular weakness (Steiss 2010; NARCH 2015).

Buoyancy can additionally be used to increase resistance to movement, namely with flotation devices (NARCH 2015). If an anatomical part moves parallel to the water surface, buoyancy eases the movement acting as support. If it moves perpendicularly, buoyancy works as a resistance to movement. (Mikail 2006).

Besides buoyancy, a body immersed in water is also subjected to gravity, which acts as an opposing force. If the centre of buoyancy and the centre of gravity are not aligned in the same vertical plane, the animal will not be in equilibrium and will tend to tip forward or tilt sideways (Lindley and Watson 2010; Monk 2016).

In practice, animals with an amputated or a flexed limb will tend to rotate down to the opposite side to reach equilibrium. Patients with spinal injury or asymmetrical tone may struggle to control trunk rotation. Flotation devices are generally used to aid but need to be placed accordingly to compensate the imbalance (Monk 2016).

b. Hydrostatic pressure

Hydrostatic pressure is the pressure force effected on an immersed body due to the weight of a liquid (Ling et al. 2018). It is directly proportional to the immersion depth and fluid density: the greater the depth and fluid density, the greater the pressure. (Bockstahler et al. 2004).

Implications for animal patients:

- Water exerts resistance to thoracic expansion when inhaling. Therefore, caution is advised when submerging patients with cardiac or respiratory conditions (Mikail 2006; NARCH 2015);
- Hydrostatic pressure is beneficial for swollen joints and oedematous tissue located in the distal portion of limbs, which are deeper submerged, and aids venous return. It also

decreases nociception due to phasic stimuli exerted to the sensory receptors on the skin, thus allowing more movement with a lesser sensation of pain (NARCH 2015).

c. Viscosity and resistance

The viscosity of a fluid refers to the frictional resistance to flow, which is dependent on the cohesive forces at a molecular level. Resistance consists of the force exerted by a solid body moving through the fluid and is dictated by viscosity (Bockstahler et al. 2004).

Implications for animal patients:

- Water provides resistance that promotes muscular strengthening and cardiovascular fitness;
- There is a possible increase in sensory awareness;
- Assistance in stabilising unstable joint/s;
- There is a greater prevention of falling by increasing the time for an animal to react, improving its willingness to move. This is particularly relevant in spinal patients (NARCH 2015);
- Both buoyancy and hydrostatic pressure provide a supporting feeling to the patient while submerged in water (Mikail 2006).

d. Turbulence

Water turbulence consists of an irregular water flux which increases water-resistance to the patient’s movement when compared to a continuous unidirectional water flux. Generating water turbulence through manual water agitation or jet streamers creates variations of pressure in different body parts. It additionally has a massaging effect, enhancing blood and lymph circulation, and gently removing wound exudates and debris (Mikail, 2006).

e. Surface tension

Water molecules tend to have greater adherence among themselves near the surface. This surface tension creates a higher resistance to movement on the surface (Bockstahler et al. 2004).

Implications for animal patients:

- Exercising near the surface is more difficult, and must be accounted for with debilitated animals (Bockstahler et al. 2004);
- Miniature breeds will be more affected by surface tension. (NARCH 2015).

2.1.1.2. Other properties

a. Temperature

Millis et al. (2004) recommend that healthy dogs exercise with a water temperature range between 26-28 °C in pools, and approximately 25,5-32 °C in aquatic treadmills.

Heated water – The main physiological effects of exercising in water temperatures above normal body temperature are: increase of respiratory frequency, increase of cardiac frequency, increase in the heart returning blood flow, decrease of blood pressure, increase in muscular blood flow, increase in peripheral circulation, increase in metabolic rate, general muscular relaxation and increase in joint flexibility. The increase in circulatory flow enhances oxygen intake and carbon dyoxide and lactic acid removal, thus reducing muscular discomfort. Due to the increased strain in cardiac output, caution is advised when exercising cardiac and geriatric patients in heated water (Millis et al. 2004; Mikail 2006).

Cold water – Water temperatures below normal body temperature are apparently well tolerated by dogs, particularly individuals with thicker coats (Millis et al. 2004). The main physiological effects of exercising in cold water are cellular metabolism decrease, reduction in capillary permeability and pain relief. The cold water also helps patients exercising with active inflammation (Mikail 2006). Subjects that perform UWT in cold water show lower heart rates than individuals exercising on land treadmills at the same velocity and length of time (Millis et al. 2004).

b. Salinity

Besides increasing the density of water, the addition of salts to water also increase osmolarity and osmotic pressure. Water with a high content in salt helps “draining” swollen tissues and open exudative wounds (Mikail 2006). The salinity changes the specific gravity much more than the temperature does (Walker 2015).

c. Oxygenation

A higher concentration of oxygen in water enhances tissue healing, similarly to the increase that occurs in hyperbaric chambers. (Sen 2009; Ladizinsky and Roe 2010). The mean oxygen content in water at room temperature is around 2,4 parts per million (ppm) and increases to 8-11 ppm when at 2°C. Using jet streamers can also contribute to improving water oxygenation (Mikail 2006).

2.1.2. Physiological effects of immersion

Body immersion in water at body temperature leads to well documented physiological changes. Some of those changes have already been discussed previously in this dissertation, and include a shift in blood volume from peripheric to central circulation caused by hydrostatic pressure, increased cardiac volume output, reduced heart rate and inspiratory volume changes (Millis et al. 2004; NARCH 2015). Although no clear mechanism has been described, it is also proposed that immersion reduces sympathetic nervous system activity. Sympathetic nervous system activation has been associated with some of the detrimental consequences of chronic stress and illness (Becker et al 2009).

2.1.3. Physiological effects of exercising in water

Exercising in water differs greatly from exercising on land (Monk 2016). Studies in humans described that metabolic requirements, oxygen uptake and heart rate were greater while exercising in water compared to performing the same exercises on land (Whitley and Schoene 1987; Johnson et al. 1977). Both in dogs and humans, it has been described that peak heart rate, blood lactate and oxygen uptake are lower in individuals exercising in water, which means that exhaustion is achieved with a smaller work rate when compared to exercising on land (Becker 2004; Mikail 2006).

A study by Nganvongpanit et al. (2014) reported that swimming significantly improved the range of motion in dogs affected by hip osteoarthritis. Another study by Marsolais et al. (2003), suggested that swimming promoted significantly greater range of motion of the stifle and tarsal joints than walking in dogs following CrCL rupture correction surgery. Yet another one by Preston and Wills (2018) concluded that aquatic therapy increases range of motion and step length in labrador retrievers with elbow pathology and can be of benefit for canine elbow dysplasia management.

Energy expenditure when exercising in water can vary significantly compared to the same exercise on land. On one hand, buoyancy reduces bodyweight and therefore reduces the amount of energy required to counter gravity. On the other hand, water viscosity, friction and turbulence require increased work to overcome resistance during movement. Water temperature also impacts energy expenditure, as thermoregulation mechanisms will need to balance body temperature if the water is too cold. Shivering due to low temperatures also increases energy consumption (Monk 2016).

2.1.4. Underwater treadmill therapy

Underwater treadmill therapy is a modality that, like swimming, reduces weight-bearing on joints and adds resistance to movement due to the water's attributes, while also enabling the execution of a range of motion similar to normal gait in land (Schmalberg 2018). Therefore, this type of aquatic therapy is selected when there is a need to exercise the patient in a normal gait pattern, especially in those cases where walking on ground would result in repeated or serious injury due to muscle weakness or improper balance (Millis et al. 2004).

2.1.4.1. Indications

The major indications for UWT are rehabilitation following orthopaedic surgery or neurological injury and improving joint and muscle strength (Bockstahler et al. 2004) (Figure 6). Animals that have been recumbent for long periods of time benefit from aquatic therapy as a means to strengthen muscle mass while bearing reduced weight (Lindley and Watson 2010). It may also be useful in patients with peripheral oedema, muscle spasm, and to improve confidence in dogs reluctant to walk on ground. Due to having a greater muscle and cardiovascular demand compared to land treadmill, it is also indicated for athletic conditioning and weight management (Millis et al. 2004).

The recommended water temperature varies with the condition treated: neurologic patients are usually recommended to walk with warmer water (approximately 29,5-32 °C), while orthopaedic patients and dogs in conditioning regimens require less warm temperatures (approximately 25,5-28,5 °C) (Millis et al. 2004).

Figure 6 – Canine patient with partial cranial cruciate ligament rupture performing UWT following stifle arthroscopy.

2.1.4.2. Contraindications and precautions

Aquatic therapy is not recommended in the case of open wounds, infections, cardiac or respiratory conditions, uncontrolled epilepsy, urinary incontinence and diarrhoea (Mikail 2006). Dogs with surgical sutures that have not healed completely and do not have a waterproof cover should not be subjected to underwater therapy. Caution should be exercised in patients with laryngeal paralysis, skin or ear problems, epilepsy, and mild systemic compromise. Geriatric patients and those with very high BCS should be monitored closely during UWT (Monk 2016). If a dog exhibits fear or aversion to water and needs aquatic therapy, it is advised to first introduce the animal slowly to the room and encourage playing and exercising before actually starting therapy. Same animals might not be able to perform aquatic therapy due to the possibility of injuring themselves or the operators (Lindley and Watson 2010).

2.1.4.3. Comparing underwater treadmill therapy and swimming

When swimming, almost the entire body is immersed, as only the head and part of the neck are outside the water. Additionally, there is no contact between the patient and the ground, requiring a constant motion of the limbs to maintain the head above the surface (Mikail 2006). As such, swimming is the modality of choice for improving range of motion and in patients with severe osteoarthritis, as they are able to exercise while bearing no weight on their limbs (Schmalberg 2018). With the ribcage immersed in water, increased respiratory work is required to overcome the pressure exerted by the water during inhaling. This results in a better cardiorespiratory capacity, and improved venous return and cardiac output (Mikail 2006).

Figure 7 – Anterior view of a canine patient performing UWT.

While swimming is certainly beneficial in some situations, underwater treadmill therapy is the better choice when the goal is improving proprioception and dynamic balance, as direct contact with the ground and the need to maintain a walking stance forces the patient to work its muscles and joints, while supporting less weight (Schmalberg 2018) (Figure 7).

2.1.4.4. Underwater treadmills used for the traineeship and study

As previously stated in the traineeship report, there were two underwater treadmills at the Physical Therapy and Rehabilitation section at the Vetmeduni.

The Keiper™ treadmill (Figure 8) was set above floor level, with a ramp and a lifting platform (Figure 9), so the patients could access it. It was equipped with a spindle lift to change the incline, a water heating system, and a counter-current jet streamer that provided the option to increase water resistance during exercise. The physiotherapist stood by one of the sides of the treadmill, within reach of both the controls and the patient, and the owner/caretaker stood at the front facing the patient for motivation and positive reinforcement.

The custom-built treadmill (Figure 10) was purposely designed for the Vetmeduni. It worked through an exterior motor with adjustable speed to run the treadmill, and a hydraulic system to lift and lower the treadmill in and out of water. It was set below floor level, with sideways access on both sides. The treadmill was lifted to floor level for the patients to access through a small incline ramp. There was also a custom-made harness lift system to facilitate access. The physical therapist stood on the right-side pit to access both controls and patient, and the patient’s caretaker was positioned either on the left-side pit or outside, facing the patient.

Figure 8 – The Keiper™ water treadmill, from the Water Walker® brand.

Figure 9 – View of the ramp and the lifting platform, used to facilitate patient access to the water treadmill.

Comparing both treadmills, the Keiper™ treadmill offered a more accurate speed control and better assessment of the patient's locomotion during exercise through its transparent panels. It was preferable for nervous dogs since some dogs stressed when they were lowered below floor level. The custom-built treadmill was more easily accessible for patients with ambulatory limitations and more practical for hoisting larger and heavier individuals. It also allowed better control over limb movement when assistance for walking underwater was needed.

Figure 10 – The custom-built water treadmill at the Vetmeduni.

Regarding maintenance, the Keiper™ was more environmentally and cost-friendly through multiple re-using of the water with filter systems, enabling greater intervals between cleaning, but being more time-consuming to clean. The custom-built treadmill had no filtering system to use between therapy sessions. It was easier to clean but required much more regular maintenance, which implied being emptied of water every time. Both treadmills were used for this study since each one presented assets that best suited the different types and conditions of the dogs.

2.2. CANINE GAIT ANALYSIS

Biomechanics is described as the study of the principles of mechanics applied to biological systems, particularly regarding structure and function. It concerns the effects of forces on body motion (Hatze 1974; Karduna 2007). Knowledge on the mechanical demands and constraints that occur during locomotion enables the assessment of compensations, secondary neuromuscular and skeletal problems and pathology that follow the failure of one or more elements. It is therefore essential in the diagnosis of numerous musculoskeletal and neurologic conditions and in the delivery of physical therapy. (Adrian 2016; Carr and Dycus 2016).

There are two primary types of locomotion: gait and nonrepetitive motions (Millis et al. 2004). Gait is a repetitive sequence of movements which drive an animal forward. It consists of a way to translocate a body from one point to another in space, developed to minimise unwanted displacements that translate into energy costs (Hildebrand 1977). Nonrepetitive motions involve single events such as sitting, jumping, and movement initiation (Millis et al. 2004).

2.2.1. Normal gait

Currently, sound dogs are considered to use four main gaits: walk, trot, canter and gallop (Zink and Carr 2018). Some authors also include swim, particularly the paddle (Millis et al. 2004; Catavitello 2015).

The dynamic of a gait is influenced by the properties of the surface, its incline, ground movement (i.e., treadmill), submersion in water, and the curvature of the path. Body conformation and breed deeply influence an individual’s moving performance as well (Bertram et al. 2000; Millis et al. 2004; Mölsa et al. 2010).

As repetitive locomotion, gait is composed of a series of strides. A stride consists of a cycle of body motion that starts with the contact of one foot and ends with that same foot again contacting the ground. In a stride, each limb undergoes a step cycle. Each limb’s complete step cycle is divided in stance phase and swing phase. Stance phase initiates with ground contact, where braking forces take place, and is followed by propulsion. After stance phase, swing phase starts, in which the foot is suspended and not contacting the ground (Millis et al. 2004).

In quadrupedal mammals, normal gait can be divided into symmetric and asymmetric gaits, according to how the body moves during each stride. In symmetric gait, the movements of the limbs are mirrored in the sagittal plane by their contralateral parts. In asymmetric gait, the left and right side of the body do not mirror each other (Alexander 1984; Budsberg et al.

1993). Examples of normal symmetric gaits are the pace, walk and trot; of asymmetric, are the rack, gallop and canter.

In a healthy standing dog, approximately 30% of its weight is supported by each of the forelimbs, and 20% is supported by each of the hindlimbs (Zebas et al. 1991). Such weight distribution positions the centre of gravity at mid-chest level, behind the scapula. This proportion equilibrium results that when moving forward in a plane ground surface, the forelimbs are mainly responsible for braking, while the hindlimbs are in charge of the majority of propulsion (Millis et al. 2004).

Because the experimental part of this dissertation involves solely the analysis of the walking gait and uses the trot for comparison purposes, the literature review will focus on these gait types.

2.2.1.1. Walk

The walk is the slowest gait a sound dog performs. It is also the only gait where there is a phase with three feet simultaneously contacting the ground.

A full walking cycle (Figure 11, left) follows the pattern: right hindfoot, right forefoot, left hindfoot, left forefoot. Simply put, it starts with a hindfoot, followed by its ipsilateral forefoot, and then the same is performed by the contralateral limbs. Each hindfoot steps right ahead of where the forefoot was before (Zink and Carr 2018). The centre of gravity remains central throughout the whole cycle (Prydie and Hewitt 2015).

Due to its speed, the walk is considered the easiest gait to visually assess. Though, it has the disadvantage of difficulting the detection of subtle lameness and that dogs are more prone to being distracted at walking speed (Millis et al. 2004).

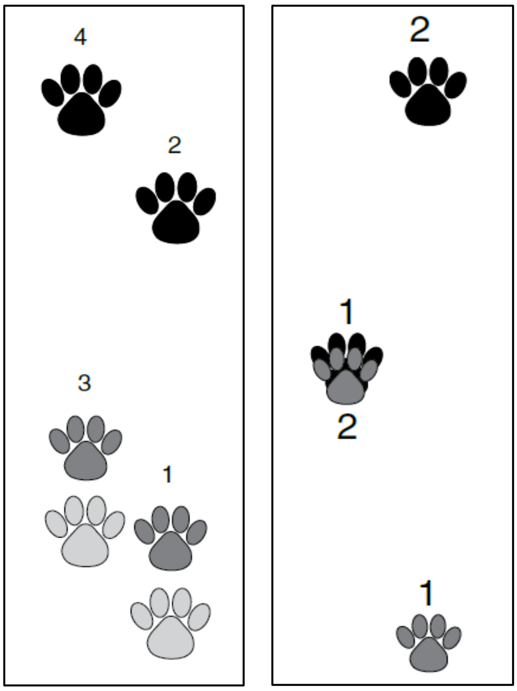


Figure 11 – Foot ground contact diagram of the walk (left) and the trot (right) gait. The numbers represent the sequence of footfall. The black prints depict the forefeet, the dark-grey depict the hindfeet, and the light-grey depict the forefoot from the precedent stride. (Adapted from Zink and Carr 2018).

2.2.1.2. Trot

In the trotting gait, the two diagonal legs contact the ground simultaneously. It follows the pattern: left forefoot with right hindfoot, then right forefoot with left hindfoot. As observed in Figure 11 (right), two of the feet contact the ground in the same spot. It occurs every time one of the hindfeet moves forward, stepping into the place where the ipsilateral forefoot was moments before (Prydie and Hewitt, 2015; Zink and Carr 2018). In most breeds, when a dog is trotting there is a moment of suspension between the contact of each diagonal pair (Elliott 2009). The trot is considered the best gait to visually detect lameness. This is due to being the only type of gait in which the limb contacting the ground is never assisted by its contralateral limb (Millis et al. 2004).

2.2.2. Lameness

Lameness consists of a disturbance of normal gait, that affects the weight-bearing of one or more limbs. It can be of anatomical or pathologic nature. Anatomical lameness can be genetic (e.g. improper body conformation) or acquired (e.g. vitamin D deficiency). It may or not be generated by pain. Pathological lameness can occur due to neural (e.g. cauda equina) or musculoskeletal causes (e.g. hip dysplasia). Typically, musculoskeletal lameness is triggered by pain (Gillette 2011).

The presence of lameness promotes complex adjustments in locomotion, which may generate secondary conditions (Wilson and Smith 2016). For instance, in the presence of unilateral lameness, a decrease in load in the lame limb is expected. This decrease is compensated by the transition of forces to other extremities (Bockstahler et al. 2009).

Analysing symmetrical gait types is recommended to assess lameness, as it is easier to detect (Colborne et al. 2011; Oosterlinck et al. 2011). Because of their symmetry and speed, the walk and trot are the two types most frequently used in lameness evaluation. Moreover, dogs tend to naturally perform them when incentivised to move (Weigel et al. 2005).

2.2.3. Methods of gait analysis

Gait analysis is currently performed resourcing both to subjective and objective methods (Carr and Dycus 2016).

Observational gait analysis, also known as subjective gait analysis, involves the visual assessment of the patient’s locomotion at all angles, usually walking and trotting. It is recommended to be performed prior to other physical examinations, since the palpation of limbs and joints may influence subtle lameness. This method of gait analysis can include videotaping, and either a numerical rating score or a visual analogue scale. It is considered quick and inexpensive and is currently the most common practice when assessing lameness in a clinical setting (Huntingford and Fossum 2019).

Instrumented gait analysis, commonly named objective gait analysis, is considered to encompass some of the most accurate methods to assess locomotion. It allows the quantification of changes in gait, and the validated methods possess a higher sensitivity power in detecting subtle lameness (Huntingford and Fossum 2019). Owing to these attributes, it has been increasingly used in the developing of treatment plans and in the monitoring of patient progress (Carr and Dycus 2016).

Numerous methods for gait analysis have been developed in the last decades. Among the most well-established techniques in veterinary practice are kinematic and kinetic gait analysis (Griffon 2008).

Kinematic analysis evaluates the characteristics of motion from a spatial perspective. It involves the positioning of reflective markers in joint landmarks, and the use of 3D cameras to subsequently measure position, velocity, and acceleration of the body, limbs and joints. 2D systems are also available but are less effective (Weigel et al. 2005). It is mostly used for measuring changes in stride length and in joint angles during gait (Millis et al. 2004).

Kinetic gait analysis quantifies the forces involved in locomotion, mainly in relation to the ground. It includes the measurement of braking, propulsive, horizontal and peak vertical forces; vertical, braking, and propulsive impulses; rates of loading and pressure distribution within the paw (Millis et al. 2004). It is the most common technique for describing normal and abnormal locomotion (Schnabl-Feichter et al. 2017). Kinetic data can be collected using one or multiple force plates, or a pressure-sensitive walkway (also referred to as “pressure plate”) (Gillette and Angle 2008). Both are considered well-validated reliable measuring tools (Bockstahler, Skalicky et al. 2007; LeQuang, Maitre, Colin et al. 2010; LeQuang, Maitre, Roger et al. 2010).

It is common for both the kinematic and kinetic methods to incorporate the time dimension in the analysis of their parameters (Gillette and Angle 2008).

Several studies comparing subjective and objective lameness assessment indicate that due to its subjective nature, observational gait analysis may not be able to consistently detect subtle lameness (Oosterlinck et al. 2011; Lane et al. 2015; Carr and Dycus 2016). Nevertheless, observational gait analysis is still a practical tool in clinical practice and should integrate a complete orthopaedic, neurological and rehabilitation examination procedure.

For the experimental part of this dissertation, a pressure plate with a video recorder was used to perform kinetic gait analysis, including temporospatial variables.

2.2.3.1. Kinetic gait analysis

In kinetic gait analysis, the measured forces occur along three axes: vertical (z), horizontal (y) and transverse (x). Because these are all reaction forces occurring at the point of contact with the ground, they are referred to as ground reaction forces (GRFs) (Zink and Carr 2018).

The assessment of GRFs is based on Newton’s third law of motion, which states that for every action force occurs an equal, collinear, and opposite reaction force (Weigel et al. 2005). The reaction force along the vertical (z) is the force that occurs perpendicular to a plane ground surface. It represents the weight-bearing dimension of the resultant force. The reaction force along the horizontal (y) axis is composed by the propulsion and the braking components. Propulsion occurs in the positive direction of the resultant force, whereas braking occurs in the negative direction. Lastly, the reaction force along the transverse (x) axis concerns mediolateral forces. It is considered minor and is usually not quantified in most kinetic studies in dogs (Millis et al. 2004).

According to the parameters measured in this dissertation’s clinical study, the following text will be dedicated to describing peak vertical force, vertical impulse, paw pressure contact area, and symmetry indexes. The parameter of stance phase duration was previously mentioned in the normal gait subchapter.

a. Ground reaction forces

Peak vertical force (PFz) represents the maximum force of the vertical GRF of a limb during stance. It is a punctual moment in time in the force time curve of a stride.

Vertical impulse (IFz) is composed of the sum of the vertical force of a limb over time. Mathematically, it is represented by the area under the force-time curve (Zink and Carr 2018)

Both PFz and IFz variables are depicted in Figure 12.

b. Paw pressure contact area

This variable represents the surface area of a paw that is contacting the ground (Millis et al. 2004).

c. Limb symmetry

As in previous human (Soudan 1982) and equine (Merkens et al. 1985) locomotion studies, in 1993 Budsberg et al. documented that healthy dogs did not present perfect right-left symmetry at a trot. Instead, they presented small but consistent variations in weight-shifting.

The percentage of asymmetry accepted in nonlame dogs has been the focus of numerous canine gait analysis studies. Symmetry or asymmetry indexes are currently considered the gold standard in the assessment of lameness in several species (Budsberg et al. 1993; Schnabl-Feichter et al. 2017). They can be calculated for each of the discussed kinetic parameters. Namely symmetry indexes of PFz and IFz are used in canine gait analysis (Oosterlinck et al. 2011), as they are considered the parameters with the higher reliability, and have been investigated by several researchers for a SI cut-off value to distinguish lame from non-lame individuals (Budsberg et al. 1993; Fanchon et al. 2007; Volstad et al. 2017). Typically lower PFz and IFz show lower values in the affected limb of a lame dog (Gillette and Angle 2008), which can generate an imbalance in a limb pair and therefore be categorized as an asymmetry.

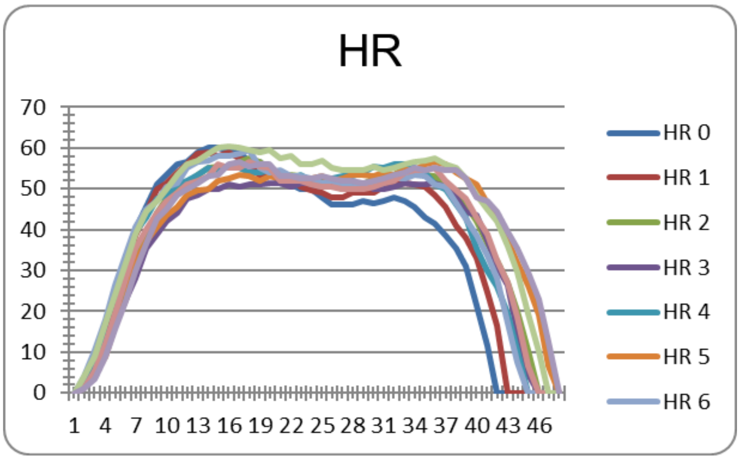


Figure 12 – Example of a normal pattern of vertical force distribution of a hindlimb over time, during the stance phase of a stride. Each coloured line represents a different trial of the same hindlimb. The PFz of each trial is their respective highest point marked in the graph. The IFz of each trial is the area under their respective curve. The stance phase of a stride typically has an "M" shape, due to the peak of the first ground contact, and then the peak of the propulsion before the foot leaves the ground (Millis et al. 2004). This graph was automatically translated using the gait analysis dedicated software available at the Vetmeduni (Pressure Analyzer 1.3.0.2; Michael Schwanda®).

3. MATERIALS AND METHODS

3.1. Introduction

Computer-assisted gait analysis is currently considered a cornerstone in the veterinary biomechanical field (Gillette and Angle 2008; Carr and Dycus 2016). Kinetic analysis is one method of gait analysis which evaluates weight-bearing alterations by measuring reaction forces. It is a reliable tool in the diagnosis of locomotion disorders, and evaluation of different treatment effects, supporting adjustments to produce a better outcome (McLaughlin 2001; LeQuang, Maitre, Roger et al. 2010). It is expected that as adherence to veterinary physical therapy and rehabilitation grows, the use of gait analysis in varied settings will increase as well (Weigel et al. 2005; Feeney et al. 2007; Griffon 2008).

The benefits of underwater treadmill therapy in dogs have been extensively recognised and discussed in veterinary literature (Levine et al. 2002; Jackson et al. 2002; Bockstahler et al. 2004; Dunning et al. 2004; Millis et al. 2004; Chauvet et al. 2011; Monk 2016; Bertocci et al. 2018). However, much data is still required to more accurately understand its influence on canine locomotion, being one of the cases individuals recovering from orthopaedic lameness.

3.2. Objective

The aim of this study was to use a pressure plate to compare ground reaction forces (GRFs) in a heterogeneous population of dogs with lameness due to appendicular orthopaedic condition(s), before and after a physical therapy session on a water treadmill. It was proposed to measure changes in symmetry variation of vertical ground reaction forces, stance phase duration, and paw pressure contact area between contralateral limb pairs, as well as variation in step length. It was also proposed to investigate whether a correlation existed between the withers height and the step length of each dog.

3.3. Candidates

Fourteen client-owned dogs enrolled in the clinical study, from April 2015 to July 2015, for voluntary participation. Eligible candidates were selected by medical record investigation. Inclusion criteria comprised a clinical history of lameness due to an orthopaedic condition originated in one or both contralateral limb pairs, and ongoing underwater treadmill treatment. Exclusion criteria included simultaneous orthopaedic conditions in both fore and hindlimbs, abnormal findings on a routine physical examination, previous neurologic diagnosis or abnormal findings on neurologic examination, or a diagnosis of a non-orthopaedic condition.

One dog was excluded due to limb suspension during locomotion, which affected the consistency of measurements; 4 dogs were excluded after measurements, as they were no longer considered lame. The 9 candidates that met the inclusion criteria were divided into two groups, based on whether the orthopaedic condition occurred in the forelimbs (Group A) or in the hindlimbs (Group B), as shown in Table 3. Each dog was assigned a number, to identify them throughout the study.

Table 3 – Breed, gender, age, body mass and BCS of all dogs taking part in this study. F – sexually intact female; FS – spayed female; M – sexually intact male; MN – neutered male.

Group A

Dog	Breed	Gender	Age (years)	Body mass (kg)	BCS (x/9)
1	Mixed breed	FS	5,25	42,0	8
2	Mixed breed	FS	8,08	26,3	7
3	Irish Terrier	F	0,50	10,0	4
4	Mixed breed	M	6,67	15,9	6

Group B

Dog	Breed	Gender	Age (years)	Body mass (kg)	BCS (x/9)
1	Icelandic Sheepdog	MN	3,42	18,8	5
2	Mixed breed	FS	11,5	32	7
3	Dogo Argentino X Labrador	FS	4,58	40,0	5
4	King Charles Spaniel	M	2,33	10	6
5	Large Münsterländer	F	10,25	36,0	5

In Group A, mean age ± standard deviation (SD) was 5.13 ± 3.29 years, ranging from 0.5 to 8.08 years. Mean body mass ± SD was 23.55 ± 14.02 kilogram (kg); mean BCS ± SD was 6.25 ± 1.71, and 3 dogs were appraised as overweight (BCS ≥ 6/9) using the Purina® Body Condition Tool for Dogs (Laflamme 1997). There were 2 individuals affected in one forelimb, and 2 in both forelimbs. Regarding medication, participant number 4 was receiving Cimicoxib (2.5 mg/kg daily) to alleviate the symptoms of bilateral elbow dysplasia aggravated by omarthrosis and cubarthrosis.

Group B participants mean age ± SD was 6.42 ± 4.17 years, ranging from 2.33 to 11.50 years. Mean body mass ± SD was 27.36 ± 12.56 kg; mean BCS ± SD was 5.60 ± 0.89, and 2 dogs were considered overweight. There were 3 dogs affected in one hindlimb and 2 in both hindlimbs. Participant number 2 was on oral Carprofen as needed (1.6 mg/kg). It was diagnosed with cranial cruciate ligament rupture and treated with unilateral tibial tuberosity advancement surgery 98 days before measurements day.

The complete general clinical and morphometric data of the candidates and its respective descriptive statistics are presented in Annex I.

3.4. Experimental setting and data collection

This study was reviewed and approved by the Animal Welfare Committee of the University of Veterinary Medicine Vienna, according to the Good Scientific Practice guidelines and Austrian legislation for research on animals (ETK-18/04/2015). Dog owners signed a consent form describing the purpose of the study and the intended procedures (template - Annex II).

All examinations and measurings were carried out at the University of Veterinary Medicine Vienna. Prior to motion analysis and UWT, all dogs were weighed on a mechanical scale, and withers height was measured, from the dorsal scapular rim to the ground. The temperature of the water of the aquatic treadmills was measured on 8 separate days using a bath thermometer, to check for water temperature consistency, throughout the days.

3.4.1. Gait analysis

Each dog was walked on the pressure plate until a valid number of trials was obtained. Afterwards, each dog was taken to the underwater treadmill for its respective therapy session, was dried with towels and then taken back to the motion analysis room. The transitions between measurements and underwater treadmill therapy were managed swiftly and did not exceed 10 minutes.

For the gait analysis, a Zebris FDM Type 2 pressure plate (Zebris Medical GmbH®, Allgäu, Germany) was set in a 7 m runway and covered with a 2 mm thick rubber mat to hide the measurement area from the dog’s sight and to avoid slipping. The pressure plate had a measurement area of 203.2 by 54.2 cm and comprised 15360 sensors with a sampling rate of 100 Hz. The gait analysis study was performed in a quiet room (Figure 13), with the owner and the research examiners. Prior to the measurements, each dog was allowed to walk

Figure 13 – Pressure plate setting in the motion analysis room. The measurement area is marked with white tape and covered under a rubber mat. In the corner, is the video camera used to film the trials.

freely in the room and over the pressure plate. After getting accustomed, the dogs were walked on a leash over the pressure platform by either their owners or by one of the research examiners, maintaining the same handler in the before and after measurements. Each dog walked over the runway at its own comfortable speed in a straight line several times, until a valid number of trials was obtained (n=5) (Strasser et al. 2014). Some dogs required motivating by placing one or two persons at the ends of the walkway, calling and praising them. A trial was deemed valid when the dog walked in a straight line with the head in a straightforward position (not looking at the handler), without apparent tension on the leash and without apparent change of velocity (Evans et al. 2005; Bockstahler et al. 2016) (Figure 14). Dogs were walked in both directions along the walkway, to reduce variance due to leash side (Keebaugh et al. 2015). Mean walking velocity ± SD in Group A was 0.96 ± 0.17 meter per second (m/s), ranging from 0.75 to 1.14 m/s; in Group B was 0.97 ± 0.17, with a range of 0.68-1.18 m/s. The difference in velocity between the before and after trials for each dog didn't exceed 0.15 m/s, thus complying with the ≤ 0.3 m/s limit suggested by Riggs et al. (1993), and Roush and Mclaughlin (1994).

All trials were filmed using a Panasonic NV-MX500 camera, and data were stored using WinFDM software (v1.2.2; Zebris Medical GmbH®).

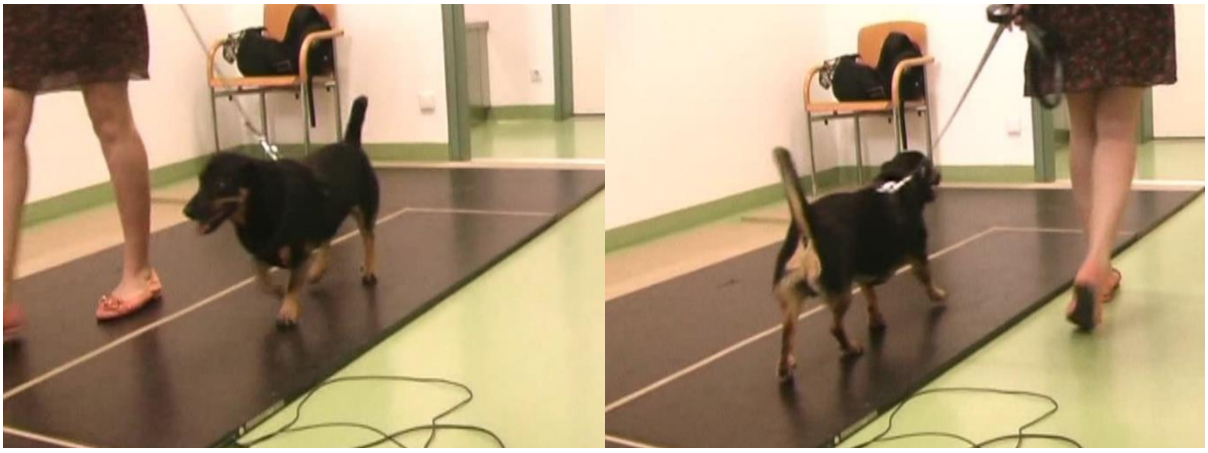


Figure 14 – Example of two valid trials from one of the participant dogs, showing the head in a straightforward position and reduced tension on the leash.

3.4.2. Underwater treadmill therapy

Two underwater treadmills were used in this study: a Keiper™ treadmill and a custom-built treadmill, purposely designed for the Vetmeduni Physical Therapy and Rehabilitation department. Further information on both underwater treadmills can be found on sub-chapter 1.6.6. Underwater treadmills used for the traineeship and study.

Mean water temperature ± SD was 25.63 ± 2.00 ºC, ranging from 23 to 29 ºC. All temperature measurements are presented in Annex III.

As shown in Table 4, all dogs had already performed underwater treadmill therapy at least twice before and therefore was no need for the previous acclimatisation to the exercise on the day of measurement. Mean elapsed time on the treadmill ± SD was 10.00 ± 7.16 minutes in Group A, and 12.40 ± 6.19 minutes in Group B. The treadmills were set to allow each dog to walk at a slow-paced comfortable speed. During the UWT session, the dogs were enticed with small treats and praised as an incentive.

Table 4 – Number of underwater treadmill therapy sessions performed by each dog, and their respective elapsed therapy time on the day of gait analysis. min – minutes.

Group A			Group B		
Dog	UWT no.	UWT time (min)	Dog	UWT no.	UWT time (min)
1	5	20	1	19	18
2	3	3	2	13	10
3	3	9	3	24	20
4	4	8	4	3	7
			5	3	7

4. DATA PROCESSING

4.1. Pressure plate data

Using WinFDM software (v1.2.2; Zebris Medical GmbH®), the ground contact area of each footfall was identified from the video recordings and manually matched with the corresponding limb to obtain the data of all four limbs. The categorised motion analysis data was processed using dedicated software (Pressure Analyzer 1.3.0.2; Michael Schwanda®).

For each limb, mean peak vertical force (PFz), vertical impulse (IFz), stance phase duration (SPD), pressure contact area (PCA) and step length were measured.

The used pressure plate software expressed the results for PFz in Newton unit (N), and for IFz in Newton per second (N/s). To enable the comparison of these parameters among dogs, they were normalised to the percentage of total force (%TF), using the equation:

$$XFz_{limb}\ (\%TF) = \frac{XFz_{limb}}{TF} \times 100$$

where XFz_{limb} is the PFz or IFz of a limb, and TF, or total force, is the sum of the PFz or IFz of all limbs. The normalised values were used for the following statistical analysis of PFz and IFz.

To investigate contralateral limb pair symmetry, an equation modified from Budsberg et al. (1993) (Bockstahler, Skalicky, et al. 2007) was used to calculate the symmetry index (SI) for the parameters PFz (SIPFz), IFz (SIIFz), SPD (SISPD), and PCA (SIPCA):

$$SIx\ (\%) = \left| \left(\frac{x_L - x_R}{x_L + x_R}\right) \times 100 \right|$$

where x is the evaluated parameter, x_L is the parameter value for the left limb (fore or hind) and x_R is for the right fore or hindlimb. The value of 0 indicates absolute symmetry for the measured variable, with variations expressed as a percentage of difference from 0. Based on a previous ground reaction forces study (Budsberg et al. 1993), a cut off value of 3% for the ground reaction force parameters (SIPFz and SIIFz) was used to categorise each dog as lame or non-lame. Therefore, dogs with SI greater than 3% were considered lame.

Mean gait velocity was measured from the left forelimb. Step length was measured as a mean of the minimum and maximum step length of all four limbs. These parameters were automatically processed by the pressure plate software.

The collected and normalised pressure plate data with their respective SI are available in Annex IV.

4.2. Statistical analysis

For both the fore and hindlimb groups, descriptive statistics (mean and standard deviation) were calculated for the morphometry, UWT and pressure plate measurements data. Using SPSS software (version 25.0), a Shapiro-Wilk test was used to check all the parameters for normal distribution. The differences between the before and after measurements for all parameters were normally distributed (Annex V). These differences were then evaluated using a paired student t-test, and a p-value equal or lesser than 0.05 was considered statistically significant. A Pearson correlation coefficient test was used to check for correlation between withers height and step length. Afterwards, several regression models were generated to assess which model presented the highest R^2 value.

5. RESULTS

The complete paired t-test results are shown in Annex VI.

5.1. Ground reaction forces

Considering the small sample number of dogs for each group, and how consequently one outlier value affected the mean group results and gave a high SD, both mean individual and collective values are presented (Table 5). Observing the baseline data from Group A, all dogs initially presented hindlimb lameness, according to the SIPFz parameter. Two dogs showed forelimb lameness in the SIPFz and SIIFz values. In Group B, all dogs also had hindlimb lameness (SIPFz), and two individuals presented forelimb lameness (SIPFz and SIIFz). After UWT, one participant was non-lame (dog number 4, from Group B).

Table 5 – Mean individual and group SIPFz and SIIFz for each contralateral limb pair, before and after UWT, with respective standard deviation. FL – forelimb pair; HL – hindlimb pair. *Lame limb pair (SI greater than 3%). [a] Significant correlation (p = 0.003); [b] Significant correlation (p = 0.01); [c] Significant correlation. (p = 0.026).

		SIPFz (%)				SIIFz (%)			
		Before		After		Before		After	
	Dog	FL	HL	FL	HL	FL	HL	FL	HL
Group A	1	1.10	5.15*	0.89	3.26*	0.85	0.03	0.63	3.59*
	2	21.61*	12.64*	24.80*	14.23*	27.75*	14.47*	31.12*	16.36*
	3	0.10	4.15*	1.33	3.67*	0.07	2.18	2.57	1.96
	4	7.95*	10.94*	8.14*	4.96*	16.59*	8.92*	15.54*	4.79*
	Mean	7.69*[a]	8.22*	8.79*[a]	6.53*	11.31*[b]	6.40*	12.46*[b]	6.67*
	SD	9.92	4.20	11.18	5.19	13.34	6.58	14.09	6.56
		Before		After		Before		After	
	Dog	FL	HL	FL	HL	FL	HL	FL	HL
Group B	1	3.61*	15.08*	1.30	12.00*	5.93*	20.90*	7.08*	15.30*
	2	0.60	8.91*	0.52	9.54*	1.97	15.95*	1.27	14.40*
	3	0.02	4.33*	1.14	3.53*	0.33	6.81*	0.06	7.41*
	4	0.50	1.44	2.41	0.58	0.11	5.06*	0.44	0.86
	5	0.40	8.17*	1.78	3.79*	6.20*	11.75*	0.33	2.21
	Mean	1.03	7.58*[c]	1.43	5.89*[c]	2.91	12.09*	1.83	8.04*
	SD	1.46	5.16	0.71	4.72	2.97	6.52	2.96	6.69

Using the paired samples t-test, no statistically significant differences were found in the SI of both parameters between the before and after measurements. In Group A, the SIPFz and SIIFz mean values in the forelimbs increased after UWT. There was a significant strong positive correlation between the before and after measurements in these limbs, which means that the effects of UWT in the SI were consistent between individuals. Regarding Group B, the SIPFz and SIIFz values in the hindlimbs were lower after UWT. There was a significant strong positive correlation between the before and after measurements of SIPFz in the hindlimbs, meaning the UWT effects in this group were consistent only for this parameter.

5.2. Stance phase duration

The mean values and respective standard deviations for stance phase duration symmetry index (SISPD) are described in Table 6. No significant differences were found between the before and after measurements, nor was any significant correlation observed. It was observed a decrease in the after-UWT SISPD mean values in all groups.

Table 6 – Mean values and respective standard deviation of SISPD before and after UWT.

		FL SISPD (%)		**HL SISPD (%)**	
		Mean	SD	Mean	SD
Group A	Before UWT	3.36	2.18	2.82	2.08
	After UWT	2.74	2.58	2.24	2.47
Group B	Before UWT	1.67	0.66	3.27	2.63
	After UWT	1.26	0.78	3.22	0.99

5.3. Pressure contact area

The mean values and respective standard deviations for pressure contact area symmetry index (SIPCA) are described in Table 7. There was a significant difference between the SIPCA before and after measurements in the forelimbs of Group B. No significant correlation was observed in the PCA measurements. In both groups, after UWT, occurred an increase in the mean SIPCA of the forelimbs, and a decrease in the hindlimbs.

Table 7 – Mean values and respective standard deviations of SIPCA before and after UWT. [a] Significantly different (p = 0.016).

		FL SIPCA (%)		**HL SIPCA (%)**	
		Mean	SD	Mean	SD
Group A	Before UWT	2.93	1.16	4.92	1.34
	After UWT	3.84	2.65	3.38	1.97
Group B	Before UWT	0.71^a	0.39	3.95	3.27
	After UWT	2.18^a	0.67	2.55	2.39

5.4. Step length

Since this study comprised dogs with considerable size variety, both mean individual and collective values and SD for step length are described in Table 8. No significant differences were found between the before and after measurements, however, there is a significant strong positive correlation between the before and after measurements of both Group A and Group B. Post-UWT mean group results revealed an increase in the step length of both groups.

Table 8 – Mean individual and group values and respective standard deviation of step length before and after UWT, in meter (m). [a] Significant correlation (p = 0.004); [b] Significant correlation.

Step length (m)

	Dog	Before	After
Group A	**1**	0.85	0.88
	2	0.57	0.61
	3	0.62	0.62
	4	0.45	0.48
	Mean	0.63^a	0.65^a
	SD	0.17	0.17

	Dog	Before	After
Group B	**1**	0.63	0.63
	2	0.73	0.81
	3	0.92	0.94
	4	0.48	0.45
	5	0.74	0.83
	Mean	0.70^b	0.73^b
	SD	0.16	0.19

5.5. Mean velocity

The mean values and SD for mean velocity are described in Table 9. No significant differences were found between the before and after measurements, however, there was a significant strong positive correlation between the before and after measurements of Group B. Mean velocity increased in both groups, after UWT.

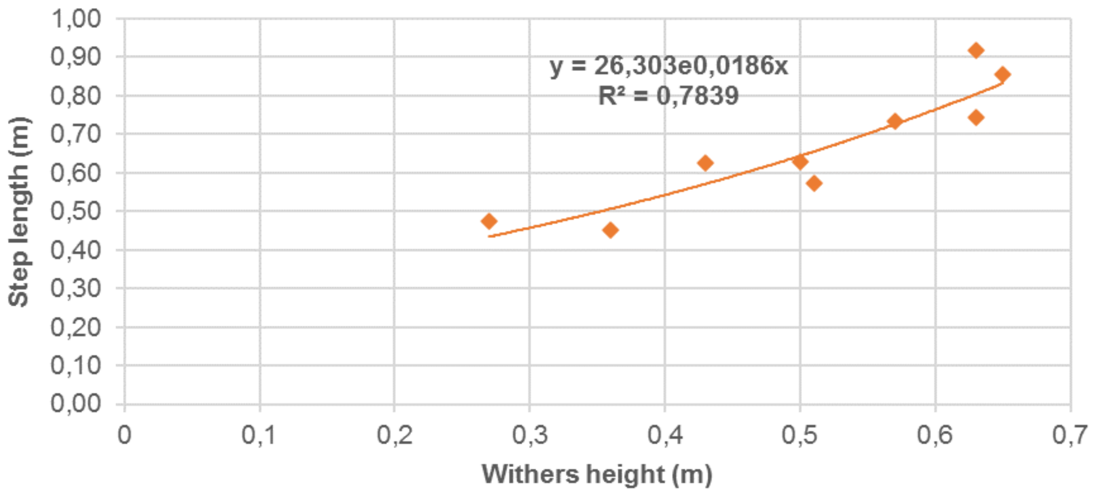
Table 9 – Mean values and respective standard deviations of mean velocity before and after UWT, in meter per second (m/s). [a] Significant correlation (p = 0.045).

		Mean velocity (m/s)	
		Mean	SD
Group A	Before UWT	0.95	0.18
	After UWT	0.98	0.16
Group B	Before UWT	0.95[a]	0.16
	After UWT	0.99[a]	0.18

5.6. Step length and withers height

Considering all 9 participants, mean withers height ± SD was 0.51 ± 0.13 m (range 0.27-0.65 m), and mean baseline step length was 0.67 ± 0.16 m (range 0.45-0.92 m). Pearson correlation between the variables height and step length found a very strong correlation coefficient ($r = 0.904$) that is statistically significant ($p < 0.005$), meaning that higher withers height proportionally corresponds to a longer step length. When exploring the regression models, exponential regression provided the highest R^2 value (0.850) with significant value ($p < 0.005$). The exponential regression graph and the respective formula are depicted in Graph 5. The complete data for the regression models can be found in Annex VII.

Graph 5 – Exponential regression for the variation of step length according to height.



6. DISCUSSION

6.1. Candidates

The number of candidates available for this clinical study limited the attainment of significant results. To achieve a compromise between candidate selection criteria and sample number, several causes of orthopaedic lameness were included. These conditions varied in location on the limb and whether it involved one or both limbs of the contralateral pair. The severity of the conditions varied as well. Ideally, these would have been divided accordingly into sub-groups. However, it was not executable for this research, as a small sample number greatly lowers the statistical power.

As the candidates were first selected by medical record investigation, the time between the diagnosis and data collection differed. This circumstance may have biased the results as, in the long term, limb ground reaction forces change over time due to the diagnosed condition progressing or resolving (Budsberg et al. 1993; Budsberg 2001).

The participant population of dogs comprised a heterogeneous sample of breeds, body size and BCS. As performed for this study, normalising the ground reaction force data to percent of total force is considered a valid method to compare results in a morphometrically heterogeneous sample (Bertram et al. 2000; McLaughlin 2001; Besancon et al. 2004; Kim et al. 2011; Krotscheck et al. 2014), and that it does not affect the SI (LeQuang, Maitre, Colin et al. 2010). Conversely, Mölsa et al. (2010) and Voss et al. (2011) reported that normalising does not reduce bias satisfactorily and should only be applied in groups with dogs of the same breed or of similar morphometry.

A high BCS may influence some ground reaction force parameters as well (Bockstahler et al. 2009; Brady et al. 2013). Excessive body weight exerts higher mechanical stress on the skeleton, which over time promotes joint degeneration and impairs locomotion (von Eisenhart et al. 1999; Mason et al. 2005). Besides, obesity can limit performance in UWT, due to associated low tolerance to exercise (Lindley and Watson 2010).

Regarding age, one of the participants from Group A was a 6-month-old Irish Terrier specimen. As mentioned by Lopez et al. (2006), the possibility of an immature skeletal system influencing measured GRFs should be taken into account. This study also comprised participants up to 11.5 years old, where there is a greater probability of undiagnosed degenerative joint disease (Anderson 2018), which can affect locomotion (Bockstahler et al. 2009; Lorke et al. 2017).

6.2. Ground reaction forces

In both groups, the results showed no statistically significant alterations in lameness immediately after UWT exercise. Nevertheless, gait alterations were observed, as 4 of the 5 individuals from Group B presented a decrease in hindlimb post-UWT SIPFz, with a strong positive correlation between the before and after measurements. No compensatory increase in forelimb ground reaction forces was observed. In a larger sample group, this parameter could potentially assess if UWT exercise reduces hindlimb weight-bearing asymmetry in dogs afflicted by orthopaedic conditions in the hindlimbs. Rumph et al. (1993) reported that in dogs with induced unilateral acute stifle synovitis, PFz increased in the sound contralateral limb, increasing hindlimb SIPFz. Amimoto et al. (2019) described that unilateral rupture of the cranial cruciate ligament in dogs resulted in a decrease in PFz and IFz in the affected limb. In accordance with the obtained results, Rumph et al. (1995) and Jevens et al. (1996) reported that both unilateral and bilateral hindlimb lameness tend to affect solely the ground reaction forces of the hindlimbs and that forces shift between both hindlimbs. However, in these two former studies, single force plates were used, and non-consecutive footfalls were measured, which are a described source of bias (Budsberg et al. 1993). More recent studies described that compensatory adaptation to unilateral hindlimb lameness also involved the ipsilateral forelimb (Souza et al. 2014; Manera et al. 2017).

The short-term effects of exercise on the ground reaction forces of orthopaedic patients were also researched by Beraud et al. (2010) and revealed a different outcome. This article compared baseline and post-exercise force plate data of a trotting exercise session (1.2 km) in 10 osteoarthritic lame dogs. The results suggested that in the short-term, moderate exercise deteriorated limb function and intensified hindlimb lameness in individuals impaired by osteoarthritis. In this case, the exercise was performed in land.

In the Group A forelimb pair, the collective mean SI values were indicative of lameness. Yet, only half of the participants were initially lame in the forelimbs. This occurred since one of the lame dogs consistently presented a fairly high SI both for PFz and IFz. A study by Braun et al. (2019) comparing sound dogs to individuals with elbow osteoarthritis observed a decrease in the PFz and IFz of the afflicted limb, in relation to the other limbs, in the osteoarthritic group. In this case, a general increase in forelimb SIPFz and SIIFz was observed.

All the participants in the study presented baseline hindlimb lameness, regardless of being diagnosed for the fore or hindlimbs. In research by Bockstahler et al. (2009), dogs with temporarily induced unilateral forelimb lameness presented a significant increase in the hindlimbs SIPFz. It occurred through a load shift between the lame limb and the respective diagonal limb. This study suggested that forelimb lameness leads to an overload of non-affected limbs and the vertebral spine.

After UWT, one dog was no longer considered lame. This participant was a two-year-old male of King Charles Spaniel breed and was diagnosed with non-graded bilateral mild hip dysplasia, bilateral severe coxarthrosis and bilateral patellar luxation. He performed 7 minutes of UWT, had not undergone surgery, and was not receiving medication. This result, however, does not necessarily express long-term improvement, as most immediate post-workout adaptive changes are transitory, and do not reflect a new baseline status (Millis 2004; Beraud et al. 2010; Preston and Wills 2018).

Regardless of dividing the participants in Group A and Group B, it is not possible to exclude the presence of subclinical pathologic changes that affect more than a single limb pair (Katic et al. 2009). Canine lameness due to soft tissue injuries are often underdiagnosed (Fitch et al. 1997; Steiss 2002), and in addition, several participants were diagnosed with degenerative joint diseases, which can also offset subtle alterations (Anderson 2018), as previously mentioned.

6.3. Stance phase duration

The measured absolute values of SPD varied according to each dog’s body size. Compared to small dogs, large dogs presented a longer SPD. These results agree with studies by Kim et al. (2011) and Fahie et al. (2018), which report that a difference in SPD alters the ratio of stance-swing times.

6.4. Pressure contact area

A significant difference in the before-after measurements was verified in Group B forelimbs. All the dogs in this group presented an increase in SIPCA. Similar results were described by Manera et al. (2017) and López et al. (2019), who observed an increase in PCA in the affected limb of dogs with unilateral forelimb lameness. However, in this case it occurred in the hindlimb lameness group. A greater area of ground contact is associated with adaptations to preserve body balance (Manera et al. 2017).

6.5. Step length and withers height-step length ratio

A strong positive correlation in the before-after measurements was verified in Group B for the step length. In this group, mean step length increased in 3 dogs, remained equal in 1 dog, and decreased in another dog. Preston and Wils (2018) described that a single aquatic therapy session enhanced the range of motion and step length in a group of healthy labradors and a group of labradors diagnosed with bilateral elbow dysplasia.

Both linear and exponential regressions of pre-UWT step length-withers height of all participants presented a high R value. Such a result suggests that in this population, as withers height increased, step length increased accordingly. Small dogs possess shorter limbs and present shorter step length when compared to large dogs (Budsberg et al. 1987; Kim et al. 2011). Therefore, if they do not alter step length, they require a higher step frequency to walk at the same velocity as large dogs. This occurrence is corroborated by studies performed by Mölsa et al. (2010) and Kim et al. (2011).

6.6. Gait type and number of trials

The chosen gait for this study was the walk. Voss et al. (2007) and Beraud et al. (2010) described that trotting presented better sensitivity and accuracy when detecting low-grade hindlimb lameness when compared to walking. However, exacerbating lameness throughout the repetition of trials enhances variance within trials, which is not desirable (Volstad et al 2016; Piazza et al 2017).

In order to obtain five valid trials on the pressure plate, some dogs needed more passages than others, and therefore inevitably received more exercise, which also affected gait (Nordquist et al. 2011; Mickelson et al. 2017).

6.7. UWT session

In the UWT session, exercise represented again a factor of variation in measurements, as the dogs walked on the aquatic treadmill different extents of time and distance. Speed also varied. Beraud et al. (2010) proposed that an exercise-based protocol could be used to enhance the sensitivity in the detection of lameness.

Immersion depth on UWT varied for each dog according to the orthopaedic condition(s). As mentioned in the literature review of this dissertation, weight-bearing varies according to the immersion depth (Levine et al. 2002). In this case, immersion depth was consistently above the stifle and around the hip level, which translates in a percentage of weight-bearing approximately ranging from 85% to 38% (Levine et al. 2002). Bertocci et al. (2018) reported that the immersion depth of UWT influenced the recovery outcome of dogs who had received surgical stabilisation for cranial cruciate ligament rupture.

6.8. Concurrent NSAID medication

Both participating groups had one element receiving an NSAID (cimicoxib and carprofen). The effects of carprofen on ground reaction forces have been described by Horstman et al. (2004), comprising 20 dogs with naturally occurring unilateral cranial cruciate disease. These authors reported no statistically significant differences between the medicated and the control groups. Nevertheless, the PFz and IFz values were substantially greater in dogs receiving carprofen.

7. CONCLUSIONS AND FUTURE DIRECTIONS

This dissertation aimed to discuss and investigate the short-term effects of underwater treadmill therapy on pressure plate data, using a population of lame dogs with appendicular orthopaedic conditions. The findings of this clinical study suggest that underwater treadmill therapy is likely to influence the dog's gait in a consistent manner. However, no statistically significant alterations were noted other than an increase in the SIPCA of the forelimbs of dogs diagnosed with an orthopaedic condition in the hindlimbs.

The obtained results were disadvantaged by small sample size and the diversity of orthopaedic conditions included, which happened due to the short duration of the traineeship period, and consequently a limited time span to collect data dedicated to a single joint or cause of lameness. Future investigation on this topic should comprise a larger sample group for increased statistical power, a control group for comparison, and ideally focus on a single cause of lameness, or on a single joint. A Fourier analysis of the ground reaction forces could also be applied in a larger sample, as it has proven its potential in detecting subtle gait alterations that traditional statistical processing does not do (Katic et al. 2009). Parameters such as the time to reach PFz (Schnabl-Feichter et al. 2018) and the distribution of pressure in the paw (Schwarz et al. 2017; López 2019) are becoming increasingly utilized in recent publications using pressure plates and should also be considered.

With the growing interest on feline gait analysis (Lascelles et al. 2007; Guillot et al. 2013; Stadig et al. 2016; Schnabl-Feichter et al. 2018), performing a similar study in cats should be considered, as surprisingly many of them tend to accept well UWT (Millis et al. 2004). Comparing the efficacy of exercising on a land treadmill vs. an aquatic treadmill in the treatment for a specific condition, as already performed in humans (Lee et al. 2015) and horses (Greco-Otto et al. 2017) would also be pertinent.

Observational gait analysis using lameness scores is still the most common practice in a clinical setting (Millis et al. 2004), but pose significant limitations due to its subjectivism (Quinn et al. 2007; Waxman et al. 2008; Conzemius and Evans 2012). Therefore, gait analysis investigation has relied on computerised systems to objectively study even subtle variations normal and abnormal gait, and appraise the effectiveness of treatments (Fanchon and Grandjean 2007). These systems allow for greater accuracy, yet they are not broadly available nor economically feasible for most practices (Griffon 2008). In the absence of a computerised system, bathroom scales have been proven as a less exact but pertinent and accessible alternative to investigate weight-bearing abnormalities at a stance, as animals commonly bear less weight on a lame limb (Millis et al. 2004; Hyytiäinen et al 2013). Another alternative is portable pressure-measuring equipment, which is a quick, objective and easy to set up a tool for evaluating gait in routine clinical practice. It allows for long term lameness follow-up and is also more cost-friendly than a traditional force plate (LeQuang, Maitre, Roger et al. 2010; Oosterlinck et al. 2011).

The results here reported are of scientific interest as a starting point to further investigate short-term effects of therapy and exercise in an aquatic treadmill, by contributing with temporospatial gait data. Much of the current information on veterinary aquatic therapy originated from already existing guidelines for human aquatic therapy. Due to this extrapolation, there is still mensurable variability in veterinary aquatic therapy protocols, and subjective prescriptions, which lack controlled studies to corroborate (Edge-Hughes 2007). As an emerging field in veterinary medicine, gait analysis is gradually building up additional baseline data. Numbers on specific populations (breeds, orthopaedic and neurological conditions) are yet missing to enhance the applicability of gait analysis in clinical practice. It is a tool still mostly used in an academic setting. However, with canine sports, working dogs and outdoor activities with pets becoming more popular, both owners and veterinarians would benefit from better understanding canine locomotion (Carr and Dycus 2016).

In human orthopaedics, gait analysis promoted significant changes in the standard of care, namely in post-operative recovery, preventive practices, sports medicine and neuromuscular rehabilitation (Griffon 2008). As processing temporospatial and pressure gait parameters involve large amounts of information, “big data” is becoming more popular as a resource to explore meaningful patterns (Phinyomark et al. 2017). In the veterinary field, future perspectives involve a need for proper teaching and training professionals in this discipline and the development of a database solid enough to be used routinely in clinical practice.

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9. ANNEXES

Annex I - General clinical and morphometric data of the candidates and its respective descriptive statistics

Group A

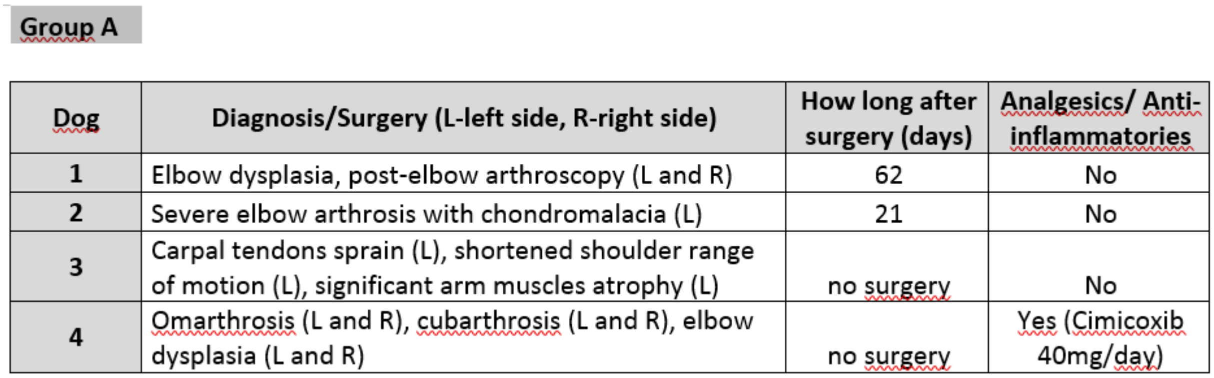
Dog	Breed	Gender	Neutered/Spayed	Age
1	Mixed breed	F	yes	5,25
2	Mixed breed	F	yes	8,08
3	Irish Terrier	F	no	0,50
4	Mixed breed	M	no	6,67

Mean	5,13
SD	3,29

Group B

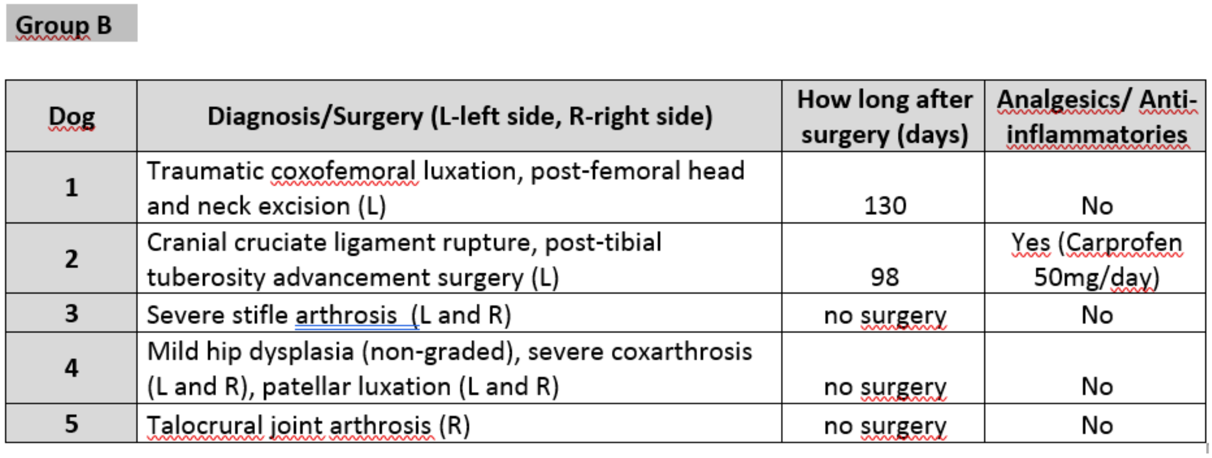
Dog	Breed	Gender	Neutered/Spayed	Age
1	Icelandic Sheepdog	M	yes	3,42
2	Mixed breed	F	yes	11,50
3	Dogo Argentino X Labrador	F	yes	4,58
4	King Charles Spaniel	M	no	2,33
5	Large Münsterländer	F	no	10,25

Mean	6,42
SD	4,17



Group A

Dog	Diagnosis/Surgery (L-left side, R-right side)	How long after surgery (days)	Analgesics/ Anti-inflammatories
1	Elbow dysplasia, post-elbow arthroscopy (L and R)	62	No
2	Severe elbow arthrosis with chondromalacia (L)	21	No
3	Carpal tendons sprain (L), shortened shoulder range of motion (L), significant arm muscles atrophy (L)	no surgery	No
4	Omarthrosis (L and R), cubarthrosis (L and R), elbow dysplasia (L and R)	no surgery	Yes (Cimicoxib 40mg/day)



Group B

Dog	Diagnosis/Surgery (L-left side, R-right side)	How long after surgery (days)	Analgesics/ Anti-inflammatories
1	Traumatic coxofemoral luxation, post-femoral head and neck excision (L)	130	No
2	Cranial cruciate ligament rupture, post-tibial tuberosity advancement surgery (L)	98	Yes (Carprofen 50mg/day)
3	Severe stifle arthrosis (L and R)	no surgery	No
4	Mild hip dysplasia (non-graded), severe coxarthrosis (L and R), patellar luxation (L and R)	no surgery	No
5	Talocrural joint arthrosis (R)	no surgery	No

Group A

Dog	Body mass (kg)	BCS (x/9)	Withers height (m)	Step length before exercise (m)
1	42,0	8	0,65	0,85
2	26,3	7	0,51	0,57
3	10,0	4	0,43	0,62
4	15,9	6	0,36	0,45

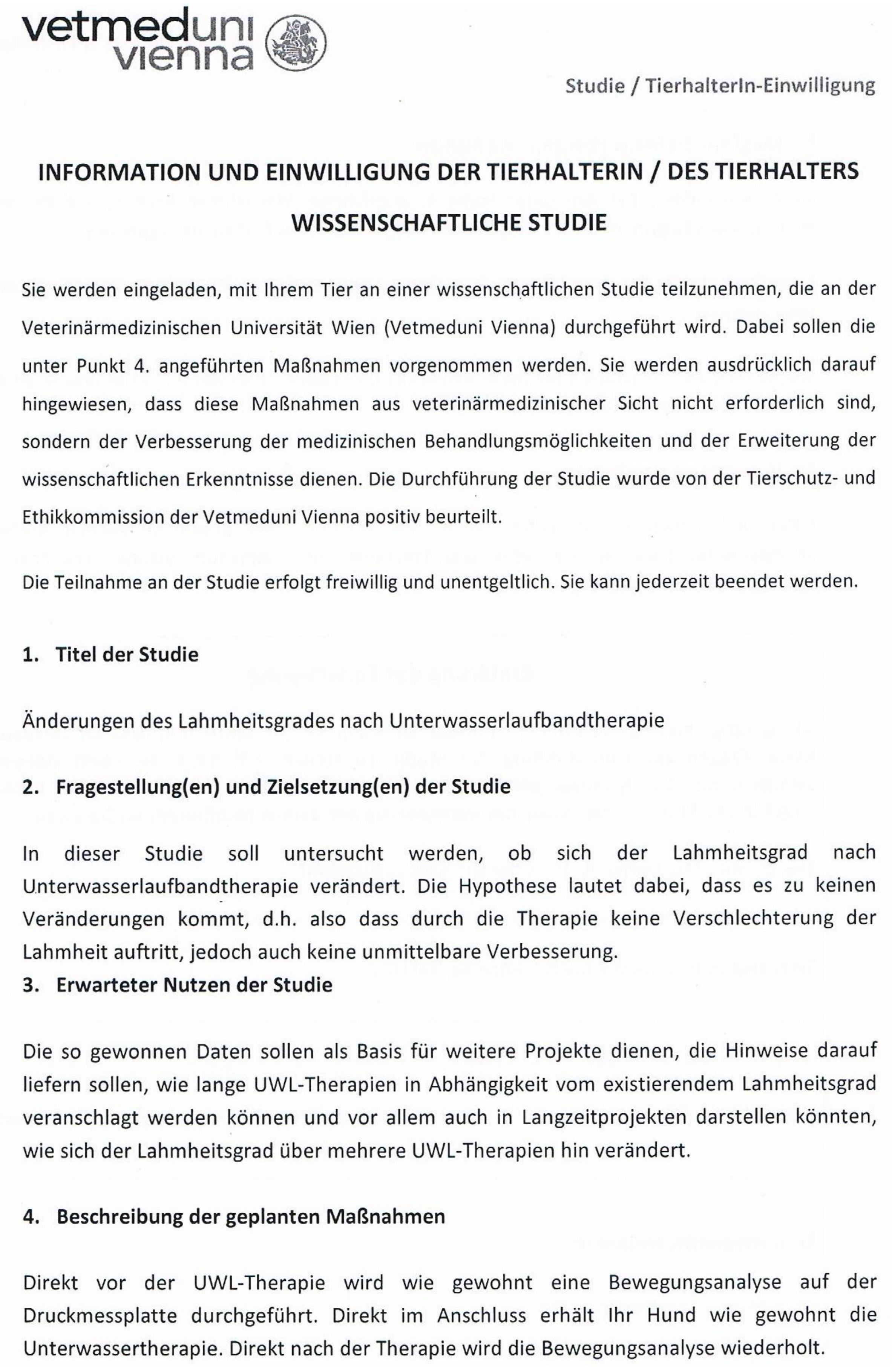
Mean	23,55	6,25	0,49	0,63
SD	14,02	1,71	0,12	0,17

Group B

Dog	Body mass (kg)	BCS (x/9)	Withers height (m)	Step length before exercise (m)
1	18,8	5	0,50	0,63
2	32,0	7	0,57	0,73
3	40,0	5	0,63	0,92
4	10,0	6	0,27	0,48
5	36,0	5	0,63	0,74

Mean	27,36	5,60	0,52	0,70
SD	12,56	0,89	0,15	0,16

Annex II – Template of Information and consent for pet owners



vetmeduni vienna

Studie / TierhalterIn-Einwilligung

INFORMATION UND EINWILLIGUNG DER TIERHALTERIN / DES TIERHALTERS

WISSENSCHAFTLICHE STUDIE

Sie werden eingeladen, mit Ihrem Tier an einer wissenschaftlichen Studie teilzunehmen, die an der Veterinärmedizinischen Universität Wien (Vetmeduni Vienna) durchgeführt wird. Dabei sollen die unter Punkt 4. angeführten Maßnahmen vorgenommen werden. Sie werden ausdrücklich darauf hingewiesen, dass diese Maßnahmen aus veterinärmedizinischer Sicht nicht erforderlich sind, sondern der Verbesserung der medizinischen Behandlungsmöglichkeiten und der Erweiterung der wissenschaftlichen Erkenntnisse dienen. Die Durchführung der Studie wurde von der Tierschutz- und Ethikkommission der Vetmeduni Vienna positiv beurteilt.

Die Teilnahme an der Studie erfolgt freiwillig und unentgeltlich. Sie kann jederzeit beendet werden.

1. Titel der Studie

Änderungen des Lahmheitsgrades nach Unterwasserlaufbandtherapie

2. Fragestellung(en) und Zielsetzung(en) der Studie

In dieser Studie soll untersucht werden, ob sich der Lahmheitsgrad nach Unterwasserlaufbandtherapie verändert. Die Hypothese lautet dabei, dass es zu keinen Veränderungen kommt, d.h. also dass durch die Therapie keine Verschlechterung der Lahmheit auftritt, jedoch auch keine unmittelbare Verbesserung.

3. Erwarteter Nutzen der Studie

Die so gewonnen Daten sollen als Basis für weitere Projekte dienen, die Hinweise darauf liefern sollen, wie lange UWL-Therapien in Abhängigkeit vom existierendem Lahmheitsgrad veranschlagt werden können und vor allem auch in Langzeitprojekten darstellen könnten, wie sich der Lahmheitsgrad über mehrere UWL-Therapien hin verändert.

4. Beschreibung der geplanten Maßnahmen

Direkt vor der UWL-Therapie wird wie gewohnt eine Bewegungsanalyse auf der Druckmessplatte durchgeführt. Direkt im Anschluss erhält Ihr Hund wie gewohnt die Unterwassertherapie. Direkt nach der Therapie wird die Bewegungsanalyse wiederholt.

5. Mögliche Nebenwirkungen und Risiken

Im Zusammenhang mit den unter Punkt 4. angeführten Maßnahmen können, wie bei jedem medizinischen Eingriff, Nebenwirkungen oder Komplikationen auftreten; dazu gehören

Ermüdung durch das Training auf dem Unterwasserlaufband, kurzzeitige Verschlechterung der Lahmheit

Sollten nach der Entlassung Ihres Tieres Nebenwirkungen beobachtet werden, so ist unverzüglich die behandelnde Klinik zu kontaktieren.

6. Verwertung von Daten

Daten und Proben, des Patienten, die im Rahmen der Studie gewonnen werden, dürfen in anonymisierter Form in der Lehre und Forschung der Vetmeduni Vienna verwendet und insbesondere auch publiziert werden.

Erklärung der Einwilligung

Ich bestätige hiermit, dass mir der Aufbau der Studie erklärt wurde und dass ich Gelegenheit hatte, Fragen zur Durchführung der Studie zu stellen. Ich habe die oben stehenden Informationen zur Kenntnis genommen und stimme der Vornahme der unter Punkt 4. angeführten Maßnahmen sowie der Verwendung der daraus resultierenden Daten zu:

Tier (Name, Art, TierNr. lt. TIS, Chip-Nr., falls vorhanden):

....

TierhalterIn (Vor- und Zuname, Adresse, Tel.Nr.):

....

Ort und Datum: **Unterschrift der Tierhalterin / des Tierhalters:**

....

Studienverantwortliche/r:

....

Fragen / Kontakt: .... @vetmeduni.ac.at

(Free translation)

Information and consent of pet owners - scientific study

You are invited to participate with your pet in a scientific study conducted at the University of Veterinary Medicine, Vienna. The procedures listed under point 4 will be carried out. We expressly point out that these procedures are not required from a veterinary point of view, but that they serve to improve medical treatment options and broaden scientific knowledge. The study was positively assessed by the Animal Welfare Commission and the Ethics Committee of the Vetmeduni Vienna.

Participation in the study is voluntary and free of charge. The study can be stopped at any time.

1. Title of the study
Changes in the degree of lameness after underwater treadmill therapy

2. Questions and objectives of the study
In this study, it will be investigated whether the degree of lameness changes after underwater treadmill therapy. The hypothesis is that there are no changes, which means that the therapy does not cause any worsening of lameness, but also no immediate improvement.

3. Expected benefits of the study
The obtained data will serve as the basis for further projects, providing information on how long underwater treadmill therapy therapies can be applied at different degree of lameness and, above all, how the degree of lameness over several underwater treadmill therapies changes.

4. Description of the planned procedures
Immediately before the underwater treadmill therapy, a motion analysis is carried out on the pressure measuring plate as usual. After that your dog will receive the underwater therapy as usual. Immediately after the therapy, the motion analysis is repeated.

5. Possible side effects and risks
As with any medical intervention, side effects or complications may occur in the context of the measures listed under point 4. These include

fatigue from training on the underwater treadmill, short-term worsening of lameness.

If side effects are observed after the discharge of your animal, the treating clinic should be contacted immediately.

6. Use of data
Data and samples of the patient obtained during the study may be used anonymously in the teaching and research of the VetmedUni Vienna and, in particular, may also be published.

Statement of consent

I hereby confirm that I have been informed of the structure of the study and that I have had the opportunity to ask questions about the conduct of the study. I have taken note of the information above and I consent to the actions listed under point 4 and the use of the resulting data.

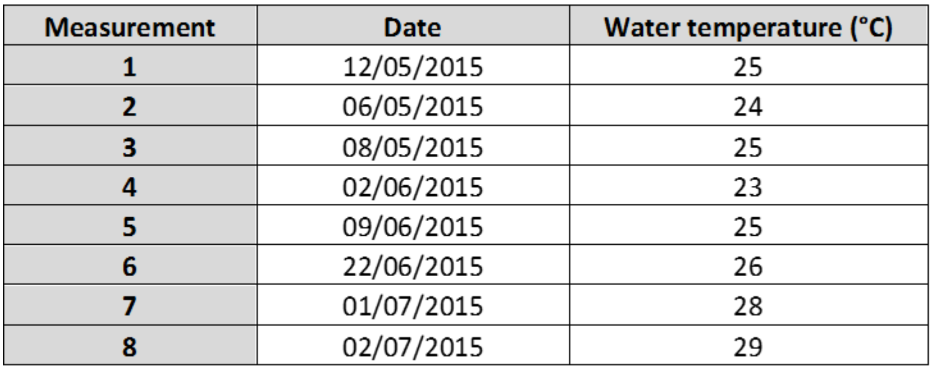
Pet (Name, Type, Pet No. according to TIS, Chip-No., if available):

Pet owner (First name and surname, Address, phone number):

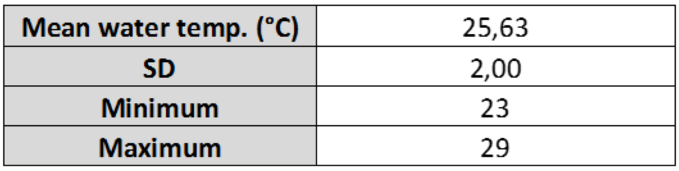
Place and date: Signature of the pet owner:
Study responsible person:

Questions/contact:

Annex III – Water temperature measurements



Measurement	Date	Water temperature (°C)
1	12/05/2015	25
2	06/05/2015	24
3	08/05/2015	25
4	02/06/2015	23
5	09/06/2015	25
6	22/06/2015	26
7	01/07/2015	28
8	02/07/2015	29



Mean water temp. (°C)	25,63
SD	2,00
Minimum	23
Maximum	29

Annex IV – Collected kinetic data normalized to percentage of total force (%TF). Values with a SI≥ 3% are highlighted in yellow. LF – left forelimb; RF – right forelimb; LH – left hindlimb; RH – right hindlimb

Group A

	PFz before UWT					
Dog	**LF (%TF)**	**RF (%TF)**	**SI_FL (%)**	**LH (%TF)**	**RH (%TF)**	**SI_HL (%)**
1	28,26	27,65	1,10	23,18	20,91	5,15
2	18,99	29,47	21,61	22,51	29,03	12,64
3	32,79	32,73	0,10	16,52	17,95	4,15
4	33,80	28,83	7,95	20,73	16,64	10,94

Group B

	PFz before UWT					
Dog	**LF (%TF)**	**RF (%TF)**	**SI_FL (%)**	**LH (%TF)**	**RH (%TF)**	**SI_HL (%)**
1	27,39	29,44	3,61	18,33	24,84	15,08
2	31,36	30,99	0,60	17,15	20,50	8,91
3	30,81	30,83	0,02	20,01	18,35	4,33
4	32,59	32,26	0,50	17,32	17,83	1,44
5	32,83	32,56	0,40	18,72	15,89	8,17

Group A

	PFz after UWT					
Dog	**LF (%TF)**	**RF (%TF)**	**SI_FL (%)**	**LH (%TF)**	**RH (%TF)**	**SI_HL (%)**
1	28,90	28,39	0,89	22,05	20,65	3,26
2	17,96	29,81	24,80	22,40	29,83	14,23
3	34,31	33,41	1,33	15,54	16,73	3,67
4	33,92	28,81	8,14	19,56	17,71	4,96

Group B

	PFz after UWT					
Dog	**LF (%TF)**	**RF (%TF)**	**SI_FL (%)**	**LH (%TF)**	**RH (%TF)**	**SI_HL (%)**
1	28,42	29,17	1,30	18,66	23,75	12,00
2	31,52	31,19	0,52	16,86	20,42	9,54
3	30,73	31,44	1,14	19,58	18,24	3,53
4	32,72	31,18	2,41	18,16	17,95	0,58
5	32,50	33,68	1,78	17,55	16,27	3,79

Group A

	IFz before UWT					
Dog	**LF (%TF)**	**RF (%TF)**	**SI_FL (%)**	**LH (%TF)**	**RH (%TF)**	**SI_HL (%)**
1	29,48	29,99	0,85	20,26	20,27	0,03
2	18,54	32,78	27,75	20,82	27,87	14,47
3	33,43	33,48	0,07	16,19	16,91	2,18
4	36,94	26,43	16,59	19,95	16,68	8,92

Group B

	IFz before UWT					
Dog	**LF (%TF)**	**RF (%TF)**	**SI_FL (%)**	**LH (%TF)**	**RH (%TF)**	**SI_HL (%)**
1	26,52	29,87	5,93	17,25	26,36	20,90
2	30,88	32,13	1,97	15,54	21,44	15,95
3	32,64	32,42	0,33	18,66	16,28	6,81
4	33,15	33,22	0,11	15,96	17,66	5,06
5	34,65	30,61	6,20	19,41	15,33	11,75

Group A

	IFz after UWT					
Dog	**LF (%TF)**	**RF (%TF)**	**SI_FL (%)**	**LH (%TF)**	**RH (%TF)**	**SI_HL (%)**
1	30,37	29,99	0,63	20,53	19,11	3,59
2	17,71	33,72	31,12	20,31	28,26	16,36
3	33,07	34,81	2,57	15,75	16,38	1,96
4	36,87	26,95	15,54	18,96	17,23	4,79

Group B

	IFz after UWT					
Dog	**LF (%TF)**	**RF (%TF)**	**SI_FL (%)**	**LH (%TF)**	**RH (%TF)**	**SI_HL (%)**
1	27,62	31,82	7,08	17,18	23,38	15,30
2	31,80	32,62	1,27	15,22	20,35	14,40
3	33,06	33,02	0,06	18,22	15,71	7,41
4	32,36	32,08	0,44	17,93	17,63	0,86
5	33,23	33,45	0,33	17,03	16,29	2,21

Group A

	PCA before UWT					
Dog	**LF (cm^2)**	**RF (cm^2)**	**SI_FL (%)**	**LH (cm^2)**	**RH (cm^2)**	**SI_HL (%)**
1	63,22	61,04	1,75	52,59	47,98	4,58
2	35,70	38,91	4,30	35,91	39,22	4,40
3	24,21	22,60	3,45	22,24	24,01	3,83
4	32,44	31,03	2,23	25,66	22,37	6,87

Group B

	PCA before UWT					
Dog	**LF (cm^2)**	**RF (cm^2)**	**SI_FL (%)**	**LH (cm^2)**	**RH (cm^2)**	**SI_HL (%)**
1	37,27	36,99	0,38	31,47	35,67	6,25
2	44,73	45,46	0,81	38,05	39,81	2,27
3	53,94	55,36	1,30	47,17	45,55	1,74
4	25,18	25,02	0,32	18,05	18,40	0,97
5	52,57	53,36	0,75	44,55	37,55	8,52

Group A

	PCA after UWT					
Dog	**LF (cm^2)**	**RF (cm^2)**	**SI_FL (%)**	**LH (cm^2)**	**RH (cm^2)**	**SI_HL (%)**
1	60,87	61,74	0,71	51,65	48,83	2,81
2	35,11	39,45	5,83	37,39	41,64	5,38
3	29,05	25,65	6,23	23,92	24,35	0,89
4	32,60	30,96	2,59	25,82	23,62	4,45

Group B

	PCA after UWT					
Dog	**LF (cm^2)**	**RF (cm^2)**	**SI_FL (%)**	**LH (cm^2)**	**RH (cm^2)**	**SI_HL (%)**
1	40,24	41,23	1,22	35,22	36,13	1,28
2	45,03	47,10	2,25	37,45	40,94	4,46
3	54,38	56,65	2,05	47,01	46,32	0,73
4	26,79	25,18	3,11	19,73	19,52	0,54
5	51,90	54,29	2,25	42,40	37,80	5,74

Group A

	SPD before UWT					
Dog	**LF (s)**	**RF (s)**	**SI_FL (%)**	**LH (s)**	**RH (s)**	**SI_HL (%)**
1	0,53	0,55	2,02	0,49	0,52	3,66
2	0,44	0,49	5,47	0,41	0,45	5,11
3	0,32	0,32	1,01	0,29	0,29	0,22
4	0,40	0,36	4,93	0,37	0,35	2,30

Group B

	SPD before UWT					
Dog	**LF (s)**	**RF (s)**	**SI_FL (%)**	**LH (s)**	**RH (s)**	**SI_HL (%)**
1	0,41	0,43	2,42	0,38	0,44	7,28
2	0,48	0,49	1,35	0,44	0,48	4,35
3	0,53	0,52	1,63	0,49	0,47	1,96
4	0,39	0,40	0,76	0,35	0,37	2,27
5	0,59	0,57	2,17	0,55	0,55	0,49

Group A

	SPD after UWT					
Dog	**LF (s)**	**RF (s)**	**SI_FL (%)**	**LH (s)**	**RH (s)**	**SI_HL (%)**
1	0,54	0,54	0,03	0,51	0,50	0,57
2	0,39	0,44	6,16	0,36	0,40	5,53
3	0,32	0,33	1,78	0,31	0,31	0,12
4	0,41	0,39	2,98	0,39	0,37	2,75

Group B

	SPD after UWT					
Dog	**LF (s)**	**RF (s)**	**SI_FL (%)**	**LH (s)**	**RH (s)**	**SI_HL (%)**
1	0,35	0,37	2,53	0,33	0,36	4,50
2	0,48	0,49	1,24	0,44	0,47	3,27
3	0,55	0,54	1,06	0,51	0,48	3,22
4	0,41	0,41	1,10	0,39	0,38	1,70
5	0,57	0,57	0,39	0,51	0,54	3,43

Group A

Dog	Step length (m)	
	Before UWT	**After UWT**
1	0,85	0,88
2	0,57	0,61
3	0,62	0,62
4	0,45	0,48

Group B

Dog	Step length (m)	
	Before UWT	**After UWT**
1	0,63	0,63
2	0,73	0,81
3	0,92	0,94
4	0,48	0,45
5	0,74	0,83

Group A

	Mean velocity (m/s)			
Dog	**Before UWT**	**After UWT**	**Mean**	**Difference between measurements**
1	1,08	1,05	1,07	0,03
2	0,83	0,98	0,91	0,15
3	1,12	1,14	1,13	0,02
4	0,75	0,76	0,76	0,01

Mean	0,95	0,98	0,96
SD	0,18	0,16	0,17
Minimum	0,75		
Maximum	1,14		

Group B

	Mean velocity (m/s)			
Dog	**Before UWT**	**After UWT**	**Mean**	**Difference between measurements**
1	0,95	1,07	1,01	0,12
2	1,00	1,09	1,05	0,09
3	1,18	1,14	1,16	0,04
4	0,74	0,68	0,71	0,05
5	0,88	0,98	0,93	0,10

Mean	0,95	0,99	0,97
SD	0,16	0,18	0,17
Minimum	0,68		
Maximum	1,18		

Overall

Mean	0,97
SD	0,16
Minimum	0,68
Maximum	1,18

Annex V – Normality tests

Group A

Lameness	Shapiro-Wilk		
	Statistic	df	Sig.
SI PFz FL	0.909	4	0.477
SI PFz HL	0.964	4	0.804
SI IFz FL	0.905	4	0.457
SI IFz HL	0.961	4	0.786
Step Length	0.841	4	0.198
SPD FL	0.748	4	0.057
SPD HL	0.739	4	0.060
PCA FL	0.996	4	0.985
PCA HL	0.859	4	0.258
Mean Velocity	0.860	4	0.261

Group B

Lameness	Shapiro-Wilk		
	Statistic	df	Sig.
SI PFz FL	0.880	5	0.309
SI PFz HL	0.940	5	0.665
SI IFz FL	0.786	5	0.063
SI IFz HL	0.985	5	0.960
Step Length	0.931	5	0.602
SPD FL	0.876	5	0.292
SPD HL	0.981	5	0.939
PCA FL	0.863	5	0.240
PCA HL	0.991	5	0.982
Mean Velocity	0.813	5	0.103

Annex VI – Paired t-test results. * - statistically significant value

Group A

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SI PFz FL Before	7,690	4	9,915	4,958
	SI PFz FL After	8,789	4	11,180	5,590
Pair 2	SI PFz HL Before	8,219	4	4,201	2,100
	SI PFz HL After	6,533	4	5,185	2,593
Pair 3	SI IFz FL Before	11,315	4	13,342	6,671
	SI IFz FL After	12,465	4	14,090	7,045
Pair 4	SI IFz HL Before	6,400	4	6,577	3,289
	SI IFz HL After	6,672	4	6,560	3,280
Pair 5	SPD FL Before	3,358	4	2,178	1,089
	SPD FL After	2,738	4	2,583	1,292
Pair 6	SPD HL Before	2,823	4	2,080	1,040
	SPD HL After	2,243	4	2,474	1,237
Pair 7	PCA FL Before	2,933	4	1,159	0,579
	PCA FL After	3,840	4	2,648	1,324
Pair 8	PCA HL Before	4,920	4	1,339	0,669
	PCA HL After	3,383	4	1,972	0,986
Pair 9	Step Length Before	0,626	4	0,169	0,085
	Step Length After	0,647	4	0,170	0,085
Pair 10	Mean Velocity Before	0,948	4	0,183	0,091
	Mean Velocity After	0,981	4	0,163	0,081

Paired Samples Correlations

	N	Correlation	Sig.
SI PFz FL Before & SI PFz FL After	4	,997	,003*
SI PFz HL Before & SI PFz HL After	4	,787	,213
SI IFz FL Before & SI IFz FL After	4	,990	,010*
SI IFz HL Before & SI IFz HL After	4	,872	,128
SPD FL Before & SPD FL After	4	,799	,201
SPD HL Before & SPD HL After	4	,737	,263
PCA FL Before & PCA FL After	4	,927	,073
PCA HL Before & PCA HL After	4	,499	,501
Step Length Before & Step Length After	4	,996	,004*
Mean Velocity Before & Mean Velocity After	4	,905	,095

Paired Samples Test

	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig.
				Lower	Upper			
SI PFz FL Before – SI PFz FL After	-1,099	1,522	0,761	-3,521	1,323	-1,444	3	,244
SI PFz HL Before – SI PFz HL After	1,686	3,198	1,599	-3,404	6,775	1,054	3	,369
SI IFz FL Before – SI IFz FL After	-1,150	2,119	1,060	-4,523	2,222	-1,085	3	,357
SI IFz HL Before – SI IFz HL After	-0,272	3,321	1,661	-5,558	5,013	-,164	3	,880
SPD FL Before – SPD FL After	0,620	1,559	0,780	-1,861	3,101	,795	3	,485
SPD HL Before – SPD HL After	0,580	1,692	0,846	-2,113	3,273	,685	3	,542
PCA FL Before – PCA FL After	-0,908	1,632	0,816	-3,504	1,689	-1,112	3	,347
PCA HL Before – PCA HL After	1,538	1,745	0,873	-1,240	4,315	1,762	3	,176
Step Length Before – Step Length After	-0,021	0,014	0,007	-0,044	0,001	-3,009	3	,057
Mean Velocity Before – Mean Velocity After	-0,033	0,078	0,039	-0,157	0,090	-,858	3	,454

Group B

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SI PFz FL Before	1,030	5	1,460	0,653
	SI PFz FL After	1,433	5	0,711	0,318
Pair 2	SI PFz HL Before	7,585	5	5,163	2,309
	SI PFz HL After	5,889	5	4,715	2,109
Pair 3	SI IFz FL Before	2,909	5	2,973	1,329
	SI IFz FL After	1,835	5	2,965	1,326
Pair 4	SI IFz HL Before	12,093	5	6,517	2,915
	SI IFz HL After	8,035	5	6,694	2,994
Pair 5	SPD FL Before	1,666	5	0,660	0,295
	SPD FL After	1,264	5	0,780	0,349
Pair 6	SPD HL Before	3,270	5	2,631	1,177
	SPD HL After	3,224	5	0,999	0,447
Pair 7	PCA FL Before	0,712	5	0,394	0,176
	PCA FL After	2,176	5	0,673	0,301
Pair 8	PCA HL Before	3,950	5	3,270	1,462
	PCA HL After	2,550	5	2,387	1,067
Pair 9	Step Length Before	0,700	5	0,162	0,073
	Step Length After	0,731	5	0,193	0,086
Pair 10	Mean Velocity Before	0,949	5	0,163	0,073
	Mean Velocity After	0,993	5	0,183	0,082

Paired Samples Correlations

	N	Correlation	Sig.
SI PFz FL Before & SI PFz FL After	5	-,094	,881
SI PFz HL Before & SI PFz HL After	5	,922	,026*
SI IFz FL Before & SI IFz FL After	5	,565	,321
SI IFz HL Before & SI IFz HL After	5	,827	,084
SPD FL Before & SPD FL After	5	,329	,589
SPD HL Before & SPD HL After	5	,582	,303
PCA FL Before & PCA FL After	5	-,106	,865
PCA HL Before & PCA HL After	5	,591	,294
Step Length Before & Step Length After	5	,978	,004*
Mean Velocity Before & Mean Velocity After	5	,886	,045*

Paired Samples Test

	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig.
				Lower	Upper			
SI PFz FL Before – SI PFz FL After	-0,403	1,683	0,753	-2,493	1,687	-,535	4	,621
SI PFz HL Before – SI PFz HL After	1,696	2,002	0,895	-0,790	4,181	1,894	4	,131
SI IFz FL Before – SI IFz FL After	1,075	2,768	1,238	-2,363	4,512	,868	4	,434
SI IFz HL Before – SI IFz HL After	4,057	3,888	1,739	-0,770	8,885	2,334	4	,080
SPD FL Before – SPD FL After	0,402	0,840	0,376	-0,641	1,445	1,070	4	,345
SPD HL Before – SPD HL After	0,046	2,205	0,986	-2,691	2,783	,047	4	,965
PCA FL Before – PCA FL After	-1,464	0,815	0,365	-2,476	-0,452	-4,015	4	,016*
PCA HL Before – PCA HL After	1,400	2,675	1,196	-1,922	4,722	1,170	4	,307
Step Length Before – Step Length After	-0,031	0,048	0,021	-0,090	0,029	-1,419	4	,229
Mean Velocity Before – Mean Velocity After	-0,044	0,085	0,038	-0,149	0,061	-1,162	4	,310

Annex VII – Step length and withers height descriptive statistics, correlations and curve fit of several regression models.

Dog	Withers height (m)	Step length (m)
1	0,65	0,85
2	0,51	0,57
3	0,43	0,62
4	0,36	0,45
5	0,5	0,63
6	0,57	0,73
7	0,63	0,92
8	0,27	0,48
9	0,63	0,74

Mean	0,51	0,67
SD	0,13	0,16
Minimum	0,27	0,45
Maximum	0,65	0,92

Correlations

		WithersHeight	StepLength
WithersHeight	Pearson Correlation	1	,904**
	Sig. (2-tailed)		,001
	N	9	9
StepLength	Pearson Correlation	,904**	1
	Sig. (2-tailed)	,001	
	N	9	9

**. Correlation is significant at the 0.01 level (2-tailed).

Curve Fit

Model Summary and Parameter Estimates

Dependent Variable: Step Length

	Model Summary					Parameter Estimates	
Equation	R Square	F	df1	df2	Sig.	Constant	b1
Linear	,818	31,423	1	7	,001	,113	1,096
Logarithmic	,754	21,475	1	7	,002	1,004	,469
Power	,798	27,660	1	7	,001	1,104	,738
Exponential	,850	39,583	1	7	,000	,274	1,709

The independent variable is Withers Height.