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Mobility and Gait Measure Instruments for the Hindlimb Functional Assessment of the Dog

Tese de Candidatura ao grau de Doutor em Ciências Veterinárias submetida ao Instituto de Ciências Biomédicas Abel Salazar da Universidade do Porto.

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*Para ti, meu **Avô**,*

pela Nobreza da tua longa vida, pela presença sempre Forte mas subtil, pelo Sorriso aberto e Sincero que me aquecia o coração e abraçava a alma, pelo Amor sem medida a cada um de nós, por cada uma das lições despretensiosas de Carácter, de Rectidão, de Humildade, de Sacrifício e Dedicação à Família e ao trabalho, por teres feito de mim a Neta mais orgulhosa e feliz que corria para os teus braços a cada tempo livre, mas acima de tudo, agora, por continuares Comigo e eu ser capaz de o Sentir.

DECLARATION

The results from research and experimental work included in this thesis are part of the scientific articles and conference proceedings published in international journals, listed below.

Scientific articles:

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ABBREVIATION LIST

2D - Two-dimensional

3D - Three-dimensional

BCS - Body condition score

BW - Body weight

DMS - Dog mobility scale

FP - Force platform

GRF - Ground reaction forces

MPI - Mean pressure index

NS - Number of activated sensors

PCA - Peak contact area

PCP - Peak contact pressure

PRISMA - Preferred reporting items for systematic review and meta-analysis

PSW - Pressure-sensitive walkway system

PV - Paw velocity

QI - Quality index

SrL - Stride lenght

SrL% - Relative stride lenght

SrT - Stride time

ST - Stance time

ST% - Relative stance time

SwT - Swing time

SwT% - Relative swing time

TPI - Total pressure index

TSV - Temporospatial variables

CONTENTS

Abstract

Kinetic and kinematic assessment of canine gait is of the utmost importance for the study and characterization of both healthy and diseased animals but their relationships with individual characteristics of the dogs are scarcely studied. Several different scales and instruments, capable of assessing diverse outcome measures in dogs, have been used, giving important contributes to evaluation and revaluation moments. Yet, the domain of mobility has not been deepen in this field. The understanding of dog movement or mobility is evolving, with particular emphasis on the causes that might affect it, including the individual characteristics of each dog. Although gait analysis of dogs with pathological conditions was widely studied, healthy normal gait was not so evaluated and there is still a need for its detailed characterisation prior to the diagnosis of abnormal or lame gait patterns, by using affordable, practical and easy methods, applicable in the daily routine of veterinary practitioners.

This thesis aimed to study the functional assessment of the dog and its measure instruments, focusing on the domains of mobility and gait. The inherent need for the study of normality and establishment of patterns was soon acknowledged and, through the accomplishment of specific goals representing progressive work stages, results were achieved with the development and validation of a novel instrument to measure mobility; a practical and suitable method for routine clinical using two-dimensional kinematic gait analysis was proposed; the influence of individual characteristics such as size, weight, height, breed, age, gender and body condition on mobility and on temporospatial gait parameters was studied; and finally a preliminary study of correlations between mobility values and temporospatial gait parameters of the hindlimb was performed.

A literature review on the subject demonstrated that several methodologies were used to understand the influence of individual characteristics on gait, the most frequent outcome variables being the ground reaction forces and the temporal variables. Velocity was the commonest outcome variable. Six studies found a significant influence of the dogs' individual characteristics. Body weight, height, age and gender seem to influence gait outcome variables in healthy dogs, deserving special data treatment with proper normalisation of the variables, although more randomized controlled trials of larger heterogeneous groups are needed.

Aiming to develop and assess the psychometric characteristics of a mobility scale for dogs, one hundred and twenty three dog owners were invited to answer a questionnaire. Its internal consistency, factor analysis, floor and ceiling effect and construct validity were studied and the questionnaire was adjusted until a good internal consistency was achieved. The final result, called the Dog Mobility Scale was capable of assessing mobility in dogs with good psychometric characteristics, and is a simple and inexpensive tool to apply in clinical practice.

A cross-sectional study aimed to analyse the relationship between individual characteristics of 36 healthy dogs and their mobility allowed concluding that males had statistically significant, although weakly correlated, higher mobility scores, while the remaining variables were not considered to affect mobility. The results of this study enhanced the robustness of the DMS as an instrument for the early detection of mobility impairment, either related to old age or, more importantly, to initial stages of disease in need for diagnosis and treatment or preventive clinical actions. The gender influence in healthy and younger populations warrants further studies to understand its influence in the clinical use of the DMS.

A cross-sectional study aimed to quantify, characterise, and compare the hindlimb temporospatial variables (TSV) of 63 healthy dogs during walk. After the measurement of several gait temporospatial parameters and the analysis of their variations according to some individual characteristics, normal patterns were established and variation factors were identified.

The last study of this thesis aimed to explore the correlations between the Dog Mobility Scale (DMS) scores and two-dimensional kinematic temporospatial variables (TSV) of the hindlimb during walking. Although its conclusions must be considered preliminary, a group of moderate but significant correlations was identified, being considered that the moderate strength of their majority indicates that larger and more balanced populations need to be studied, including dogs with mobility impairment pathologies, aiming to progress in the criterion validity analysis of the DMS.

The elaboration of this thesis aimed to contribute for the improvement of knowledge in a field that has not received much focus in veterinary research, the dog's functional assessment. Information in the mobility and gait domains was added, providing effective, practical, and inexpensive instruments for daily use in veterinary practices, potentially allowing for the early detection of diseases, and thus earlier and more successful treatments, enhancing the health promotion and disease prevention of canine patients.

Resumo

A avaliação cinética e cinemática da marcha do cão é de máxima importância no estudo e caracterização de animais saudáveis e com patologia, no entanto, a relação destas avaliações com as características individuais dos cães estão ainda pouco estudadas. Diversas escalas e instrumentos, capazes de diferentes avaliações e medidas, têm vindo a ser usados, contribuindo de forma importante para a avaliação e reavaliação do cão. No entanto, neste âmbito, o domínio da mobilidade não foi ainda estudado de forma aprofundada. O estudo e a compreensão da mobilidade tem vindo a evoluir com particular ênfase nas causas que a poderão afectar, incluindo as próprias características individuais de cada cão. Embora a análise da marcha do cão portador de patologia, seja bastante estudada, o estudo da marcha do cão saudável não tem acompanhado o mesmo ritmo de investigação, e há ainda uma necessidade da sua caracterização detalhada, antes mesmo do diagnóstico de padrões de marcha patológicos, feita a partir de métodos práticos, económicos e de fácil utilização, aplicáveis no quotidiano de uma clínica ou hospital veterinário.

Esta tese teve o objectivo geral de estudar a avaliação funcional do cão e os seus instrumentos de medida, com foco nos domínios da mobilidade e da marcha. Desde logo foi reconhecida a necessidade do estudo do normal e o estabelecimento de padrões, que com o cumprimento de objectivos específicos foram realizadas etapas progressivas de trabalho, resultados importantes foram atingidos com a construção e validação de um novo instrumento/escala para medir a mobilidade do cão; foi proposto um método prático e adequado à prática clínica, utilizando a análise cinemática da marcha a duas dimensões; foi estudada a influência das características individuais do cão, como o porte, o peso, a raça, a idade, o género e a condição corporal na mobilidade e nos parâmetros espácio-temporais da marcha; e por fim, foi realizado um estudo preliminar de correlações entre os valores de mobilidade e as variáveis espácio-temporais do membro pélvico do cão.

Uma revisão da literatura no tema demonstrou que várias metodologias foram usadas no sentido de compreender a influência das características individuais na marcha, sendo as variáveis de medida mais frequentemente utilizadas as força de reacção do solo e as variáveis temporais. A velocidade da marcha do cão foi a variável comum a todos os estudos. O peso, a altura, a idade e o género parecem influenciar as variáveis da marcha nos cães saudáveis, merecendo especial tratamento de dados com normalização apropriada das variáveis, apesar de mais estudos controlados e randomizados sejam necessários, em grupos maiores e mais heterogéneos de cães.

Com o objectivo de construir e avaliar as características psicométricas de uma escala de mobilidade para cães, cento e vinte e três donos de cão foram convidados a

responder a um questionário. Foi avaliada a consistência interna, os efeitos de tecto-chão e a validade de constructo, feita a análise factorial, e o questionário foi ajustado até atingir uma boa consistência interna. A Escala de Mobilidade do Cão (EMC) demonstrou ser capaz de medir mobilidade em cães, com boas características psicométricas, sendo um instrumento rápido, barato e de simples utilização prática clínica.

Um estudo observacional analítico transversal, com o objectivo de analisar as relações entre as características individuais de 36 cães saudáveis e a sua mobilidade, permitiu concluir que os machos tinham valores mais altos de mobilidade, estatisticamente significativos, apesar de a correlação encontrada ter sido fraca. Mais nenhuma das restantes características individuais do cão mostrou afectar a sua mobilidade.

Estes resultados reforçaram a robustez da EMC como um instrumento de detecção precoce de alterações de mobilidade, relacionadas quer com idade mais avançada do cão quer com, ainda mais importante, estadios iniciais de patologia a precisarem de serem diagnosticados e tratados ou a precisarem de actuação clínica preventiva. A influência do género em populações de cães mais jovens e saudáveis justifica a necessidade da realização de estudos futuros no sentido de compreender a sua influência na utilização clínica da EMC.

Um estudo observacional analítico transversal foi realizado com o objectivo de quantificar, caracterizar e comparar as variáveis espácio-temporais de 63 cães saudáveis durante o passo. Através da medição de vários parâmetros espácio-temporais da marcha e da análise da sua variação segundo algumas das características individuais dos cães, padrões normais foram estabelecidos e factores de variabilidade foram identificados.

O último estudo desta tese teve como objectivo a exploração das correlações existentes entre os valores de mobilidade, obtidos através da aplicação da Escala de Mobilidade do Cão, e as variáveis cinemáticas espácio-temporais do membro pélvico do cão durante o passo. Apesar de as conclusões alcançadas serem consideradas preliminares, foi identificado um conjunto de correlações estatisticamente significativas, de força moderada. Considera-se, no entanto, que populações de cães maiores e mais equilibradas precisam de ser estudadas, incluindo cães com patologias que afectem a mobilidade, no sentido de evoluir na análise da validade de critério da EMC.

A elaboração desta tese teve como objectivo principal contribuir para o aumento de conhecimento numa área que não tem recebido muita atenção da investigação veterinária, a avaliação funcional do cão. Informação sobre a mobilidade e a marcha do cão foi acrescentada, tendo sido apresentados e desenvolvidos instrumentos eficazes, práticos e económicos para uso quotidiano em clínicas e hospitais veterinários, permitindo a detecção precoce de patologias, e portanto, tratamentos mais precoces e com maior taxa de sucesso, fomentando a promoção da saúde e a prevenção da doença nos cães.

CHAPTER I

Introduction

In the International Classification of Functioning, Disability and Health (ICF) of the World Health Organization (WHO), it is stated that *"functioning is an umbrella term for body functions, body structures, activities and participation. It denotes the positive aspects of the interaction between an individual (with a health condition) and that individual's contextual factors (environmental and personal factors)."*(Kostanjsek, 2011; World Health Organization, 2013) (Figure 1).

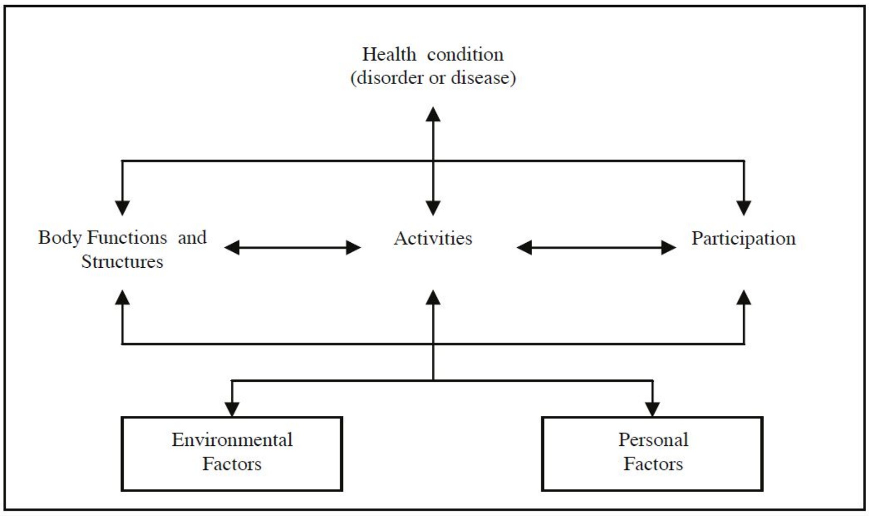

Figure 1. Interactions between the components of ICF. In Kostanjsek: Use of the International Classification of Functioning, Disability and Health (ICF) as a conceptual framework and common language for disability statistics and health information systems. BMC Public Health 2011, 11 (Suppl 4): S3.

The functional mobility of a dog, as a concept that includes all postures and movements involved in daily function, from maintenance of static recumbent, sitting and standing postures, to the dynamic transitions to and from these postures and positions, requiring adequate concentric and eccentric motor control, comes in accordance with the set ICF categories that advise for the evaluation of changing basic body position; maintaining a body position; transferring oneself; walking; moving around; and moving around in different locations (Hesbach, 2007; World Health Organization, 2013).

The evaluation of function or functionality in dogs encompasses a very wide set of factors and may be perceived from different perspectives. Both detection and interpretation of functional abnormalities are dissimilar between animal owners and veterinary practitioners or physical therapists. These different perspectives are, however, complementary. Cook (2007) stated that in the context of veterinary orthopaedics, the development of standardized client questionnaires and clinical assessment forms for function and quality of life, which have been validated using kinetic, kinematic, imaging, and other objective measures of outcome, seems to be the most logical option to address clinically relevant questions, by obtaining essential information about the patient, since not all veterinary surgeons have access to sophisticated, modern and objective outcome measures.

Veterinary medicine is evolving and outcome measures have been treading a path of development, getting closer to the accomplishments achieved in human medicine, regarding measurement and assessment. Evidence-based practice (EBP) enforces the need for decisions based on selected scientific research studies, implying the use of instruments with properly evaluated psychometric properties. An outcome instrument is a specific tool for providing data that measures a specific outcome. It should be standardized, reliable (measuring in a consistent and repeatable way) and valid (measuring what it was proposed to measure) (Cook, 2007). The Canine Outcome Measures Program (COMP) is an excellent example of how veterinarians are interested in outcome standardisation to improve quality and impact of orthopaedic studies, addressing attention to the definition of an outcome measure, clarifying the whole methodological stepwise for development of subjective outcomes, showing concern on the level of the evidence produced as well as proposing standard definitions and criteria for reporting time frame, outcome and complications for clinical orthopaedic research (Brown, 2007; Cook, 2007; Innes, 2007; Kapatkin, 2007; Schulz, 2007; Cook et al., 2010).

The current awakening for the value of preventive veterinary medicine brought enhanced attention to the importance of regular evaluation and assessment of animals without obvious clinical signs, settled in a subjective-objective-assessment-plan (SOAP) methodology addressed to healthy animals, aimed to promoting early intervention, preventive care, and the delivery of optimal patient care and more effective treatments (Spofford, Lefebvre, McCune, & Niel, 2011).

Several measurements can be useful for accessing outcomes, including subjective and objective methods such as client reports with historical information and description of pain-related behaviours, as well as measures of body condition, vital signs, limb circumference, range of motion, spontaneous or induced pain, quality of life, or gait analysis, gathering information on important domains such as functional strength, motor control, static and dynamic balance and proprioception (Hesbach, 2007; Millis, 2014).

Functional scales or functional scoring systems are largely used in human medicine but the best way to use them in veterinary studies is uncertain. Some adaptations of human scales have been proposed, although not yet validated, such as the Functional Stifle Scale (Millis, 2014), the Canine Functional Independence Measure (C-FIM) (Hesbach, 2006), and the Canine Timed Up and Go Test (Hesbach, 2003). As an outcome measure of functional exercise capacity, the 6-minute walk test (6MWT) is a useful instrument in human medicine, providing functional assessment of cardiopulmonary reserves by measuring the distance that an individual can comfortably walk in 6 minutes (Guyatt et al., 1985; Enright, 2003; Kervio, Carre, & Ville, 2003). It has been evaluated by Boddy, Roche, Schwartz, Nakayama, and Hamlin (2004) in dogs with congestive heart failure and by Swimmer and Rozanski (2011) in dogs with pulmonary disease, both studies finding decreased distances walked by diseased animals when compared to healthy dogs. Some important advances have been achieved with the development and validation of two neurologic scales: the Functional Scoring System in dogs with acute spinal cord injuries (Olby et al., 2001) and the Texas Spinal Cord Injury Score for dogs (Levine et al., 2009).

Physical activity, defined as any bodily movement produced by skeletal muscles that results in energy expenditure (Caspersen et al, 1985), may be assessed by pedometers (record the number of steps taken) and by accelerometers, whose use has been validated as objective outcome measure of spontaneous activity monitoring, quantifying and detecting changes in activity intensity. Accelerometers are portable, lightweight and non-invasive devices with motion sensors that measure time-varying accelerations up to the three axes (the most recent devices), monitoring in real-time the frequency, duration and intensity of all activities, which allow accurate quantification of physical activity levels. The ventral aspect of the dog's collar showed to be the most convenient place to attach the accelerometer that is a device (Chan, Spierenburg, Ihle, & Tudor-Locke, 2005; Hansen, Lascelles, Keene, Adams, & Thomson, 2007; Brown, Boston, & Farrar, 2010; Brown, Michel, Love, & Dow, 2010; Wrigglesworth, Mort, Upton, & Miller, 2011; Yam et al., 2011; Preston, Baltzer, & Trost, 2012).

Mobility and activity are closely related concepts that, when undiminished, represent a state of health, well-being and quality of life. In this way, and as far as we are aware, the dog functional mobility lacks specific attention, in what refers to it assessment as an individual domain, with proper instruments development, but rather has been studied in association with signs of disease or clinical features, as a sub-category of pain or quality of life instruments (Holton, Reid, Scott, Pawson, & Nolan, 2001; Hielm-Bjorkman et al., 2003; Wiseman-Orr, Nolan, Reid, & Scott, 2004; Brown, Boston, Coyne, & Farrar, 2007). It is our belief that changes in mobility, as part of a preventive approach, may be an indicator of further complications or of the settlement of progressive pathologies that, when identified in a sub-clinical state, allow for early intervention, potentially more effective in preventing its evolution with less suffering, lower costs and higher quality of life. Impaired mobility, besides being favourable to the settlement and consolidation of chronical diseases, causes also behaviour changes, thus representing a priority domain for therapeutically restoring.

Although lacking technical training and skills, it is reasonable to assume that dog owners possess the most reliable information about changes in their animal's routines and behaviours, even if they often struggle to understand what is really different, hampering both the willingness to report it to practitioners and the correct description of the actual situation. Furthermore, it is common that owners consider such changes as natural phenomena, often attributable to old age or pure behaviour issues. Hence, a well-developed questionnaire, that undergoes the entire stepwise process of constructing a health measurement instrument addressed to the owners, is capable of detecting and measuring subclinical reductions in the dog's mobility that may justify the investigation of its aetiology. If an appropriate psychometric methodology is used, a questionnaire containing subjective outcomes and statuses may be converted into a scale and be reliably quantified, as often performed in human medicine. Some good and successful examples are the Short-Form 36 (SF-36), the International Physical Activity Questionnaire (IPAQ), the Falls Efficacy Scale (FES) and the Movement Imagery Questionnaire-3 (MIQ-3) (Ware & Sherbourne, 1992; McHorney, Ware, & Raczek, 1993; McHorney, Ware, Lu, & Sherbourne, 1994; Craig et al., 2003; Yardley et al., 2005; Lee, Macfarlane, Lam, & Stewart, 2011; Williams et al., 2012). Well-validated instruments would be extremely useful to the daily routine of veterinary practices, enhancing the clinical decision process.

Mobility may also be inferred from an individual assessment of joint motion through goniometry. Goniometry measures the angles created by the rotational motion of the long bone shafts. Joint excursion is quantified by the angle formed between two arms, a stationary and a moving arm, which are represented by lines joining superficial anatomic benchmarks or lines representing long axis of the bones (Figure 2). For this purpose, a reliable and valid instrument is used, the universal goniometer, which is able to measure minimum angles, maximum angles and full ranges of motion. Some dogs may experience discomfort or pain when assessing extreme angles because the passive range of motion that is being explored is wider than its active equivalent, and usually not required during gait (Jaegger, Marcellin-Little, & Levine, 2002; Thomas, Marcellin-Little, Roe, Lascelles, & Brosey, 2006; Crook, McGowan, & Pead, 2007; van der Walt, Stewart, Joubert, & Bekker, 2008; Norkin & White, 2009).

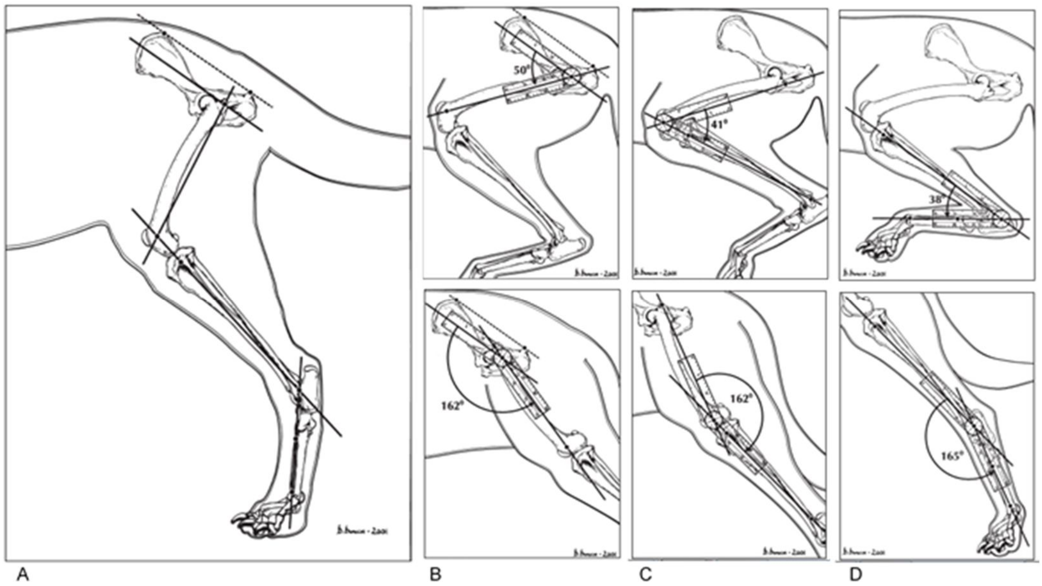

Figure 2. Goniometry of the hind limb: A - Representation of the axes for angular measurements. B – Hip joint flexion and extension are measured as the angles formed by the line joining the lateral femoral epicondyle of the femur and greater trochanter and a line joining the *tuber sacrale* and *ischiadicum*; C - Flexion and extension of the stifle joint are measured as the angles formed by the long axis of the tibial shaft and the line joining the lateral femoral epicondyle and greater trochanter; D - Tarsal flexion and extension are measured as the angles formed by the long axis of metatarsal bones III and IV and the long axis of the tibial shaft. Flexion measurement is represented in the upper images and extension in the bottom images. Adapted from Jaegger, G., Marcellin-Little, D. J., & Levine, D. (2002). Reliability of goniometry in Labrador Retrievers. American Journal of Veterinary Research, 63(7), 979-986.

The concept of locomotion is intimately linked to the study of mobility. Locomotion requires a balanced and synergic relation between joints, bones and the neuromuscular system that depends on the sensory input to develop adequate static or dynamic responses able to result in fluid movements. It is accomplished by a set of repetitive limb movements such as walking, trotting, galloping, and swimming, and non-repetitive and non-sequential motions like jumping, seating or lying.

Gillette and Angle (2014) defined a stride as "*the cycle of body movements that begins with the contact of one foot with the ground and ends when that foot contacts the ground again*." Gait results from the repetition of strides in which each limb passes through a step cycle composed by a stance and a swing phase. During the stance phase the foot is in contact with the ground. Braking forces result from the paw contact in the first part of the phase, followed by a final propulsion moment (Figure 3-A). In the swing phase, a period during which the foot is off the ground, the limb swings backward after the propulsion, then the muscles bring it forward and finally backward again and down to return to the ground (Figure 3-B).

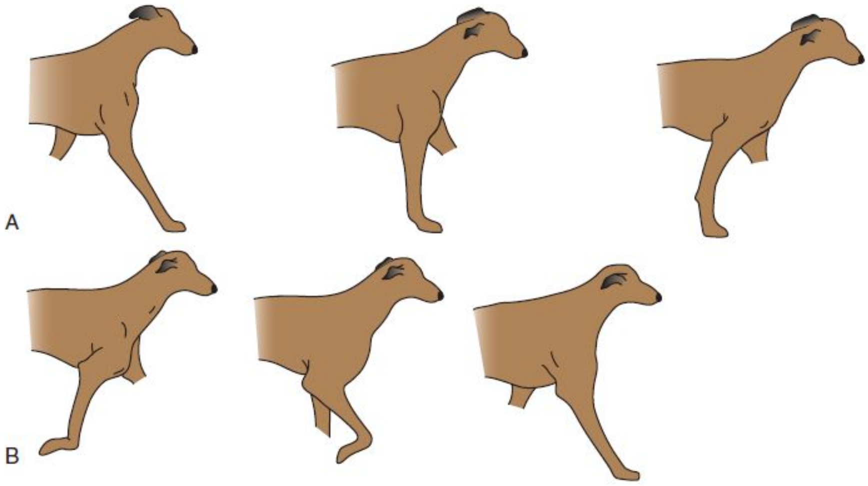

Figure 3. A -The stance phase. B - The swing phase. Adapted from Gillette, R. L., & Angle, T. C. (2014). Canine Locomotion Analysis. In D. L. Millis & D. Levine (Eds.), Canine Rehabilitation & Physical Therapy (Second Ed., pp. 201-210). St. Louis, MO, USA: Saunders, Elsevier.

Walk and trot are symmetrical gaits whereas gallop is assymmetrical. Walk is mainly characterised by being a very efficient energy saving pattern of locomotion, with 2 and 3 limb simultaneouly in the support phase and a few momentary 4-limb support phase. Each foot lifts up only when its contralateral pair contacts the ground (Figure 4). While trotting, dogs use diagonally coupled limbs with nearly synchronised supports (Figure 5). Gallop is the preferred fast gait of dogs, in which there are usually two full body suspension moments per stride (Figure 6) (Wentink, 1976; Nunamaker & Blauner, 1985; Hottinger, DeCamp, Olivier, Hauptman, & SoutasLittle, 1996; Weigel, Arnold, Hicks, & Millis, 2005), highlighting yet that there is scientific data demonstrating that a flight or aerial moment is not a prerequisite for a running gait as gallop (Cavagna, Heglund, & Taylor, 1977; Biknevicius & Reilly, 2006)

Based in the study of the centre of mass mechanics, it is known that during walk there is an alternate exchange between kinetic and gravitational potential energies that may account for up to 70% of the total energy changes whithin a stride, leaving only 30% of energy to be supplied by muscles, as a pendulum; In trot, no kinetic-gravitational transfer takes place but instead dogs store energy in muscular elastic elements and recover it in reacelerations; While galloping, dogs combine the two described energy-conserving mechanisms (Cavagna et al., 1977; Griffin, Main, & Farley, 2004).

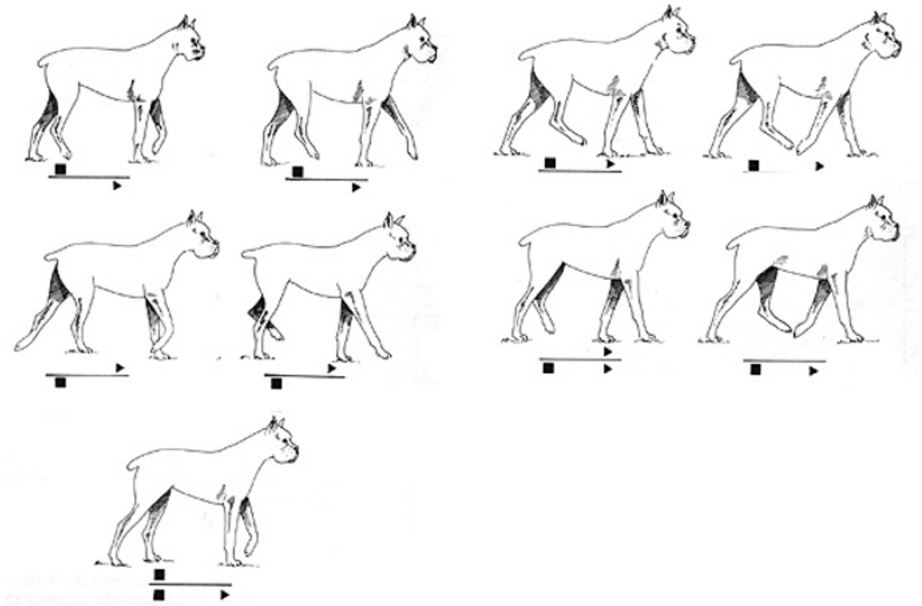

Figure 4. Dog walking. Feet in contact with the ground are represented under each diagram. Adapted from Nunamaker, D. M., & Blauner, P. D. (1985). Textbook of Small Animal Orthopaedics. In C. D. Newton & D. M. Nunamaker (Eds.), Normal and Abnormal Gait. New York: J.B. Lippincott Company.

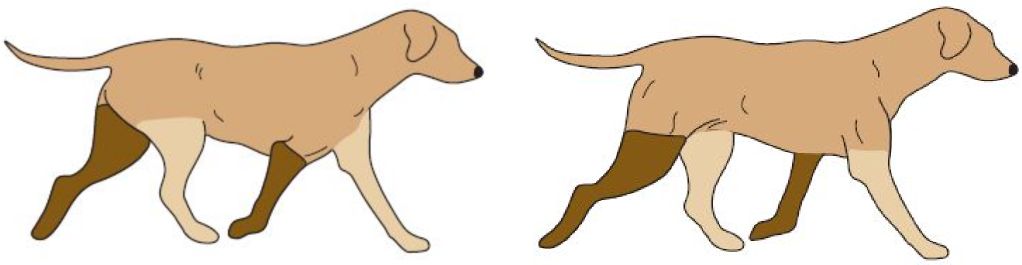

Figure 5. Dog trotting – light-coloured limbs are in the stance phase while dark-coloured limbs are in the swing phase. Adapted from Gillette, R. L., & Angle, T. C. (2014). Canine Locomotion Analysis. In D. L. Millis & D. Levine (Eds.), Canine Rehabilitation & Physical Therapy (Second Ed., pp. 201-210). St. Louis, MO, USA: Saunders, Elsevier.

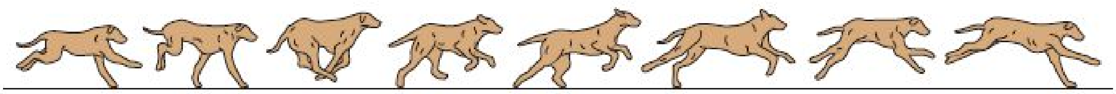

Figure 6. Dog galloping. In Gillette, R. L., & Angle, T. C. (2014). Canine Locomotion Analysis. In D. L. Millis & D. Levine (Eds.), Canine Rehabilitation & Physical Therapy (Second Ed., pp. 201-210). St. Louis, MO, USA: Saunders, Elsevier.

The description of these pendulum and spring-like mechanisms propelled investigators to deepen the study of the underlying muscular activity, initiated by Wentink (1976) (Figure 7). Complementary findings on the individual muscle activity of the hindlimb during a walking stride were then unveiled in a consistent way in subsequent studies, and it is now known that the *vastus lateralis* muscle, active during 81% of the stance phase, has an activity pattern with 2 peaks: the first occurs in the early stance phase, followed by a decrease in activity during mid-stance, and a second peak occurs just before the quick activity decrease in the late stance phase, reaching a minimum activity early in the swing phase; the cranial part of the *biceps femoris*, active during 69% of the stance phase, has one peak activity at the transition between swing and stance phase at the time of the maximal stifle extension; the *gluteus medius*, active during 62% of the stance phase, shows a small activity width over almost the entire cycle, that starts to increase when hip extends and reaches its maximum when the contralateral limb leaves the ground and the supporting hind limb has to receive the body weight transference; the medial head of *gastrocnemius* starts activity at foot-down moment and remains active during 81% of the stance phase; and the cranial part of *sartorius* becomes active before the foot leaves the ground, remaining active for 73% of the swing phase (Wentink, 1976; Goslow, Seeherman, Taylor, McCutchin, & Heglund, 1981; Bockstahler et al., 2009; Bockstahler et al., 2012).

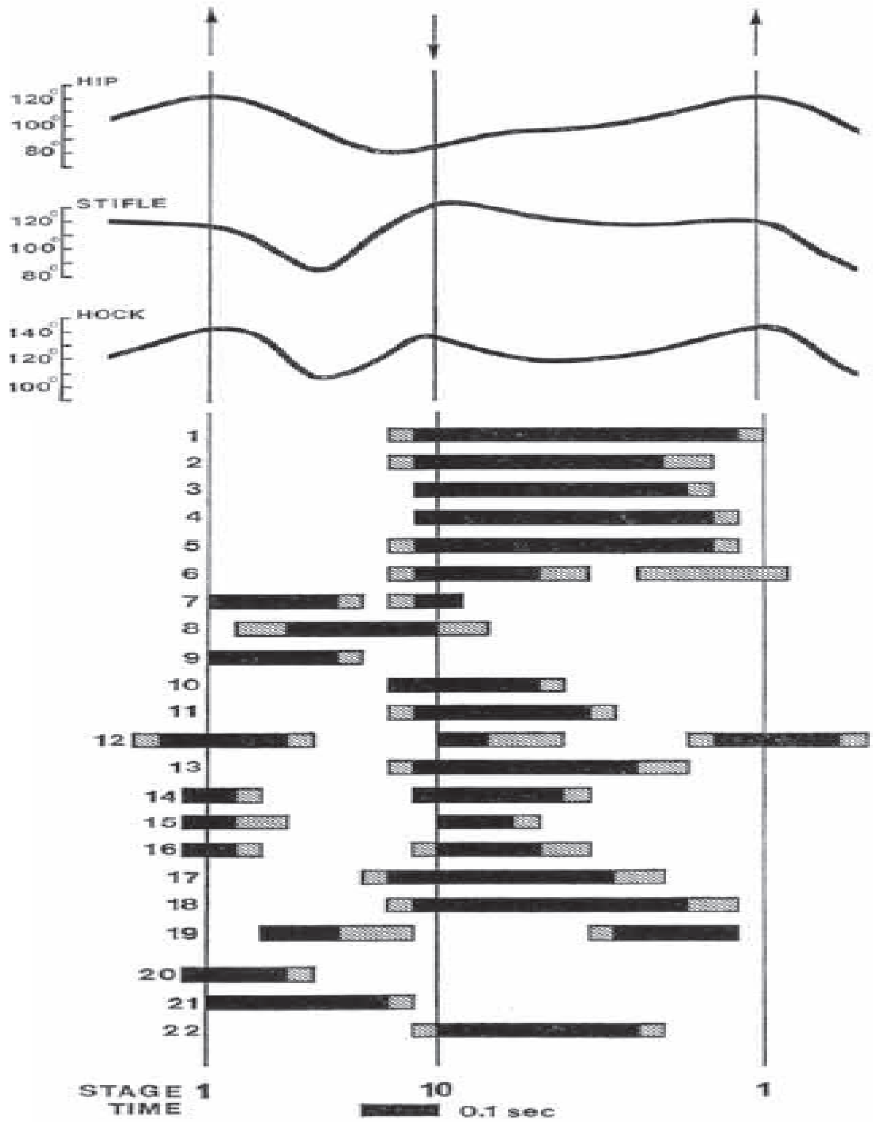

Figure 7. Action of the canine hindlimb musculature during the walk. The up arrow indicates lifting and the down arrow indicates replacing of the foot. Upper graph shows angular changes and lower scheme represents the periods of muscular activity (black blocks with variation in grey). 1- m. interosseus; 2- m. gastrocnemius medialis; 3- m. gastrocnemius lateralis; 4- m. flexor digitorum superficialis; 5- m. hallucis longuis; 6- m. popliteus; 7- m. peroneus longus; 8- m.extensor digitorum longus; 9- m. tibialis cranialis; 10- m. gracilis; 11- m.aductor; 12- m.pectineus; 13- m.semimembranosus pars cranialis; 14- m. semimembranosus pars caudalis; 15- m. semitendinosus; 16- m. bíceps femoris pars caudalis; 17- m. bíceps femoris pars cranialis; 18- m. vastus lateralis (represents the whole vastus group); 19- m. rectus femoris; 20- m.tensor fasciae latae; 21- m.sartorius; 22- m. gluteus medius. In Wentink, G. H. (1976). The action of the hind limb musculature of the dog in walking. Acta Anatomica (Basel), 96(1), 70-80.

Subjective gait analysis is probably the most common locomotion assessment in veterinary consultations. It should be performed in a wide area, in a solid, flat and non-slippery surface, by observation of the dog at rest, then walking and trotting in a straight line, observed from the front, the rear, and both sides, and finally walking in wide circles in both directions (which may accentuate the inner limb lameness) (Malikides, McGowan, & Pead, 2007; Millis & Mankin, 2014). Specific movement activities such as stair-climbing, going up and down slopes, sitting, and turning (also sharp turns) may be helpful to identify some subtle disability. The handler should not interfere with dog pace, allowing for a self-selected rhythm, on a short leash but with no excessive tension (Bockstahler, 2004; Malikides et al., 2007). Each limb must be analysed independently and the four limbs as a whole, so that the examiner detects the phase where the problem may arise or exacerbate. Head movements are also important to assess because head usually nods up when the afected limb is in stance, if a forelimb lameness is present, and down when the affected limb is in stance, if a hindlimb lameness is present. This happens because the dog uses the head and neck movements in the attempt of diminishing weight bearing on the affected limb by dislocating the centre of gravity. A lame limb may be detected only because of its eccentric placement during stance or for circumducting during the stride (Millis, Taylor, & Hoelzler, 2004). The dog is then placed in lateral recumbence, as relaxed as possible, and gentle muscle palpation is performed to assess its size, tonus, temperature changes, and potential painful areas. Each joint is then individualy palpated and a full range of motion is induced to evaluate its amplitude, absence of crepitus and pain. After exploring full range of motions it may be helpful to reassess gait because a subtle lameness may have been accentuated. Finally, a deeper muscle and bone palpation is performed to search for deformities, changes in muscle consistency and areas of pain or discomfort. Major abnormalities will be detected by these techniques but minor alterations may not, not only because they may not be enough to cause visible gait alterations but also because dogs are capable of inperceptible gait adjustments to avoid pain or discomfort. If sustained, these compensatory strategies may evolve to further complex pathologies, not only in the affected region but also in other segments of the body. Subjective gait analysis is frequently scored using a 5-grade lameness score of walk and trot separately: 0 – normal, 1 – slight intermitent lameness, 2 – obvious weight-bearing lameness, 3 - severe weight-bearing lameness, 4 – intermittent non-weight-bearing lameness, and 5 – continuous non-weight-bearing lameness (Millis & Mankin, 2014)

In the normal standing position, the dog's centre of gravity is located at the mid-chest level behind the scapula, resulting from the way the body weight is distributed between the four limbs. Each thoracic limb bears 30% and each pelvic limb bears 20% of the total body weight. This results in stronger braking forces in the forelimb, while the hindlimb propulsion forces are higher and particularly involved with dynamic activities like jumping, trotting, and galloping.

Pelvic limb muscles constitute most of the anti-gravity and the main movers. They have a great capacity of generating force and must be at optimal lines of action to apply adequate forces to skeletal structures for efficient stance, propulsion and force absorption (Gillette & Angle, 2014; Riegger-Krugh, Millis, & Weigel, 2014; Weigel & Millis, 2014).

Objective gait analysis is based on the assessment of ground reaction forces with a force platform (kinetic evaluation) and/or by the analysis of the dogs' movements acquired by video cameras (kinematic evaluation). Such analysis will be detailed in the Chapter III of this thesis.

The foot, as a final link of the pelvic limb to the ground, is a complex structure that provides both balance and support during the stance phase, ensures adequate restraint and propulsion during gait, and is able to simultaneously change the loading pattern during standing, being fairly compliant to keep its functional integrity (Besancon, Conzemius, Evans, & Ritter, 2004).

Lameness in dogs has a calculated incidence of 56%, of which 27.3% involve the hindlimbs (Mohsina et al., 2014). Bennour et al. (2014) found, on a retrospective study of appendicular fractures, that hindlimbs were more affected than forelimbs. Of the orthopaedic hindlimb disorders, and based on a seven year retrospective study, 31.9% are long bone fractures, 15.1% are hip dysplasias, 13% are patella luxations, and 11.7% are cranial cruciate ligament injuries (Souza, Rahal, Padovani, Mamprim, & Cavini, 2011). All of the above lead, in the majority of cases, to the development of degenerative joint disease, the number one musculoskeletal condition of geriatric dogs (Marcellin-Little, Levine, & Millis, 2014). In dogs attending primary-care veterinary practices, musculoskeletal-related disorders constitute the third most prevalent disease category, with a prevalence of 11.8%, next to entero-hepatic (17.8%) and dermatological (15.5%) diseases. Limbs were found to be the third most prevalent body location for pathology (17.5%), after head and neck (32.8%), and abdomen (25.6%). The fifth most prevalent disorder was degenerative joint disease (6.6%), next to otitis externa (10.2%), periodontal disease (9.3%), anal sac impaction (7.1%) and overgrown nails (7.1%) (O'Neill, Church, McGreevy, Thomson, & Brodbelt, 2014). This epidemiological information and prevalence data helps to outline preventive actions and therapeutic interventions.

Although canine gait disorders have been widely studied and described, the characterization of normality has been somehow neglected, and the definition of normality in healthy dogs has often been accomplished, not as the main goal, but in parallel with the study of diseased animals by the creation of control groups for comparison purposes, with limited and very specific outcome assessments. However, this is a critical issue for early subclinical detection of mobility alterations, although difficult to assess in such a diverse breed phenotype species such as the dog. Pelvic limb functional assessment instruments are warranted so that normality values may be clearly defined and available to daily routine use in veterinary practice.

Useful, simple, and affordable but reliable instruments are needed so that veterinary practitioners are able to use them in a preventive medicine perspective, by promptly detecting subtle signs of illness, promoting earlier prevention or intervention, reducing treatment costs, and increasing successful treatment rates that will foster a trustworthy relationship with the owners. This thesis aims to contribute to such purpose.

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CHAPTER II

Aims and Outline

Aims

General

This thesis aimed to study the functional assessment of the dog and its measure instruments focusing on the domains of mobility and gait.

Specifics

1. To systematically review the literature reporting gait analysis on healthy dogs, assembling and compiling the existent information on the influence of the dogs' individual characteristics on gait outcome variables;

2. To develop and to assess the psychometric characteristics of a mobility scale for dogs;

3. To analyse the relationship between individual characteristics of healthy dogs (size, weight, height, breed, age, gender and body condition) and their mobility scores;

4. To quantify, characterise, and compare, considering individual characteristics, hindlimb temporospatial variables of healthy dogs during walk;

5. To study the correlation between mobility scores and temporospatial parameters of the healthy dog – a preliminary study.

Thesis outline

The present thesis is constituted by eight chapters.

CHAPTER III

Hindlimb gait analysis in dogs
– A review of the literature

Abstract

Introduction: The kinetic and kinematic assessment of canine gait is extremely useful in the study and characterization of both healthy and diseased animals. More information is needed on to what extent does the gait depends on individual characteristics of the dog.

Objective: The purpose of this study was to systematically review the literature reporting gait analysis of healthy dogs, assembling and compiling the existent information on the influence of the dogs' individual characteristics on gait outcome variables.

Methods: A systematic literature search was performed in the electronic databases PubMed, Web of Science® and Scopus®, focusing on publications between January 1st, 1990 and December 31st, 2011. Data from publications were extracted with regard to gait analysis method, outcome variables for healthy dogs, and influence of the individual characteristics of the dog in outcome variables.

Results: The search retrieved 239 references. After removal of the duplicated records, screening of title and abstract and full text analysis, 34 met the inclusion criteria. Of the 34 studies, 14 (41.2%) used force platform, 7 (20.6%) used combined force platform with three-dimensional analysis, 4 (11.8%) used two-dimensional analysis, 4 (11.8%) used pressure-sensitive walkway systems, 4 (11.8%) used three-dimensional analysis and 1 (2.9%) used both force platform and pressure-sensitive walkway system. A treadmill was used in the gait analysis of 7 (20.6%) studies. Regarding gait outcome variables, the most frequent were the ground reaction forces in 24 (70.6%) studies, and the temporal variables in 19 (55.9%) studies. Velocity was the common outcome variable, among all studies. Six studies found a significant influence of the dogs' individual characteristics, including body weight, height, age and gender, in the gait outcome variables. The influence of body condition was not studied in the analysed manuscripts.

Conclusions: Body weight, height, age and gender seem to influence gait outcome variables in healthy dogs, deserving special data treatment with proper normalisation of the variables, although more randomized controlled trials of larger heterogeneous groups are needed.

Introduction

Starting from the study of the biomechanics of quadruped walking, the canine gait analysis is a subject of scientific interest since the second half of the twentieth century with Muybridge and Hildebrand, and later with Budsberg studies (Cavagna, Heglund, & Taylor, 1977; Wentink, 1977; Budsberg, Verstraete, & Soutas-Little, 1987; Budsberg, Verstraete, Soutas-Little, Flo, & Probst, 1988; Griffin, Main, & Farley, 2004; Biknevicius & Reilly, 2006). The evaluation of the canine gait has received growing interest among veterinary practitioners and, as such, has undergone important developments and improvements during the last decades. Although subjective gait evaluation has been largely used, it is almost impossible to detect minimal changes in fractions of time, and therefore computer assisted gait analysis has been evolving in parallel with the scientific investigation, allowing for a better understanding of the canine locomotion. Kinetic analysis quantifies ground reaction forces (vertical, craniocaudal and mediolateral) applied by the dog when, during the stance phase of the gait, the paw contacts a force platform. Although several variables may be studied with this method, there appears to be a higher usefulness of peak vertical force and vertical impulse; peak braking and propulsion forces and corresponding impulses. Pressure-sensitive walkway systems or pressure mats also detect ground reaction forces through integrated sensors, having the advantage of recording consecutive footfalls. Kinematic approach studies quantify the positions, velocities, accelerations, and joint angles performed by the excursion of segments in space, currently using high speed digital cameras. Two dimensional and three dimensional kinematic analyses are also possible. The first one is less expensive, is able to evaluate sagittal plane movements but provides limited information regarding rotational and circumduction data; the second one is more advanced and expensive and, as so, limited to investigation centres, but allows for a much more complete set of information (Gillette & Angle, 2008; Millis, 2014). Both kinematic methods use markers to identify anatomical references that may consist on reflective or non-reflective materials or even LEDs (Nunamaker & Blauner, 1985; Budsberg, 2008; Gillette & Angle, 2008). Kinetic and kinematic combined analyses are also possible and frequent, giving more complete information (DeCamp et al., 1996; Boddeker et al., 2012; Brady et al., 2013).

Both kinetic and kinematic canine gait assessments are extremely useful for the study and characterization of several pathologies like rupture of the cranial cruciate ligament (Evans, Horstman, & Conzemius, 2005; Ragetly, Griffon, Mostafa, Thomas, & Hsiao-Wecksler, 2010; Sanchez-Bustinduy, 2010; Ragetly, Griffon, Hsu, Klump, & Hsiao-Wecksler, 2012); muscular dystrophy (Marsh, 2010); osteoarthritis (Budsberg, 2001; Madore, Huneault, Moreau, & Dupuis, 2007; Beraud, Moreau, & Lussier, 2010; Bockstahler et al., 2012a; Bockstahler et al., 2012b); cervical spondylomyelopathy (Foss, da Costa, & Moore, 2013; Foss, da Costa, Rajala-Schuttz, & Allen, 2013); hip dysplasia (Bockstahler, Henninger, et al., 2007; Miqueleto et al., 2013); spinal cord disease (Gordon-Evans, Evans, & Conzemius, 2009; Gordon-Evans,

Evans, Knap, et al., 2009); and degenerative lumbosacral stenosis (van Klaveren, 2005; Suwankong et al., 2007). It may also be useful in the study of the surgical effectiveness of procedures such as tibial plateau levelling osteotomy (Ballagas, Montgomery, Henderson & Gillette, 2004; Robinson, Mason, Evans & Conzemius, 2006; Lee, Kim, Kim & Choi, 2007; Kim, Pozzi, Banks, Conra, & Lewis, 2009a; Au et al., 2010; de Medeiros, Bustinduy, Radke, Langley-Hobbs & Jeffery, 2011) and tibial tuberosity advancement (Voss, Damur, Guerrero, Haessig & Montavon, 2008; Kim, Pozzi, Banks, Conrad & Lewis, 2009b; Butler, Syrcle, McLaughlin & Elder, 2011); or even to diagnose or more accurately evaluate lameness (Hudson, Slater, Taylor, Scott, & Kerwin, 2004; Brebner, Moens & Runciman, 2006; Mlanick, 2006; Fanchon & Grandjean, 2007; Waxman, 2008; Lequang, Maitre, Roger, & Viguier, 2009; Oosterlinck et al., 2011; Abdelhadi, Wefstaedt, Nolte, & Schilling, 2012; Kaijima, Foutz, McClendon, & Budsberg, 2012; Abdelhadi et al., 2013).

The need for a standardization of methods and the rarity of normal gait quantitative measurements soon emerged. Its pursue started in the last years of the 20th century (Budsberg et al., 1987; Jevens, Hauptman, DeCamp, Budsberg, & Soutas-Little, 1993; McLaughlin & Roush, 1994; Roush & McLaughlin, 1994; Rumph et al., 1994; Budsberg, Verstraete, Brown, & Reece, 1995; McLaughlin & Roush, 1995; Rumph, Steiss, & Montgomery, 1997; Rumph, Steiss, & West, 1999) and continued, in a fervent way, in the 21th century with attempts of clustering dogs by breed, weight or body conformation during walking (Besancon, Conzemius, Evans & Ritter, 2004; Kim, Kazmierczak, & Breur, 2011; Tian, Cong & Menon, 2011); trotting (Bertram, Lee, Case & Todhunter, 2000; Lee, Stakebake, Walter & Carrier, 2004; Lascelles et al., 2006; Colborne, 2008; Voss, Wiestner, Galeandro, Hassig & Montavon,2011); galloping and rapid accelerations (Walter & Carrier, 2009); jumping (Pfau, de Rivaz, Brighton, & Weller, 2011); stair and ramp ascending (Durant, Millis, & Headrick, 2011); and during therapeutic exercises (Holler et al., 2010). Even a direct comparison of human and canine kinematics during walking, stair ascent and descent has been done (Richards, 2009).

With such scientific research on the subject, it became mandatory to compile and summarise information on techniques and approaches. The purpose of this study was to systematically review the literature reporting gait analysis on healthy dogs, assembling and compiling the existent information, aiming to answer the following research questions:

1. “Do individual characteristics of the dog influence their gait?”
2. “What relations were found between the dogs’ individual characteristics and their gait variables?”
3. “What individual characteristics are more influential in gait outcome variables?”

The article is written in compliance with the PRISMA statement (Liberati et al., 2009).

Methods

Search strategy

A systematic literature search was performed, aiming to identify relevant evidence on the subject, by combining specific terms with the Boolean logic strategies in the following expression: "(gait* OR walk* OR trot* OR gallop*) AND (kinetic OR kinematic) AND (healthy OR sound OR normal) AND (dog OR dogs OR canine)", in the electronic databases PubMed, Web of Science® and Scopus®, between January 1st, 1990 and December 31st, 2011. Consensus over ambiguous information was achieved between the two first authors.

Eligibility

Inclusion criteria:

- Experimental studies aiming to quantify, characterise, and/or define normal gait values of healthy dogs;
- Studies including a minimum of 10 dogs (N $\geq$10) (Bergh & Budsberg, 2014);
- Published in peer-review journals;
- Manuscripts written in English or Portuguese.

Exclusion criteria

- Studies exclusively performed in dogs with pathologies or/and submitted to surgery or to induction of symptomatology or pathology;
- Analyses addressed to forelimbs and spine;
- Studies in non-canine animals;
- Studies using models or cadavers;
- Studies using non-kinetic or kinematic gait assessments;
- Case-studies and reviews.

Elimination of duplicated records was automatically performed by EndNote software. Title and abstracts were reviewed for the eligibility process. This process was synthetized using worksheets of Excel 2010 (Microsoft®). Numerical data from eligibility process is summarized in the PRISMA flow diagram (Figure 1).

Data collection and extraction

Data from publications were extracted on the basis of the following variables: Author, year; number, body weight and age of the dogs; Gait analysis method: two dimensional (2D), three dimensional (3D), force platform (FP), pressure sensitive walkway system (PSW), treadmill; Outcome variables for normal healthy dogs: joint angular displacement, joint angular velocity, velocity, cadence, spatial variables, temporal variables, ground reaction forces (GRF), number of activated sensors (NS), total or mean pressure index (TPI/MPI), peak contact area (PCA), and peak contact pressure (PCP). The methodological quality of the studies was assessed using an established risk of bias assessment tool containing questions about study reporting, external validity, bias and power (Downs & Black, 1998). An adapted version of Downs and Black (1998) checklist was used, with 25 questions and with a maximum score or quality index (QI) of 26, with higher scores corresponding to higher quality of studies (McCready & Ness, 2016) (Figure A1, in Appendix). Consensus over the classification was achieved between authors. Data were extracted, compiled and tabulated in Word 2010 (Microsoft®).

Results

Study selection

The search for records retrieved 239 references, 227 from the searched databases and 12 through the examination of the references identified by electronic search. After removal of the duplicated records (99), 140 remained and upon screening of title and abstract for the established criteria, 99 were excluded, thus remaining 41 manuscripts. Seven were eliminated after full text analysis because they did not address the proposed questions for this review. In total, thirty-four studies were included (Figure1). The most common reasons for exclusion were: studies performed in dogs with pathologies, clinical signs and/or submitted to surgical procedures; addressing small samples (< 10 dogs); performed in other species; addressed to forelimbs and spinal segments; review articles; written in Chinese and German; and studies on mathematical models or ex-vivo or in-vitro models.

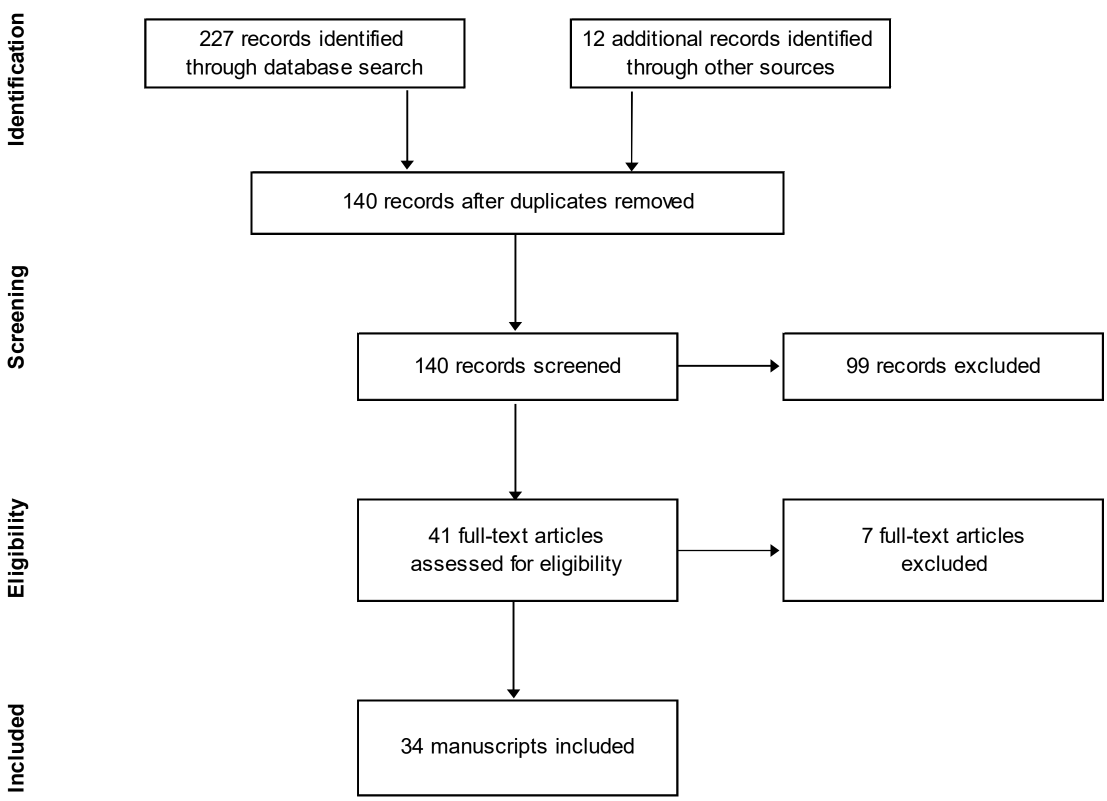

Figure 1. Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) flow diagram.

Data extracted

Regarding methodological quality, 35.3% (12) of the studies were rated as fair and 64.7% (22) as poor. The mean Quality Index (QI) score of the studies was 12 (range 10 to 14).

The analyses with larger groups of dogs were the studies of Rumph et al. (1997) with 133 dogs; Voss, Galeandro, Wiestner, Haessig, and Montavon (2010) with 129 dogs; and Light, Steiss, Montgomery, Rumph, and Wright (2010), Voss, Wiestner, Galeandro, Hassig, and Montavon (2011) and Rumph et al. (1999) with 56, 54 and 52 dogs, respectively.

The gait analysis methods of the total 34 studies included: 14 (41.2%) using FP, 7 (20.6%) using combined FP with 3D analysis, 4 (11.8%) using 2D analysis, 4 (11.8%) using PSW, 4 (11.8%) using 3D analysis and 1 (2.9%) using non-combined FP and PSW. A treadmill was used in the gait analysis of 7 (20.6%) studies.

The most studied outcome variables were ground reaction forces (GRF) in 24 (70.6%) studies; and the temporal variables in 19 (55.9%) studies. Velocity was the commonest outcome variable, present in all studies.

Twenty-two (64.7%) of the 34 records studied exclusively large breed dogs, 23 (67.6%) studied the trot, 10 (29.4%) studied the walk, and 1 (2.9%) studied the jump.

Six studies found a significant influence of some dogs' individual characteristics, such as body weight (BW), height, age and gender in the gait outcome variables.

Results are summarized in Tables 1 to 4.

Table 1. Summary of the data collected from the manuscripts included in the review

	Dogs			Gait analysis method					Gait outcome variables for healthy dogs									
Author, year	*N*	Age*	BW[#] (Kg)	2D	3D	FP	PSW	Treadmill	Joint Angular Excursion	Joint Angular Velocity	Velocity	Cadence	Spatial Variables	Temporal Variables	GRF	NS	TPI/ MPI	PCA / PCP
Allen et al, 1994	14	NS	28 ± 4.5	-	+	-	-	-	+	-	+	+	+	+	-	-	-/-	-/-
Rumph et al, 1994	43	NS	18-32	-	-	+	-	-	-	-	+	-	-	+	+	-	-/-	-/-
Budsberg et al, 1995	30	NS	23-45	-	-	+	-	-	-	-	+	-	-	+	+	-	-/-	-/-
Hottinger et al, 1996	15	NS	NS	-	+	+	-	-	+	+	+	+	+	+	+	-	-/-	-/-
Rumph, Steiss, and Montgomery, 1997	133	NS	22-39	-	-	+	-	-	-	-	+	-	-	+	+	-	-/-	-/-
Gillette and Zebas, 1999	16	2-8 y	NS	+	-	-	-	-	+	+	+	+	+	+	-	-	-/-	-/-
Rumph, Steiss and West, 1999	52	NS	22-35	-	-	+	-	-	-	-	+	-	-	-	+	-	-/-	-/-
Bertram et al, 2000	8+5	5 mon 6-18 mon	17.6 ± 1.8 24.2 ± 3.0	-	-	+	-	-	-	-	+	+	+	+	+	-	-/-	-/-
Marsolais et al, 2003	13	1.7 ± 1.2 y	30.0 ± 7.1	-	+	-	-	+	+	+	+	-	-	-	-	-	-/-	-/-
Besancon et al, 2004	8+8	NS	27.30-36.36 31.40-41.82	-	-	-	+	-	-	-	+	-	-	-	+	-	-/-	-/-
Clements et al, 2005	10	1-5 y	29.5 ± 3.7	+	-	-	-	+	+	+	+	-	-	-	-	-	-/-	-/-
Colborne et al, 2005	6+6	6 y 6.5 y	30.3 ± 3.6 32.3 ± 3.5	-	+	+	-	-	+	-	+	-	-	-	+	-	-/-	-/-
Fanchon et al, 2006	10	2-6 y	26-34	-	-	+	-	+	-	-	+	-	+	+	+	-	-/-	-/-
Lascelles et al, 2006	34	NS	20-40	-	-	+	+	-	-	-	+	-	+	+	+	-	-/-	-/-
Bockstahler et al, 2007	20	1.5-11 y	21-32.6	-	+	+	-	+	+	+	+	-	-	-	+	-	-/-	-/-
Bockstahler et al, 2007	10	1.2-4 y	21.6-33.7	-	-	+	-	+	-	-	+	-	-	+	+	-	-/-	-/-
Feeney et al, 2007	10	>18 mon	NS	+	-	-	-	-	+	-	+	-	-	-	-	-	-/-	-/-
Kapatkin et al, 2007	10	NS	18.5-56.7	-	-	+	-	-	-	-	+	-	-	-	+	-	-/-	-/-
Van der Walt, 2008	30	1-7 y	20-35	+	-	-	-	-	+	-	+	-	-	-	-	-	-/-	-/-
Fanchon and Grandjean, 2009	28	1-10 y	17-51	-	-	+	-	+	-	-	+	-	-	-	+	-	-/-	-/-

* Age (in months or years), [#] BW - body weight expressed as mean, mean ± standard deviation or range, accordingly to authors; 2D - two dimensional, 3D - three dimensional, FP - force platform, PSW - pressure sensitive walkway system, GRF - ground reaction forces, NS - number of activated sensors, TPI/MPI – total and mean pressure index, PCA - peak contact area, PCP - peak contact pressure. NS – not stated, + - collected, - non-collected.

Table 1. Summary of the data collected from the manuscripts included in the review (cont.)

	Dogs			Gait analysis method					Gait outcome variables for healthy dogs									
Author, year	***N***	**Age***	**BW[#] (Kg)**	**2D**	**3D**	**FP**	**PSW**	**Treadmill**	**Joint Angular Excursion**	**Joint Angular Velocity**	**Velocity**	**Cadence**	**Spatial Variables**	**Temporal Variables**	**GRF**	**NS**	**TPI/ MPI**	**PCA / PCP**
Light et al, 2010	56	1-11 y	17.7-35.5	-	-	-	+	-	-	-	+	-	+	+	-	+	+/+	-/-
Molsa, Bjorkman and Vapaavuori, 2010	9+12	44 ± 20.5 34.5 ± 18.5 mon	43.6 ± 5.6 29.4 ± 2.8	-	-	+	-	-	-	-	+	-	-	+	+	-	-/-	-/-
Pfau et al, 2010	11	NS	12.6-19	-	+	+	-	-	-	-	+	-	-	+	+	-	-/-	-/-
Voss et al, 2010	129	4.1 ± 2.8 y	39.6 ± 14.5	-	-	+	-	-	-	-	+	-	-	+	+	-	-/-	-/-
Agostinho et al, 2011	10+ 10	2.1-5.1y 2-5.9y	33.3-39.4 37.4-44.8	-	+	-	-	+	+	+	+	-	-	-	-	-	-/-	-/-
Colborne et al, 2011	19	NS	28.6 ± 3.7	-	+	+	-	-	+	-	+	-	+	-	+	-	-/-	-/-
Kim, Kazmierczak and Breur, 2011	12	NS	2.6-8.7 29.1-44.7	-	-	-	+	-	-	-	+	+	+	+	+	-	-/-	+/+
Voss et al, 2011	54	4.2 ± 2.8 y	45.1 ± 11.7	-	-	+	-	-	-	-	+	-	-	+	+	-	-/-	-/-

* Age (in months or years), [#] BW - body weight expressed as mean, mean ± standard deviation or range, accordingly to authors; 2D - two dimensional, 3D - three dimensional, FP - force platform, PSW - pressure sensitive walkway system, GRF - ground reaction forces, NS - number of activated sensors, TPI/MPI – total and mean pressure index, PCA - peak contact area, PCP - peak contact pressure. NS – not stated, + - collected, - non-collected.

Table 2. Summary of the data collected from the manuscripts included in the review that used healthy dogs as controls for experimental surgery or diseased dogs (only healthy dogs information is summarised)

	Dogs			Gait analysis method					Gait outcome variables for healthy dogs									
Author, year	***N***	**Age***	**BW[#] (Kg)**	**2D**	**3D**	**FP**	**PSW**	**Treadmill**	**Joint Angular Excursion**	**Joint Angular Velocity**	**Velocity**	**Cadence**	**Spatial Variables**	**Temporal Variables**	**GRF**	**NS**	**TPI/ MPI**	**PCA / PCP**
Bennett et al, 1996	12	NS	30.0 ± 3.7	-	+	+	-	-	+	+	+	+	+	+	+	-	-/-	-/-
Poy et al, 2000	10	NS	32.1 ± 3.3	-	+	+	-	-	+	+	+	-	+	-	+	-	-/-	-/-
Evans, Horstman and Conzemius, 2005	17	NS	29.3 ± 0.8	-	-	+	-	-	-	-	+	-	-	-	+	-	-/-	-/-
Gordon-Evans et al, 2009	42	1-12.7 y	22.8 ± 3.1	-	-	-	+	-	-	-	+	-	+	+	-	-	-/-	-/-
Beraud, Moreau and Lussier, 2010	10	2.0 ± 1.5 y	31.2 ± 8.0	-	-	+	-	-	-	-	+	-	-	-	+	-	-/-	-/-
Ragetly et al, 2010	14	72-144 mon	36.2 ± 8.3	-	+	+	-	-	+	+	+	-	+	+	+	-	-/-	-/-

* Age (in months or years), [#] BW - body weight expressed as mean, mean ± standard deviation or range, accordingly to authors; 2D - two dimensional, 3D - three dimensional, FP - force platform, PSW - pressure sensitive walkway system, GRF - ground reaction forces, NS - number of activated sensors, TPI/MPI – total and mean pressure index, PCA - peak contact area, PCP - peak contact pressure. NS – not stated, + - collected, - non-collected.

Table 3. Summary of the data collected from the manuscripts included, regarding the influence of individual characteristics (age, body weight, height, gender, and body condition) in gait outcome variables.

	Individual characteristics				
Author, year	**Age**	**BW**	**Height**	**Gender**	**BCS**
Allen et al, 1994	-	-	-	-	-
Rumph et al, 1994	-	-	-	-	-
Budsberg et al, 1995	-	-	-	-	-
Bennett et al, 1996	-	-	-	-	-
Hottinger et al, 1996	-	-	-	-	-
Rumph, Steiss, and Montgomery, 1997	-	-	-	-	-
Gillette and Zebas, 1999	-	-	-	-	-
Rumph, Steiss and West, 1999	-	-	-	-	-
Bertram et al, 2000	-	-	+	-	-
Poy et al, 2000	-	-	-	-	-
Marsolais et al, 2003	-	-	-	-	-
Besancon et al, 2004	-	-	-	-	-
Clements et al, 2005	-	-	-	-	-
Colborne et al, 2005	-	-	-	-	-
Evans, Horstman and Conzemius, 2005	-	-	-	-	-
Fanchon et al, 2006	-	-	-	-	-
Lascelles et al, 2006	-	-	-	-	-
Bockstahler et al, 2007a	-	-	-	-	-
Bockstahler et al, 2007b	-	-	-	-	-
Feeney et al, 2007	-	-	-	-	-
Kapatkin et al, 2007	-	-	-	-	-
Van der Walt, 2008	-	-	-	-	-
Fanchon and Grandjean, 2009	-	-	-	-	-
Gordon-Evans et al, 2009	+	+	+	+	-
Beraud, Moreau and Lussier, 2010	-	-	-	-	-
Light et al, 2010	-	-	-	-	-
Molsa, Bjorkman and Vapaavuori, 2010	-	+	+	-	-
Pfau et al, 2010	-	-	-	-	-
Ragetly et al, 2010	-	-	-	-	-
Voss et al, 2010	-	+	+	-	-
Agostinho et al, 2011	-	-	-	-	-
Colborne et al, 2011	-	-	-	-	-
Kim, Kazmierczak and Breur, 2011	-	+	-	-	-
Voss et al, 2011	-	+	+	-	-

BW - body weight, BCS – body condition score, + - variable with influence, - - non-studied influence

Table 4. Summary of the results from the manuscripts that found influence of individual characteristics in hindlimb gait outcome variables.

		Author, year								
		Bertram et al, 2000		**Gordon-Evans et al, 2009**	**Molsa, Bjorkman and Vapaavuori, 2010**		**Voss et al, 2010**	**Kim, Kazmierczak and Breur, 2011**		**Voss et al, 2011**
Gait outcome variables		5 LR	8 GH	42	9 Rtw	12 LR	129	6 S	6 L	54
Velocity (m/s)		2.46 ± 0.27	2.47 ± 0.29	1.00 (0.45-1.45)	2.28 ± 0.05	2.25 ± 0.06	1.97 ± 0.04	0.76 ± 0.08	1.02 ± 0.03	1.98 ± 0.04
Cadence (stride/s)		2.32 ± 0.016*	2.17 ± 0.028	-	-	-	-	3.58 ± 0.52	1.80 ± 0.20*	-
Spatial Variables (m)	**SrL**	1.05 ± 0.008*	1.13 ± 0.013	70% cv with V 90% cv with H 80% cv with W	-	-	-	0.37 ± 0.08	0.83 ± 0.06*	-
	Rel. SrL	2.95 ± 0.026	2.96 ± 0.055	-	-	-	-	-	-	-
Temporal Variables (s)	**SrT**	0.43 ± 0.003*	0.46 ± 0.006	20% cv with V	-	-	-	0.51 ± 0.08	0.84 ± 0.06*	-
	Rel. SrT	2.28 ± 0.019	2.29 ±0.043	70% cv with H 70% cv with W	-	-	-	-	-	-
	STDF/Rel	-	-	10% cv with V 60% cv with H	0.238 ± 0.016	0.213 ± 0.016*	0.261 ± 0.039 1.01 ± 0.10†	0.28 ± 0.06	0.53 ± 0.04*	- 1.04 ± 0.08†
	ST	0.401 ± 0.028	0.377 ± 0.039	60% cv with W	-	-	-	0.55 ± 0.04	0.62 ±0.02*	-
	SwT	-	-	40% cv with V 70% cv with H 50% cv with W	-	-	-	0.23 ± 0.02	0.32 ± 0.04*	-
Ground Reaction Forces (N)	**MVF**	0.43 ± 0.04*§	0.57 ± 0.07§	-	-	-	-	3.18 ± 1.70 5.52 ± 0.96§	70.22 ± 7.96* 19.28 ± 1.48*§	-
	PVF	0.76 ± 0.08*§	1.07 ± 0.13§	-	71.9 ± 2.8§	72.5 ± 4.8§	277 ± 98.3 72.2 ± 7.4§	15.95 ± 6.22 27.83 ± 3.02§	97.76 ± 10.02* 26.86 ± 1.83§	71.21 ± 7.79§
	PVF T	-	-	-	0.102 ± 0.007	0.092 ± 0.008	-			-
	VI	-	-	-	9.3 ± 0.6§	8.3 ± 0.6*§	42.2 ± 19.0 10.5 ± 1.3§ 40.7 ± 3.3†	0.99 ± 0.69 1.54 ± 0.63§	36.91 ± 5.83* 10.10 ± 0.90*§	41.51 ± 2.81†§
	RS	-	-	-	0.71 ± 0.06§	0.78 ± 0.11*§	-	-	-	-
	FS	-	-	-	- 0.99 ± 0.09§	- 1.08 ± 0.13*§	-	-	-	-
	PBrF	-	-	-	- 6.6 ± 2.3§	-6.3 ± 1.7§	-	-	-	-
	BrI	-	-	-	- 0.27 ± 0.13§	- 0.25 ± 0.11§	-	-	-	-
	Br T	-	-	-	0.028 ± 0.006	0.028 ± 0.009	-	-	-	-
	PPropelF	-	-	-	10.8 ± 1.9§	11.3 ± 1.5§	-	-	-	-
	Propel I	-	-	-	0.87 ± 0.17§	0.81 ± 0.16§	-	-	-	-
	Propel T	-	-	-	0.149 ± 0.009	0.134 ± 0.01*	-	-	-	-
PCA (cm^2)		-	-	-	-	-	-	3.59 ±1.40	19.34 ± 2.51*	-
PCP (kPa)		-	-	-	-	-	-	35.75 ± 9.35	68.99 ± 6.77*	-

GH – Greyhounds, LR – Labrador retriever, Rtw – Rottweiler, S – small size dogs, L – large size dogs, SrL – stride length, SrT – stride time, SwT – swing time, ST – stance time, DF – duty factor – defined as the fraction of the total stride time in which the foot is in contact with the ground, Rel – relative, FL – forelimb, HL – hindlimb, Diag – diagonal pair, MVF – mean vertical force, PVF – peak vertical force, PVF T – time to PVF, VI – vertical impulse, RS – rising slope, FS – falling slope, PBrF – braking peak force, BrI – braking impulse, Br T – braking time, PPropelF – propelling peak force, Propel I – propelling impulse, Propel T – propelling time, PCA - peak contact area, PCP - peak contact pressure, s – seconds, m – meters, N – Newtons, kPa – kilopascal, Max – maximum, * - significant differences between groups, § - body weight normalised variable, † - height normalised variable, cv – covariation.

Discussion and Conclusions

This study represents an overview of the scientific investigation on kinetic and kinematic analysis of canine gait through a systematic review methodology, assembling and compiling the existent information from healthy dogs' assessment.

A preliminary establishment of a normative database is needed to define gait parameters and explain their variability. Based on this premise, the trigger research questions for this review were: "Do individual characteristics of the dog influence their gait?", "What relations were found between the dogs' individual characteristics and their gait variables?" and "What individual characteristic(s) are more influential in gait outcome variables?"

From the 34 manuscripts included in this systematic review, only 6 studied the influence of individual characteristics such as age, body weight, height, and gender in the canine gait, expressed as gait outcome variables (Bertram et al., 2000; Gordon-Evans, Evans, & Conzemius, 2009; Molsa, Hielm-Bjorkman, & Laitinen-Vapaavuori, 2010; Voss et al., 2010; Kim et al., 2011; Voss et al., 2011). The influence of body condition on gait outcome variables was not studied in the analysed manuscripts.

In order to study such influences, it is imperative that the study design contemplates a minimally heterogeneous group of dogs, although that was not the reality in the majority of the analysed studies, where groups were very homogeneous in size, body weight or breed. Actually, from the total 34, sixteen studies focused on specific breeds such as Labrador Retrievers (Gillette & Zebas, 1999a; Clements, Owen, Carmichael, & Reid, 2005; Evans et al., 2005; Light et al., 2010; Ragetly, Griffon, Mostafa, Thomas, & Hsiao-Wecksler, 2010; Colborne, Good, Cozens, & Kirk, 2011), Greyhounds (Rumph et al., 1997; Rumph et al., 1999), Malinois Belgian Shepherds (Fanchon, Valette, Sanaa, & Grandjean, 2006; Bockstahler et al., 2007), and Border Collies (Pfau et al., 2011) or compared two breeds: Labrador Retrievers with Greyhounds (Bertram et al., 2000; Besancon et al., 2004; Colborne, Innes, Comerford, Owen, & Fuller, 2005) and Labrador Retrievers with Rottweilers (Molsa et al., 2010; Agostinho et al., 2011). These investigators reported that an important percentage of variance was attributable to the individual dogs, both when comparing different breeds and within dogs of the same breed, suggesting that morphology is a major determinant in a baseline gait analysis and postulating that the study of morphologic and body conformation differences deserve better attention in further studies. Baselines for these breeds had been complemented over time and are very useful to compare dogs, but animals from other breeds and mixed breed dogs lack reference values, hampering their standardised evaluation. The vast number of existing and emerging breeds is an important handicap for the definition of normal values so its evaluation according to individual characteristics may be a way to overcome such an important heterogeneity.

In order to answer the first question, “Do individual characteristics of the dog influence their gait?”, we found an affirmative answer from the studies that did studied this influence. Individual characteristics such as age (Gordon-Evans, Evans, & Conzemius, 2009), gender (Gordon-Evans, Evans, & Conzemius, 2009), height (Bertram et al., 2000; Gordon-Evans, Evans, & Conzemius, 2009; Molsa et al., 2010; Voss et al., 2010; Voss et al.,2011) and BW (Gordon-Evans, Evans, & Conzemius, 2009; Molsa et al., 2010; Voss et al., 2010; Kim et al., 2011; Voss et al., 2011) demonstrated to influence gait outcome variables.

Such influence was detailed in the answer to the second and third questions: “What relations were found between the dogs’ individual characteristics and their gait variables?” and “What individual characteristics are more influential in gait outcome variables?”.

Gordon-Evans, Evans, and Conzemius (2009) addressed the walking temporospatial variables (TSV) of an heterogeneous group of dogs (mixed-breed, and other diverse breeds) and their covariation, and found that 25% of the swing time (SwT) variability was attributable to the age of the dog, and that female dogs had significantly longer stride length (SrL) and non-significantly longer stride time (SrT) than male dogs. Both height and body weight of the dogs showed a strong direct relationship with SrT, SwT, SrL, and stance time (ST). Even after a normalisation of the TSV to height, an influence of body weight remained on SrT, ST, and SwT. This influence of BW comes in accordance with the findings of Kim et al. (2011) that compared small with large breed dogs walking in a PSW and recorded a positive correlation of BW with TSV of small dogs and with peak vertical forces of both small and large breeds. The authors also demonstrated that small dogs have lower TSV and kinetic variables than large ones.

Bertram et al. (2000), by comparing the trotting gaits of Labrador Retrievers and Greyhounds, attributed differences to the height of the dogs, measured by the functional limb length (distance from the ground to the elbow joint plus one third of the distance from the elbow joint to the highest point of the back at midstance), resulting in longer but fewer strides in Greyhounds than in Labradors. Functional limb length was also defined by Molsa et al. (2010) as being the most influential anatomical measurement in kinetic values when trotting Labrador Retrievers and Rottweilers were compared using a FP. Other less significant variables were humeral and femoral bone length and dog height. In addition to this body conformation effect, investigators also demonstrated that the dogs’ BW correlated with all FP values that were significantly different between the two breeds. Rottweilers showed higher absolute ST and times to peak vertical forces (PVF) than Labradors. In the study of Voss et al. (2010) higher ST were also showed in large dogs when compared to medium dogs trotting on a FP, demonstrating strong positive correlations between BW and height with ST, PVF and vertical impulses. After full normalisation of the variables to the presumed influential characteristics, not all variability was eliminated, leading the investigators to attribute some important variation to the individual velocity and some residual variance to unknown factors, possibly related to motivational issues (Voss et al., 2010; Voss et al., 2011). Aspects like general body build and muscle mass may represent some source of variability but have been till the moment ignored factors in the analysis of covariation between the dogs' individual characteristics and gait outcome variables.

Bockstahler, Skalicky, Peham, Muller, and Lorinson (2007b), though not having studied the relationship between height and gait variables, hypothesized that the ST variability of dogs trotting at a treadmill imposed velocity, was due to height differences, since dogs were not allowed to self-select an individual velocity.

After analysis of the studies, it was possible to conclude that very few records aimed at studying the individual influence of the dog in its movement. From the six records that studied such influence, we concluded that BW and height proved to significantly influence both kinetic and kinematic gait variables, deserving special data treatment with proper normalisation of the variables.

Only 2 studies included dogs under 10 Kg of BW (Gordon-Evans, Evans, & Conzemius, 2009; Kim et al., 2011), hence small dogs are underrepresented when compared to medium and, mainly, large dogs. Therefore, many conclusions, albeit extremely valid, may not be useful when small breeds are to be assessed. Furthermore, none of the studies assessed animal sizes independently of their breed, once again imposing doubts on the validity of their conclusions in the evaluation of mixed breed dogs.

Another important conclusion is that the most frequently used methods - FP (41,2%) and combined FP with 3D (20,6%) – relied on sophisticated and expensive equipment and software that are hardly a cost effective investment in clinical veterinary centres but rather exist only in biomechanical and motion analysis laboratories for scientific purposes. As a consequence, it may be assumed that objective gait analysis instruments are not available for daily clinical practice where the need to assess canine gait in an objective and comparable way is of the utmost importance. 2D analysis may represent a simple and less expensive instrument for kinematic gait assessment with high intraobserver repeatability (Feeney et al., 2007), and the additional advantage of allowing for motion image collection in distinct locations (Gillette & Zebas, 1999b).

Methodological quality assessment was performed using an adapted version of the Downs and Black (1998) checklist. The main identified quality deficits were randomisation methods, poor information on dogs' characteristics, and lack of information about dog's allocation, the non-blindness assessors, and the omission about losses. The mean QI score of the reviewed studies was 12, which reflects the upper limit of the poor methodological quality grade. The majority were non-randomised prospective studies which, according to

Aragon and Budsberg (2005), are class III level of evidence studies and represent low quality evidence. Although randomisation and blinding methods are important to reduce biases (Cook et al., 2010), time-consuming, valuable and meritorious work led to valuable conclusions about the influence of individual characteristics of the dogs in their gait outcome variables.

Kinetic and kinematic gait analysis has widely evolved, albeit more large randomised controlled trials with higher heterogeneity are warranted.

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Appendix

	Yes No Unable to determine
Reporting:	
1. Is the hypothesis/aim/objective of the study clearly described?	1 0 0
2. Are the main outcomes to be measured clearly described in the introduction or methods section?	1 0 0
3. Are the characteristics of the patients included in the study clearly described?	1 0 0
4. Are the interventions under study clearly described	1 0 0
5. Are the distributions of principal confounders in each group of study participant to be compared, clearly described?	2 0 0 1=P
6. Are the main findings of the study clearly described?	1 0 0
7. Does the study provide estimates of the random variability (e.g. standard error, standard deviation, confidence intervals, inter-quartile range) in the data for the main outcomes?	1 0 0
8. Have all important adverse events/negative outcomes that may be a consequence of the intervention been reported?	1 0 0
9. Have the characteristics of patients lost to follow-up been described?	1 0 0
10. Have actual probability values been reported (e.g. 0·035 rather than <0·05) for the main outcomes except where the probability value is less than 0·001?	1 0 0
Total reporting score____	
External validity:	
11. Were the patients who participated representative of the entire population from which they were recruited?	1 0 0
12. Were the staff, places, and facilities where the study participants received the intervention representative of the intervention the majority of subjects received?	1 0 0
Total external validity score____	
Bias:	
13. Was an attempt made to blind those measuring the main outcomes of the intervention?	1 0 0
14. If any of the results of the study were based on "data dredging," was this made clear?	1 0 0
15. In trials and cohort studies, do the analyses adjust for different lengths of follow-up of study participants, or in case–control studies, is the time period between the intervention and outcome the same for cases and controls?	1 0 0
16. Were the statistical tests used to assess the main outcomes appropriate?	1 0 0
17. Was compliance with the intervention/s reliable?	1 0 0
18. Were the main outcome measures used accurate (valid and reliable)?	1 0 0
Total bias score____	
Selection bias:	
19. Were the study participants in the different intervention groups (trials or cohort studies) or were the cases and controls (case–control studies) recruited from the same population?	1 0 0
20. Were the study participants in the different intervention groups (trials and cohort studies) or were the cases and controls recruited over the same time period?	1 0 0
21. Were the study participants randomised to intervention groups?	1 0 0
22. Was the randomised intervention assignment concealed from both study participants and intervention staff until recruitment was complete and irrecoverable?	1 0 0
23. Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?	1 0 0
24. Were losses of study participants to follow-up taken into account?	1 0 0
Total selection bias score____	
Power	
25. Did the study mention having conducted a power analysis to determine the sample size needed to detect a significant difference in effect size for one or more outcome measures?	1 0 0
Total Quality Index score____	

Grade of quality	Quality Index score
Poor	≤12
Fair	13 to 17
Good	18 to 23
Excellent	24 to 26

Figure A1 - Adapted methodological quality index checklist for randomised controlled trials an observational studies (Downs & Black 1998). Adapted from McCready, D. J., & Ness, M. G. (2016). Systematic review of the prevalence, risk factors, diagnosis and management of meniscal injury in dogs: Part 2. J Small Anim Pract, 57(4), 194-204. doi:10.1111/jsap.12462

‖ CHAPTER IV

Development of a scale to evaluate mobility in dogs

Abstract

Introduction: There are already several different scales and instruments capable of assessing diverse outcome measures in dogs, giving an important contribute to evaluation and revaluation moments. The domain of mobility has not been deepen yet in this field.

Objectives: The purpose of this study was to develop and assess the psychometric characteristics of a mobility scale for dogs.

Methods: The original ten questions were reduced to eight, using validation process. One hundred and twenty three healthy dog owners were invited to answer the questionnaire. Internal consistency, factor analysis, floor and ceiling effect and construct validity were studied.

Results: Good internal consistency (Cronbach's Alpha = 0.854) was determined upon the elimination of two items. The instrument comprises 8 final questions, each one with five possible answers (never, rarely, sometimes, often and always) scored between 0 and 4 or between 4 and 0 (for items with inverse score). Three hypotheses proposed for the construct validity were verified: 1) gender does not influence dog mobility ($p = 0.584$); 2) mobility decreases with age ($p < 0.001$); 3) dogs with diagnosed orthopaedic or neurological conditions have lower mobility scores (median score (P25; P75) 46.9% (31.3; 68.8)) than healthy dogs (median score (P25; P75) 81.3% (71.9; 93.8)) ($p < 0.001$). The total score range was 0 to 32 points, with higher values indicating greater mobility of dogs.

Conclusions: The Dog Mobility Scale was capable of assessing mobility in dogs, with good psychometric characteristics, and is a simple and inexpensive tool to apply in clinical practice.

Introduction

Companion animal function and activities of daily living have been a concern to owners and veterinary practitioners (Millis & Levine, 2014). Its objective evaluation must rely, however, in the quantification of rather subjective, variable, and often biased, assessments. The increased longevity of companion dogs has strengthened the dog-owner relationship, with the pet assuming the status of a family member in many households. This evolution has been accompanied by the search for better veterinary care, in many circumstances approaching the levels of human health care, in preventive, diagnostic, and therapeutic terms. In both species, aging often results in mobility issues, and the assessment of function and its response to management and therapy are important. However, it is difficult to identify and quantify subtle clinical signs, often subjected to human personal interpretation and modulated by the dog behaviour and temperament characteristics, both individual and breed-related (Hsu & Serpell 2003).

In an attempt to overcome sometimes confusing and misleading interpretations, veterinary professionals have developed or adapted several different scales for the measurement of acute and chronic pain, quality of life, or lameness, with the intent of standardizing evaluations to assess an animal's status and response to treatment. Examples include Visual Analogue Scales and Numerical Rating Scales (Hellyer et al 2007; Quinn et al 2007; Epstein, 2010), the Short-Form Glasgow Composite Measure Pain Scale (Holton et al 2001; Reid, 2007), the Composite Orthopaedic Pain Scale (Bussiéres et al 2008), the Functional Stifle Score (Millis & Levine, 2014), the Canine Functional Independence Measure (Hesbach, 2006), the proposed model of the Canine Timed Up and Go (Hesbach, 2003), the Melbourne Pain Scale (Firth & Haldane 1999), the Helsinki Chronic Pain Index (Hielm-Bjorkman et al 2003), the Canine Brief Pain Inventory (Brown et al 2007), the CHQLS-21 (Lavan, 2013) and the HRQL structured questionnaire (Wiseman-Orr et al 2004).

One problem that subjective scores often face is their agreement with objective measurements (e.g. force platforms, pressure walkways). Indeed, although the former are quicker and more practical to use in routine clinical practice, and remain as valuable outcome measures in many studies provided that the observer is always the same (Johnson et al 1997; Ballagas et al 2004; Monk et al 2006; Jandi & Schulman 2007; Jerre, 2009), mild conditions may still remain undetected (Quinn et al 2007; Waxman et al 2008).

The domains of pain and quality of life have been extremely well studied and explored. Properly developed and validated complex instruments, based on the multifactorial combination of visual analogue scales with the description of behaviour, temperament, demeanour and locomotion of the dog, have been compared with objective assessments, such as measurement of ground reaction forces (Brown et al 2008; Hielm-Bjorkman et al 2009; Hielm-Bjorkman et al 2011; Brown et al 2013).

In this contemporaneous and evolving science, we believe that it is necessary to improve the knowledge and deepen the study of another aspect of canine function, the functional mobility. To the best of our knowledge, this dimension has received relatively little attention at the individual level, but rather has been studied in association with signs of disease or clinical features, as a sub-category of pain or quality of life instruments. Focusing on the assessment of mobility during daily activities would allow for the evaluation of the dog's ability to move and perform its daily functional routines, as well as quantifying its changes over time. A change in mobility does not always imply the presence of pain, lameness or other clinical signs but rather precedes them, so recognizing changes in mobility allows for early interventions that are potentially more effective in preventing its evolution with less suffering, lower costs and higher quality of life.

Functional mobility includes all postures and movements involved in daily function, from maintenance of static recumbence, sitting and standing postures, to the dynamic transitions to and from these positions, requiring appropriate concentric and eccentric motor control (Hesbach, 2007). A properly developed and validated scale or questionnaire to assess mobility is lacking in the veterinary literature.

Assessment of mobility in a new, strange and stressful environment, such as a veterinary centre, may be hindered by the influence of such conditions on the dog's behaviour. Consequently, we believe that the assessment of individual dog mobility should rely on the observation of the components of a mobility scale in familiar environments, such as the family household. The owner or caretaker may be the appropriate person to evaluate mobility because he/she has a better knowledge of the dog behaviour, attitude and movements that allows for an earlier detection of the first changes, thus providing good and valuable information for a more accurate mobility assessment. Therefore, the evaluation of mobility in the household environment may provide valuable information regarding the degree of return to function, which may represent the best indication of a successful outcome following treatment (Millis & Levine, 2014). In addition, the inter-observer differences are eliminated by having the owner as the sole evaluator, hard to achieve in the clinical context where it is probable that multiple staff elements are involved in the patient follow-up (Quinn et al 2007; Waxman et al 2008).

The purpose of this study was to develop and to assess the psychometric characteristics of a mobility scale for dogs, the Dog Mobility Scale (DMS). To further evaluate the validity of the construct scale, the following hypotheses were tested: (1)

there is no gender-related mobility variation in dogs; (2) older dogs have reduced mobility; (3) dogs affected by diseases have reduced mobility.

Methods

The development of the questionnaire underwent sequential procedures. Ten initial questions were created by a veterinary practitioner and a physiotherapist aiming to assess simple daily vital activities, such as eating, sleeping, and elimination (micturition and defecation), and more active abilities, including running, jumping and climbing stairs. Besides questions to characterize each dog (name, age, gender, breed, weight, vaccination, type of feeding), owners were questioned if the dog had been diagnosed with potential mobility-limitation conditions. Dogs with diagnosed orthopaedic or neurological conditions constituted the group "with pathology". Questions were then presented to an experts committee composed of 2 small animal veterinary practitioners, 2 physiotherapists and 1 dog owner to further evaluate grammar and language issues, individual value and meaning to the composite scale, utility of interpretation and understanding of the information contained in the scale. A final evaluation was then performed by application of the questionnaire to 6 dog owners to detect any other formal imperfection.

One hundred and twenty three dog owners were invited to personally complete the questionnaire after being informed of the objectives and procedures of the study and signing an informed consent declaration. Inclusion criteria were that no recent changes were made to the household environment. Data were excluded if the owners declared that they did not observe their dog's routines. No individual owner information was disclosed. This study was approved by the scientific commission and the board direction of the PhD program in veterinary sciences of the University of Porto, Portugal.

Statistical methods and Data Analysis

Psychometric methodology was used to analyse the scale. Its internal consistency was evaluated through inter-item correlation methods (r) and Cronbach's Alpha (α). For the first analysis, an inter-item correlation coefficient under 0.30 was considered to be weak, between 0.30 and 0.70 moderate, and over 0.7 as a strong correlation.

Factor analysis was used to verify the way items grouped themselves into different dimensions, setting 0.4 as an acceptable minimum for correlation between original variables and main components. The final scale score was calculated by summing all items followed by conversion to a percentage: [(score– minimum) / (maximum – minimum) *100]. The floor and ceiling effect was studied to understand if the extreme scores of the scale (lower and higher) were visible between the others. In case of the absence of the effect, it was considered positive for the content validity of this instrument and also for it responsiveness and reliability (Terwee et al., 2007).

Mann-Whitney test was applied to study the construct validity, comparing male with female scores, and scores of dogs with and without known conditions that could affect mobility. The Spearman's Correlation Coefficient was used to compare the scale scores with the dogs' ages, and Kruskal-Wallis test was applied to compare the scale scores between quartiles of dogs' ages.

All statistical analyses were tested as 2-tailed with $\alpha=0.05$. Analyses were performed using Statistical Package for the Social Sciences (SPSS), version 19.0, software for Windows.

Results

During the review process, the expert committee made changes primarily related to syntax and grammar. No changes were deemed necessary after the preliminary test so the questionnaire was considered to be adequate for use.

The final sample consisted of 123 owner-dog pairs, with 62 female (50.4%) and 61 (49.6%) male dogs. Fifty-eight dogs were mixed breed (47.2%). Labrador retrievers (n=11; 8.9%), German Shepherd Dogs (n=6; 4.9%), Poodles (n=5; 4.1%), Miniature Pinschers (n=4; 3.3%), Cocker Spaniels (n=4; 3.3%) and Golden Retrievers (n=3; 2.4%) were the most frequent pure breeds. Dogs weighed 1.2 to 52 Kg, with a mean of 19.34 Kg. The median age of the dogs was 54.0 months (percentile 25: 36 months; percentile 75: 120 months).

Initial exploratory data analysis, using bar graphs and frequency measures (Table 1), resulted in the inversion of scores of items 1, 2, 7, 8, 9 and 10 as they were scored in the opposite direction of the other questions. None of the options had a frequency of zero and there was only one missing answer for item 4.

Table 1.

Dog mobility scale items analysis and response frequencies (*N*, %).

Regarding your dog's mobility during the last week…

N=123	**Never n (%)**	**Rarely n (%)**	**Sometimes n (%)**	**Often n (%)**	**Always n (%)**
1. ...did you notice difficulty in the first steps after waking up and arising?	90 (73.2)	11 (8.9)	9 (7.3)	10 (8.1)	3 (2.4)
2. …did he/she show difficulty climbing stairs?	93 (75.6)	10 (8.1)	6 (4.9)	8 (6.5)	6 (4.9)
3. …did he/she desire to play?	4 (3.3)	13 (10.6)	26 (21.1)	33 (26.8)	47 (38.2)
4. …did he/she react when offered food? [a]	1 (0.8)	5 (4.1)	9 (7.3)	19 (15.4)	88 (71.5)
5. …did he/she run?	13 (10.6)	14 (11.4)	20 (16.3)	38 (30.9)	38 (30.9)
6. …did he/she climb easily on to the sofa, bed or some other higher plane?	22 (17.9)	11 (8.9)	10 (8.1)	22 (17.9)	58 (47.2)
7. …did he/she show fatigue during longer walks?	47 (38.2)	35 (28.5)	14 (11.4)	14 (11.4)	13 (10.6)
8. …did he/she often change position while sleeping?	41 (33.3)	51 (41.5)	25 (20.3)	4 (3.3)	2 (1.6)
9. …did he/she show changes in the way he/she walked?	87 (70.7)	22 (17.9)	5 (4.1)	4 (3.3)	5 (4.1)
10. …did he/she spend too much time in the same position?	57 (46.3)	40 (32.5)	16 (13.0)	9 (7.3)	1 (0.8)

Items translated into English (Portuguese in the original document)
[a] One missing

Internal Consistency

In order to validate the scale for its proposed objective, mobility assessment, its internal consistency was analysed for the sum of all items (Table 2). The Cronbach's alpha was 0.822. After analysing the individual item-total correlations and the Cronbach alpha if the item was deleted, items 4 (…did he/she react when offered food?) and 8 (…did he/she often change position while sleeping?) were removed due to weak item-total correlation and an increased Cronbach's alpha after deletion. After such eliminations, the final Cronbach's alpha was 0.854.

Table 2.

Dog mobility scale internal consistency.

Regarding your dog's mobility during the last week…

	Item-Total Correlation	**Cronbach's Alpha if eliminated item**	**Global Cronbach's Alpha**
1. ...did you notice difficulty in the first steps after waking up and arising? (inverted)	0.640	0.792	0.822
2. …did he/she show difficulty climbing stairs? (inverted)	0.731	0.781	
3. …did he/she desire to play?	0.437	0.812	
4. …did he/she react when offered food?	**0.153**	**0.833**	
5. …did he/she run?	0.598	0.795	
6. …did he/she climb easily to the sofa, bed or some other higher plane?	0.608	0.795	
7. …did he/she show fatigue during longer walks? (inverted)	0.551	0.801	
8. …did he/she often change position while sleeping? (inverted)	**0.096**	**0.838**	
9. …did he/she show changes in the way he/she walked? (inverted)	0.641	0.793	
10. …did he/she spend too much time in the same position? (inverted)	0.573	0.800	

Items translated into English (Portuguese in the original document)

Factor Analysis

The factor analysis allowed for the identification of a solution with one component or dimension - mobility - explaining 50.8% of the total variance. The final solution (Table 3) was identified by the factor loads in the correlations matrix (factor load over 0.4 for every item), with no need for the elimination of any other item (Figure 1).

Table 3.

Factor loading obtained from exploratory factor analysis of the Dog Mobility Scale: one-factor model.

Regarding your dog's mobility during the last week…

		Factor Analysis 1
1.	...did you notice difficulty in the first steps after waking up and arising? (inverted)	0.745
2.	…did he/she show difficulty climbing stairs? (inverted)	0.831
3.	…did he/she desire to play?	0.541
4.	…did he/she run?	0.723
5.	…did he/she climb easily on to the sofa, bed or some other higher plane?	0.733
6.	…did he/she show fatigue during longer walks? (inverted)	0.672
7.	…did he/she show changes in the way he/she walked? (inverted)	0.735
8.	…did he/she spend too much time in the same position? (inverted)	0.689

Items translated into English (Portuguese in the original document)

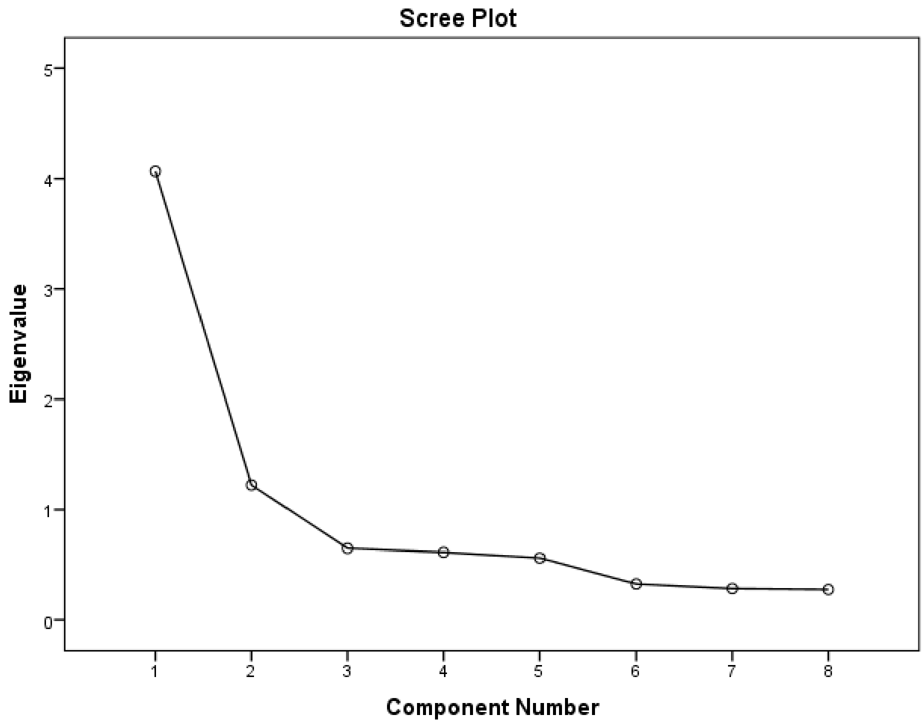

Figure 1. Scree plot of eigenvalues after exploratory factor analysis. The shape of the graph indicates that the Dog Mobility Scale is best explained as a single component index, including all of the 8 items (N=123). This component is referred to as a mobility component.

Floor or ceiling effect

Each of the eight items had five possible answers: never, rarely (once or twice/week), sometimes (3 times/week), often (4 or 5 times/week), and always scored between 0 and 4 (items 3, 4 and 5) or between 4 and 0 (items 1, 2, 6, 7 and 8) (Figures 2a and 2b). The total score range was 0 to 32 points, with higher values indicating greater mobility of dogs. Ten dogs (8.1%) reached the maximum score (32 points or 100%) and none had the minimum score (0 points or 0%). Thus, because these values are lower than 15% it was concluded that there was no floor or ceiling effect (Terwee et al 2007) (Figure 3).

DOG MOBILITY SCALE

Regarding your dog's mobility during the last week (compared to 4 months ago)...

	Never	Rarely[1]	Sometimes[2]	Often[3]	Always
1. ...did you notice difficulty in the first steps after waking up and arising? (slower or stiffer movements)	□ (4)	□ (3)	□ (2)	□ (1)	□ (0)
2. ...did he/she show difficulty climbing stairs? (reluctance or avoidance of stairs)	□ (4)	□ (3)	□ (2)	□ (1)	□ (0)
3. ...did he/she desire to play? (assuming playful body postures)	□ (0)	□ (1)	□ (2)	□ (3)	□ (4)
4. ...did he/she run? (usual runs, alone or encouraged)	□ (0)	□ (1)	□ (2)	□ (3)	□ (4)
5. ...did he/she climb easily to the sofa, bed or some other higher plane? (jumping or climbing)	□ (0)	□ (1)	□ (2)	□ (3)	□ (4)
6. ...did he/she show fatigue during longer walks? (usual or regular walks)	□ (4)	□ (3)	□ (2)	□ (1)	□ (0)
7. ...did he/she show changes in the way he/she walked? (awkward or strange walking movements)	□ (4)	□ (3)	□ (2)	□ (1)	□ (0)
8. ...did he/she spend too much time in the same position? (while awakened)	□ (4)	□ (3)	□ (2)	□ (1)	□ (0)

[1] – Once or twice/week; [2] – Three times/week; [3] – Four or five times/week.

Total score: _____

Figure 2a. Dog Mobility Scale (DMS), in English.

ESCALA DE MOBILIDADE DO CÃO

Relativamente à mobilidade do seu cão durante a última semana…
(compare com os últimos 4 meses)…

	Nunca	Poucas Vezes[1]	Algumas Vezes[2]	Muitas Vezes[3]	Sempre
1. ... notou dificuldade nos seus primeiros passos depois de acordar? (movimentos mais lentos ou mais rígidos)	□ (4)	□ (3)	□ (2)	□ (1)	□ (0)
2. … subiu as escadas com dificuldade? (mostrou relutância ou evitou escadas?)	□ (4)	□ (3)	□ (2)	□ (1)	□ (0)
3. … procurou-o(a) para brincar? (fazendo movimentos corporais típicos)	□ (0)	□ (1)	□ (2)	□ (3)	□ (4)
4. … fez corridas? (corridas habituais, sozinho ou motivado)	□ (0)	□ (1)	□ (2)	□ (3)	□ (4)
5. … subiu facilmente para o sofá, para a cama ou algo elevado? (saltar ou subir)	□ (0)	□ (1)	□ (2)	□ (3)	□ (4)
6. … mostrou cansaço em caminhadas mais longas? (caminhadas habituais)	□ (4)	□ (3)	□ (2)	□ (1)	□ (0)
7. … mostrou alterações na forma de andar? (movimentos estranhos)	□ (4)	□ (3)	□ (2)	□ (1)	□ (0)
8. … passou muito tempo na mesma posição? (enquanto acordado(a))	□ (4)	□ (3)	□ (2)	□ (1)	□ (0)

[1] – 1 a 2 vezes/semana; [2] – 3 vezes/semana; [3] – 4 a 5 vezes/semana.

Pontuação total: _____

Figure 2b. Dog Mobility Scale (DMS), in Portuguese.

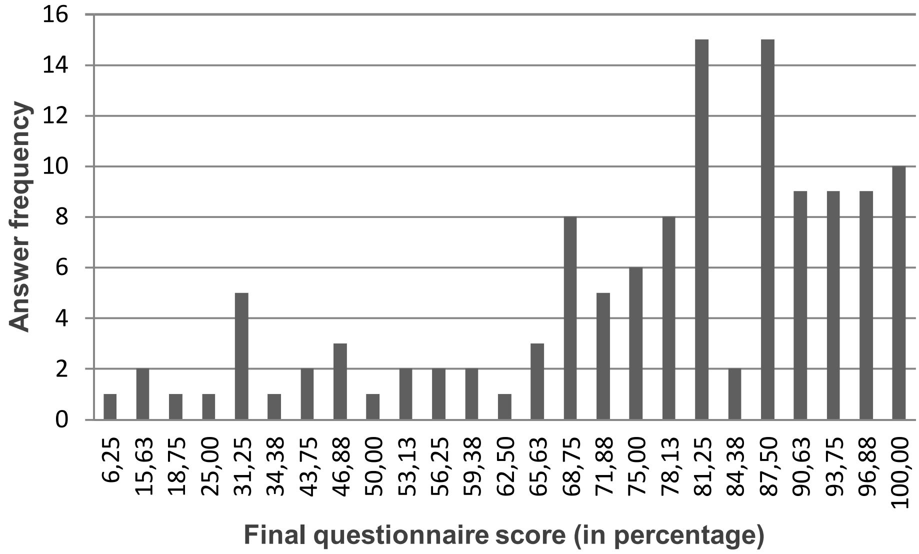

Figure 3. Final score frequency distribution: floor and ceiling effect analysis.

Construct Validity and Testing of Hypotheses

Differences between genders were found not to be statistically significant. There was a statistically significant difference in the mobility scores between age quartiles ($p < 0.001$). Finally, the reported orthopaedic or neurological conditions, diagnosed by veterinary practitioners, included hip dysplasia (4; 3.25%) osteoarthritis (3; 2.44%), vertebral disc herniation (2; 1.63%), elbow dysplasia, spondylitis, amputation and limb dysmetria (each one with 1 case; 0.81%). Statistically significant differences (p<0.001) were found in the mobility scores between dogs with and without orthopaedic or neurologic conditions (Table 4).

Table 4.
Median (percentile 25; percentile 75) of the Dog Mobility Scale Score by demographic groups.

	Scale Mobility Score (%) *Median (P25; P75)*	*p*	
Gender			
Male	81.3 (70.3; 90.6)		
Female	81.3 (68.0; 90.6)	0.584*	
Age (months)			
<36 (1st Quartile)	87.5 (81.3; 93.8)		
36-54 (2nd Quartile)	87.5 (78.1; 92.2)		1st vs 2nd *p* = 0.653*
55-120 (3rd Quartile)	75.0 (65.6; 89.1)	**<0.001#**	2nd vs 3rd ***p* = 0.022***
>120 (4th Quartile)	46.7 (31.3; 71.1)		3rd vs 4th ***p* < 0.001***
Orthopaedic/Neurological Conditions			
With Pathology	46.9 (31.3; 68.8)	**<0.001***	
Without Pathology	81.3 (71.9; 93.8)		

P25: 25th percentile; P75: 75th percentile.* Mann-WhitneyTest # Kruskal-Wallis Test

Discussion and Conclusion

Among the minimum requirements for companion animal well-being, sufficient mobility is essential to autonomously perform basic needs (eating and drinking, elimination, social behaviour, family interactions). Furthermore, success in the management of many irreversible orthopaedic conditions (e.g. degenerative joint disease) requires prompt intervention in the early stages when minor mobility reductions are the only clinical manifestation, long before pain or other signs of advanced disease are obvious. It is frequent for dog owners to feel that “something is wrong” with their dogs, but they are unable to clarify to what extent and how severe the problem is. When such subjectivity is accompanied by excitement; stoicism; fear; or other behaviours during veterinary examination, it becomes very difficult, if not impossible, to objectively decide if further preventive, diagnostic or therapeutic actions are warranted, with potential consequences in its planning, execution, and monitoring, as well as in the effectiveness of diagnostic and therapeutic workup.

Although clinical metrology has received relatively little attention in veterinary medicine, there are already some dog owner questionnaires that are able to evaluate the patient and compare outcome measures following a surgical procedure or during a treatment. Some of these questionnaires have proved to be valid, with good correlation with veterinary assessment and force platforms data (Hielm-Bjorkman et al., 2003; Brown et al., 2013; Christopher et al 2013; Walton et al., 2013). As with the creation of the DMS, the main and most common concern of these instruments is to focus on the studied domain (e.g. pain, osteoarthritis, quality of life). Questionnaires must be precise to evaluate the primary domain and use commonplace and clear grammar to prevent client misunderstanding (Innes & Barr 1998; Hudson et al., 2004; Boyd et al., 2007).

Item elimination during the validity procedure reduced two items from the DMS, items 4 and 8, because they resulted in a weaker total item correlation, and did not contribute to the validation of mobility. Reasons for the low value of the reaction of the dog to food may include the fact that it is not solely dependent on his/her mobility, but also on factors such as hunger or positive behavioural reinforcement. Position or changing of position during sleeping also failed to show significant correlation to dog mobility, suggesting that sleep behaviour may not be a good indicator of mobility. Reasonable justifications for this fact may be that the sleep-wake rhythm of the dogs depends on environmental factors, such as temperature, humidity or noise, and on the different ability of each dog to dream. Furthermore, it is possible that owners do not perceive their dog movements throughout the night-time since they also are sleeping. Although these two items were initially thought to be strategic to evaluate mobility, they failed to demonstrate significant value in this population of dogs. The items removal resulted in a final questionnaire composed by eight items with better internal consistency than the initial ten items version. The Cronbach's alpha of 0.854, considered by the literature as a strong value, represents good internal consistency (Terwee et al., 2007).

The construct validity of the DMS was supported by testing specific hypotheses concerning the measured concept, mobility. Although our first hypothesis - no gender-related mobility variation – was confirmed, it is possible that differences exist between intact and neutered animals of both genders, in line of reasoning with Hart (2014) that found that Labrador Retrievers and Golden Retrievers neutered before the age of 6 months, showed an increased incidence of joint disorders (hip dysplasia, cranial cruciate ligament tear and elbow dysplasia), doubled incidence and 4-5 times more incidence, respectively, when compared to intact dogs. Further studies are warranted to evaluate the effects of neutering on mobility. As hypothesised, there were age-related differences in mobility, with younger dogs having higher values when compared to older ones. Several reasons may explain this result, including both natural (young dogs tend to be more curious and interactive) and disease factors (old dogs are prone to occult joint and nervous degenerative processes) (Siwak et al., 2002). A detailed analysis revealed that the first important decline in mobility occurred in dogs after 55 months of age; a second decline, even greater, occurred in dogs that were 120 months of age or older. Our third hypothesis – that dogs affected by orthopaedic and/or neurologic diseases have reduced mobility - was also confirmed by the results of this study. Similar decreases of mobility have been reported in other studies (Poy et al., 2000; Marsolais et al., 2003; Tashman et al., 2004; van Klaveren et al., 2005; Cook, 2010; Marsh et al., 2010; Ragetly et al., 2010; Sanchez-Bustinduy et al., 2010; Anderson, 2011).

The absence of floor and ceiling effects on the DMS suggests a favourable sensitivity of this scale for the evaluation of additional validity studies (Innes & Barr 1998; Terwee et al., 2007).

It is our belief that owners are able to assess mobility of their dogs, with valid assessment instruments (Innes & Barr 1998; Walton et al., 2013). The DMS developed in this study may be a valuable tool to identify dogs with initial, non-clinical, stages of disease, in need for further diagnostic workup and early preventive or therapeutic intervention. The DMS is an easy and simple tool to obtain useful information, with the added advantage that it does not require owners to have advanced evaluation skills.

Suggestions for future studies include the exploration of the DMS responsiveness to the treatment of mobility-impairing diseases and conditions, further evaluation of its reproducibility (agreement and reliability), as an additional validation of the scale, similar to further validation of other questionnaire scales with positive and encouraging results (Hudson et al., 2004; Walton et al., 2013), and comparison of the DMS with other qualitative methods of assessing mobility, such as tracking movement with GPS technology, with an accelerometer or even with a pressure-sensitive walkway system (criterion validity).

In conclusion, the DMS demonstrated good psychometric properties and may be a clinically useful and quick instrument to assess mobility in dogs.

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‖ CHAPTER V

Understanding the effects of individual characteristics on canine mobility.

Abstract

Introduction: The understanding of dog movement or mobility is evolving, with particular emphasis on the study of the causes that might affect it, including the individual characteristics of each dog. Dog Mobility Scale (DMS) was developed and validated to assess mobility in dogs.

Objectives: The aim of this study was to analyse the relationship between individual characteristics of healthy dogs (size, weight, height, breed, age, gender and body condition) and their mobility.

Methods: Size, weight, height, breed, age, gender, body condition score (BCS 1-9) and mobility score (DMS 0-32) were recorded from 36 healthy owned dogs. Statistical analysis of data included a descriptive analysis, the study of correlations using Pearson and Spearman coefficients, the comparison of groups (Mann-Whitney test) and the analysis of variance (ANOVA). Significance level was set for $p<0.05$.

Results: Dogs had an average (min-max) age of 35.25 months (3-216), BW of 18.61 Kg (1.1-42) and height of 47 cm (21-70). Of the total population, 58.3% (n=21) were female and 18 breeds were recorded, being 38.9% (n=14) large, 27.8% (n=10) medium, and 33.3% (n=12) small breed dogs. Mean BCS was 4.6/9 and mean DMS score was 26.5/32. Males had statistically significant higher mobility scores, but with a weak correlation between the two variables. The remaining variables were not considered to affect mobility. As expected, a strong correlation was found between size, height and body weight.

Conclusions: The mobility of healthy dogs is not affected by individual characteristics such as size, weight, height, breed or body condition, with the exception of gender. The results of this study enhance the robustness of the instrument, as the DMS was developed to detect changes in mobility caused by orthopaedic or neurological pathologies. Further studies are needed to evaluate the DMS as an instrument for such purpose.

Introduction

Dogs may be characterized by a set of individual morphometric features like size, age, breed, body weight (BW), height (H), gender and body condition.

The literature shows that one of the most studied morphometric parameters of the dog is the BW. As in humans, overweight or obesity in dogs has overcome a mere aesthetic issue to become a medical concern due to the mounting evidence that it represents a well-known health risk factor, with an estimated worldwide canine prevalence reaching 41.1 – 44.4% (McGreevy et al., 2005; Mao, Xia, Chen, & Yu, 2013) and 40% in Portugal (Payan-Carreira, Sargo, & Nascimento, 2015). Obesity is defined as an accumulation of adipose tissue in the body (Burkholder & Toll, 2000) and considered to be present when bodyweight exceeds optimum weight for the body size by at least 15% (Laflamme, 2006). McGreevy et al. (2005) found that the prevalence of canine obesity is influenced by a variety of factors, including age, breed, and environment, concluding that there is a higher probability of a dog to be obese in its first 10 years of age if it was neutered and if it is a rural or semi-rural dog. An activity monitoring study in companion dogs proved that for every 1Kg increase in BW there was a 1,7% decrease in activities such as trotting up and downstairs, and that for every 1 year increase in age there was a decrease of 4,2% in such activities. Hence, spayed older and larger dogs appear to have lower activity levels than intact younger and smaller ones (Brown, Michel, Love, & Dow, 2010). Weight also seems to be the significant predictor of life span or longevity, as suggested by the fact that healthy smaller breed dogs generally live longer than heavier ones (Kealy et al., 2002; Greer, Canterberry, & Murphy, 2007). Successful obesity treatment seems to be dependent on a triad formed by dietary management, lifestyle management and monitoring of weight loss (German, 2006). With a proven reduced quality of life (Yam et al., 2016), overweight and obese dogs who benefit from a successful weight loss program, see their vitality increased with a decreased emotional disturbance and pain, enhancing the quality of life (German et al., 2012) . Even a modest weight loss of 6-11% is able reduce the severity of associated diseases such as osteoarthritis (Impellizeri, Tetrick, & Muir, 2000; Mlanick, 2006; Marshall et al., 2010).

In a survey, conducted in China, the identified risk factors for canine obesity were food type (noncommercial food), age (older dogs), activity control (restriction in a cage and short exercise duration), neutering, sex (neutered females and intact males) and feeding frequency (several times per day). Apparently, some breeds are more susceptible and a higher prevalence of obesity was found in Pugs, Cocker Spaniels, Pekingese, Pomeranians and Golden Retrievers (Mao et al., 2013). Similar conclusions were obtained from a more recent survey, performed in Japan, in which the overweight dogs were characterized by increased age and neuter status and the obese dogs were characterized by increased age and female sex. From 103 different breeds, the Miniature Dachshund and the Chihuahua had the highest percentages of obese and overweight dogs, respectively (Usui, Yasuda, & Koketsu, 2016).

Accordingly, Corbee (2013) studied a population of show dogs and also found a significantly higher body condition score (BCS) in some breed groups (e.g. Molossoid breeds, Swiss Mountain and Cattle dogs, Asian Spitz and related breeds, Scenthounds, Retrievers, Water dogs, Bichons and related breeds), but no significant differences were found between males and females. However, Courcier, Thomson, Mellor, and Yam (2010) found no associations between breed or breed group and obesity, stating though that obese dogs had a higher median age and were more likely to be neutered females. Although a breed effect on the body composition has been detected, its boundaries remained unclear due to numerous intra breed variations and to various breed specifications (Jeusette et al., 2010).

The nine point Body Condition Score system - BCS, proposed by Laflamme (1997) provides a semi quantitative, reliable and practical assessment of body composition. It defines that a dog has an ideal body condition when ribs are palpable without excess fat covering, waist is observed caudal to the ribs when viewed from above and the abdomen is tucked up when viewed from the side, attributing it a BCS of 5. Dogs with a higher BCS are considered to be overweight (BCS=6), heavy (BCS=7), obese (BCS=8) or grossly obese (BCS=9). In overweight dogs, ribs are palpable with slight excess fat covering, waist is discernible from above but not prominent and the abdominal tuck is apparent. In heavy animals, ribs are palpable with difficulty, with heavy fat cover and noticeable fat deposits over the lumbar area and base of the tail, the waist is absent or barely visible and abdominal tuck may be present. In obese dogs, ribs are not palpable under very heavy fat cover, or palpable only with significant pressure, heavy fat deposits are identified over the lumbar area and base of tail, waist is absent, there is no abdominal tuck, and obvious abdominal distention may be present. In grossly obese animals, massive fat deposits exist over the thorax, spine and base of tail, waist and abdominal tuck are absent, fat deposits on the neck and limbs and obvious and there is abdominal distention. The author recommends a weight reduction program for dogs with BCS of 8 or 9, while client counselling may be adequate for dogs with BCS of 6 or 7.

Functional mobility in dogs should be studied by the assessment of different outcome measures, using different instruments since it includes all postures and movements required for daily function, from maintenance of static recumbence, sitting and standing postures, to the dynamic transitions to and from these positions, requiring appropriate concentric and eccentric motor control (Hesbach, 2007). Some examples of such techniques and instruments would be the kinetic and kinematic gait analysis, lameness and pain scales and, more specifically, the Functional Stifle Score (Millis, 2014), the Canine Functional Independence Measure, and the proposed model of the Canine Timed Up and Go (Hesbach, 2007).

Typical physical modifications associated with aging in healthy dogs manifest as changes in behaviour, appearance, and daily function and include decreased activity and mobility (Brown, Boston, & Farrar, 2010; Bellows et al., 2015).

The individual characteristics such as size, age, breed, BW, H, gender and body condition, as well as their inter-relationships, have been, as previously reported, widely studied in recent years, accompanying the growing care for the well-being of companion animals. However, the influence of each characteristic in dogs' mobility is still unclear.

Therefore, the aim of this study was to analyse the relationship between several individual characteristics of healthy dogs (size, weight, H, breed, age, gender and body condition) and their mobility scores.

Methods

Dog selection

Thirty six healthy companion dogs were used in this observational transversal analytic study, recruited from staff elements and students from ICBAS and Escola Superior de Saúde de Vale do Sousa. Owners of all included dogs provided informed written consents.

Dogs were included if no clinical signs were detected in the physical and orthopaedic examination performed by a veterinary practitioner. Any prior diagnosed pathology was an exclusion criteria.

Data collection

Size, BW, H, breed, age, gender, body condition score (BCS 1-9) and mobility score (DMS 0-32) of each dog were collected.

Grouping of dogs according to size used the criteria and breed standards of *Féderation Cynologique Internationale* (FCI), and dogs were clustered into three categories: small (<10 Kg), medium (10–23 Kg), and large breeds (>23 Kg) (Santos et al., 2013).

Height at the withers was measured with a tape measure (Voss, Galeandro, Wiestner, Haessig, & Montavon, 2010).

The body condition assessment was based on the BCS system which has a repeatability of 0.93 and a reproducibility of 0.86 (Laflamme, 1997). It is a non-invasive, simple, inexpensive and reasonably accurate commonly used technique, and has a good correlation with more accurate methods such as chemical analysis, dual-energy X-ray absorptiometry, total body water using D_2O and bioelectrical impedance (Mawby et al., 2004; German, Holden, Morris, & Biourge, 2010). These authors recognized that BCS did correlate well with the dual-energy X-ray absorptiometry and bioelectrical impedance measurements, allowing for the conclusion that BCS may be effectively used to determine the amount of fat mass in dogs of different breeds. For a BCS of 5, classified as ideal, Laflamme (1997) estimated a percentage of body fat mass of 19±8% and for each unit increase in BCS was associated with an increase of approximately 5% body fat.

After a visual observation from the top and from the side, and after palpation of the rib cage, dorsal spinous processes and waist, a graduation was attributed: 1=Emaciated, 2=Very thin, 3=Thin, 4=Underweight, 5=Ideal, 6=Overweight, 7=Heavy, 8=Obese and 9=Grossly obese (Laflamme, 1997)

Mobility scores were assessed using the Dog Mobility Scale (DMS). This eight-item owner questionnaire has five possible answers: never; rarely (once or twice/week); sometimes (3 times/week); often (4 or 5 times/week); and always) to each question, scored between 0 and 4 (items 3, 4 and 5) or between 4 and 0 (items 1, 2, 6, 7 and 8), for the items with inverse score. The total score range was 0 to 32 points, with higher values indicating greater mobility.

Statistical analysis

The statistical analysis of data included a descriptive analysis, the study of correlations using Pearson and Spearman coefficients, the comparison of groups with the Mann-Whitney test, and the analysis of variance (ANOVA).

Statistical Package for the Social Sciences (SPSS), version 23, software was used and a significance level was set for $p<0.05$.

Results

Dogs had an average (min-max) age of 35.25 months (3-216), BW of 18.61 Kg (1.1-42) and height of 0.47 m (0.21-0.70).

Of the 36 dogs, 58.3% (n=21) were female and 18 breeds were recorded, being 38.9% (n=14) large; 27.8% (n=10) medium; and 33.3% (n=12) small breed dogs (Table 1).

The mean BCS of the 36 dogs was 4.6/9 and the mean DMS score was 26.5/32. DMS frequency distribution is illustrated in Figure 1.

Table 1.

Characterization of the 36 dogs by age (months), gender, height (m), BW (Kg), size, breed and BCS and DMS scores.

Dog	**Age** (months)	**Gender**	**Height** (m)	**BW** (Kg)	**Size**	**Breed**	**BCS**	**DMS**
1	71	Male	0.68	37.0	Large	Mixed Breed	6	24
2	11	Female	0.61	27.0	Large	German Shepherd Dog	5	29
3	16	Male	0.56	20.0	Medium	Golden Retriever	3	24
4	6	Female	0.53	17.0	Medium	Golden Retriever	5	27
5	84	Female	0.54	25.0	Large	Golden Retriever	5	28
6	36	Female	0.62	27.0	Large	Majorca Shepherd Dog	3	29
7	5	Female	0.43	15.0	Medium	German Shepherd Dog	3	21
8	13	Male	0.61	35.0	Large	Labrador Retriever	5	29
9	7	Male	0.33	6.4	Small	Mixed Breed	3	29
10	6	Female	0.35	7.5	Small	Cocker Spaniel	4	22
11	20	Female	0.53	28.0	Large	Golden Retriever	5	29
12	21	Male	0.38	25.0	Large	Basset Hound	5	28
13	30	Female	0.60	20.0	Medium	Alaskan Malamute	3	28
14	39	Male	**0.70**	32.0	Large	English Pointer	5	28
15	60	Male	0.55	30.0	Large	Boxer	3	29
16	48	Female	0.57	35.0	Large	Labrador Retriever	5	25
17	15	Male	0.28	5.0	Small	Miniature Pinscher	4	27
18	14	Female	0.34	8.0	Small	Mixed Breed	5	27
19	6	Male	0.53	27.0	Large	Labrador Retriever	5	29
20	7	Female	0.60	20.0	Medium	German Shepherd Dog	4	24
21	4	Male	0.58	17.0	Medium	German Shepherd Dog	4	24
22	**3**	Male	0.46	13.0	Medium	Dobermann	4	28
23	4	Female	0.22	1.3	Small	Miniature Pinscher	3	25
24	21	Female	0.61	38.0	Large	Labrador Retriever	7	23
25	60	Male	0.33	5.3	Small	Poodle	5	28
26	22	Male	0.44	9.8	Small	Jack Russel Terrier	5	29
27	5	Female	**0.21**	**1.1**	Small	Yorkshire Terrier	4	25
28	60	Female	0.59	34.0	Large	Golden Retriever	5	25
29	18	Male	0.68	**42.0**	Large	Rottweiler	5	27
30	84	Female	0.40	15.0	Medium	Portuguese Water Dog	7	22
31	24	Female	0.42	10.0	Medium	Poodle	5	**20**

32	**216**	Female	0.36	8.5	Small	Poodle	5	24
33	36	Male	0.26	5.5	Small	Pekingese	7	**32**
34	24	Female	0.42	4.5	Small	Mixed Breed	5	**32**
35	156	Female	0.38	10.0	Medium	Mixed Breed	5	24
36	17	Male	0.33	8.0	Small	Portuguese Podengo	5	30

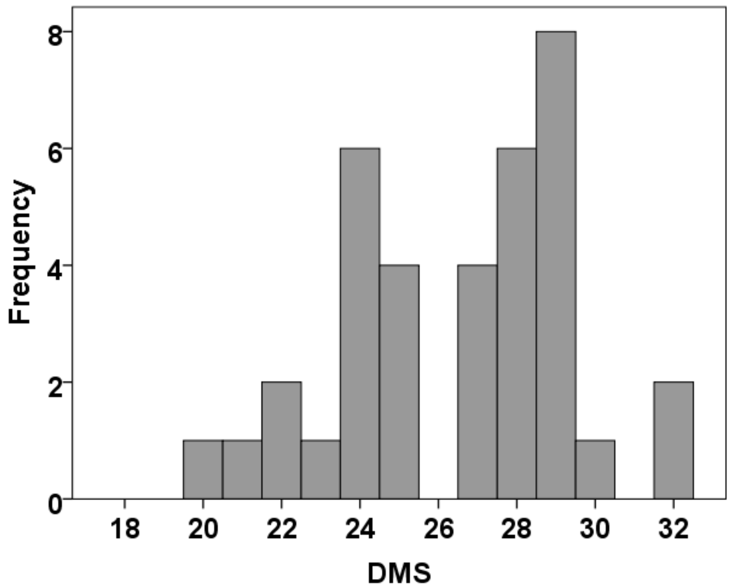

Figure 1. Histogram of the DMS frequency distribution.

Males had statistically significant higher mobility scores (Figure 2), but with a weak correlation between the two variables (Table 2).

The remaining variables were not considered to affect mobility. As expected, a strong correlation was found between size, H and BW (Table 2).

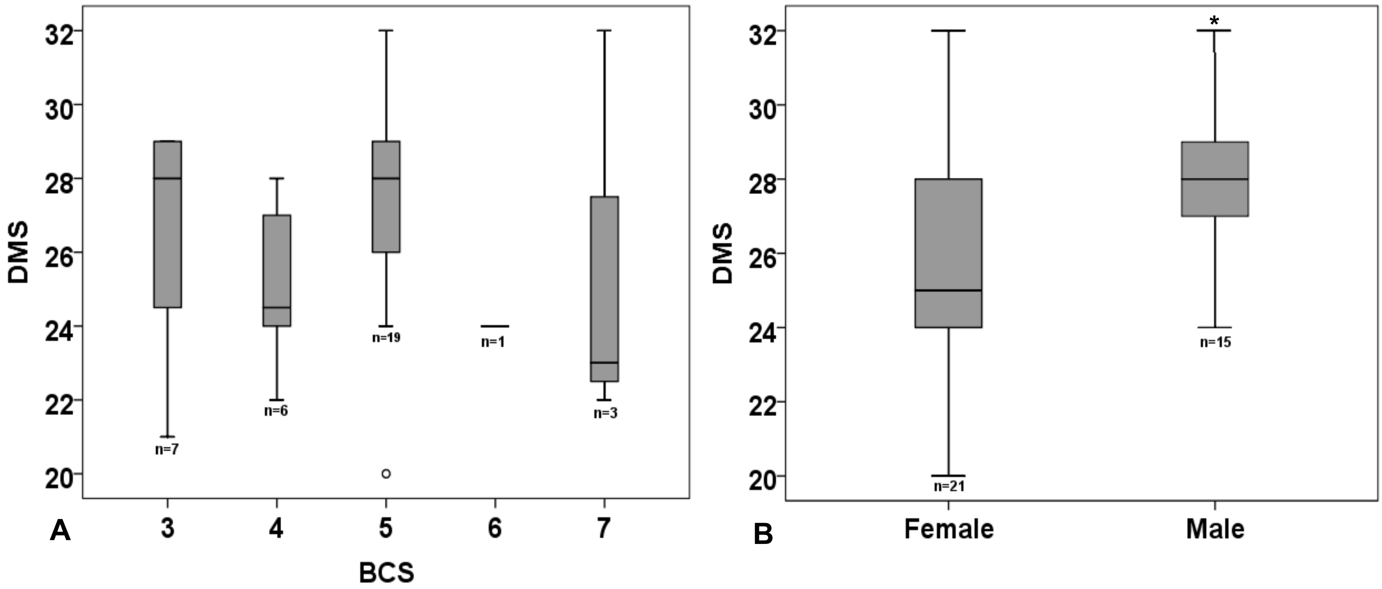

Figure 2. Box-and-whisker plot of the analysis of DMS according the BCS category (A) and gender (B).

Table 2.

Pearson and Spearman correlation coefficients between age, gender, height, body weight, size, BCS and DMS of the 36 dogs.

		Age (months)	**Gender**	**Height** (m)	**Body Weight** (Kg)	**Size**	**BCS**	**DMS**
Age (months)	*Pearson*	-----	-0.160	-0.043	-0.005	0.009	0.268	-0.175
	Spearman	-----	0.003	0.160	0.244	0.230	**0.469****	0.016
Gender	*Pearson*	-0.160	-----	0.060	0.124	0.011	0.022	**0.375***
	Spearman	0.003	-----	0.027	0.090	0.017	0.044	**0.370***
Height (m)	*Pearson*	-0.043	0.060	-----	**0.881****	**0.816****	0.051	-0.001
	Spearman	0.160	0.027	-----	**0.887****	**0.805****	0.086	-0.022
Body Weight (Kg)	*Pearson*	-0.005	0.124	**0.881****	-----	**0.932****	0.203	0.004
	Spearman	0.244	0.090	**0.887****	-----	**0.941****	0.240	-0.030
Size	*Pearson*	0.009	0.011	**0.816****	**0.932****	-----	0.143	-0.011
	Spearman	0.230	0.017	**0.805****	**0.941****	-----	0.200	0.027
BCS	*Pearson*	0.268	0.022	0.051	0.203	0.143	-----	0.022
	Spearman	**0.469****	0.044	0.086	0.240	0.200	-----	0.034
DMS	*Pearson*	-0.175	**0.375***	-0.001	0.004	-0.011	0.022	-----
	Spearman	0.016	**0.370***	-0.022	-0.030	0.027	0.034	-----

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Discussion and Conclusion

A group of healthy dogs has been recruited to search for the effect that individual characteristics of each dog may had in their mobility.

The mobility of the dogs was assessed by the DMS, a scale developed and validated to assess mobility in dogs. Thus far, the inexistence of a specific measure instrument forces mobility to be inferred from other assessments whose primary goals are to evaluate pain and quality of life. Thus, adding to its primary goals, this study also aims to enhance the robustness of the mentioned instrument.

A strong correlation was found between size, height and BW as it was expected. All sizes had a representative number of dogs in this sample, with twelve small, ten medium and fourteen large breed dogs, but no influence of size or height on mobility was found. Similarly, no mobility differences were found between the eighteen breeds represented in this study. The breed did not influence the dog's mobility.

In what concerns the gender of the dogs, males had statistically significant higher mobility values but the correlation between gender and mobility was weak. Female gender and neutering had already been associated with a higher prevalence of obesity, probably due to hormonal changes and reduced metabolic rates (McGreevy et al., 2005; Zoran, 2010; Mao et al., 2013; Payan-Carreira et al., 2015), although no association between gender and levels of activity or mobility have been reported in the literature.

BW was not considered to affect mobility in this study. Although there was a wide range of BW (1.1 to 42 Kg), heavy dogs may be considered under-represented, as showed by the mean BW of 18.61 Kg. Therefore, the sample may have not been the ideal to study an influence of BW in the mobility of the dogs, because the weight categories were not evenly distributed. In previous studies, higher BW were related to lower activity levels, as well as reduced quality of life and longevity (Greer et al., 2007; Brown et al., 2010; German et al., 2012; Bellows et al., 2015). More specifically, Brown et al. (2010), found a 1.7% decrease in activity counts for every kilogram increase in the dog BW, manifested by less controlled activities, such as trotting up and down stairs.

The mean BCS was 4.6/9, with more than half of the dogs (19 of the 36) having a BCS of 5 that matches the ideal body composition of a dog, and only 4 dogs being considered to be overweight or obese. The imbalance of the sample is illustrated by the fact that there were no dogs in the emaciated (1), very thin (2), obese (8) and grossly obese (9) categories. Having stated this, it was not possible to confirm an influence of the BCS on mobility, as stated by Morrison, Penpraze, Beber, Reilly, and Yam (2013) that demonstrated an inverse relationship between obesity and activity, with significantly less vigorous activity (running outdoors off leash) in obese dogs, but no less sedentary (lying still or sleeping) and light-moderate intensity (slow walking on leash) activities in such animals. Despite the fact that monitoring physical activity is not the same as evaluating mobility, it must be said that the majority of the functional activities mentioned in the mobility questionnaire that was applied in this study (DMS), correspond to well controlled, sedentary and light-moderate intensity activities (Brown et al., 2010; Morrison et al., 2013).

It must also be said that the use of BCS as a uniform standard for all breeds has been discussed, and the development of a BCS by breed or by groups of breeds, has been proposed because of the variation in body composition between breeds. Breed differences were proved to exist regarding body composition in dogs, when 19 dogs from 6 different breeds (of 4 genetic groups) were compared (Jeusette et al., 2010). Once there were eighteen breeds represented in this study, it is not known, in what extent the results would be different if there would be breed specific BCS.

Concerning the age of the dogs, some potential bias must be stated. The first one is that the majority (nearly 72%) of the dogs was very young and additionally, there were only two geriatric dogs. A second consideration is that the wide range of ages forced a comparison between dogs with different characteristics, i.e. a puppy of 3 months with a dog of 18 years (216 months) that may represent either a positive (variability of the sample) or a negative aspect (comparison of too different dogs) of the study methodology. In this group of dogs, age did not seemed to affect mobility scores, contrasting with the findings of Siwak, Murphey, Muggenburg, and Milgram (2002) where puppies had significantly higher activity levels than young dogs, and the latter had higher levels than old dogs and contrasting also with the findings of Brown et al. (2010) and Morrison et al. (2014) that detected an important negative effect of the age on activity, quantifying a decrease of 4.2% in less controlled physical activity counts and a decrease of 26% in vigorous activity, respectively, for every 1-year increase in age.

Mobility scores had a mean of 26.5 which in a total of 32 is considered to be a high mobility score, supporting the concept that healthy dogs have a good and preserved mobility. However, further work on the mobility scores stratification, through cut points, should be done to reach the creation of mobility categories.

In conclusion, the mobility of healthy dogs does not seem to be affected by individual size, weight, height, breed or body condition. Only gender seems to be implicated in mobility, with female dogs having less mobility than males. The results of this study enhance the robustness of the DMS, as an instrument to detect subtle changes in mobility caused by orthopaedic or neurological pathologies. Further studies are needed to evaluate the DMS as an instrument for such purpose, specifically the study of its reproducibility and responsiveness.

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║ CHAPTER VI

Temporospatial gait analysis of the hindlimb in healthy dogs - a clinical approach.

Abstract

Introduction: Although gait analysis of dogs with pathological conditions was widely studied, healthy normal gait was not so frequently evaluated and there is still a need for its detailed characterisation, prior to the diagnosis of abnormal or lame gait patterns, by using affordable, practical and easy methods, applicable in the daily routine of veterinary practitioners.

Objective: The aim of this study was to quantify, characterise, and compare, considering individual characteristics, hindlimb temporospatial variables of healthy dogs during walk.

Methods: Size, body weight, height, breed, age, gender, and body condition score (BCS) from 63 healthy owned dogs were recorded. Video images of each dog walking along a walkway, in a self-selected velocity, with a retroreflective marker placed on the fifth metatarsal bone of each hindlimb, were recorded and analysed using the DVideow software. Stride time, stance time, swing time, stride length, paw velocity, cadence, relative stance time, and relative swing time were measured. Statistical analysis included a descriptive analysis; the study of the differences between right and left side (Student's t-test); the study of the intra-individual variation (one-way ANOVA and Levene's test); the study of differences between dogs' sizes, age and BCS (ANOVA-1 factor and Post Hoc analysis by Tukey method); the study of differences between dogs' genders (Student's t-test and chi-squared test); the study of differences between dogs' heights (Student's t-test); and the study of the influence of the independent variables in the temporospatial variables (TSV) with a multiple linear regression analysis for each TSV. A particular focus was given to ST and PV and their relation to size, weight, age, height, BCS and gender. Significance level was set at $p<0.05$.

Results: Of the 60 dogs, 58.3% (n=35) were female and 24 breeds were recorded, being 45% (n=27) large, 28.3% (n=17) medium, and 26.7% (n=16) small breed dogs. The majority (n=31) had a BCS of 5 and most dogs (n=35) were adult. All TSV were significantly lower in small size dogs when compared to medium and large, with the exception of relative swing time (SwT%) and cadence that were significantly higher. Males had significantly higher stride length (SrL) and SrL% while geriatric dogs showed shorter SrL and SrL%. Puppies had lower PV while taller dogs had higher stride time (SrT), swing time (SwT), SwT% and lower paw velocity (PV). Overweight dogs have significant higher SrT, stance time (ST) and SwT and significant lower cadence. Height of the dog was identified has influencing all TSV. The SrL% variability was explained in 4.4% by age, body weight and gender.

Conclusions: The gait temporospatial parameters of the walk in healthy dogs were analysed and characterised, establishing a normal pattern and identifying variation factors.

Introduction

Clinical gait analysis is often performed resorting to visual observation, assessing potential lameness by the use of a numeric rating score (NRS) or a visual analog scale (VAS) which provide measure and report of the limb function, resulting in a simple, quick, and easy application. However, they are not the most accurate methods of assessing canine gait, since kinetic and kinematic approaches offer more objective and reliable information, and poor agreement was found between subjective and objective measurements of limb function, except in severe lameness cases (Quinn et al., 2007; Waxman et al., 2008).

Three-dimensional kinematic analysis has been used to assess gait in multiple different pathologies such as the cranial cruciate ligament disease (Sanchez-Bustinduy et al., 2010), hip dysplasia (Poy, DeCamp, Bennett, & Hauptman, 2000), hip osteoarthritis, cervical spondylomyelopathy (Foss, da Costa, & Moore, 2013), and neurologic dysfunction (Gradner, Bockstahler, Peham, Henninger, & Podbregar, 2007) as well as in the post-surgical follow-up of interventions such as tibial tuberosity advancement and cranial tibial wedge osteotomy (Lee, Kim, Kim, & Choi, 2007; de Medeiros, Bustinduy, Radke, Langley-Hobbs, & Jeffery, 2011). In the study of healthy dogs, some work has been done in a three-dimensional approach: the evaluation and comparison of kinematic patterns of Labrador retrievers and Rottweilers trotting on a treadmill (Agostinho et al., 2011), the assessment of forelimb and hindlimb joint kinematics during walking exercise regimens (Holler et al., 2010), the evaluation of the pelvic limb joints' range of motion during descending stairs and decline slope walking (Millard, Headrick, & Millis, 2010) as well as stairs ascending (Durant, Millis, & Headrick, 2011) and the comparison of overground and treadmill-based gaits (Torres et al., 2013). However, this type of analysis, in virtue of their technical complexity, are very difficult to include in daily routine practice. Hence, there is still a need for a more practical method of overcoming the pitfalls and biases of the subjective gait assessment scales, although not as unachievable as a 3D kinematic system.

Pressure-sensitive walkway systems have been applied in scientific studies to objectively analyse canine gait, by recording temporospatial and kinetic variables in a more practical methodology than force platforms and 3D kinematic systems, but yet implying relevant financial investments (Light, Steiss, Montgomery, Rumph, & Wright, 2010; Kim, Kazmierczak, & Breur, 2011).

A two-dimensional gait analysis is able to provide important kinematic parameters while keeping the accuracy and repeatability of the data, implying the engagement of a smaller financial investment and representing a less time-consuming technique, as suggested by Kim, Rietdyk, and Breur (2008) that found that a 2-D video system allows for the analysis of the sagittal angular motion of canine hindlimbs during walk.

From the most commonly collected and analysed kinematic parameters, two temporospatial variables stand out because they were found to be reliable for assessment of the hindlimb dysfunction associated with the cranial cruciate ligament rupture: pelvic limb paw velocity and pelvic limb stance duration. Paw velocity may be the most reliable and helpful variable when assessing the success of a surgical procedure in restoring full limb function (Sanchez-Bustinduy et al., 2010; de Medeiros et al., 2011).

As stated by Colborne, Good, Cozens, and Kirk (2011), orthopaedically normal gait needs to be analysed and characterised prior to the assessment of an abnormal gait pattern or a detection of a lame gait and so far, to the best of our knowledge, the two dimensional analysis has been used only to characterize the functional phenotype of Golden Retriever Muscular Dystrophy (Marsh, Kornegay, Markert, & Childers, 2010), to assess the effects of the habituation of treadmill-naïve Labrador retrievers on trotting gait (Clements, Owen, Carmichael, & Reid, 2005), to assess and compare joint range of motion of the forelimb between ascending stairs and incline slope walking (Carr, Millis, & Weng, 2013), and to study limb symmetry (Gillette & Zebas, 1999), but never for temporospatial profile characterization purposes.

To the best of our knowledge, the first attempt to study and compare the TSV of walking dogs (Kim et al.,2011) addressed small and large dogs. Though the authors have reached important conclusions, they recognised some limitations of the study: medium size dogs were not included, hampering their characterization and comparison with other sizes; a very small number of dogs per group (N=6) was studied; no individual characteristics, such as age, height, gender, and corporal condition, were accounted for.

In this work, a two-dimensional methodology is proposed with an important practical advantage by using one single reflective marker on each paw, leading to an overall time saving. Faster preparation of the dog for the collection moment, faster digitising of movies, and consequently expeditious acquisition of results result in less time expenditure, less excitement and distraction of the animal and, consequently, more repeatable and accurate results. Such advantages attract bot the practitioner and owners to accept and adhere to their use on a routine daily basis, even if signs of pathology are not obvious.

Therefore, the aim of this study was to quantify, characterise, and compare, considering individual characteristics, the hindlimb temporospatial variables of healthy dogs during walk, by developing a clinical approach, so that veterinary practitioners would rely on an affordable, practical, and easy method, usable in daily routine.

Methods

Dog selection

This study was approved by the Ethics Committee of ICBAS for studies using animals. The methodology involved no invasive or stressful techniques to the dogs and fresh water was always available in the collection room. A signed Informed Consent Form was requested from each dog's owner.

Sixty three healthy companion dogs were recruited from staff elements and students from ICBAS and Escola Superior de Saúde de Vale do Sousa. Three dogs were excluded because no valid data/video was obtained, resulting in a final sample of 60 dogs.

Inclusion criteria were normal physical and orthopaedic examinations, no previous history of injury, orthopaedic or neurologic pathologies and no history of lameness. A standard veterinary assessment was performed to each dog with free gait observation and manual mobilization of the limb joints to confirm that the dogs were healthy and pain free at the moment of data collection.

Data collection and gait analysis

Size, body weight, height, breed, age, gender, body condition score (BCS 1-9) (Laflamme, 1997) of each dog were collected. After the scoring of BCS, dogs were grouped in three groups: thin (BCS<5), ideal weight (BCS=5) and overweight (BCS>5).

Grouping according to size used the criteria and breed standards of *Féderation Cynologique Internationale* (FCI), and dogs were clustered into three categories: small (<10 Kg), medium (10–23 Kg), and large breeds (>23 Kg) (Santos et al., 2013).

Dogs were grouped by age groups puppy, adult, senior and geriatric, adjusted to breed size (Hall & Jewell, 2012; Bellows et al., 2015; Nesic, Kukolj, Marinkovic, Vucicevic, & Jovanovic, 2017).

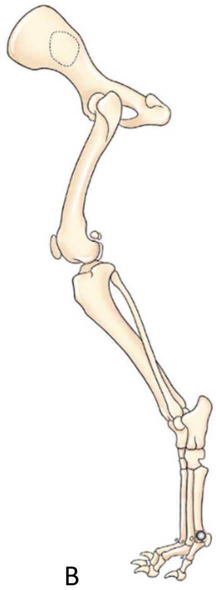
Spherical adhesive reflective markers with 20 mm diameter (Figure 1-A) were placed on each dog by the same individual at the distolateral aspect of the fifth metatarsal bone (5^{th} MT) (Figure 1-B) on both sides. This location was elected for being the closest to the ground and in an area with minimal subcutaneous loose tissues, thus reducing oscillations and unrelated movements.

Each dog walked along the walkway, led by the same handler that did not interfere in the pace speed, allowing for the dogs to walk in a self-selected velocity (Gordon-Evans et al., 2009; Colborne et al., 2011). The walkway area (2.4 x 1.2m) was carpet flooring to avoid slippery surfaces and normalize the collection set. Every dog was allowed to acclimate to the room prior to data collection, by being allowed to move freely in the area.

Each dog was filmed till the acquisition of three valid passes across the walkway, of both left and right hindlimbs. A pass where the dog showed distraction, turned the head or pulled on the leash was considered invalid. In each pass, 2 consecutives strides, for both left and right side, were recorded, resulting in a total of 12 strides (6 of the right and 6 of the left hindlimbs).

The walkway was illuminated by a LED spotlight (Figure 2-A), the collection room was maintained darkened to highlight the marker reflection and a black sheet was placed in the set background to enhance contrast. A Sony® HDR-PJ10E video camera was placed on a Cullmann® extensible tripod (Figure 2-B). The tripod was 55cm height and 3 meters away from the walkway, placing the video camera in a perpendicular plane of the walkway plane. An overview of the set film can be seen in Figure 3.

A



B

Figure 1. A - Reflective markers; B - Canine hindlimb illustration with the reflective marker in the lateral distal aspect of the fifth metatarsal bone. Adapted from Evans, H.E., de Lahunta A.: Miller's guide to the dissection of the dog, ed 7, Philadelphia, 2010, WB Saunders.

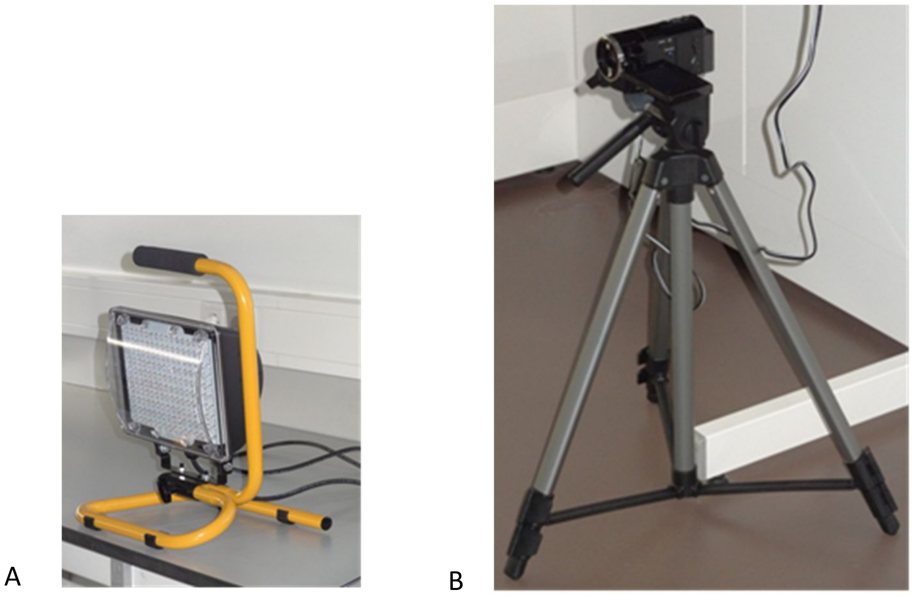


Figure 2. A - LED spotlight; B - Video camera and tripod.

Figure 3. Set film overview.

Video images were analysed by Dvideow software – Digital Video for Biomechanics for Windows, developed by the Instrumentation for Biomechanics Laboratory – UNICAMP, as a flexible and economic system. The methodology used in human movement analysis was adapted to the dog gait analysis, going throughout the processes of calibration, tracking the marker dislocation, measurement and 2D reconstruction (Barros, 1999; Figueroa, Leite, & Barros, 2003).

A 1.80x1.00m calibrator was constructed with white dots stickers measuring 1cm in diameter, equally distant from each other (Figure 4) so that the recorded area would be measurable by the video software and the tracking of the markers' position would deliver a numerical output. Calibration was performed at the start of each collection and the video camera was maintained turned on during the entire collection. The calibration process included the analysis of the video of the calibrator by the software and marking of each reference point, resulting in a matrix (Figure 5).

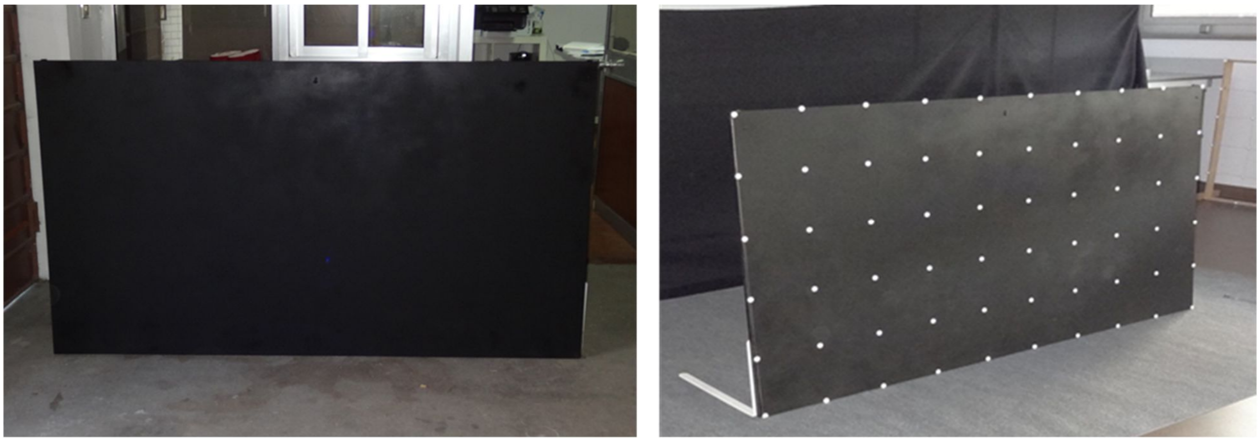


Figure 4. Construction of the calibrator: black ink painting (left image), placement of stable feet and final placement of the white dots, 20 cm apart (right image).

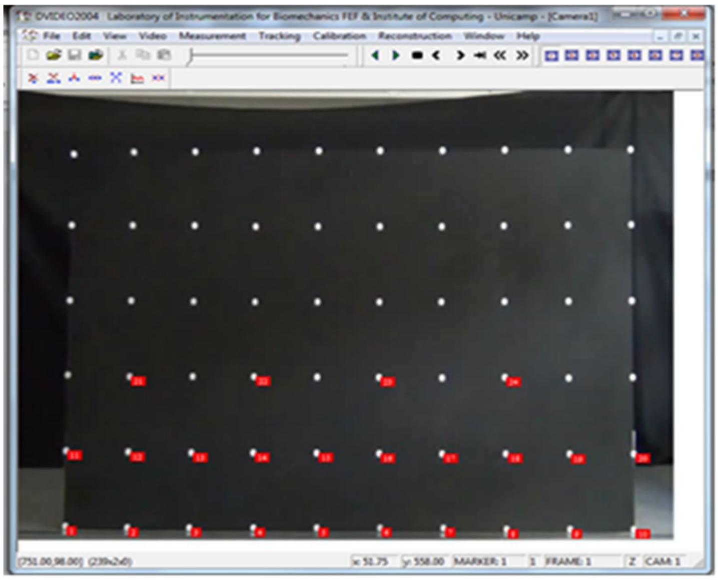


Figure 5. Matrix obtained from the reading of the video calibrator by the software, containing the coordinates.

The temporospatial variables (TSV), evaluated for each hindlimb, arose from the analysis of the movement of the fifth metatarsal marker:

- **Stride Time (SrT)** (in seconds): time between two consecutive paw ground contacts, from the end of the stance phase to the beginning of the following stance phase;
- **Stance Time (ST)** (in seconds): time of the stride during which the paw contacts the ground;
- **Swing Time (SwT)** (in seconds): time of the stride during which the paw is out of the ground, oscillating;
- **Relative Stance Time (ST%)** (in percentage): percentage of the Stride Time in which the paw contacts the ground ((Stance Time/Stride Time) x100);
- **Relative Swing Time (SwT%)** (in percentage): percentage of the Stride Time in which the paw is out of the ground, oscillating ((Swing Time/Stride Time) x100);
- **Cadence** (strides per second): number of strides per second (1/Stride time);
- **Paw velocity (PV)** (in meter per second): hindlimb paw velocity (SrL/Stride Time);
- **Stride Length (SrL)** (in meters): distance between two consecutive paw ground contacts, from the end of the stance phase to the beginning of the following stance phase;
- **Relative Stride Length (SrL%)**: height normalization of the SrL, expressed as % of dogs' height (in meters).

Instruments and materials

1. DVideow Software
2. Sony® HDR-PJ10E Video Camera;
3. Cullmann® Tripod;
4. Reflective Markers;
5. Calibrator;
6. Double side adhesive tape;
7. Black adhesive tape;
8. Scissor and X-acto knife;
9. Black sheet;
10. Carpet;
11. Level gauge;
12. Measure tape.

Statistical analysis

Statistical analysis of data included a descriptive analysis; the study of the differences between right and left side measurements with Student's t-test for paired samples; the study of the intra-individual variation with the analysis of variance ("one-way" ANOVA) and with the Levene's test; the study of differences between dogs' sizes, age and BCS with the analysis of variance (ANOVA-1 factor) and Post Hoc analysis by Tukey method; the study of differences between dogs' gender with Student's t-test for two independent samples and with the chi-squared test; the study of differences between dogs' heights with Student's t-test for two independent samples; and the study of the influence of the independent variables of the dog in the TSV with a multiple linear regression analysis by the stepwise method, for each TSV. A characterization of the variables ST and PV was performed, by percentiles (25, 50 and 75), for size, body weight, age, height, BCS and gender groups, and by the calculation of the 95% confidence interval (CI) for age groups.

Statistical Package for the Social Sciences (SPSS), version 24, software was used and a significance level was set for $p<0.05$.

Results

From the initial 63 dogs, 3 animals were excluded due to constant distraction and pulling on the leash (2 dogs), and marker intolerance (1 dog), precluding data extraction.

The dogs had an average age of 43.63 months, BW of 20.81 Kg and H range of 0.21-0.70 m (Table 1).

Table 1.
Dogs' characterization by age, body weight and height (Minimum, Maximum, Mean, and Standard Deviation).

	Min	Max	Mean	SD
Age (months)	3	216	43.63	45.35
Body Weight (Kg)	1.10	57.00	20.81	12.92
Height (m)	0.21	0.70	0.48	0.13

Of the 60 dogs, 58.3% (n=35) were female and 24 breeds were recorded, being 45% (n=27) large; 28.3% (n=17) medium; and 26.7% (n=16) small breed dogs. The majority of the dogs (n=31) had a BCS of 5, corresponding to an ideal body condition score and most dogs (n=35) were adult (Table 2).

Table 2.
Dogs' characterization by size, gender, BCS and breed.

	N (%)
Size	
Small	16 (26.7)
Medium	17 (28.3)
Large	27 (45.0)
Gender	
Female	35 (58.3)
Male	25 (41.7)
BCS	
Thin	18 (30.0)
Ideal	31 (51.7)
Overweight	11 (18.3)
Age	
Puppy	15 (25.0)
Adult	35 (58.3)
Senior	3 (5.0)
Geriatric	7 (11.7)
Breed	
Alaskan Malamute	1 (1.7)
Basque Shepherd Dog	1 (1.7)
Basset Hound	1 (1.7)

Beagle	3 (5.0)
Boxer	2 (3.3)
Cocker Spaniel	1 (1.7)
Dobermann	1 (1.7)
Dogue de Bordeaux	2 (3.3)
English Pointer	1 (1.7)
German Shepherd Dog	4 (6.7)
Golden Retriever	5 (8.3)
Jack Russel Terrier	1 (1.7)
Labrador Retriever	9 (15.0)
Majorca Shepherd Dog	1 (1.7)
Medium Poodle	2 (3.3)
Miniature Pinscher	1 (1.7)
Miniature Poodle	1 (1.7)
Mixed Breed	12 (20.0)
Pekingese	1 (1.7)
Pinscher	2 (3.3)
Portuguese Podengo	3 (5.0)
Portuguese Water Dog	1 (1.7)
Rottweiller	1 (1.7)
Syberian Husky	2 (3.3)
Yorkshire Terrier	1 (1.7)

In Table 3 the right and left side measurements of the temporospatial kinematic variables are presented.

Table 3.

Differences between right and left side measurements of temporospatial variables (Mean ± Standard Deviation).

	Right Side *M ± SD*	**Left Side** *M ± SD*	*t*	*p*
SrT (s)	0.71 ± 0.22	0.70 ± 0.21	1.349	0.178
ST (s)	0.48 ± 0.19	0.47 ± 0.19	1.377	0.169
SwT (s)	0.24 ± 0.05	0.24 ± 0.05	-0.749	0.454
ST%	64.92 ± 9.71	63.91 ± 12.10	1.299	0.195
SwT%	35.03 ± 9.22	36.17 ± 9.76	-1.835	0.068
Cadence (strides/s)	1.54 ± 0.53	1.59 ± 0.62	-1.846	0.066
PV (m/s)	0.68 ± 0.24	0.69 ± 0.22	-0.995	0.321
SrL (m)	0.55 ± 0.19	0.55 ± 0.18	-0.977	0.330
SrL%	110.93 ± 25.98	113.17 ± 26.43	-1.417	0.157

SrT-stride time; ST-stance time; SwT-swing time; PV-paw velocity; SrL-stride length; SrL%-relative stride length.

No statistically significant differences were found between right and left side measurements ($p > 0.05$).

Intra-individual variability was studied for both right and left sides, between the 6 strides (Figure 6 and 7).

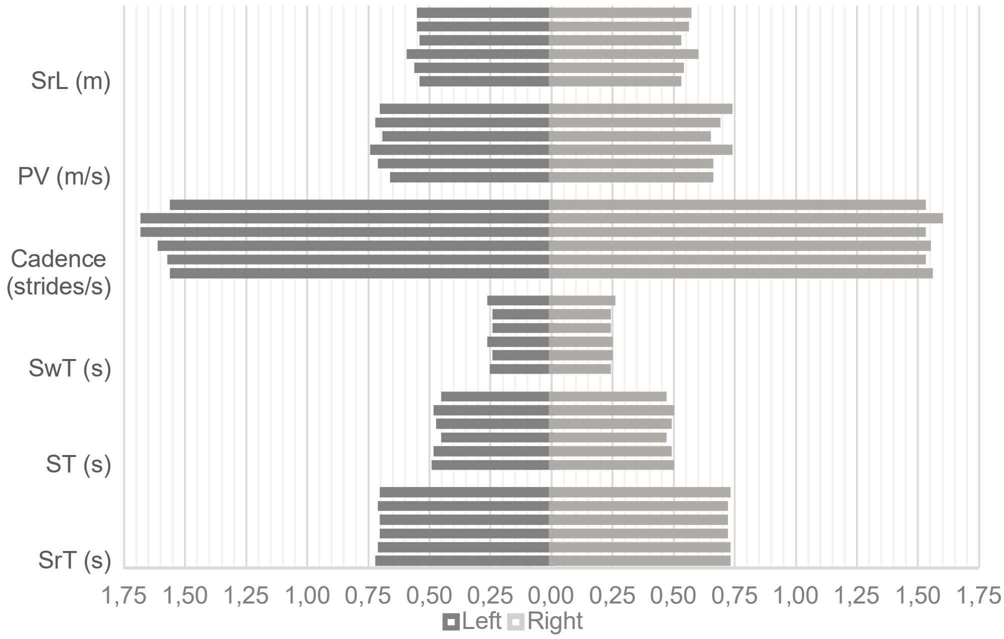


Figure 6. Graphic representing the mean values of TSV: SrL - stride length, PV - paw velocity, Cadence, SwT - swing time, ST - stance time, and SrT - stride time, for each of the 6 strides, on both right and left sides. No statistically significant differences were found between the intra-individual evaluations on the right side neither on the left side: $p > 0.05$.

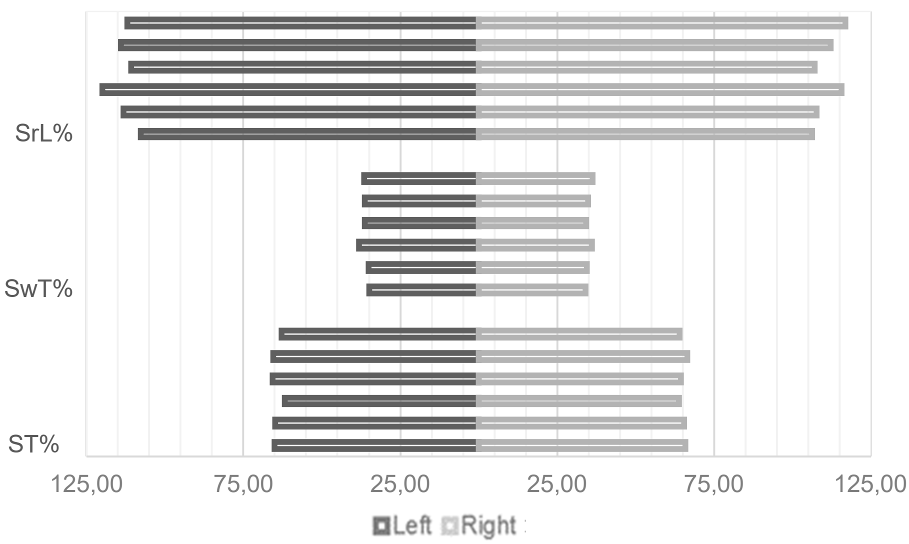


Figure 7. Graphic representing the mean values of TSV: SrL% - relative stride length, SwT% - relative swing time, and ST% - relative stance time, for each of the 6 strides, on both right and left sides. No statistically significant differences were found between the intra-individual evaluations on the right side neither on the left side: $p > 0.05$.

Homogeneity of variances was studied and no statistically significant variance was found between strides.

The absence of significant differences between right and left sides, and between the intra-individual evaluations allowed for the use of all 720 records in subsequent analysis of the differences in the temporospatial gait variables according to size (Figures 8 and 9), gender (Table 4), age (Table 5), height (Figures 10 and 11), and body condition (Table 7).

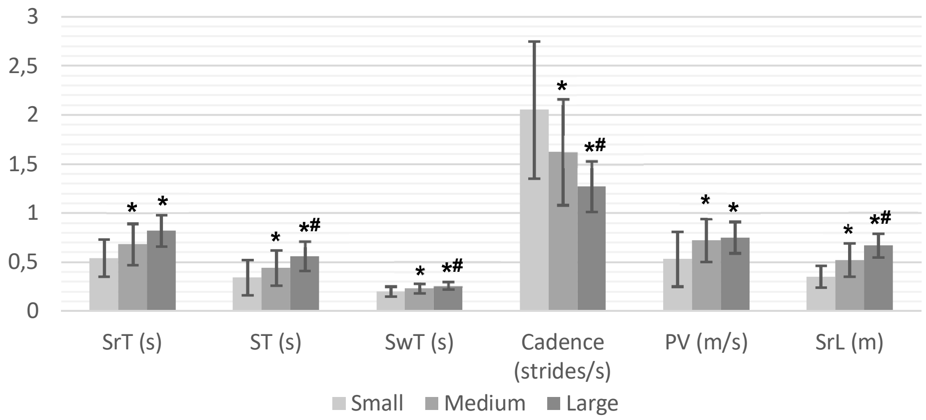


Figure 8. Graphic representing the mean values and standard deviations of TSV: SrT-stride time, ST-stance time, SwT-swing time, Cadence, PV-paw velocity, and SrL-stride length for small, medium and large size dogs. *different from small size dogs (p < 0.001); #different from medium size dog (*p* < 0.001).

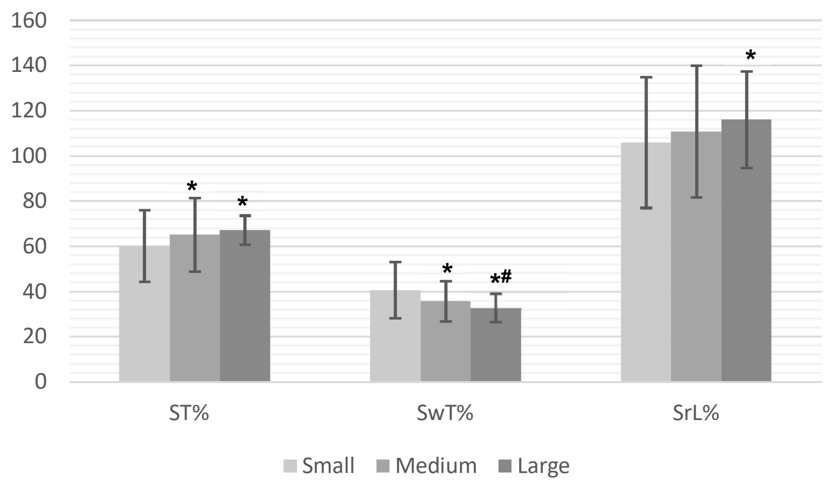


Figure 9. Graphic representing the mean values and standard deviations of TSV: ST% - relative stance time, SwT% - relative swing time, and SrL% - relative stride length, for small, medium and large size dogs. *different from small size dogs ($p < 0.001$); #different from medium size dog ($p < 0.001$).

Statistically significant differences were found in all variables, at least between two of the three groups:

- Medium size dogs presented higher values than small size dogs in all variables, except in SwT% and Cadence, in which small dogs have higher values and in SrL% where no statistically significant differences were found between the two groups;
- Large size dogs have higher values than small size dogs in all variables, with the exception of SwT% and Cadence, in which small dogs have higher values;
- Large size dogs have higher values than medium size dogs in all variables, except in the SwT% and Cadence, in which medium dogs have higher values, and in the ST%, PV and SrL% , where no statistically significant differences were found;

The Table 4 presents the differences in the temporospatial kinematic variables between dogs' gender.

Table 4.
TSV according to gender (Mean ± Standard Deviation).

	Female	Male	*t*	*p*
	M ± SD	*M ± SD*		
SrT (s)	0.70 ± 0.22	0.72± 0.22	-0.892	0.373
ST (s)	0.47 ± 0.19	0.47± 0.19	-0.547	0.585
SwT (s)	0.23 ± 0.06	0.24 ± 0.05	-1.548	0.122
ST%	64.94 ± 11.56	64.35 ± 14.51	0.582	0.561
SwT%	35.25 ± 9.21	36.05 ± 9.98	-1.075	0.283
Cadence (strides/s)	1.58 ± 0.59	1.56 ± 0.58	0.498	0.619
PV (m/s)	0.68 ± 0.22	0.70 ± 0.25	-1.171	0.242
SrL (m)	0.52 ± 0.19	0.58 ± 0.18	-4.580	<0.001*
SrL%	109.12 ± 26.53	115.65 ± 25.01	-3.207	0.001*

SrT-stride time; ST-stance time; SwT-swing time; PV-paw velocity; SrL-stride length; SrL%-relative stride length *Statistically significant differences $p < 0.05$

Significantly higher SrL and SrL% were detected in males when compared to females.

The Table 5 presents the differences in the temporospatial kinematic variables between age groups.

Table 5.

TSV according to age (Mean ± Standard Deviation).

	Puppy	Adult	Senior	Geriatric	*F*	*p*
	M ± SD	*M ± SD*	*M ± SD*	*M ± SD*		
SrT (s)	0.77 ± 0.26	0.69 ± 0.19[a]	0.76 ± 0.22	0.66 ± 0.19[a]	7.304	<0.001*
ST (s)	0.52 ± 0.24	0.45 ± 0.17[a]	0.54 ± 0.17[b]	0.44 ± 0.15[a,c]	7.530	<0.001*
SwT (s)	0.24 ± 0.05	0.24 ± 0.05	0.25 ± 0.05	0.22 ± 0.06[a]	3.848	0.010*
ST%	65.37 ± 10.53	64.03 ± 13.62	65.95 ± 6.51	65.97 ± 15.05	0.856	0.464
SwT%	34.40 ± 10.53	36.37 ± 9.57	34.05 ± 6.51	34.82 ± 7.95	2.142	0.094
Cadence (strides/s)	1.47 ± 0.60	1.59 ± 0.53	1.46 ± 0.54	1.71 ± 0.75[a]	3.661	0.012*
PV (m/s)	0.58 ± 0.23	0.71 ± 0.23[a]	0.81 ± 0.15[a]	0.73 ± 0.19[a]	18.617	<0.001*
SrL (m)	0.56 ± 0.20	0.55 ± 0.18	0.64 ± 0.22[b]	0.47 ± 0.16[a,b,c]	6.74	<0.001*
SrL%	113.69 ± 29.46	114.74 ± 24.38	121.21 ± 21.62	92.19 ± 18.39[a,b,c]	20.708	<0.001*

SrT-stride time; ST-stance time; SwT-swing time; PV-paw velocity; SrL-stride length; SrL%-relative stride length
*Statistically significant differences $p < 0.05$; [a] different from puppy dogs; [b] different from adult dogs; [c] different from senior dogs.

Statistically significant differences were found in all TSV except ST% and SwT%:

- Puppy dogs presented higher SrT and ST than adult dogs;
- Puppy dogs presented higher SrT, ST, SwT, SrL, and SrL% than geriatric dogs;
- Senior dogs presented higher ST, SrL than adult dogs;
- Senior dogs presented higher ST, SrL, SrL% than geriatric dogs;
- Puppy dogs presented lower Cadence and PV than geriatric dogs;
- Puppy dogs presented lower PV than adult dogs;
- Senior dogs presented higher PV than puppy dogs;
- Geriatric dogs presented lower SrL and SrL% than adult dogs.

Two groups were created on the basis of the median height of each size group (Table 6): Under Median Height and Above Median Height, in order to study the influence of height in the TSV (Figure 10 and 11).

Table 6.

Height medians by size groups.

Size	Height (cm)
Small	34
Medium	44
Large	59

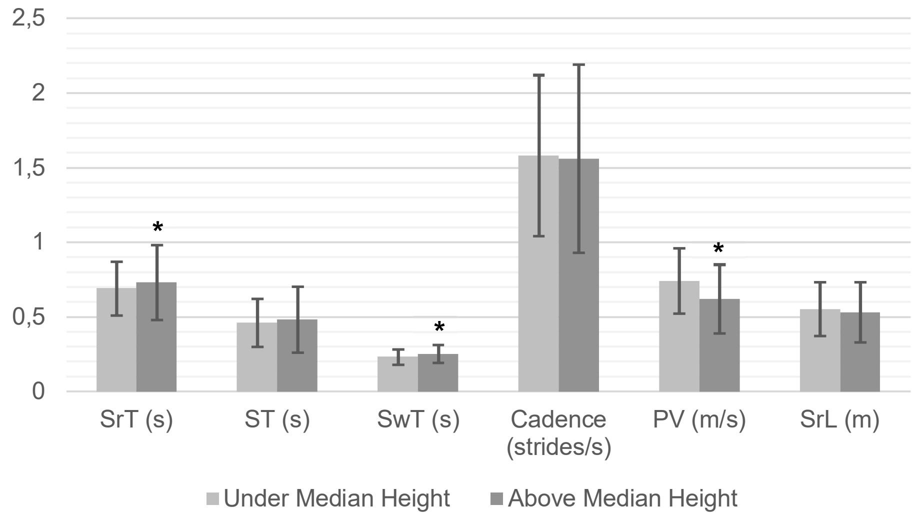


Figure 10. Graphic representing the mean values and standard deviations of TSV: SrT-stride time, ST-stance time, SwT-swing time, Cadence, PV-paw velocity, and SrL-stride length for dogs under median height and for dogs above median height. *Statistically significant differences $p < 0.05$ (SrT $p = 0.014$; SwT $p < 0.001$, PV $p < 0.001$).

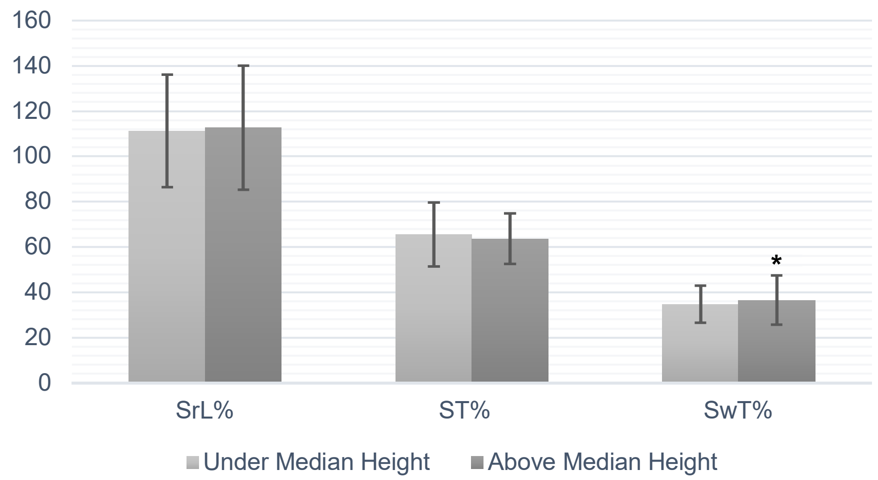


Figure 11. Graphic representing the mean values and standard deviations of TSV: SrL%-relative stride length, ST%-relative stance time, and SwT%-relative swing time for dogs under median height and for dogs above median height. *Statistically significant differences $p < 0.05$ (SwT $p = 0.024$).

Statistically significant differences were found: dogs above median height have higher values of SrT, SwT, SwT% and lower values of PV.

The Table 7 presents the differences in the TSV between BCS categories.

Table 7.

TSV according to the body condition scores (Mean ± Standard Deviation).

	Thin	Ideal	Overweight	*F*	*p*
	M ± SD	*M ± SD*	*M ± SD*		
SrT (s)	0.68 ± 0.24	0.69 ± 0.22	0.78 ± 0.17[a,b]	9.148	<0.001*
ST (s)	0.44 ± 0.21	0.46 ± 0.19	0.53 ± 0.14[a,b]	8.041	<0.001*
SwT (s)	0.24 ± 0.06	0.23 ± 0.05	0.25 ± 0.05[a,b]	9.111	<0.001*
ST%	62.73 ± 11.80	65.17 ± 15.13	66.35 ± 5.74[a]	3.546	0.029*
SwT%	37.44 ± 11.08	35.39 ± 9.61[a]	33.32 ± 5.52[a]	7.474	0.001*
Cadence (strides/s)	1.66 ± 0.65	1.60 ± 0.60	1.36 ± 0.36[a,b]	11.434	<0.001*
PV (m/s)	0.63 ± 0.27	0.69 ± 0.23[a]	0.75 ± 0.16	10.584	<0.001*
SrL (m)	0.52 ± 0.21	0.54 ± 0.18	0.59 ± 0.16[a]	4.904	0.008*
SrL%	116.93 ± 29.52	109.51 ± 25.86[a]	110.65 ± 19.33	5.250	0.005*

SrT-stride time; ST-stance time; SwT-swing time; PV-paw velocity; SrL-stride length; SrL%-relative stride length
*Statistically significant differences $p < 0.05$; [a] different from thin dogs; [b] different from ideal weight dogs.

Statistically significant differences were found in all temporospatial kinematic variables, regarding the different BCS categories:

- Thin dogs have higher values of SwT% e SrL% than ideal weight dogs;
- Ideal weight dogs have higher values of PV than thin dogs;
- Overweight dogs have higher values of SrT, ST, SwT, ST%, and SrL than thin dogs;
- Overweight dogs have lower values of SwT% and Cadence than thin dogs;
- Overweight dogs have higher values of SrT, ST and SwT than ideal weight dogs;
- Overweight dogs have lower values of Cadence than ideal weight dogs.

Mean values and standard deviations of SrL% of all dogs, grouped by the different categories are represented in Figure 12.

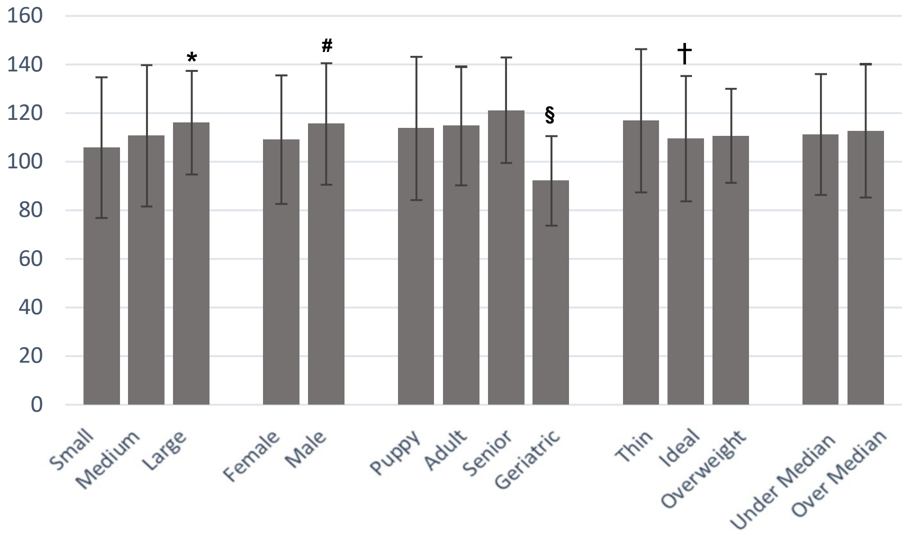


Figure 12. Graphic representing the mean values and standard deviations of relative stride length of dogs grouped by size (small, medium, large), gender (female and male), age (puppy, adult, senior, geriatric), body condition (thin, ideal, overweight) and height (under median height, above median height). *different from small size dogs (p < 0.001); #different from female dogs (p = 0.001); § different from puppy, adult, and senior dogs (p < 0.001); † different from thin dogs (p = 0.005).

The influences of size, gender, age, body condition, body weight and height, as independent variables of the dog, in the kinematic TSV were studied by a multiple linear regression analysis:

- SrL variability is explained in 40.4% by the height and body weight of the dog;
- ST variability is explained in 30.3% by the height, body weight and gender of the dog;
- SrT variability is explained in 22.1% by the height and the body condition of the dog;
- Cadence variability is explained in 21.0% by the height, age, gender and size of the dog;
- PV variability is explained in 13.1% by the height and age of the dog;
- SwT variability is explained in 12.6% by the height and the body condition of the dog;
- SwT% variability is explained in 4.6% by the height and gender of the dog;
- SrL% variability is explained in 4.4% by the age, body weight and gender of the dog;
- ST% variability is explained in 4.1% by the height and the body condition of the dog;

Variables PV and ST were characterized for each group by calculation of the 25th, 50th and 75th percentiles (Table 8), and by the calculation of the 95% confidence interval (CI 95) (Table 9) according to age (Table 10).

Table 8.

Characterization of the variables ST and PV by percentiles (P25, P50 and P75) according to size, weight, age, height, BCS and gender.

	Stance Time (s)			Paw Velocity (m/s)		
	P25	P50	P75	P25	P50	P75
Size						
Small	0.20	0.28	0.40	0.34	0.46	0.70
Medium	0.32	0.44	0.52	0.59	0.69	0.85
Large	0.48	0.54	0.64	0.64	0.75	0.84
Weight						
<10Kg	0.24	0.32	0.44	0.36	0.51	0.72
10-23Kg	0.36	0.44	0.52	0.60	0.71	0.87
>23Kg	0.48	0.54	0.64	0.64	0.74	0.84
Age Groups						
Puppy	0.36	0.52	0.64	0.42	0.61	0.73
Adult	0.36	0.44	0.56	0.56	0.70	0.85
Senior	0.36	0.58	0.68	0.72	0.80	0.86
Geriatric	0.32	0.46	0.56	0.61	0.75	0.84
Height						
<Median / size	0.36	0.44	0.56	0.61	0.73	0.87
>Median / size	0.32	0.48	0.60	0.45	0.64	0.76
BCS						
Thin	0.28	0.44	0.56	0.42	0.67	0.81
Ideal	0.32	0.44	0.56	0.54	0.69	0.82
Overweight/Obese	0.44	0.52	0.64	0.65	0.73	0.83
Gender						
Female	0.35	0.44	0.56	0.54	0.70	0.81
Male	0.36	0.48	0.60	0.54	0.68	0.83

The characterization above is expressed in the following box plot graphics (Figures 13-18).

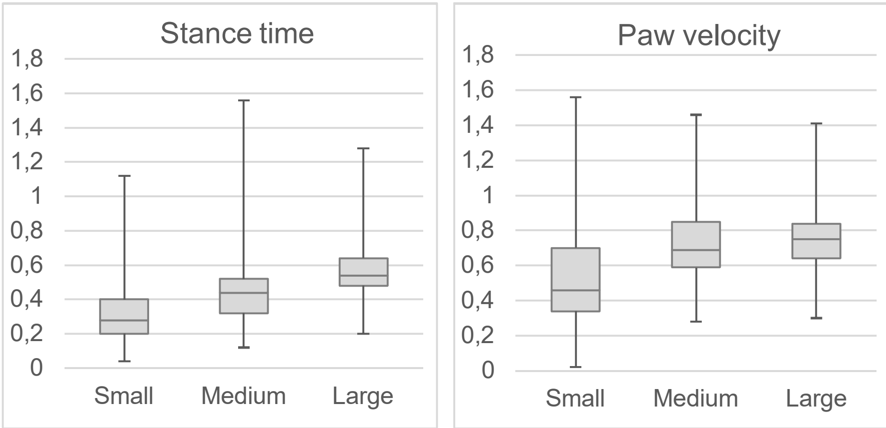


Figure 13. Box plot for the characterization of the variable ST (s) (left) and PV (m/s) (right), according to size.

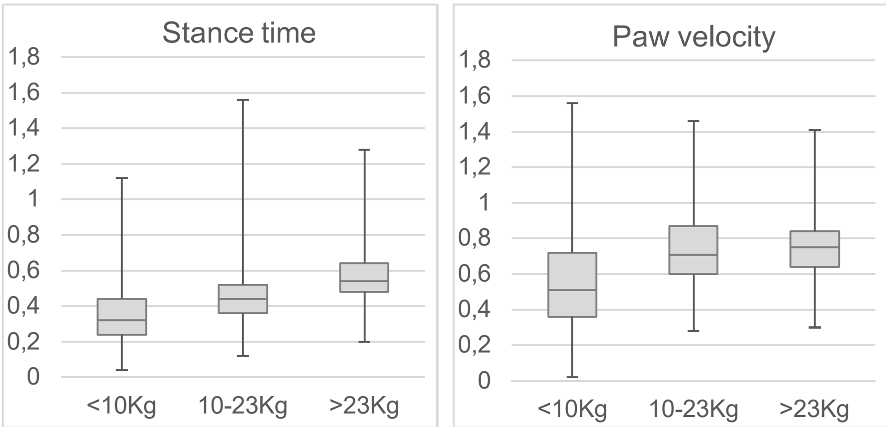


Figure 14. Box plot for the characterization of the variable ST (s) (left) and PV (m/s), according to weight.

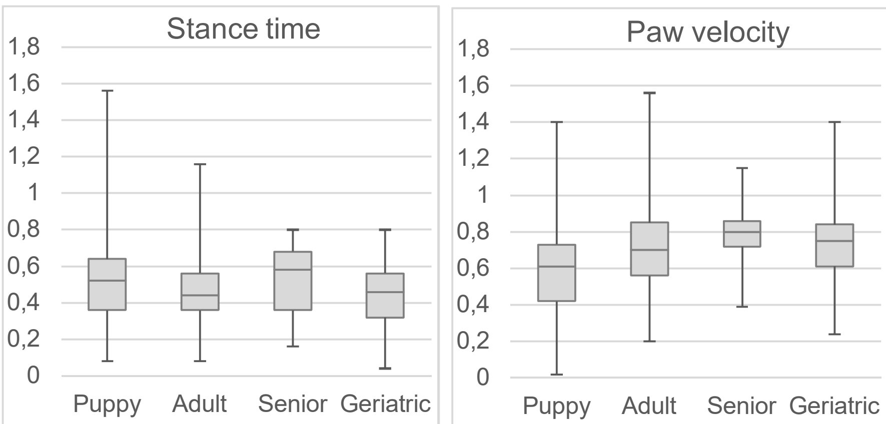


Figure 15. Box plot for the characterization of the variable ST (s) (left), and PV (m/s) (right), according to age.

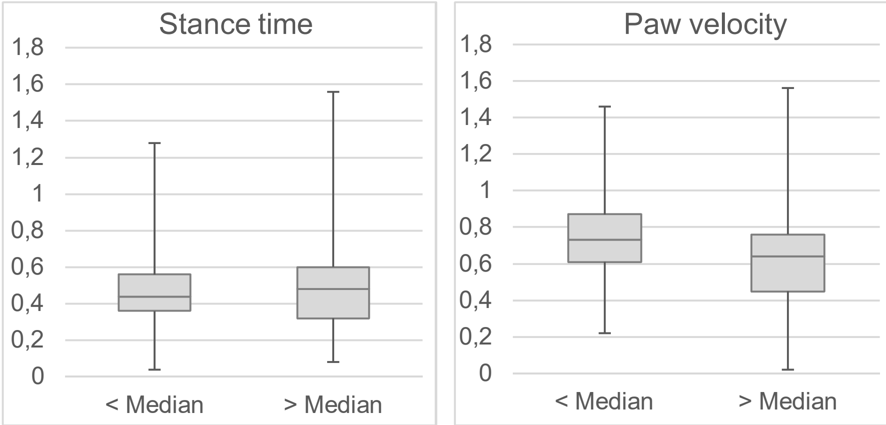


Figure 16. Box plot for the characterization of the variable ST (s) (left), and PV (m/s) (right), according to height.

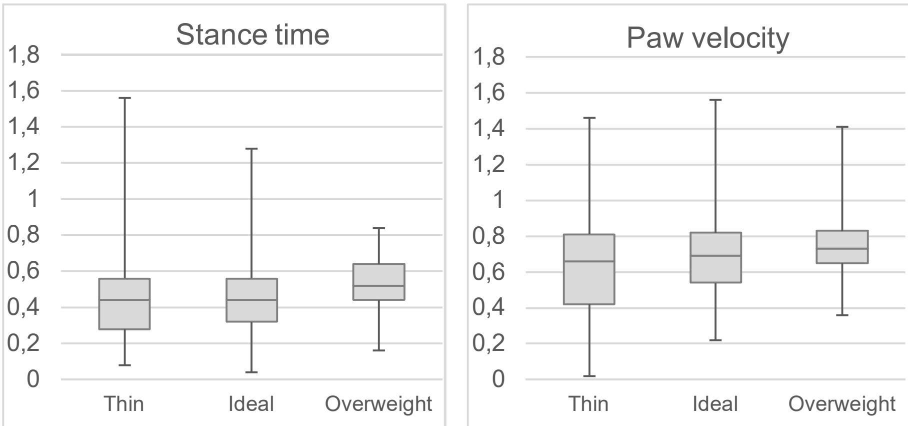


Figure 17. Box plot for the characterization of the variable ST (s) (left), and PV (m/s) (right), according to BCS.

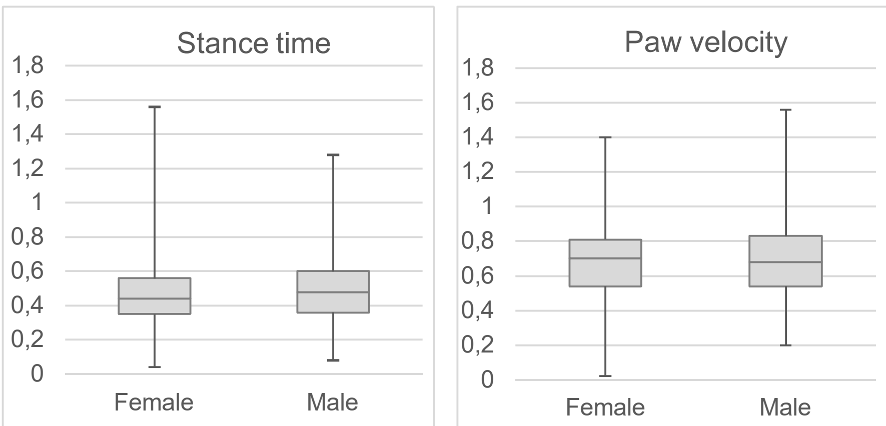


Figure 18. Box plot for the characterization of the variable ST (s) (left), and PV (m/s) (right), according to gender.

Table 9.

Lower and upper limits of the 95% confidence interval (CI) for the variables stance time, in seconds, and paw velocity, in meters per second, according to age groups.

	Stance Time (s)		Paw Velocity (m/s)	
	Lower Limit	Upper Limit	Lower Limit	Upper Limit
Puppy	0.20	0.92	0.15	0.90
Adult	0.16	0.72	0.33	1.11
Senior	0.28	0.76	0.66	1.02
Geriatric	0.24	0.64	0.44	0.96

Table 10.

Age groups according to breed sizes.

	Breed Size		
	Small	Medium	Large
Age Groups	<10 Kg	10-23 Kg	>23 Kg
Puppy	< 9 mo	< 12 mo	< 18 mo
Adult	< 7 y	< 7 y	< 6 y
Senior	7 - 10 y	7 - 10 y	6 - 8 y
Geriatric	≥ 11 y	≥ 11 y	≥ 9 y

mo – months, y – years.

Discussion and Conclusion

Canine kinetic gait analysis has been widely performed, particularly for breed characterization purposes in Labrador Retrievers, German Shepherd Dogs, Pitbulls and Doberman Pinschers (Evans, Horstman, & Conzemius, 2005; Light et al., 2010; Nordquist et al., 2011; Foss, da Costa, Rajala-Shultz, & Allen, 2013; Souza, Pinto, Marvulle, & Matera, 2013; Souza, Tatarunas, & Matera, 2014; Lima, da Costa, Foss, & Allen, 2015), and breed comparison purposes in Labrador Retrievers, Beagles, Greyhounds, Border Collies and Rottweilers (Bertram, Lee, Case, & Todhunter, 2000; Besancon, Conzemius, Evans, & Ritter, 2004; Colborne, Innes, Comerford, Owen, & Fuller, 2005; LeQuang, Maitre, Colin, Roger, & Viguier, 2010; Molsa, Hielm-Bjorkman, & Laitinen-Vapaavuori, 2010; Agostinho et al., 2011; Carr, Canapp, & Zink, 2015). Nevertheless, and even though some inter-breed variability may be present, the studies that focused in homogeneous groups also found differences among dogs of the same breed (Gustås, Pettersson, Honkavaara, Lagerstedt, & Byström, 2013)

The majority of the performed kinematic studies centred their approach on the range of motion of diverse joints. Instead, the present study represents a temporospatial quantitative characterization of the gait of healthy dogs, focused on the pelvic limb, using a heterogeneous group representative of natural variability, constituted by mongrels and individuals from 24 breeds. Hindlimb pathologies, namely the cranial cruciate ligament disease and hip dysplasia, have been more frequently diagnosed during the last 40 years (Witsberger, Villamil, Schultz, Hahn, & Cook, 2008). Hip dysplasia and secondary osteoarthritis were reported as the most common reason for euthanasia or end of service in military working dogs (Moore, Burkman, Carter, & Peterson, 2001)

The primary goal of this study was attained through a temporospatial analysis and characterization of the pelvic limb gait of healthy dogs, with a special standardisation of the variables ST and PV, by definition of reference values that may be useful in further studies focusing on dogs with orthopaedic and/or neurologic conditions. Lower and upper limits were defined for these two variables through the calculation of the 95% CI establishing that dogs with values above or under these limits deserve individual further investigation, considering their age group and breed size.

Additionally, a multiple linear regression analysis was performed to unveil the influence of several independent variables in the studied TSV.

The temporospatial parameters PV and stance duration have been selected from a group of kinematic variables because they proved to be the most sensitive to the existence of hindlimb pathologies thus being potentially the most useful for analysis of their evolution, either with or without clinical intervention. A decline of PV or stance duration was observed in dogs with cranial cruciate ligament rupture, but the reported lameness may be generated by several other pelvic limb conditions, widening its utility in the evaluation of multiple situations (Sanchez-Bustinduy et al., 2010; de Medeiros et al., 2011).

Dogs were walked at their preferred self-selected velocity, allowing for a more realistic characterisation and permitting the establishment of relations between the dogs' characteristics and their gait pattern. It was also considered that a slower gait would enhance individual characteristics and avoid the concealment of possible variations, even more knowing that when gait speed increases a drop in stability is observed (Tian, Cong, & Menon, 2011). In this study, PV variance was explained in the final model, in 13.1% by the height and age of the dog: taller dogs presented lower PV mean values (0.62±0.23) than shorter dogs (0.74±0.22) and puppies presented lower PV mean values (0.58±0.23) than adult (0.71±0.23), senior (0.81±0.15), and geriatric dogs (0.73±0.19). Unlike LeQuang et al. (2010) that did not find significant velocity differences between Beagles and Labrador Retrievers, we found significant differences between small and medium, and between small and large size dogs. The recorded PV mean values are compliant with a walking gait pattern (Lauer, Hillman, Li, & Hosgood, 2009; Sanchez-Bustinduy et al., 2010; de Medeiros et al., 2011; Foss, da Costa, & Moore, 2013; Gustas, Pettersson, Honkavaara, Lagerstedt, & Bystrom, 2016), approaching, but being slightly lower, the velocity values of other studies also on walking gait (0.9-1.2 m/s) (LeQuang et al., 2010; Carr, Canapp, & Zink, 2015; Gustas et al., 2016; Kano et al., 2016). Although several studies chose trot as the preferred gait pattern to assess, we believe that walk is more suitable due to its proper sequence of limb support during a complete cycle, its particularly prolonged stance phase (2/3 stride versus 1/3 stride in trot), and its high consistency in temporal and spatial variables (DeCamp et al., 1993; Allen, Decamp, Braden, & Bahns, 1994; Hottinger, DeCamp, Olivier, Hauptman, & SoutasLittle, 1996).

Relative stride length (SrL%) that represents a normalisation of the variable SrL to the height of the dog, as proposed by Bertram et al. (2000), showed lower median values in small dogs than in large, but not medium size dogs. Male dogs had greater SrL% than female dogs. Geriatric dogs had lower SrL% than puppies, adult and senior dogs. Thin dogs had greater SrL% than ideal weight dogs. In the final model, 4.4% of the SrL% variation was explained by body weight, age and gender of the dog.

The height of the dog is therefore an important measure when studying gait. The exact length of the limbs are difficult to calculate and the height of the dogs has been assessed using different methods: quantification of bone length (Budsberg, Verstraete, & Soutas-Little, 1987); height at the withers (Gordon-Evans et al., 2009; Voss, Galeandro, Wiestner, Haessig, & Montavon, 2010; Voss, Wiestner, Galeandro, Hassig, & Montavon, 2011); or functional limb length (Bertram et al., 2000). We chose to measure the height at the withers because it is more practical, quicker, and easier to obtain, therefore contributing to faster measurement and easier repeatability.

Intra-individual variability was studied, and no statistically significant differences were found in this study.

All TSV were significantly lower in small size dogs when compared to medium and large, with the exception of SwT% and cadence that were significantly higher. This pattern has also been found in other studies, with a negative correlation between cadence (stride frequency), and most temporospatial parameters (Kim et al., 2011; Kano et al., 2016). Cadence and SwT% decreases, whereas ST, SwT and SrL increased, as the size of the dog augments. SrL% was only significantly different between small and large size dogs. ST% and PV were significantly different between small and medium, and between small and large, but no differences were found between medium and large size dogs. These findings are in accordance with the ones of Kim et al. (2011) that, by performing a temporospatial and kinetic comparison between small and large dogs, found shorter SrT, ST, SwT, SrL, PV and higher cadences in the former. Higher cadences in small dogs were also found when comparing Labrador Retrievers and Beagles (LeQuang et al. (2010), together with lower ST, ST%, SrT and SrL in Beagles but no significant differences in velocity. All TSV mean values found in the present study were similar to the ones found by Kim et al. (2011) for small and large size dogs and by Lima et al. (2015) and Light et al. (2010) for large size dogs, achieved by the use of a pressure-sensitive walkway system.

In a recent quantitative comparison of gait, walk and trot of Border Collies and Labrador Retrievers, the authors found shorter SrL in Border Collies but no SrT differences, similar to the present study (medium and large size dogs); In addition, they found significant higher ST% in Labrador Retrievers than in Border Collies (55.6% vs 49.9%) (Carr, Canapp, & Zink, 2015), both values inferior to ours (67% to large size dogs and 65% to medium) but closer to the findings of Light et al. (2010) of 50.2% in Labrador Retrievers. Analysis of the relative time of stance and swing phases during one gait cycle (ST%-Sw%), determined mean values of 67%-33% (mean velocity of 0.75 m/s) for large size dogs, whereas Kano et al. (2016) found, also for large size dogs, 60%-40% (velocity around 0.9 m/s). These differences may be attributed to the faster gait velocity in these studies, in comparison with ours, that reduces the time of paw ground contact (stance), due to the inverse relation between velocity and ST (Titianova, Mateev, & Tarkka, 2004; Kim et al., 2011). These two variables were not influenced by the age of the dogs.

Geriatric dogs showed shorter SrL and SrL(%) than puppies, adult and senior dogs. Puppy dogs had lower PV than adult, senior and geriatric dogs. Overall age-related differences were expected, since different stages of skeletal maturation were compared. An interesting phenomenon was also observed: most of the TSV increased with age but decreased from senior to geriatric dogs, creating a tipping point between these two age categories, significant in ST, SrL, and SrL(%). The reduction of the stance phase duration can be due to the attempt of elder dogs to support their weight for less time as a way to alleviate discomfort caused by muscle weakness or subclinical joint degenerative processes, including lumbosacral instability/degeneration. Geriatric dogs showed higher cadence than all other age categories (reaching significance when compared to puppies) that complies with the notion of shortened stride, shortened stance phase, and more strides per second. Gordon-Evans et al. (2009) also found an increased SwT with age, although with a weaker relation.

Males and females recorded very similar mean TSV values. Differences were only recorded in SrL and SrL% where male dogs had significantly higher values, in opposition to the findings of Gordon-Evans et al. (2009) of higher SrT and SrL in females. However, in the final model it was identified an influence of gender in ST (in 30.3%, together with height and body weight), in SwT% (in 4.6%, together with height), in cadence (in 21%, together with height, age and size) and in SrL% (in 4.4%, together with age and body weight).

Taller dogs have significantly higher SrT, SwT, and SwT% but lower PV, as Molsa et al. (2010) found in their study of kinetic comparison of Labrador and Rottweilers. Although there were no statistical significant differences between the ST of under and above median height dogs, we calculated that ST variability was explained in 30.3% by height, body weight and gender, corroborating the previously reported direct relation between height and ST (Budsberg et al., 1987; Gordon-Evans et al., 2009; Voss et al., 2010). However, height, as an independent variable, has shown influence in all TSV when the multiple linear regression analysis was performed to find a final model able to explain all influences. Indeed, when the height of each dog was used to normalise the stride length, the three remaining influent variables (age, body weight and gender) represented a minor influence of 4.4% in SrL(%).

When the differences between BCS categories in the TSV were studied, we found that overweight dogs have significant higher SrT, ST and SwT and significant lower cadence, comparatively to both thin and ideal weight dogs. Furthermore, overweight dogs showed longer ST% and SrL but lower Sw% than thin dogs. Similar values, albeit of greater magnitude of ST% were found by Carr, Canapp, & Zink (2015) between ideal weight Labrador Retrievers (mean BCS=5.4) and thin Border Collies (mean BCS=4.3). The authors also determined shorter SrL in Border Collies, in accordance with our findings but not with Brady et al. (2013) that found shorter SrL in obese dogs. Unlike our expectations, obese dogs had faster PV than both ideal weight and thin dogs, although not statistically significant. Although not addressing BCS, J. Kim et al. (2011) found a significant positive correlation between body weight and SrT, ST, SwT in small dogs and Carr, Canapp, & Zink (2015) found a strong trend to a correlation between body weight and ST in large dogs (Labrador Retrievers)

Although the use of a treadmill was considered in this study, it would require time for familiarization that could go from 1 day of three sessions (Gustås et al., 2013) or 2 consecutive days of five 8- to 10-min sessions (Gustas et al., 2016), to two weeks of around 10 minutes sessions every other day (Torres et al., 2013), so that variability could be reduced and a stable gait pattern achieved, not existing the assurance that more subtle adaptations would occur if the training continues (Gustås et al., 2013; Gustas et al., 2016). Moreover, Sanchez-Bustinduy, et al. (2010) found that the use of treadmill is not critical for accuracy in the measurement of either of the variables PV and stance duration, and Torres et al. (2013) stated that sagittal kinematic gait data from dogs on overground or treadmill-based walking was not dissimilar.

An important advantage of the proposed two dimensional methodology is that the analysis relies on the use of a single reflective marker on each paw, which saves time during the video collection, and facilitates the utilisation of the method. This should represent an argument to further this two-dimensional gait analysis in veterinary practices, as an added resource to the functional assessment of dogs in a preventive medicine context.

Efforts have been made to reduce error in this experimental study. It is documented that some error may arise from the placement and movement of markers during the images collection and some inherent subjectivity of the videography digitising process. Being aware of this possibility, and in order to minimise these flaws, the same person placed all markers and the same person did the digitising process. Marker dislocation was calculated and the value ranged from 0.03 to 0.06 m, which we cannot compare with other studies because the movement of the 5th metatarsal bone skin marker was never reported. This displacement is attributed to the movement of the skin and soft tissues under the markers (Sanchez-Bustinduy, et al., 2010), but in such a distal aspect of the limb, where skin is not so loose and the amount of subcutaneous tissue is scarce, such artefact would be predictably low. We found a higher marker displacement in obese dogs than in thin dogs, attributable to wider movements of heavier skin and subcutaneous tissues (Brady et al., 2013). The markers dimension could also have furthered displacement. In this study we used markers with 20mm diameter while in other studies the dimensions were 18mm (Agostinho et al., 2011; Miqueleto et al., 2013), 16mm (Kim, Kim, Hayashi, & Kapatkin, 2011), 15mm (Bockstahler et al., 2007), 14mm (Ragetly, Griffon, Klump, & Hsiao-Wecksler, 2012) and 8mm (Torres et al., 2013). To minimize the possible influence of different handlers, all dogs were walked by the same person during the collection moment. A recent study, however, postulated that changing handlers or the side of the leash do not influence hindlimb variables (Keebaugh, Redman-Bentley, & Griffon, 2015).

The gait temporospatial characteristics and relationships reported in this study established a normal pattern and identified some variation factors that should be taken into consideration when using quantitative gait analysis to identify lameness and diagnose neurologic or musculoskeletal diseases.

To strengthen its utility and clinical value, this two-dimensional methodology of gait analysis should be compared with the results of a pressure-sensitive walkway system and assessed in clinically hindlimb lame dogs in the near future.

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‖ CHAPTER VII

Mobility scores and temporospatial gait parameters of healthy dogs – a preliminary correlation study

Introduction

Upon the construction and validation of the Dog Mobility Scale and the 2D kinematic analysis of healthy dogs, we aimed to understand their correlations so that the practical utility of the two instruments, considering both their strengths and weaknesses, may be known. A mobility score that is able to correlate to kinematic temporospatial variables, in a known way, would be an extremely useful instrument of first approach. The correlation between instrument outcomes is often performed in order to analyse criterion validity (Brown, Boston, Coyne, & Farrar, 2007; Hercock, Pinchbeck, Giejda, Clegg, & Innes, 2009; Rialland et al., 2012; Walton, Cowderoy, Lascelles, & Innes, 2013).

Objective

The aim of this chapter was to study the correlations between the Dog Mobility Scale (DMS) scores and the two-dimensional kinematic temporospatial variables (TSV) of the hindlimb during walking in healthy dogs.

Methods

Correlations between mobility scores and temporospatial variables of 36 dogs were analysed by age, gender, size, height, and body condition using and Spearman coefficient. Scatter plots were constructed to illustrate the statistical significant correlations.

Statistical Package for the Social Sciences (SPSS), version 24, software was used and a significance level was set for $p < 0.05$.

Results

Table 1 displays the Spearman's correlation coefficients calculated between mobility scores (DMS) and each one of the temporospatial variables: stride time (SrT), stance time (ST), swing time (SwT), relative stance time (ST%), relative swing time (SwT%), paw velocity (PV), stride length (SrL), and relative stride length (SrL%), collected by two-dimensional kinematic analysis, and age, gender, size, height, and body condition (BCS).

Statistically significant correlations are illustrated in scatter plots in Figures 1-8. Correlations for geriatric, senior, and overweight dogs were not possible to calculate due to the small number of dogs.

Table 1.

Spearman's correlation coefficients between mobility scores (DMS) and temporospatial variables by age, gender, size, and body condition.

			TSV								
			SrT (s)	ST (s)	SwT (s)	ST%	SwT%	Cadence (strides/s)	PV (m/s)	SrL (m)	SrL%
DMS		**All** *N*=36	-0.070	-0.092	0.012	-0.151	0.151	0.069	0.128	0.205	**0.437****
	Age	**Puppy** *n*=13	0.063	0.058	0.061	0.051	-0.051	-0.025	0.249	0.248	0.208
		Adult *n*=19	-0.421	-0.402	-0.398	-0.279	0.279	0.413	0.139	-0.074	0.398
	Gender	**Male** *n*=16	**-0.549***	**-0.547***	**-0.506***	-0.385	0.385	**0.506***	0.119	-0.243	0.332
		Female *n*=20	0.376	0.394	0.332	0.312	-0.312	-0.391	0.098	0.369	0.351
	Size	**Small** *n*=12	0.078	0.035	0.119	-0.116	0.116	-0.025	**0.589***	0.570	**0.683***
		Medium *n*=10	0.514	0.330	0.557	-0.044	0.044	-0.483	0.125	0.433	0.383
		Large *n*=14	-0.180	-0.137	-0.172	-0.069	0.069	0.173	-0.032	0.068	0.299
	Height	**Under median height** *n*=18	-0.104	-0.157	0.036	-0.294	0.294	0.131	0.064	0.282	0.450
		Above median height *n*=18	-0.275	-0.259	-0.073	-0.213	0.213	0.242	0.271	0.323	**0.527***
	BCS	**Thin** *n*=13	0.042	0.018	0.365	-0.128	0.128	-0.072	0.304	0.304	0.234
		Ideal *n*=19	-0.069	-0.073	-0.003	-0.169	0.169	0.050	0.061	0.271	0.344

SrT-stride time; ST-stance time; SwT-swing time; ST% - relative stance time; SwT% - relative swing time; PV-paw velocity; SrL-stride length; SrL%-relative stride length; BCS – body condition score * Correlation is significant at the 0.05 level (2-tailed) ** Correlation is significant at the 0.01 level (2-tailed). Not possible to establish a correlation for senior, geriatric, and overweight dogs.

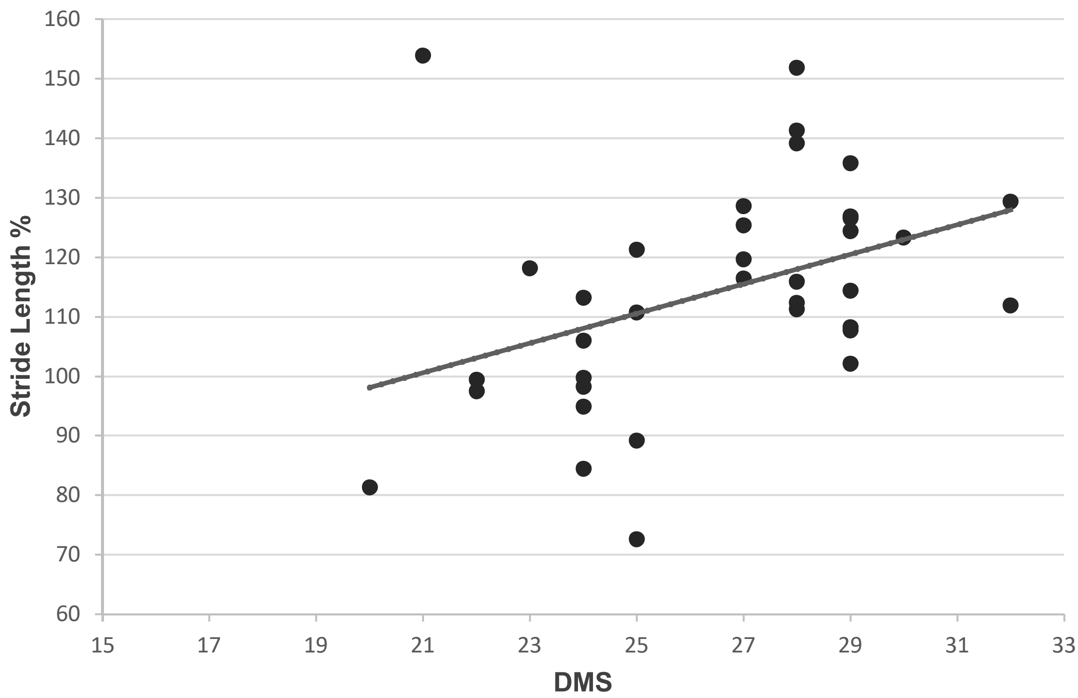

Figure 1. Scatter plot illustrating the low positive correlation between mobility scores (DMS) and relative stride length (SrL%) (r_s=0.437; p=0.008).

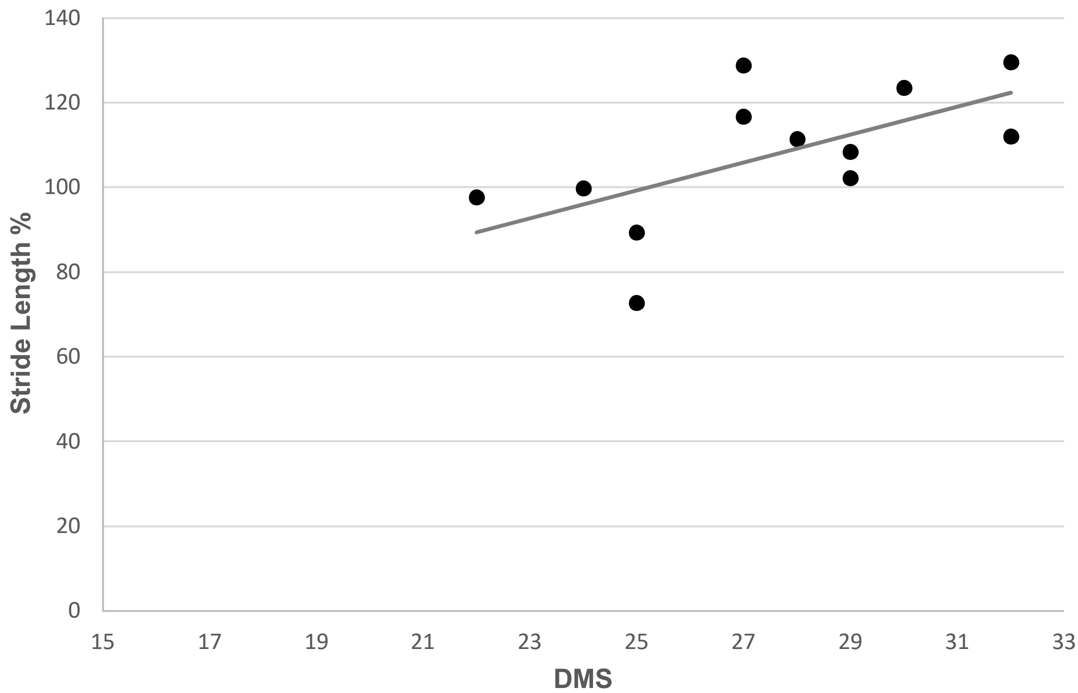

Figure 2. Scatter plots illustrating the moderate positive correlation between mobility scores (DMS) and relative stride length (SrL%) (r_s=0.683; p=0.014) of twelve small size dogs.

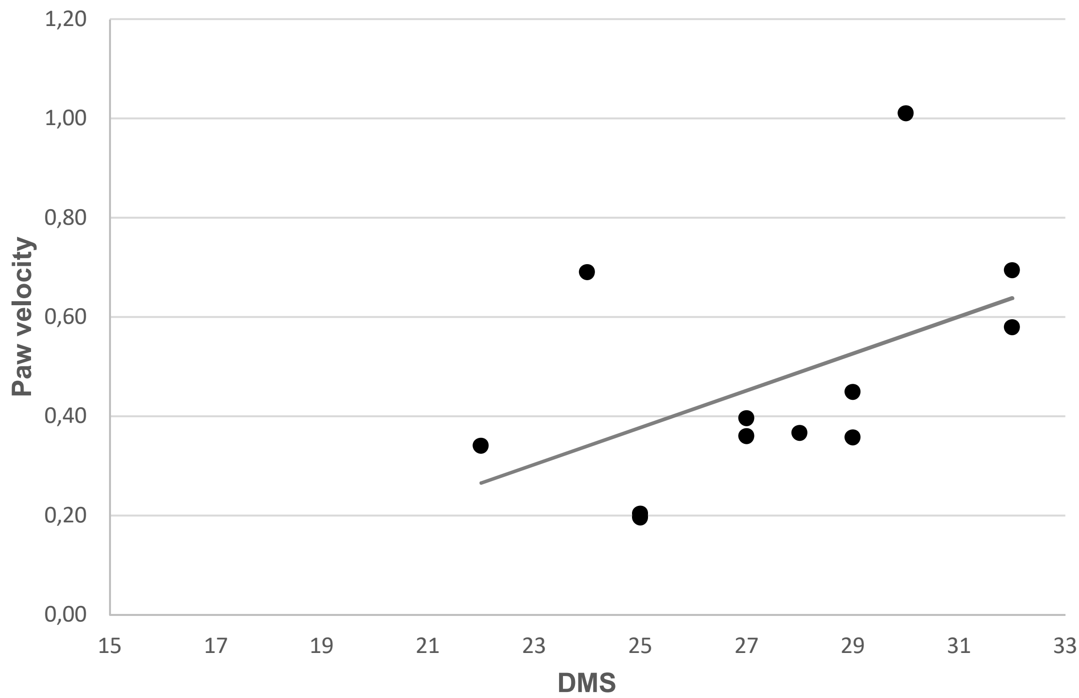

Figure 3. Scatter plots illustrating the moderate positive correlation between mobility scores (DMS) and paw velocity (PV) (r_s=0.589; p=0.044) of twelve small size dogs.

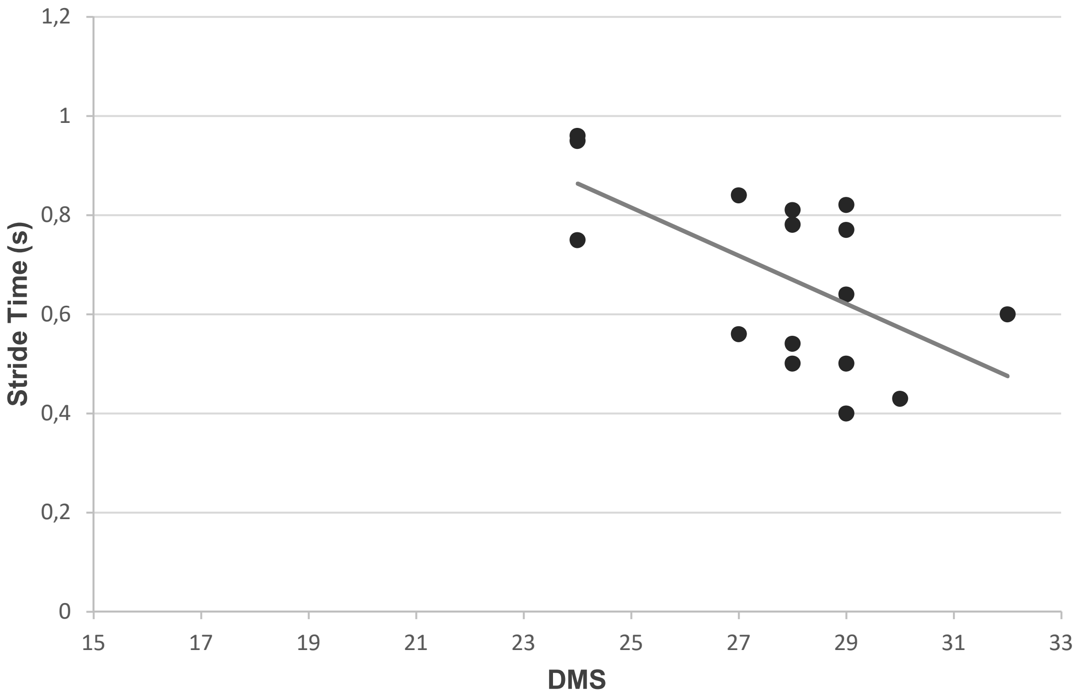

Figure 4. Scatter plots illustrating the moderate negative correlation between mobility scores (DMS) and stride time (SrT) (r_s=-0.549; p=0.028) of sixteen male dogs.

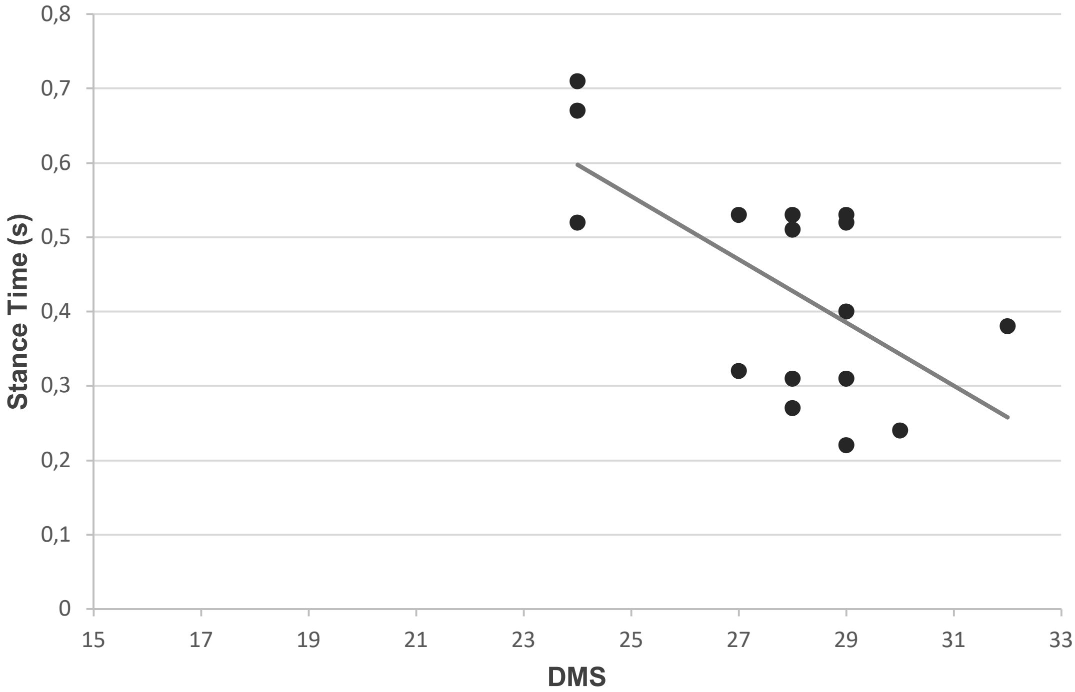

Figure 5. Scatter plots illustrating the moderate negative correlation between mobility scores (DMS) and stance time (ST) (r_s=-0.547; p=0.028) of sixteen male dogs.

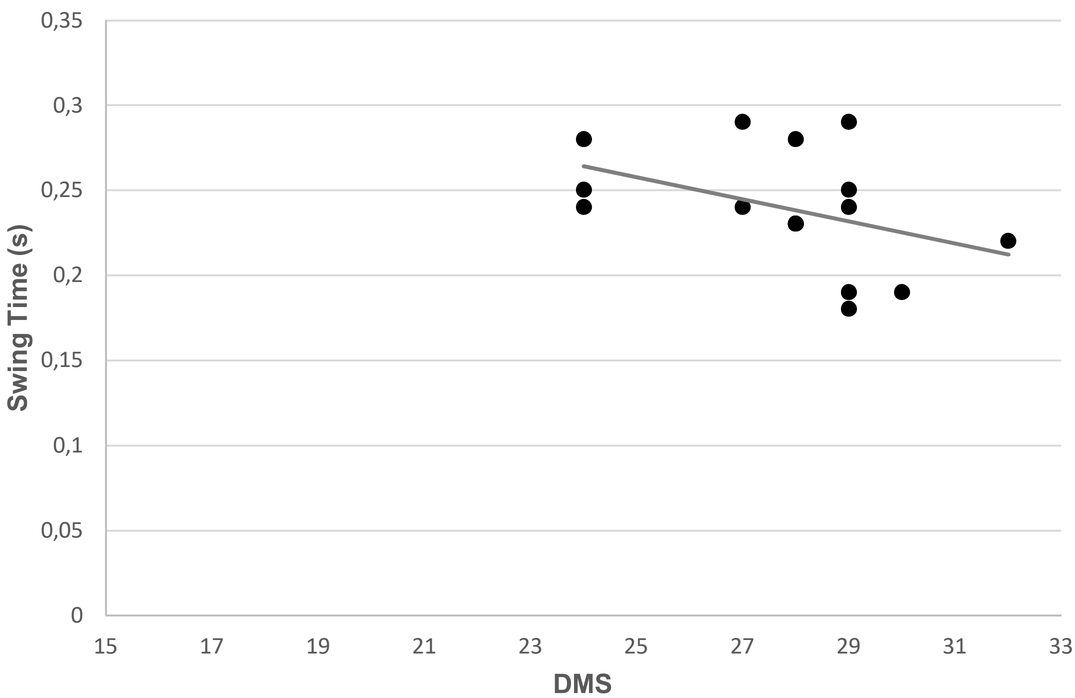

Figure 6. Scatter plots illustrating the moderate negative correlation between mobility scores (DMS) and swing time (SwT) (r_s=-0.506; p=0.046) of sixteen male dogs.

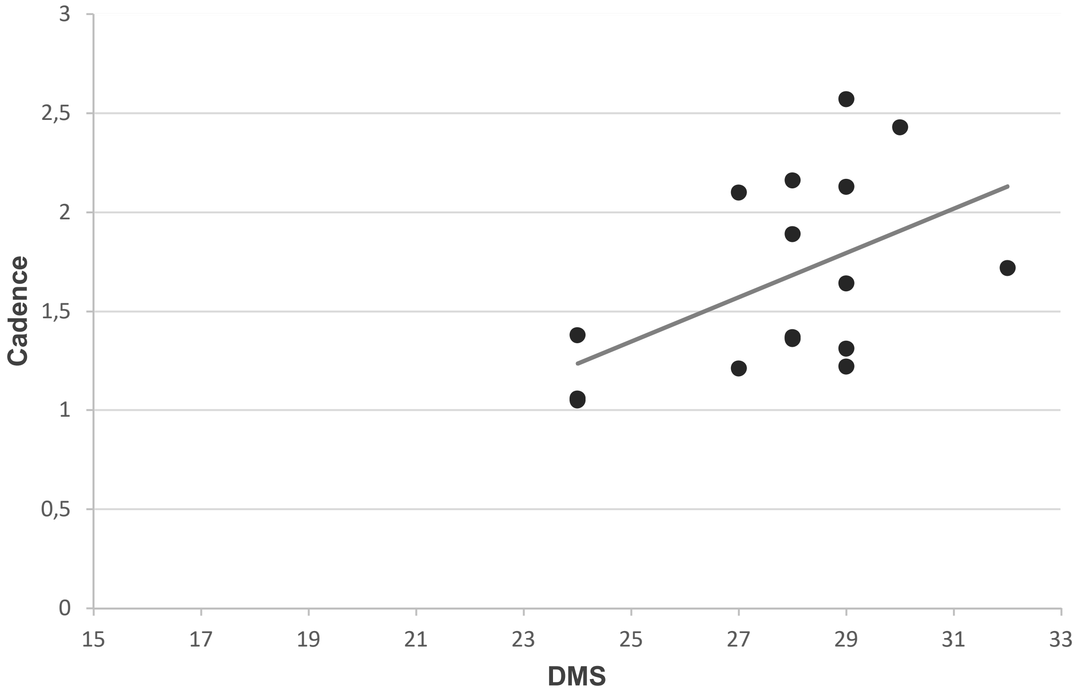

Figure 7. Scatter plots illustrating the moderate positive correlation between mobility scores (DMS) and cadence (r_s=0.506; p=0.046) of sixteen male dogs.

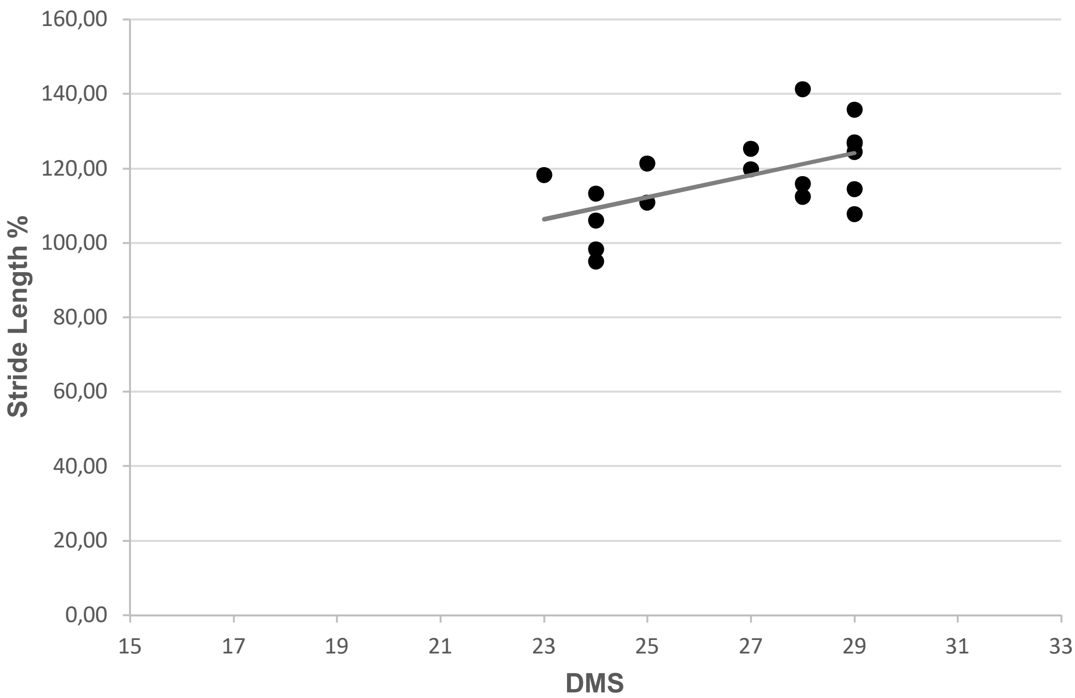

Figure 8. Scatter plot illustrating the moderate positive correlation between mobility scores (DMS) and relative stride length (SrL%) of eighteen taller dogs (above median height) (r_s=0.527; p=0.025).

Preliminary analysis:

All statistically significant correlations were of moderate strength with the exception of the low correlation between the DMS scores of the entire group (N=36) and SrL%, which means that there is an identified correlation between the two outcome variables although the moderate strength of this linear association warrants careful interpretation (Mukaka, 2012).

Group analysis of the entire population (N=36) showed a positive correlation between SrL% and mobility scores. This correlation was also found for specific analyses of small size dogs, and taller dogs. Longer strides (normalised to height) reflected higher mobility, unveiling that longer spatial progression corresponds to higher mobility.

In male dogs, the temporal variables SrT, SwT, and ST, were negatively correlated to mobility, foreseeing that larger time expenditure during stride and during swing and stance times result in decreased mobility. In the same group, the inverse correlation was found for cadence, with dogs performing more strides per second being attributed higher mobility scores.

The paw velocity was positively correlated with mobility in small size dogs, indicating a higher mobility of faster dogs.

The data analysis regarding age groups may be biased by the fact that older dogs (senior and geriatric) were under-represented (4 in 36) so we refrain from interpreting them. A wider study of an equally age distributed population is warranted to strengthen its conclusions. We hypothesise, however, that gender differences may have been concealed in the DMS validation study (N=123) by the two main reasons for its differences (age and the existence of pathologies). Once the number of elderly and diseased dogs was reduced, then a gender effect emerged. It is important to highlight that DMS measures the dog's mobility, considering the dog as a whole, which means that, besides the hindlimb, the frontlimb and spine movements have a contribution to the final mobility score, justifying the moderate value of the correlation.

These preliminary results represent initial relations between mobility scores, calculated with the Dog Mobility Scale, and the temporospatial outcome variables obtained from two-dimensional kinematic analysis of the hindlimb. The moderate strength of the correlations indicates that larger and more balanced populations need to be studied, including dogs with mobility impairment pathologies, aiming to progress in the criterion validity analysis of the DMS.

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║ CHAPTER VIII

Final considerations and future perspectives

This thesis aimed to study the functional assessment of the dog and its measure instruments focusing on the domains of mobility and gait. The inherent need for the study of normality and establishment of patterns was soon acknowledged and, through the accomplishment of specific goals representing progressive work stages, results were achieved with the development and validation of a novel instrument to measure mobility; a practical and suitable for routine clinical use two-dimensional kinematic methodology for gait analysis was proposed; the influence of individual characteristics such as size, weight, height, breed, age, gender and body condition on mobility and on temporospatial gait parameters was studied; and finally a preliminary study of correlations between mobility values and temporospatial gait parameters was performed, shaping the path of further work on the subject.

In the first part of the study, described in chapter III, a systematic review of the literature reporting gait analysis on healthy dogs was conducted, assembling and compiling the published information on the influence of individual characteristics on gait outcome variables of healthy dogs. All kinetic and kinematic gait analysis methods were considered aiming to include as much information as possible. Two hundred and thirty-nine references were retrieved of which 34 studies complied with the inclusion criteria. Methodological analysis allowed for the conclusion that two-dimensional analysis was most uncommon method, albeit its low-cost advantage and aptitude for providing accurate and reliable data on sagittal plane movements. Although more randomized controlled trials of larger heterogeneous groups were deemed necessary, body weight, height, age and gender seemed to influence the gait outcome variables in healthy dogs. This literature review provided orientations for ensuing work: to deepen the knowledge on the influence of individual characteristics using cost-effective techniques, such as two-dimensional kinematic gait analysis evaluation, with potential utility in the clinical practice context.

In the second part of the study, we aimed to develop and to assess the psychometric characteristics of a mobility scale for dogs, the Dog Mobility Scale (DMS). Its need emerged from the observation that there was no validated instrument available able to measure dog mobility other than a limited number of questions related to mobility that were included in pain and quality of life scales. After the validation process and confirmation of its good internal consistency (Cronbach's Alpha=0.854) was determined, the three hypotheses proposed for the construct validity were verified: 1) gender does not influence dog mobility ($p = 0.584$); 2) mobility decreases with age ($p < 0.001$); 3) dogs diagnosed with orthopaedic or neurological conditions have lower mobility scores than clinically healthy dogs ($p < 0.001$). The Dog Mobility Scale was capable of assessing mobility in dogs, with good psychometric characteristics, and is a simple, quick, and inexpensive practical tool. Its purpose is to identify dogs with initial, non-clinical, stages of mobility impairment that may benefit from further diagnostic workup and/or early preventive or therapeutic intervention. The validation of the instrument is an on-going task and we aim to explore the DMS responsiveness to the treatment of mobility-impairing diseases as well as its reproducibility (agreement and reliability) with repeated assessments. Further validation of the scale will also be accomplished by studying the correlation of the DMS scores with a gold standard such as the pressure-sensitive walkway system (PSW) (criterion validity) (Hudson, Slater, Taylor, Scott, & Kerwin, 2004; Terwee, et al., 2007; Brown, Boston, Coyne, & Farrar, 2008; Hielm-Björkman, Rita, & Tulamo, 2009). This study is already being outlined and designed as a randomized double-blind placebo-controlled clinical trial resorting to the Tekscan Walkway^{TM} (PSW) from Porto Biomechanics Laboratory - LABIOMEP.

In the third part of the study, the objective was to analyse the relationships between individual characteristics of healthy dogs (size, weight, height, breed, age, gender and body condition) and their mobility scores. This study had a dual purpose of applying the novel DMS, aiming to enhance its robustness, and also to investigate the influence of individual characteristics of the dog on its mobility. Results found that males had statistically significant, albeit weakly correlated, higher mobility scores. The remaining variables were not considered to affect mobility. Considering that the DMS was developed to detect changes in mobility caused by orthopaedic or neurological conditions, rather than to detect individual differences, our conclusions were that the DMS is applicable to all canine phenotypes, although such statement requires further and wider studies. It would also be very interesting to prospectively study a group of young healthy dogs and follow their natural aging by regular application of the DMS, trying to define values, or their variations, able to predict the subsequent development of pathologies.

Interestingly, when the DMS was applied to a smaller (N=36), younger (35.25 months) and pathology-free group, a gender influence on mobility emerged, with males having statistically significant higher mobility scores. Although it may be argued that the DMS applicability is universal, upon its validity for the larger group, it may be possible that its accuracy may improve by considering males and females separately, an issue that deserves further attention.

The fourth part of the study was devoted to characterise and quantify the hindlimb temporospatial variables of healthy dogs during walk. A two-dimensional approach was developed aiming for its application by veterinary practitioners in the early detection of gait abnormalities. All TSV were significantly lower in small size dogs when compared to medium and large, with the exception of relative swing time (SwT%) and cadence that were significantly higher. Males had significantly higher stride length (SrL) and SrL% while geriatric dogs showed shorter SrL and SrL%. Puppies had lower PV while taller dogs had higher stride time (SrT), swing time (SwT), SwT% and lower paw velocity (PV). Overweight dogs have significant higher SrT, stance time (ST) and SwT, and significant lower cadence. Height of the dog was identified has influencing all TSV. The SrL% variability was explained in 4.4% by age, body weight and gender. The gait temporospatial parameters of the walk in healthy dogs were analysed and characterised, establishing a normal pattern and identifying variation factors. To enhance the value of this methodology we aim, in near future, to compare it with the LABIOMEP Tekscan Walkway^{TM} PSW in order to study the agreement between TSV obtained from the two instruments, both in healthy and dogs affected by neuromuscular conditions.

In the fifth part of the study the objective was to assess the correlations between mobility scores and temporospatial parameters of the hindlimb in healthy dogs. Correlations of moderate strength were found. These preliminary results represent first interpretation on the subject. Further work is warranted to determine the exact cut points for mobility scores that will arise from the responsiveness or sensitivity analysis of the DMS.

It is both surprising and rewarding to realise that, since the outline and realisation of our studies, scientific investigation on the subject has followed a path very similar to the one traced in this work. The veterinary research community seems to be aware of the need of developing practical and useful instruments available so that veterinary practitioners are able to providing better and more effective medical care to their patients. Examples of such are the owner self-administered questionnaire Canine Orthopedic Index (COI) to assess dogs with orthopaedic diseases in four domains: stiffness, gait, function, and quality of life (Brown, 2014c, 2014a, 2014b); the use of bathroom scales as a reliable measure of asymmetry of hindlimb static weight bearing in dogs with osteoarthritis (Hyytiainen, Molsa, Junnila, Laitinen-Vapaavuori, & Hielm-Bjorkman, 2012); the evaluation of a simplified method of walking track analysis using footprint parameters to compare locomotor differences between normal and spinal cord injured dogs (Song et al., 2016); the scoring of hindlimb stepping and coordination in dogs with naturally occurring spinal cord injury using a treadmill and a video camera (Olby et al., 2014; Rousse et al., 2016); and various physiotherapeutic evaluation methods for assessing hindlimb functionality in dog with stifle disorders (Hyytiainen, Molsa, Junnila, Laitinen-Vapaavuori, & Hielm-Bjorkman, 2013). This trend is also true regarding the most recent gait analysis studies where collection and analysis of temporospatial gait parameters was performed more often (Carr, Canapp, & Zink, 2015; Lima, da Costa, Foss, & Allen, 2015; Kano et al., 2016), the walking gait has been more privileged (Gustas, Pettersson, Honkavaara, Lagerstedt, & Bystrom, 2016; Schwarz, Tichy, Peham, & Bockstahler, 2017), and heterogeneous populations of clinically normal dogs were studied (Hans, Zwarthoed, Seliski, Nemke, & Muir, 2014; Volstad, Nemke, & Muir, 2016).

The elaboration of this thesis aimed to contribute for the improvement of knowledge in a field that has not always received proper attention in veterinary scientific investigation, the dog's functional assessment. With the investigation reported in this thesis, information in the mobility and gait domains was added, providing effective, practical, and inexpensive instruments for daily use in veterinary practices, allowing for the early detection of diseases, and thus earlier and more successful treatments, enhancing the health promotion and disease prevention of canine patients.

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