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A comparison of human and canine kinematics during level walking, stair ascent, and stair descent

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Summary

Stair ambulation is sometimes unavoidable for humans and canines, and changes several parameters of the gait cycle in comparison to level walking. The purpose of this paper is to review and investigate stair ambulation kinematics and kinetics for the human and canine when compared with gait on level surfaces. Data collected from 2 laboratories in a similar manner were analyzed to compare the ankle (tarsal) joint, knee (stifle) joint, and hip joint kinematics for level walking, stair ascent, and stair descent in dogs and humans. The comparison of humans and dogs reveals humans use a greater overall range of motion (ROM) in the hip and knee compared to dogs in all tasks. Dogs use a much greater ROM in the ankle or tarsal joint compared to humans in all tasks. The decreased amount of ROM used at the hip and stifle joints of dogs during level gait, stair climbing, and stair descent when compared to humans is likely a direct result of the increased amount of tarsal flexion dogs use when compared to people. This paper identifies the peak angles of flexion and extension, overall ranges of motion of the hindlimb during normal walking, stair ascent and descent. This information may be used to help devise rehabilitation programs for dogs that need to increase the motion in a particular hindlimb joint through targeted movement tasks.

Abbreviations: CAST = calibrated anatomical system technique; ROM = range of motion

Schlüsselwörter: Biomechanik, Kinematik, Hund, Mensch, Treppensteigen.

Zusammenfassung

Ein kinematischer Vergleich des Gehens von Mensch und Hund auf ebener Fläche und auf Treppen

Das Steigen von Treppen ist für Menschen und Hunde oftmals unvermeidbar und bedingt Veränderungen verschiedener Parameter des Bewegungszyklus im Vergleich zum Gehen auf der Ebene. Das Ziel der vorliegenden Arbeit war es, die Kinematik von Mensch und Hund während des Treppensteigens zu untersuchen und mit der Kinematik während des normalen Gehens zu vergleichen. In 2 verschiedenen Laboratorien wurde auf die gleiche Art und Weise die Kinematik des Tarsal-, Knie- und Hüftgelenks während des Gehens auf der Ebene und auf Treppen (auf- und abwärts) analysiert. Der Vergleich von Menschen und Hunden ergab beim Menschen ein größeres gesamtes Bewegungsausmaß des Knie- und Hüftgelenks während aller getesteten Bewegungen. Hunde verwenden im Rahmen aller untersuchten Bewegungen ein sehr viel größeres Bewegungsausmaß des Tarsalgelenkes als Menschen. Das im Vergleich zum Menschen verminderte Bewegungsausmaß von Hüft- und Kniegelenk der Hunde während des Gehens auf der Ebene und auf Treppen ist wahrscheinlich ein direktes Resultat der gesteigerten Flexion des kaninen Tarsalgelenkes. Die in dieser Studie untersuchten Parameter (maximale Flexion und Extension der Winkel und das Bewegungsausmaß) können dazu beitragen, Rehabilitationsprogramme für Hunde zu planen, bei denen die Beweglichkeit der entsprechenden Gelenke der Hinterextremität trainiert werden muss.

Introduction

Walking, or gait, is a motor skill essential to every day living. Humans and terrestrial animals alike depend on the ability to move from place to place to hunt or gather food, find shelter and complete other tasks that are important to sustain or enhance life. Geographic surfaces vary in topography and ambulation over uneven terrain is often necessary. Stairs were developed over 6,000 years ago to add semi-permanency to steep paths (TEMPLER, 1995).

Stair ambulation is often unavoidable for humans and canines, and changes the joint kinematics in comparison to level walking. The degree of difference is dependent upon the characteristics of the specific step. The tread and riser are 2 important components of stair construction. Risers are the vertical stair height whereas the tread comprises the horizontal stair depth. Dimensions of a standard step vary from country to country, and whether it is outdoors or indoors (TEMPLER, 1995). According to the INTERNATIONAL CODE COUNCIL (2003) a standard outdoor step has a tread of 0.25 meters and a riser no more than 0.21 meters high (ANDRIACCHI et al., 1980).

The convention of goniometry is different in humans and dogs and to fully understand the similarities and differences between the species in gait the normal angles need to be understood. Many references discuss human goniometry (NORKIN et al., 2009), in dogs the standard convention was described and examined for reliability and validity by JAEGGER et al. (2002). In this study, level gait and stair ascent and descent was compared between bipeds (*Homo sapiens* or humans), and quadrupeds (*Canis familiaris* or dogs). Only one study to the authors' knowledge has compared the gait characteristics of these species (CHARTERIS et al., 1979).

Stair ambulation

Stairs are different from level-surface gait in that one must either ascend or descend to cover a specified distance. Stair ascent and descent present unique challenges from the context of joint kinematics and muscle effort. In humans, several studies have been conducted investigating the special challenge of stair ambulation. When ascending, humans are required to raise their centre of gravity during the pull up and then actively carry it forward to the next step. This is achieved through concentric muscular contraction, which displaces the centre of gravity vertically (SELFE et al., 2008). Stair ascent has stance and swing phases. Stance during ascent includes weight acceptance, pull-up, and forward continuance whereas swing phase includes foot clearance, swing, and foot placement (MCFADYEN and WINTER, 1988). The muscle actions are concentric within the lower extremity and primarily employ extensor activity during stance and flexor activity during swing phase (SELFE et al., 2008). When descending, humans must actively carry their centre of gravity forwards and then resist gravity during the controlled lowering phase. This is achieved through eccentric muscular contraction, which controls the rate of lowering of the centre of gravity by absorbing kinetic energy. Descent on a staircase also contains stance and swing phases, and is relatively more demanding than stair ascension with respect to angular motion and muscle control. Stance during descent consists of weight acceptance, forward continuance, and controlled lowering whereas swing consists of leg pull-through and foot placement (MCFADYEN and WINTER, 1988). Eccentric muscle action predominates during descent, and the quadriceps must provide the majority of muscle force for controlled lowering of body mass while stepping down (MCFADYEN and WINTER, 1988; LIVINGSTON et al., 1991; PROTOPAPADAKI et al., 2007). If strong eccentric contractions were not employed, the centre of gravity would accelerate under the influence of the gravitational pull of the earth (WHITTLE, 2007).

Both stair ambulation and level walking could be performed while walking backwards, but the focus of the discussion the following sections is upon various parameters while walking forwards.

Clinical relevance of stair ambulation

The rehabilitation implications for stair ambulation are to restore adequate joint range of motion, motor control, muscle strength, and appropriate balance. Assuming that stair descent is relatively more demanding than ascension from a control perspective, the rehabilitation specialist should pattern exercise interventions specific to the demands of descent (SELFE et al., 2008).

The danger of stair ambulation is present during ascent and descent. According to MCFADYEN and WINTER (1988), the point of greatest instability during stair activities occurs when the support limb moves into single support with all 3 joints in a flexed position. Of the various motions necessary in humans, knee flexion requires the relatively greatest amount of motion within the lower extremities and should be targeted with specific range of motion activities to ensure adequate rehabilitation prior to stair training.

Motor control and muscle strength are also important for stair ambulation. Eccentric muscle strength of the quadriceps is especially important to regain following lower extremity injury. Eccentric activity of the quadriceps controls the lowering of one's body mass during descent, and reduced motor control from arthrogenic inhibition may cause collapse and subject the person to falling.

Activities that promote controlled loading of the quadriceps during stair descent should progress gradually in rehabilitation. For example, mini-squats and small step-ups should be employed prior to introducing the patient to stairs of normal height. Step-up height can be adjusted until the person has enough strength and muscle control to attempt stair ambulation.

To the authors' knowledge, in contrast to human beings, there is no study investigating effects of stair ambulation in canines. Knowledge in canine biomechanics during stair ambulation is therefore lacking, despite the fact clinically the majority of dogs suffering from conditions such as osteoarthritis have problems during stair ambulation. Therefore, the purpose of this paper is to review and investigate stair ambulation kinematics for the humans and canines when compared with gait on level surfaces.

Material and methods

Dogs

5 client-owned dogs (1 Labrador Retriever, 3 Golden Retrievers, and 1 Large Münsterländer) were used in this study. The mean and standard deviation of their age was 4.1 ± 1.9 years and the mean and standard deviation of their body mass was 26.9 ± 3.3 kg at the time of measurement. All dogs received a thorough medical, neurological (BAUMGARTNER, 2005), and orthopedic examination (BRUNNBERG, 2001) and no orthopedic or neurological problems were identified.

Equipment and measurement procedure for canine kinematics

5 reflective markers with a diameter of 10 mm were used for digitalization of the movement which were positioned in anatomical defined places on the right rear leg. The markers were directly fixed to the skin. The markers were placed on the cranial dorsal iliacal spine of the tuber sacrale, greater trochanter, stifle joint between the lateral epicondyle of the femur and fibular head, lateral malleolus, and the distal aspect of the fifth metatarsal bone of the right hind leg (BOCKSTAHLER et al., 2007, 2009) (Fig. 1). Motion capture was performed using 10 infra red Eagle Digital Cameras (Motion Analysis Corporation, Santa Rosa, CA, USA), at a frequency of 120 Hz. For each session, the system was calibrated with a calibration frame of known dimensions. The stairs were made of wood with non-slip carpeting and consisted of 4 steps purpose built at the laboratory. The dimensions of the stairs were 0.16 m riser and 0.25 m tread. Prior to measurements, each dog

Tab. 1: Peak sagittal plane joint motion in humans (in degrees of flexion, given in mean ± SD) at various joints during stair ascent and descent from previous studies, compared with humans and dogs in the current study

	Previous studies						Current study			
Author	ANDRIACCHI et al. (1980)		LIVINGSTON et al. (1991)		PROTOPAPADAKI et al. (2007)					
Joint	Ascent human	Descent human	Ascent human	Descent human	Ascent human	Descent human	Ascent human	Descent humans	Ascent dog	Descent dog
Hip	40.8 ± 8.7	23.0 ± 10.5	52 ± 3.5	33 ± 4.0	65.1 ± 7.2	40.0 ± 7.8	72.7 ± 7.3	31.7 ± 5.2	26.0 ± 2.6	16.1 ± 6.4
Knee	73.4 ± 12.4	81.6 ± 11.3	101 ± 6.5	103 ± 3.0	93.9 ± 7.4	90.5 ± 7.1	98.1 ± 5.2	97.4 ± 5.0	61.9± 3.3	73.1 ± 6.0
Ankle PF	25.3 ± 11.5	25.6 ± 5.3	25 ± 12.0	28 ± 1.5	31.3 ± 5.1	40.1 ± 6.0	18.9 ± 4.2	32.9 ± 3.7	22.2 ± 9.4	26.7 ± 9.8
Ankle DF	13.6 ± 8.6	24.7 ± 8.9	19 ± 5.0	26 ± 2.0	11.2 ± 3.8	21.1 ± 4.5	15.9 ± 4.3	24.1 ± 6.8	88.3 ± 9.7	91.6 ± 15.2

PF = plantar flexion; DF = dorsiflexion

was led over the stairs multiple times to get the dogs accustomed to the experimental setup, each dog was allowed to walk at a comfortable walking speed. After the training period, the dogs were led over the stairs for 3 to 6 times to obtain consistent data on the correct stairs. The 3 dimensional angles of the coxofemoral, femorotibial, and tarsal joints were calculated for each time frame using a minimum of 5 motion cycles of each trial. Data were captured with EVaRT (Version 5.0.4, Motion Analyses Corporation, Santa Rosa, CA, USA) and analyzed with SIMI (SIMI Motion 3D, Simi Reality Motion Systems GmbH, Unterschleissheim, Germany). Parameters were calculated as described previously (BOCKSTAHLER et al. 2008a, 2008b). In this convention of measurement (Fig. 1), flexion angles of the hip, stifle, and tarsus are described in a similar manner to human angles. As the joint flexes, the angle becomes larger, and as the joint extends the angle becomes smaller.

Humans

6 healthy participants, with a mean age of 38 ± 9.1 years and a mean body mass of 67.8 ± 6.5 kg were recruited from staff and student populations at the University of Central Lancashire. All participants reported to be free from any pain or pathology affecting the spine or lower limbs at the time of testing.

Equipment and measurement procedure for human kinematics

Data were collected using a 10 camera Oqus motion analysis system (Qualisys medical AB, Gothenburg, Sweden) at 100 Hz. 12 10 mm reflective markers were placed on the foot, shank and thigh using the Calibrated Anatomical System Technique (CAST) (CAPPOZZO et al., 1995). Raw kinematic and kinetic data were exported to Visual 3D (CMotion Inc., Germantown, MD, USA). Kinematic data were filtered using fourth order Butterworth filters with cut off frequencies of 6 Hz. The sagittal plane ankle, knee and hip joint angles were quantified from initial contact to initial contact for the different tasks data about the providing information on stance and swing phase for the motion cycle.

Statistical analysis

All data were tested for normal distribution using the Kolmogorov-Smirnoff test. Data are given as arithmetic mean ± SD. To detect differences between the evaluated parameters during normal gait and stair up and stair down walk respectively, we used an ANOVA for repeated measurements with a Bonferroni-post hoc test. The ROM and temporal parameters of humans and dogs were compared using an unpaired t-test. Values of $p<0.05$ were considered significant. Microsoft Excel (Microsoft Office 2007 for Windows, Microsoft, Redmont, WA, USA) and SPSS (Version 14.0, SPSS Inc., Chicago, IL, USA) were used for statistical analysis.

Results

All data were found to be normally distributed. For dogs the mean walking velocity on normal ground was 1.09 ± 0.2 m/s, during stair ascent 0.73 ± 0.2 m/s and 0.81 ± 0.1 m/s during stair descent. For human mean walking velocity on normal ground was 1.42 ± 0.22 m/s, during stair ascent 0.48 ± 0.04 m/s and 0.60 ± 0.05 m/s during stair descent. Joint kinematics during ascent and descent from previous studies are presented in comparison to this current study of both human and dog ascent and descent (Tab. 1).

Canine tarsal joint

During canine walking, the tarsal joint (Fig. 2a) reached its maximal flexion (55.2 ± 11.6 °) in the middle of the swing phase at 80.6 ± 1.3 % of the motion cycle. After flexion, the joint quickly extended throughout remainder of the swing phase and the paw touched the ground while the joint was slightly extended. During the early and middle stance phase, the joint was slightly flexed to reach its maximal extension (20.1 ± 10.4 °, 61.4 ± 2.9 % of the motion cycle) at transition of the stance to the swing phase. There was a statistical significant increase in the degree of flexion when stair ascent (88.3 ± 9.7 °, $p < 0.01$) and stair descent (91.6 ± 15.2 °, $p < 0.01$) compared to walking. Walking caused flexion later than descending stairs (75.8 ± 2.9 % of the motion cycle, $p = 0.04$). Stair ascending caused a later flexion (83.8 ± 1.9 % of the motion cycle, $p = 0.02$) compared to walking stair down. The amount of extension showed no significant differences between stair ascending (22.2 ± 9.4 °), descending (26.7 ± 9.8 °) and level walking although both stair activities did show an increased in the amount extension in relation to level walking. However when descending stairs we found that maximal extension switched to the end of the swing phase (at 98.6 ± 1.5 % of the motion cycle, $p = 0.01$), which also caused a significant difference to going stairs up (59.8 ± 1.8 % of the motion cycle, $p = 0.01$). The range of motion (ROM) of the tarsal joint showed a significant difference in both stair ascent (66.0 ± 5.3 °, $p < 0.01$) and stairs descent (64.9 ± 6.8 °, $p < 0.01$) compared to that of level walking (35.1 ± 7.2 °).

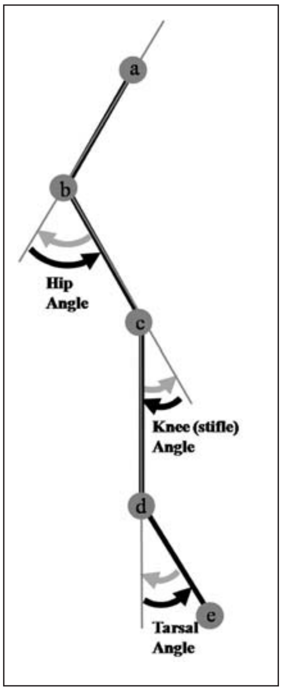

Fig. 1: Marker placement and definitions of joint angles in dogs; a = cranial dorsal iliacal spine of the tuber sacrale; b = greater trochanter; c = stifle joint between the lateral epicondyle of the femur and fibular head; d = lateral malleolus, and e = the distal aspect of the fifth metatarsal bone; grey arrow = extension; black arrow: flexion

Human ankle joint

Tarsal flexion in the dog is the equivalent of human ankle dorsiflexion and tarsal extension in dogs is the equivalent of plantarflexion in humans. During human walking the ankle joint (Fig. 2b) reached its maximal dorsiflexion (10.5 ± 3.6 °) at 47 % of the motion cycle. After dorsiflexion the joint quickly plantarflexed (-18.9 ± 6.9 °) at transition of the stance to the swing phase (64 % of the motion cycle). There was a statistical significant increase in the amount of dorsiflexion during stair ascent (15.9 ± 4.3 °, p = 0.05) and stair descent (24.1 ± 6.8 °, p = 0.04) compared to level walking. Significant differences were also seen between the amount of plantarflexion during stair descent (32.9 ± 3.7 °) compared to both level walking (18.9 ± 6.9 °, p = 0.02) and stair ascent (18.9 ± 4.2 °, p = 0.01), with stair descent causing a peak plantarflexion at 98 % of the motion cycle, much later than ascending stairs (67 % of the motion cycle) and level walking. Stair descent showed a significantly greater ankle ROM (57.0 ± 5.2 °) compared to that of stair ascent (34.8 ± 6.3 °, p < 0.01) and level walking (29.5 ± 5.2 °, p < 0.01).

Comparison of dog tarsal joint and human ankle joint (Fig. 3)

There was no significant difference in the ROM of the tarsal joint between dogs and humans ROM during level walking and stair descent. However significant differences were seen during ascent (p < 0.01) with the dogs tarsal ROM being increased compared to human ankle ROM.

Canine knee (stifle) joint

During canine walking, the stifle joint (Fig. 4a) reached its maximal flexion (60.3 ± 10.6 °) during the first part of the swing phase (76.8 ± 2.3 % of the motion cycle), followed by a rapid extension resulting in its maximal extension (17.4 ± 11.3 °) at touchdown (99.4 ± 0.9 % of the motion cycle) which then decreases throughout the stance phase. The joint was significantly more flexed when ascending (93.6 ± 6.8 °, p < 0.01) and descending stairs (88.7 ± 12.3 °, p < 0.01), when compared with level walking. Again the flexion during normal gait was significantly later than when walking stair down (71.2 ± 3.1 % of the motion cycle, p = 0.01). Ascending stairs (80.0 ± 1.7 % of the motion cycle) caused flexion later than stair descending (p = 0.02).

Descending stairs (15.6 ± 10.6 °) and walking (17.4 ± 11.3 °) caused a decreased amount of extension compared to stair ascent (31.8 ± 10.6 °, p < 0.01). The maximal extension occurred at about the same time during level walking and stair descent (99.0 ± 1.0 % of the motion cycle), whereas during stair ascent the maximal extension was found at the transition from the stance to the swing phase (55.4 ± 2.1 % of the motion cycle) resulting in significant differences to level walking and stair descent (p = 0.01).

The overall ROM used was significantly higher during stair ascent (61.9 ± 3.3 °, p < 0.01) and stair descent (73.1 ± 6.0 °, p < 0.01) when compared to level walking (42.9 ± 4.4 °). Comparing the overall ROM of ascending and descending stairs displayed no significant differences.

Human knee joint

During human walking, the knee joint (Fig. 4b) reached its maximal flexion (70.6 ± 6.9 °) during the first part of the swing phase, followed by a rapid extension resulting in its maximal extension (4.9 ± 6.3 °) during initial contact (99.4 ± 0.9 % of the motion cycle). The knee joint was significantly more flexed when ascending (110.5 ± 4.7 °, p < 0.01) and descending stairs (106.4 ± 8.5 °, p < 0.01) than during level walking. The flexion during walking (72 % of the motion cycle) was also later than when stair descent (67 % of the motion cycle) and earlier than stair ascent (83 % of the motion cycle). Ascending stairs caused a increase in the amount of movement towards extension (12.5 ± 5.9 °) compared to normal walking (4.9± 6.3 °, p = 0.05). No significant differences were seen between stair descent (9.1 ± 5.1 °) and ascent or level walking. The maximal extension occurred at about the same time during normal walk and stair descent, 98 % and 96 % of the motion cycle, respectively, however during stair ascent, as with dogs, the maximal extension was found at the transition from the stance to the swing phase (61 % of the motion cycle) resulting in significant differences to level walk and stair down (p = 0.01).

The overall ROM used was significantly higher when ascending (98.1 ± 5.2 °, p < 0.01) and descending stairs (97.4 ± 5.0 °, p < 0.01) compared to level walking (65.7 ± 6.4 °). Comparing the overall ROM of ascending stairs and descending stairs displayed no significant differences.

Comparison of dog stifle joint and human knee joint (Fig. 5)

Significant differences were seen in the ROM for stifle compared with the knee joint for walking (p < 0.01), for stair ascent (p < 0.01) and for stair descent (p < 0.01), with the human knee requiring greater ROM compared with the dogs stifle.

Canine hip joint

During canine walking the hip joint (Fig. 6a) reached its maximal flexion (62.0 ± 3.6 °) during the late swing phase (93.0 ± 4.7 % of the motion cycle), followed by a constant increase of the extension during the stance phase resulting in its maximum value of extension (32.1 ± 2.0 °) at the end of the stance phase (56.8 ± 0.8 % of the motion

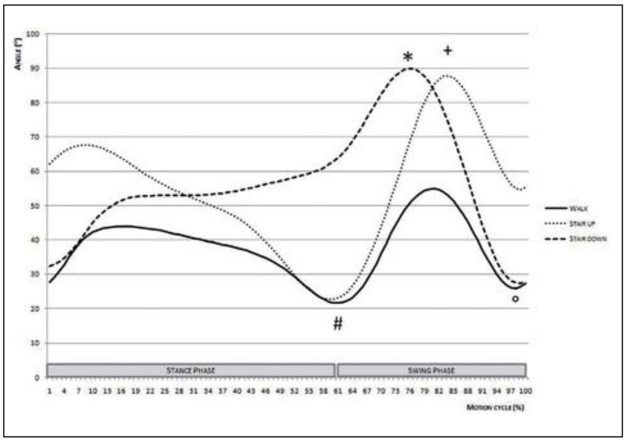

Fig. 2a: Angulations of the tarsal joint during walk (black), stair up (dotted line) and stair down (dashed line) in dogs; ***** indicates an significant earlier occurrence and higher flexion during stair down compared to normal walk, ° a significant higher degree of extension than during normal walk and the maximal extension switched from the late stance during normal walk and stair up to the late swing phase, **+** a significant higher flexion during stair up compared to normal walk and a significant later flexion compared to stair down, **#** a significant higher extension compared to normal walk and earlier extension compared to stair down

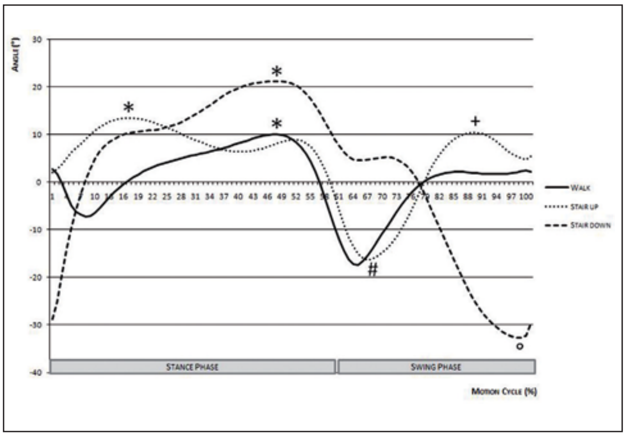

Fig. 2b: Angulations of the ankle joint during walk (black), stair up (dotted line) and stair down (dashed line) in humans; significant difference between the amount of ankle dorsiflexion (*****), with the peak dorsiflexion occurring earlier during step up than level walking and step down; peak plantarflexion showed a significant difference between step down and walk (°), and step down and step up (+), but no significant difference between step up and level walking (#).

cycle). Stair descent showed a significant increase in the amount of flexion (70.9 ± 7.4 °) of the hip joint compared to normal walk ($p < 0.05$). No significant changes in the temporal occurrence of the maximal flexion could be detected. The maximal amount of extension, during stair descent (54.8 ± 9.0 °) caused significant higher values in comparison to walking ($p < 0.01$) and stair ascent (26.0 ± 2.6 °, $p = 0.01$), without any changes in the timing. In contrast to the tarsal and stifle joint, the hip joint showed a significant lower range of motion when walking stair descent down (16.1 ± 6.4 °, $p = 0.02$) compared to level gait (29.9 ± 3.4 °). Interestingly, there was a significant higher ROM during stair ascent (36.3 ± 7.2 °, $p < 0.01$) than stair descent.

Human hip joint

During human walking the hip joint (Fig. 6b) reached its maximal flexion (30.4 ± 5.1 °) during the late swing phase (88 % of the motion cycle), followed by a constant increase of the extension during the stance phase resulting in its maximum value of extension (-13.4 ± 6.0 °) at the end of mid stance (52 % of the motion cycle). Stair descent caused a significant difference in the amount of flexion (41.2 ± 7.6 °) of the hip joint at 75 % of the motion cycle compared to normal walk ($p = 0.03$) and compared to stair ascent (68.0 ± 5.8 °, $p = 0.01$) which occurred at 91 % of the motion cycle. Significant differences were also seen between stair ascent and walking ($p < 0.01$). The maximal amount of extension when descending stairs (9.5 ± 5.8 °) at 30 % of the motion cycle and ascending stairs (-4.7 ± 4.9 °) at 60 % of the motion cycle showed significant less extension in comparison to walking ($p < 0.01$), and between stair descent and stair ascent ($p < 0.01$). The hip joint showed a significant lower ROM during stair descent (31.7 ± 5.2 °, $p = 0.05$) compared to walking (43.8 ± 3.9 °) and stair ascent (72.7 ± 7.3 °, $p < 0.01$). Significant differences were also seen between stair ascent and walking ($p < 0.01$).

Comparison of dog hip joint and human hip joint (Fig. 7)

The dogs' hip joint required significantly lower hip ROM for all tasks than humans ($p < 0.01$), with the greatest numerical difference between dog and human during stair ascent.

Discussion

Kinematics of stair ambulation

Normal gait on even surfaces and stairs consists of single and double support phases. Stance and swing phases are similar between level-surfaces and stair ambulation accounting for 60 and 40 % of the gait cycle, respectively. Stance phase during stair ambulation occurs from 0-60 % of the cycle regardless of whether one is ascending or descending the stairs whereas swing phase occurs from 60-100 % of the cycle (PROTOPAPADAKI et al., 2007). However the joint kinematics are very different during stair ambulation compared to that required during level ambulation in humans (LIVINGSTON et al., 1991).

The changed kinematical patterns of the joint have been described by PROTOPAPADAKI et al. (2007) for humans, although the range of joint motion varies according to the specific step dimensions and also for different height and limb characteristics of the subjects (LIVINGSTON et al., 1991). During stance phase in ascension, the hip and knee extend towards more stable joint positions, and the ankle into plantarflexion. Joint angles during ascent swing phase with normal step dimensions have previously been reported, however the amount of joint movement is dependant on the stair height and depth. Typical maximum joint angles for stair ascension are: 65 degrees of hip flexion, 94 degrees of knee flexion and 11 degrees of dorsiflexion to 31 degrees of plantarflexion at the ankle.

During stance phase in descent, the hip and knee move

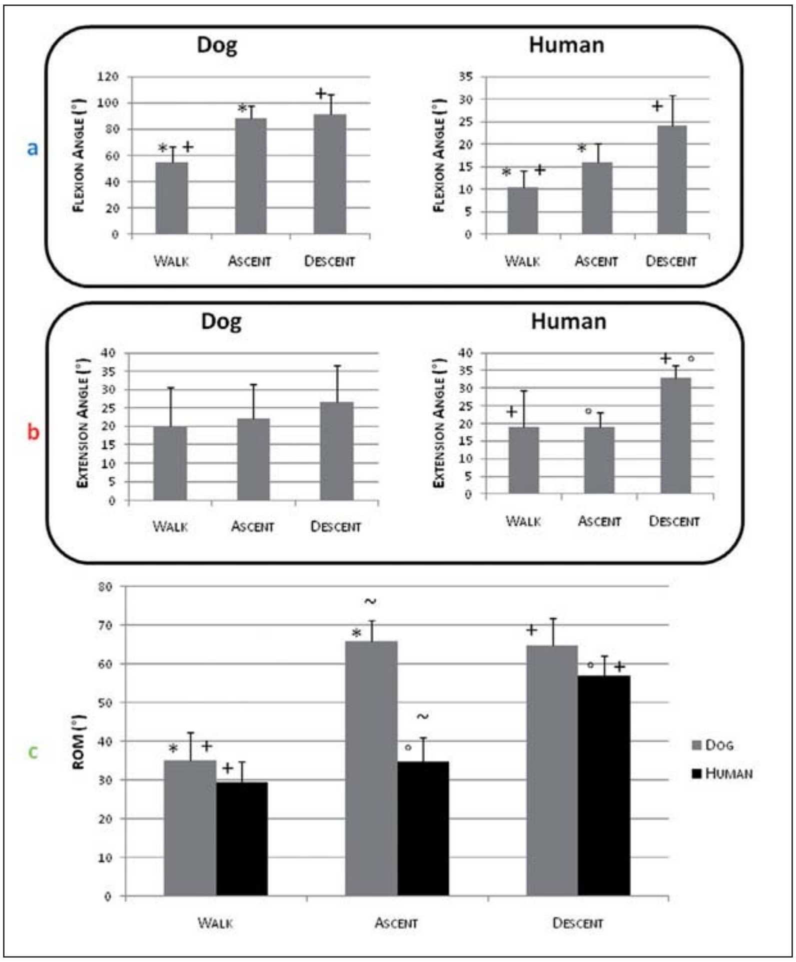

Fig. 3: Peak tarsal/ankle flexion (a), peak tarsal/ankle extension (b) and total tarsal/ankle ROM (c) in degrees (°) with error bars showing standard deviations; whereas * indicating significant differences between Walk and Ascent, + between Walk and Descent and ° significant differences between Ascent and Descent; ~ indicates a significant alteration of the human and canine ROM during Ascent.

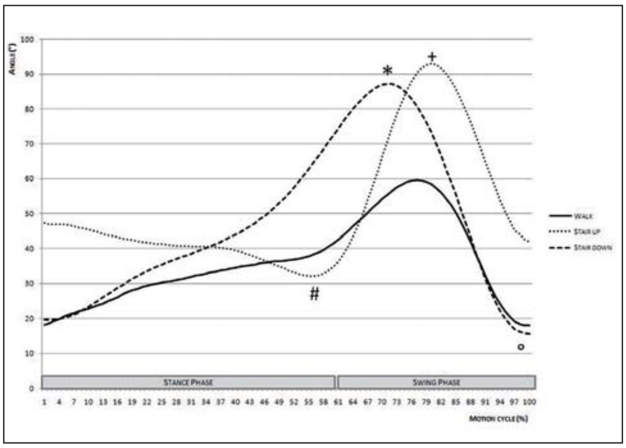

Fig. 4a: Angulations of the knee joint during walk (black), stair up (dotted line) and stair down (dashed line) in dogs; * indicates a significant earlier occurrence and higher flexion during stair down compared to level walk, ° a significant higher extension than during normal walk and stair up. The time of occurrence of the maximal extension occurred significant later than during stair up. + indicates a significant higher flexion during stair up compared to normal walk and a significant later flexion compared to stair down, # a significant earlier extension compared to stair down and level walking.

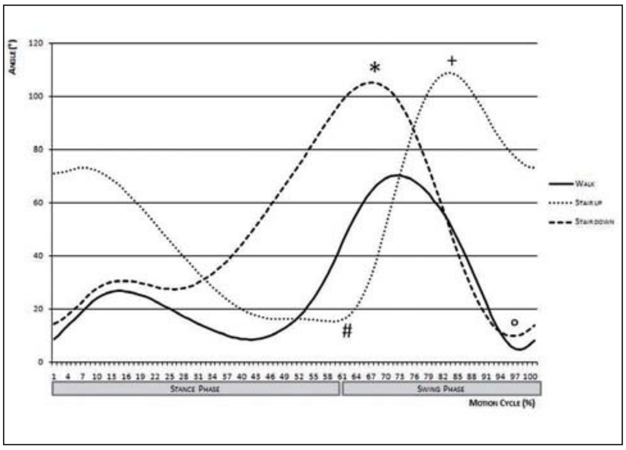

Fig. 4b: Angulations of the knee joint during walk (black), stair up (dotted line) and stair down (dashed line) in humans; * indicates a significantly higher flexion during stair down compared to normal walk, ° no significant difference between stair up and walking in extension than during normal walk, but a significant difference between walk and step down compared with stair up. The time of occurrence of the maximal extension occurred significant later than during stair up. + indicates a significant higher flexion during stair up compared to normal walk and a significant later flexion compared to stair down, # stair up shows a significant later movement towards extension compared to stair down and normal gait.

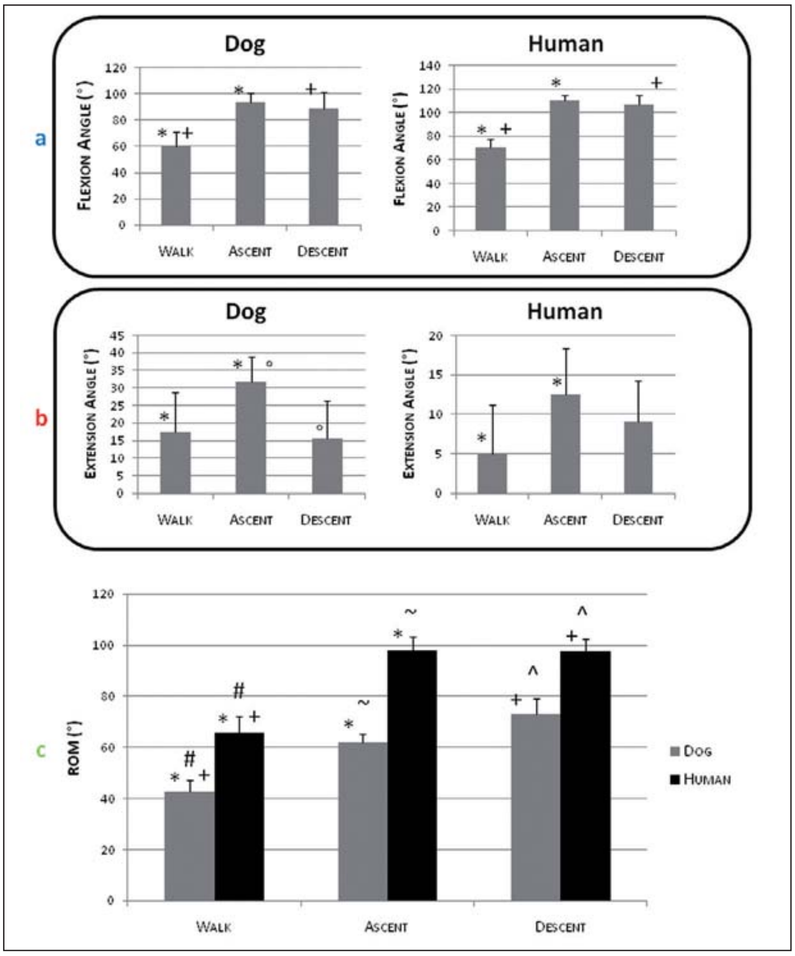

Fig. 5: Peak knee/stifle flexion (a), peak knee/stifle extension (b) and total knee/stifle ROM (c) in degrees (°) with error bars showing standard deviations; whereas * indicates significant differences between Walk and Ascent, + between Walk and Descent and ° significant differences between Ascent and Descent, # indicates a significant alteration of the human and canine ROM during Walk, ~ during Ascent and ^ during Descent.

into further flexion from an initially slightly flexed position, into a more unstable position, and the ankle into dorsiflexion from an initially plantarflexed position at foot contact. Stair descent swing phase on steps of normal dimensions require hip flexion of 40 degrees, 91 degrees of knee flexion, and the ankle moves through a range from 21 degrees of dorsiflexion during stance to 40 degrees of plantarflexion just prior to foot contact (PROTOPAPADAKI et al., 2007). Maximal hip and knee flexion occurred during swing phase for both ascent and descent, which is consistent for gait on level surfaces. Likewise, maximal extension for the hip and knee occurs in terminal stance (PROTOPAPADAKI et al., 2007).

Comparison of joint kinematics in humans and dogs

At the hip joint, the pattern of motion is very similar during level walking with flexion peaking during the swing phase and extension peaking during stance for push off. However, humans tend to use a greater amount of ROM for this task compared to dogs. Climbing stairs again displays a very similar pattern of hip movement between humans and dogs although humans increase their extension to a greater degree than dogs, and again use a greater overall amount of ROM. Stair descent produces the least overall ROM in both humans and dogs when compared to level waking and stair ascent although dogs again use less ROM when compared to humans.

At the knee joint, the pattern of motion between humans and dogs is very similar during walking with flexion peaking during the first half of the swing phase and extension peaking just before heel strike (or touchdown). Humans achieving close to a straight knee at heel strike, approximately 5 ° flexed, whereas dogs are approximately 17 degrees short of full extension. Humans tend to use a greater overall amount of knee ROM during walking compared to dogs. Climbing stairs again displays a very similar pattern of knee movement between humans and dogs although humans increase their flexion to a greater degree than dogs, and again use a greater overall amount of ROM. Stair descent produces a very similar peak angle of flexion to stair ascent in both humans and dogs but in both species it is slightly earlier in the swing phase. Stair descent in humans again produces a greater amount of overall ROM used when compared to dogs.

The tarsal or ankle joint produced some of the greatest differences between the species. During walking, both dogs and humans produce maximal dorsiflexion (tarsal flexion) during swing and produce maximal plantarflexion (tarsal extension) during push-off. Dogs use a much greater tarsal flexion and lower extension during normal walking than humans do. During descent, the same holds true although the difference is not as dramatic due to the increased amount of plantarflexion humans use during descent. During stair ascent, dogs use a much greater overall ROM than people do.

The decreased amount of ROM used at the hip and stifle joints of dogs during normal gait, stair climbing, and stair descent when compared to humans is likely a direct result of the increased amount of tarsal motion dogs use when compared to people. The tarsal joint is a relatively

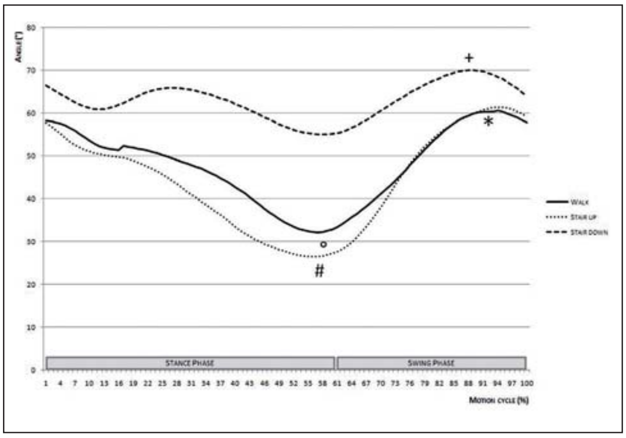

Fig. 6a: Angulations of the hip joint during walk (black), stair up (dotted line) and stair down (dashed line) in dogs; * indicates a significant decrease of flexion compared to normal walk and to stair up, ° a significant lower degree of extension while stair descent than during normal walk and stair up, + a significant higher flexion during stair up compared to walking and stair down and # a significant higher extension compared to stair down.

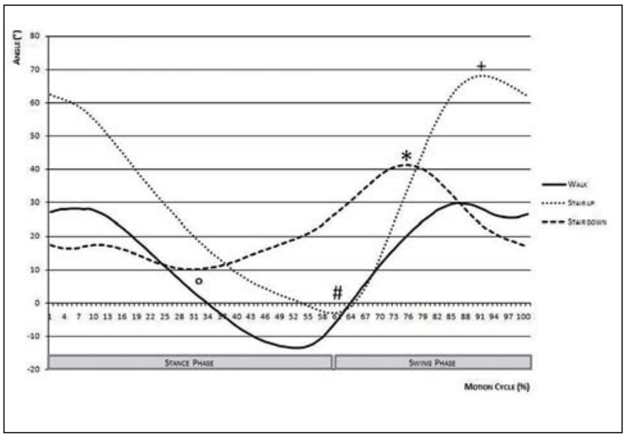

Fig. 6b: Angulations of the hip joint during walk (black), stair up (dotted line) and stair down (dashed line) in humans; * indicates a significant decrease of flexion compared to stair up, ° a significant lower degree of extension while stair descent than during normal walk and stair up, + a significant higher flexion during stair up compared to walking and stair down, and # a significant higher extension compared to stair down.

long limb segment of the lower limb, compared to people, and as the metatarsals create a long lever arm the tarsal joint must flex enough for the metatarsals and phalanges to clear the ground. In doing so it allows less motion to occur at more proximal joints. In addition, it is reasonable to believe that it is much more efficient to flex the tarsus rather than larger, heavier joints like the knee and hip and dogs preferentially use the tarsal joint.

In all such studies some limitations should be considered, these include the error due to skin movement and differences in the velocities during the different tasks. However despite these potential sources of error the differences in movement strategy seen between the different tasks and between humans and dogs are unlikely to have been affected unduly.

Clinical relevance

To create adequate physical therapy programs it is of vital importance to acquire closer insights into the distinctive biomechanics of the limbs during stair ascent and descent. In many physical therapy treatments, such as transcutaneous electrical nerve stimulation, knowledge from the human medicine can be translated to veterinary usage, however this is not the case in stair ambulation as dogs and humans have notably different strategies. This paper identifies the peak angles of flexion and extension, and overall ranges of motion used during normal walking, and stair ascent and descent. This can be used to help devise rehabilitation programs for dogs that need to increase the motion in a particular hindlimb joint. At the tarsal joint, the peak angles of flexion occur during stair ascent and descent, and the peak extension angles are similar in all 3 conditions although they occur at different times (Fig. 2a). Overall range of motion at the tarsal joint is much greater during both stair ascent and descent compared to level walking (Fig. 3). At the stifle joint walking up and down stairs provides much greater peak flexion than level walking. If increased stifle extension is desired, walking down stairs and level walking provides more peak extension than walking up stairs. Overall range of motion at the stifle joint is greatest during stair decent followed by stair ascent, followed by level walking (Fig. 5). At the hip joint walking down stairs provides the greatest peak flexion, followed by level walking, followed by stair ascent. Peak hip extension is greatest during stair ascent followed by level walking followed by stair descent. Overall range of motion at the hip is greatest during stair ascent, followed by level walking, followed by stair descent (Fig. 7).

This information is very valuable, as dogs cannot be told to perform an exercise such as range of motion. It either must be performed manually or through specific tasks, for example stair climbing or wheel barreling. If a dog has decreased stifle extension, which is common after extracapsular imbrication for cruciate stabilization, information from this study would indicate that walking on level ground would promote more peak stifle extension than walking either up or down stairs. Having exercises either clinicians or owners can perform to help regain range of motion of joints is useful for dogs with a variety of conditions such as osteoarthritis, cranial cruciate ligament stabilization, fracture repair, and other rearlimb conditions seen clinically.

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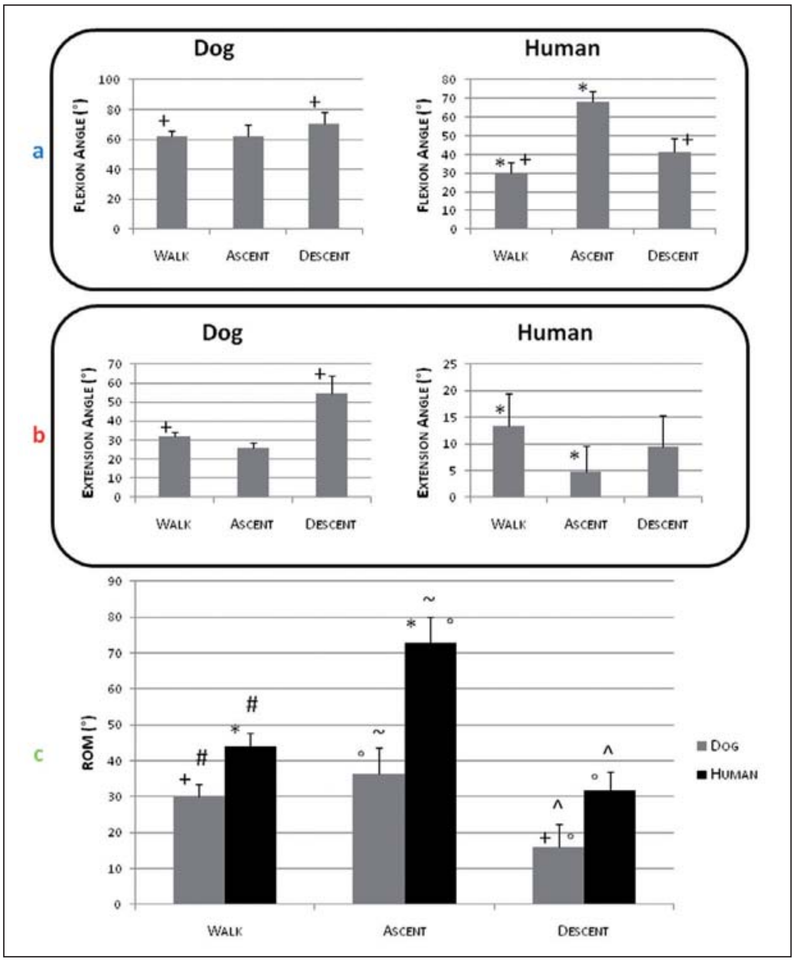

Fig. 7: Peak hip flexion (a), peak hip extension (b) and total hip ROM (c) in degrees (°) with error bars showing standard deviations; whereas * indicates significant differences between Walk and Ascent, + between Walk and Descent and ° significant differences between Ascent and Descent, # indicates a significant alteration of the human and canine ROM during Walk, ~ during Ascent and ^ during Descent.

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