Effect of water depth on muscle activity of dogs when walking on a water treadmill.

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Abstract

Evidence-informed practice is currently lacking in canine hydrotherapy. This study aimed to investigate if the estimated workload of the gluteus medius (GM) and longissimus dorsi (LD) increased in dogs at different water depths when walking on a water treadmill. Seven dogs were walked for two minutes continuously on a water treadmill at depths of no submersion (depth 1), mid-tarsal (depth 2), between lateral malleolus and lateral epicondyle (depth 3) and between the lateral epicondyle and greater trochanter (depth 4). Continuous electromyographic data from the right and left sides of GM and LD were collected simultaneously during exercise. Friedman's analyses with post-hoc Wilcoxon tests established if significant differences in GM and LD muscle activity occurred between the water depths for mean estimated-workload. Significant differences occurred in estimated-workload in GM and LD between water depths ($P<0.05$). Mean estimated-workload decreased in the right and left GM between depths 2 (mid-tarsal) and 3 (between lateral malleolus and epicondyle) ($P<0.007$) and depths 2 and 4 (between lateral epicondyle and greater trochanter) ($P<0.001$), a pattern which was repeated for left and right LD ($P<0.007$). Right GM mean estimated-workload increased between depth 1 (no submersion) and depth 2 only ($P<0.013$). Water depth influences GM and LD activity in dogs walking on a water treadmill. Increasing knowledge of canine locomotion in water treadmills could be used to inform individualised rehabilitation regimes for dogs undertaking hydrotherapy.

Key words: rehabilitation; canine; hydrotherapy; water treadmill; water depth

Introduction

Canine rehabilitation is a rapidly developing aspect of veterinary medicine with a growing range of methods and techniques such as manual therapy, therapeutic exercise, physical modalities, massage and hydrotherapy becoming widely available for use in veterinary practice (Tomlinson, 2012). These rehabilitation methods are utilised to restore animals to full health post-operatively, to manage long-term conditions such as osteoarthritis and to maintain general fitness (McGonagle and Taylor, 2004). With scientific research informing changes in industry practice, improvements in training and rehabilitation of non-canine animals have been achieved using evidence-based practice (McGowan et al. 2002). However, many areas such as hydrotherapy still lack an evidence base despite them being widely used in canine rehabilitation (Waining, Young and Williams, 2011; Kirkby and Lewis, 2012).

A range of rehabilitation exercises using hydrotherapy exist; swimming and water treadmills (WT; also known as under water treadmills) have been found to be beneficial in the recovery of dogs postoperatively (Monk, Preston and McGowan, 2006). WTs are commonly utilised in hydrotherapy for dogs presenting with hind limb and spinal pathologies as a core component of rehabilitation regimes, and are also used as a fitness and conditioning tool within canine performance training (Davies, 2011). Controlled swimming and WT exercise increase limb flexion and extension and can produce a larger range of motion (ROM) in the limbs when compared to overground walking in dogs (Marsolais, Dvorak and Conzemius, 2002; Marsolais et al. 2003; Monk, Preston and McGowan, 2006). Altering the depth of water during exercise on the WT will also influence kinematics; studies have demonstrated that increased flexion and extension of the stifle and stride lengths (SL) occur with increasing water depth, whilst in contrast stride frequency (SF) decreases as water level height increases (Jackson et al. 2002; Barnicoat and Wills, 2016).

Although there is limited research to date into the use of WTs for dogs, the impact of WT exercise on equine kinematics has been more extensively researched and, as a quadruped species, could provide a comparative evidence base for canine WT studies, although more canine-specific studies are needed to confirm this as anatomical differences do exist between the species. In horses, water depths at carpal, tarsal, metacarpophalangeal and metatarsophalangeal joint levels are commonly utilised during rehabilitation (Nankervis et al., 2017). Kinematic evaluation of equine locomotion at different water depths on the WT suggest that if the horse can, it will step out and over the water (Mooij et al., 2013) subsequently increasing flexion and extension in joints above the water level, with the greatest variation in ROM occurring at tarsal height (Mendez-Angulo et al. 2013). Higher water levels correspond to increased buoyancy and reduced ground reaction forces (King, 2016) and when used within a five week rehabilitation regime have been shown to reduce postural sway and to increase limb joint stability in horses (King et al., 2013). Nankervis et al. (2015) have also demonstrated horses adapt their locomotion at higher water levels (stifle and above), resulting in greater cranial thoracic extension and thoracolumbar flexion when compared to walking at lower water depths due to alterations in head position and increased buoyancy. At the same time, at higher depths, increases in flexion and rotation of the back of horses also occur, attributed to increased axial rotation and pelvic flexion (Mooij et al. 2013). However, understanding the influence of water height on kinematics does not provide definitive information on how muscle function adapts to generate the locomotion patterns observed. Joint ROM is influenced by muscle activity, consequently, kinematic studies evaluating joint ROM can provide a broad visual representation of muscle activity during rehabilitation (Kaneda et al. 2007; Agostini et al. 2014; Gommans et al. 2016). Therefore to fully understand the impact of WT treadmill exercise at different water depths in both dogs and horses, further studies evaluating how muscle recruitment and workload varies with changing water heights and speeds are required. The research base within equine WT exercise has developed recommendations for use in practice (Nankervis et al., 2017). A similar approach bringing together kinematic and electromyographic assessment of canine performance on the WT to inform canine rehabilitation protocols is warranted.

Surface electromyography is a non-invasive technology, which can be used to assess muscle activity in animals (Williams, 2017). The role of muscles within the axial musculoskeletal system of dogs is not currently well understood despite their functional importance in terms of facilitating postural stability and locomotion (Webster et al., 2014). Schilling and Carrier (2010) identified that the epaxial muscles were involved in stabilisation and sagittal extension of the spine during movement. Similar roles have been established in equine epaxial musculature, where longissimus dorsi (LD) has been demonstrated to ensure stiffness and stabilisation of the vertebral column during locomotion in horses (Licka et al. 2004; Robert et al. 2001; 2002). As horses and dogs utilise comparable gaits, similar roles are expected for LD across species (Robert et al. 2001; Groesel et al. 2010). Ritter et al (2010) and Schilling and Carrier (2010) used EMG to demonstrate LD activity during the trot stride cycle. In the equine a burst of activity is related to push off of the ipsilateral hind limb and a second burst at push off of the contralateral hind limb whilst in the canine a similar biphasic activity is seen but initially during the second half of ipsilateral stance and then again in the second half of the contralateral stance (Ritter et al, 2010), although Schilling and Carrier (2010) report the second burst as during the last third of the ipsilateral hindlimb swing. Therefore in the canine and equine spine it appears that LD acts to counteract the tendency of the trunk to flex and extend in the sagittal plane and therefore provide stiffness of the spine during gait.

In dogs, as in horses, movement is initiated in the gluteal and hamstring muscles (Williams et al., 2008; Payne et al., 2005; Wentink, 1976). Few studies have investigated canine caudal musculature to date despite their key contribution to locomotion. The role of gluteus medius (GM) during locomotion has been evaluated, with Deban, Schilling and Carrier (2012) reporting wide involvement of the muscle throughout hind limb movement, propelling the hind limb backwards during retraction and assisting with braking during swing phase. Further understanding the functional remit of canine muscles and how muscles respond during therapeutic modalities and through electromyographic assessment could aid veterinary surgeons, veterinary physiotherapists (UK) and animal rehabilitation therapists globally in designing effective rehabilitation regimes for individual patients.

This study aimed to use surface electromyography (sEMG) to measure muscle workload in the GM and LD of sound dogs on the WT at increasing water depths: no submersion (control), mid tarsal, mid stifle and the midpoint between the stifle and the greater trochanter. We hypothesised that as water depth increased, estimated muscle workload measured by integrated EMG (iEMG) in the GM and LD would increase rather than decrease due to increased buoyancy.

Materials and Methods

The high level of inter-subject variance for EMG data observed in between subjects' designs combined with differences seen between individuals may preclude reliable comparison of muscle performance between groups (Williams, 2017). Therefore, a repeated measures, within subjects' framework was applied to control for differences in spatial characteristics, and to increase the accuracy and internal validity of the study's outcomes. Within this design dogs also acted as their own controls which further reduced the potential for variation in EMG data recorded due to different physiological factors such as subcutaneous fat levels (De Luca et al., 2010), muscle fibre profile (Nordander et al., 2003; Wijnberg et al., 2003) and health status and fitness level Lopez-Rivero and Letelier, 2000).

Sample selection

A convenience sample of seven dogs of various breed, age (mean age ±SD: 5.9 ± 3.36 years), weight (mean weight ±SD: 25.06 ± 6.89kg) and size (mean forelimb length ±SD: 40.13± 6.38cm, mean hind limb length ±SD: 42.5 ± 6.52cm) participated in the study (Table 1). Dogs were recruited from staff and students working at the university. All dogs were deemed clinically sound by the referring veterinary surgeon and hydrotherapist (National Association of Registered Canine Hydrotherapists (NARCH) member; BSc (Hons) Bioveterinary Science), had a normal body condition score and had no history of lameness or musculoskeletal pathology (Holler et al. 2010; Breitfuss et al. 2015). Prior to WT sessions, veterinary consent was requested in accordance with the Veterinary Surgeon Act 1966 (Exemptions order 1962) to ensure dogs were physically able to participate. Dogs also underwent a pre-hydrotherapy assessment by a NARCH hydrotherapist. Ethical approval was gained from the Hartpury University Centre Ethics Committee.

(Table 1)

Electrode placement

Surface EMG (sEMG) sensors (rectangle dimensions: 41 x 20 x 5mm, with integral double differential 99.9% Ag electrodes fixed at a 10mm inter-electrode distance providing a $10mm^2$ detection area; Delsys EMG system™; USA) were used to measure muscle activity of the GM and LD muscles. Self-adhesive Delsys surface electrodes were attached onto the shaved skin of the GM and LD, over the maximum circumference of the muscle belly and perpendicular to the direction of the muscle fibres (De Luca et al., 2010; Morris and Lawson, 2009; De Luca, 1997; Fridlund and Cacioppo, 1986), using the Delsys adhesive sensor patches (Figure 1) (Garcia et al. 2014). Poor adherence of electrodes has been found to reduce the accuracy of EMG recordings and provide misleading results (De Luca et al., 1997; Chowdray et al., 2013). Therefore before each trial, the dog's skin was shaved to remove all hair using grooming clippers followed by disposable razors and then sterilised with alcohol wipes (70% isopropyl alcohol) prior to electrode attachment to improve the impedance of the sensors to the skin in accordance with St George and Williams (2013). Electrode adherence to the skin was further improved through the use of duct tape and vet wrap which was applied over the sensors to reduce movement and prevent loss of adherence (Figure 1) (St George and Williams, 2013).

Further duct tape was then loosely applied to protect the EMG sensors from water damage. To improve reliable placement of the electrodes, placement was performed by a single researcher (Hesse and Verheyen, 2010) using the anatomical landmarks specified by Breitfuss et al. (2015) under the guidance of the NARCH registered hydrotherapist prior to each WT session undertaken (Table 2). Due to restraints of the placement of the harness during this study, electrode location for the back was restricted to the lumbar region to ensure sensor connection was not impeded by the harness. Potential interference to the EMG signal due to movement artefacts from the duct tape and vet wrap was assessed subjectively throughout data collection through experimenter observation of live streamed data; runs which displayed interference were excluded from subsequent analysis. However it should be noted that movement artefacts may be present in the data collected due to the presence of the duct tape.

(Figure 1a)

(Figure 1b)

Kinematic assessment

Two-dimensional circular reflective adhesive markers (radius 7 mm) were produced from silver duct tape and placed on to two pre-defined bony anatomical landmarks on the left side of the dog by the same investigator. This took place whilst the dog was standing squarely with equal weight distribution on all four limbs.

A digital video camera (Sony HDR-CX405, 9.2 mega pixels, 60fps interlaced, New York, USA), was situated 58cm from the WT at a height of 1.09m and recorded the left sagittal view of dogs for the entirety of each WT session to facilitate 2D kinematic analysis (Mendez-Angulo et al., 2013). A calibration frame was placed along the side of the water treadmill to allow for the measurement of stride parameters. Data were synchronised via time stamp on both the video and EMG data. Kinematic data were analysed using Dartfish™ (Dartfish Analyser Software, Version 7.0, Fribourg, Switzerland) to enable identification of limb contacts and obtain matched strides between subjects in subsequent EMG data analysis.

Data Collection

Research was conducted with the assistance and supervision of a NARCH registered hydrotherapist. A Westcoast canine Hydrotherapy treadmill (Westcoast Hydrotherapy, Norfolk, UK) with internal dimensions of 1.82 m (length)×0.68 m (width)×0.90 m (height) was used for the study. To ensure the safety of participants, water temperature, pH and chlorine levels were measured before each dog entered the WT and were kept within safe parameters. Each dog performed three acclimatisation sessions on the WT prior to data collection; this allowed subjects to become used to walking on the WT and ensured that their gait was repeatable (Scott et al. 2010; Fanchon et al., 2009). During these sessions, individual dogs preferred walking speeds were established and recorded, based on the subjective opinion of the NARCH hydrotherapist, in accordance with normal industry practice. EMG data were collected using the Delsys Trigno™ EMG system (Massachusetts; USA) at a sampling rate of 2000Hz, Gain set at 1000 V/V, actual Gain: 1025 and common mode rejection ratio of ≥80dB (Delsys, 2017).

Experimental protocol

Dogs were fitted with a standard safety harness and EMG electrodes were secured prior to WT exercise. Dogs then completed a 30 second warm up to allow them to adjust to the activity of the treadmill and to attain their preferred walking speed under the supervision of the hydrotherapist. During this time, the quality of the EMG signal was subjectively assessed though observation of the consistency and visual appearance of the live-streamed EMG data to ensure the electrodes were securely attached; if data signals were intermittent, asynchronous or distorted the contact of the EMG electrode was assessed before continuing. Once the warm up was completed, each dog walked for two minutes continuously on the WT at each water depth: no submersion (depth 1), mid-tarsal (depth 2), between the lateral malleolus and lateral epicondyle (depth 3) and between the lateral epicondyle and greater trochanter (depth 4) in accordance with Barnicoat and Wills (2016) (Figure 2), facilitating simultaneous continuous EMG data collection for the right and left sides of the GM and LD. Water depths followed guidelines recommended by Goddard et al. (2014). Water depths were adapted to the individual conformation of each participant in accordance with industry practice. To control for the potential impact of fatigue during testing the order of completion was randomised; four of the dogs were tested from depth 1 > 2 > 3 > 4 and the remaining three from depth 4 > 3 > 2 > 1 (Nankervis et al. 2015). The order of randomisation was set sequentially from high to low or vice versa rather than completely randomised, to ensure data collection could be undertaken within the timeframe of one standard hydrotherapy session to ensure the health and welfare of participants was maintained. Dogs were also rested for 60 seconds after each 2 minute trial, before the next trial commenced, in accordance with the standard practice of the hydrotherapy centre.

(Figure 2)

Data Analysis

Video analysis was used to select visually 10 strides from the middle of each trial at each water depth to ensure uninterrupted, consistent and matched strides were used for analysis for each participant. Gait event detection for the left pelvic limb were visually defined in accordance with the method used by Barnicoat and Wills (2016), with a single stride defined as two successive footfalls of the left hind limb. The first and last 30 seconds of each trial were removed to avoid inaccuracies that may occur when dogs adjusted their locomotion to the new water level.

Raw electromyograms were analysed using Delsys EMG works™ analysis version 4.3.1 with an internal band-pass filter applied to remove noise (<20Hz and >450Hz) (De Luca et al., 2010; Zsoldos et al., 2010). Estimated muscle workload was calculated from the internal band-pass filtered EMG data using the iEMG function of Delsys EMG works™ which integrates the facility to remove DC offset from the signal, rectifies the data and analyses the amplitude of the signal. iEMG represents the area under the curve of a rectified EMG trace (Winter, 2009) and provides an approximation of the percentage of work done in muscles for defined exercise periods, enabling comparison across exercise sessions (Richards et al., 2008). In humans, iEMG uses a pre-assessed maximum voluntary contraction (MVC) to provide a baseline value for maximal workload of a defined muscle to facilitate comparison of workload in the same muscle during subsequent tasks (Borghuis et al., 2008; Winter, 2009). MVC cannot be achieved in animals therefore dynamic contraction values are used to normalise data for comparison allowing the work done by a muscle for a defined period to be calculated (Halaki and Ginn, 2012). One method of normalizing EMG data which produces high reliability between trials is to utilise the trial anticipated to require the highest muscle workload to obtain the maximum dynamic contraction as a proxy measure of MVC (Halaki and Ginn, 2012). For this study, depth 4 was hypothesised to require the highest muscle activity (Marsolais et al. 2003) and the highest dynamic contraction for each dog across one stride within this trial was selected to normalise EMG data across all trials (Valentin and Zsoldos, 2016). Mean, maximum and minimum iEMG percentage workload for the left and right GM and LD were then calculated for each water depth, for each participant. Mean and standard deviation of the mean, minimum and maximum iEMG at all water depths across the cohort and for each individual dog were calculated.

Statistical analysis was undertaken using IBM Statistical Package for the Social Sciences (SPSS) Statistics 23. Kolmogorov-Smirnov analyses determined data were non-parametric therefore a series of Friedman's analyses were used to establish if significant differences in lateral GM and LD muscle activity, considered independently, occurred across the different water depths investigated for mean iEMG percentage values. Significance was set at $P<0.05$. Subsequent post-hoc Wilcoxon Signed Rank analyses, with a Bonferroni correction applied to adjust for repeated measures (Brown et al, 2015) determined where statistical differences in muscle workload occurred between water depths (revised alpha: $P<0.01$).

Results

iEMG data for a total of 28 trials were analysed with each of the seven dogs that took part in the study completing four water depths.

iEMG estimated workload

As expected, a high degree of individual variability was found within iEMG values between participants (Table 2), although this was less in LD than GM. Across the cohort, minima values increased from depth 1 to 2 for GM but showed little change for LD (RGM: +5%; LGM: +10%; RLD: -3%; LLD: 0%). In contrast, maxima contractions and mean estimated workload for GM and LD increased for both GM and LD from depth 1 to 2 (maxima: RGM: +9%; LGM: +3%; RLD: +13%; LLD: +9%; mean: RGM: +11%; LGM: +11%; RLD: +6%; LLD: +1%). This was followed by a trend for all iEMG values to reduce between depths 2 and 3 (minima: RGM: -30%; LGM: -20%; RLD: -22%; LLD: -2%; maxima: RGM: -39%; LGM: -24%; RLD: -27%; LLD: -11%; mean: RGM: -41%; LGM: -20%; RLD: -26%; LLD: -6%). Further reductions in workload were reported from depth 3 to 4 (minima: RGM: -4%; LGM: -3%; RLD: +3%; LLD:

-4%; maxima: RGM: -4%; LGM: -16%; RLD: 0%; LLD: -5%; mean: RGM: -8%; LGM: -10%; RLD: -3%; LLD: -3%).

(Table 2)

Differences between water heights

Significant differences in mean estimated workload (mean iEMG) were found between the water levels for both GM (mean iEMG: RGM: P=0.004; LGM: P=0.002) and LD (mean iEMG: LLD: P=0.002, RLD: P=0.001). Post hoc analyses found significant decreases in mean estimated workload occurred in right and left GM between depths 2 (mid-tarsal) and 3 (between lateral malleolus and lateral epicondyle), and depths 2 and 4 (between the lateral epicondyle and greater trochanter); a pattern which was repeated for left and right LD (Table 3). Only one significant increase was reported for the right GM mean estimated workload between depth 1 (no submersion) and depth 2 (mid-tarsal). No significant differences were found between the other water depths for any of the muscles investigated (P>0.01).

(Table 3)

(Table 4)

Discussion

The results confirm that water depths used within canine WTs can have a significant impact on the mean estimated workload of both GM and LD. Although descriptive increases in estimated workload were observed at depth 2 (mid-tarsal) compared to the dry treadmill (depth 1) in all participants, these were only found to be significant for mean estimated workload in the right GM. Higher water depths reduced mean estimated workload in the GM and LD muscles for participating dogs. This suggests that water levels above the stifle translate to reduced recruitment of GM and LD in dogs undertaking walk exercise on a WT. Therefore, we have to reject the hypothesis that as water depth increases in a WT, estimated muscle workload also increases in the GM and LD.

Gluteus medius activity

Descriptive data indicate that for dogs undergoing WT exercise, GM workload increases on average by 11% when water height is set directly above the tarsal joint. However, within this sample, only right GM workload increased significantly from individual dogs' workload on the dry treadmill. Few studies in animals have used EMG to assess the impact of changing water depth on muscle activity in the hind limb. Human research has utilised EMG alongside kinematic gait analysis, and has directly related increased joint ROM in the limb to increases in muscle workload (Kaneda et al. 2007; Agostini et al. 2014; Gommans et al. 2016). Kinematic analysis of quadruped locomotion on the WT has found increased flexion of equine forelimb and pelvic limb joints as horses elevate their limbs to *step out and over* water at tarsus level rather than pushing the limb through it. Adopting this locomotor pattern reduces the effect of water resistance but would require increased GM activity to facilitate this movement (Mendez-Angulo et al., 2013). Similar findings are reported in the dog. Barnicoat and Wills (2016) found the flight arc of canine limbs increased as dogs lifted their limbs above the water level during walk exercise on the WT with water set at tarsal height. In the current study, we observed similar locomotive patterns in the pelvic limb, with dogs lifting the pelvic limb out and above water at depth 1: mid-tarsal height. Conversely at higher water levels, i.e. between lateral malleolous and lateral epicondyle (depth 3) and above, dogs propelled the pelvic limb through the water and did not attempt to step above the water level. Given the small sample size with this study, future kinematic research using more dogs and a wider range of breeds is warranted to confirm these findings.

Higher water levels (above the stifle: depths 3 and 4) appear to reduce the estimated workload of GM compared to walking on a dry treadmill (depth 1). Right and left GM estimated workload reduced from depth 1 to depths 3 and 4, by 34% and 40%, and by 11% and 20%, respectively. If as postulated above, dogs adapt their gait to push the hind limb through higher water heights then the activity of GM will be altered. GM propels the pelvic limb backwards during retraction (Deban et al., 2012); this function would be assisted on the WT by the action of the treadmill belt and the dog's mass would be affectively reduced due to the increase in buoyancy associated with higher water levels (King, 2016), thereby reducing GM workload. Another function of GM is to stabilise the pelvic limb during swing (Deban et al., 2012). Barnicott and Wills (2016) reported lengthened swing duration in the pelvic limb in dogs walking at higher water heights. The impact of increased buoyancy at higher water levels is thought to assist the vertical lift in the pelvic limb resulting in a longer flight arc and by association more economical locomotion requiring less GM input to stabilise the limb (Scott et al., 2010; Barnicott and Wills, 2016).

Longissimus dorsi activity

A similar pattern to GM estimated workload was found for LD, however differences reported were of a lesser magnitude. This could represent the more general role of LD in stabilising the spine (Groesel et al., 2010). Descriptively LD workload increased from depth 1 (dry) to depth 2 (mid-tarsal), but again muscle workload only significantly reduced as water height increased from depth 2 (mid-tarsal) to depth 3 for the left LD (between lateral malleolus and lateral epicondyle), and depth 3 to depth 4 (between the latera malleolus and greater trochanter). Right and left LD estimated workload reduced from depth 1 to depths 3 and 4, by 21% and 23%, and by 4% and 7%, respectively. Limited research has evaluated canine spinal kinematics on the WT. However for horses, Nankervis et al (2015) reported walk exercise with water at the height of the femoropatellar joint (equivalent to depth 4 in this study) produced maximum T10, T13, T18 and L3 vertebra flexion. Whilst, in contrast, water depth at tarsal level (equivalent to depth 3 here) resulted in higher extension in T18, L3 and L5 vertebra, accompanied by increased pelvic movement. The increased flexion-extension range of motion observed in the thoracolumbar spine at water heights above the fetlock (equivalent to depth 2 here) suggests that higher water levels could be detrimental within rehabilitation regimes designed to engage equine core and epaxial musculature, unless head and neck position are manipulated to place the back in flexion. The reduced workload found at higher water levels in the current study support a reduced role for LD. Further research incorporating more EMG sensors at a range of loci along LD combined with concurrent spinal kinematic analysis is required to confirm the role water levels have on canine epaxial musculature activity.

During testing, dogs were encouraged with either treats or toys to motivate them to walk continuously on the treadmill, which resulted in variable head and neck positioning. Whilst this is normal practice, it has the potential to alter spinal kinematics and muscle function, as dogs lifted their heads up and down in response to handlers' actions. There is a lack of research to show the effect of head and neck position on canine gait, however studies have shown that in horses, having a high head and neck position reduces stride length and disrupts normal gait, whilst flexion and extension of the thoracic and lumbar spinal regions varies with changing head position (Rhodin et al. 2005; Alvarez et al. 2006; Rhodin et al. 2009). This suggests that inconsistent positioning of the head and neck of dogs in this study may have altered their natural gait and the flexion and extension of the spinal muscles, possibly influencing the muscle activity for the GM and LD. Further studies exploring the influence of head and neck position on canine WT kinematics and muscle activity are needed. This study only utilised 2D kinematic analysis to define limb contacts rather than for the quantification of angular or linear kinematic variables, however, water distortion may have resulted in some minor inaccuracies in these measurements. Previous literature has demonstrated that the error in kinematic analysis associated with this type of experimental set-up (water turbulance, light refraction) is minimal, with less than 3° error associated with joint movements (Mendez-Angulo et al, 2013).

During data collection, it was also observed that some dogs displayed lateral bending when walking on the WT (Figure 3). A similar phenomenon has been observed in horses; higher water levels above the midline of the shoulder are thought to reduce this occurring (Mooji et al., 2013). Lateral bending during movement in quadrupedal animals is controlled by the epaxial muscles, including LD (Faber et al., 2000; Musienko et al., 2014), therefore lateral bending at lower water levels could be responsible for the increased LD workload found at depth 2. Future research assessing the impact of water depth on lateral bending is warranted to evaluate the optimal water heights to use in WTs during rehabilitation of dogs following spinal surgery.

(Figure 3)

Implications for practice

The results suggest that WT exercise at higher water levels would be appropriate during the early stages of canine rehabilitation regimes where stability is prioritised as a key goal over strength. As rehabilitation progresses and the challenge to the patient needs to be increased to facilitate greater muscular action, then tarsal water height would be recommended. However, it is important that practitioners consider the clinical history and fitness of individual dogs when designing rehabilitation regimes. The water depth used must be selected with sound clinical reasoning and be altered according to presenting movement patterns and post hydrotherapy response. Therefore post-exercise, re-evaluation of gait and assessment of clinical signs of pain or fatigue should be used to inform progression within rehabilitation regimes.

Asymmetric recruitment of GM and LD was found across the dogs used in the study. The reasons for the laterality observed across the cohort examined are not clear. These may be associated with lateral bending or could be due to innate dominant limb laterality (Garcia et al., 2014), may be due to recruitment of additional muscles to compensate for a lack of strength in GM or LD or could be a sign of subclinical pathology. Practitioners should carefully consider the impact of the handler at the front of treadmill including their location (right, left or centre of the patient's visual field) and how the methods they use to encourage movement in the dog and the influence these could have on head and neck position, and therefore on kinematic patterns and muscle recruitment. The length of WT exercise sessions should be considered; short sessions with rest are recommended to prevent fatigue, as anecdotally muscular asymmetry increases with fatigue (Williams et al., 2012). Straightness is a benefit of WT exercise and the unintentional introduction could have a potentially detrimental impact within rehabilitation cases such as post-spinal surgery. We would recommend that one role of the hydrotherapist within the WT should be to control and facilitate straightness in dogs undergoing treatment. Additional training for handlers at the front of the treadmill, particularly if dog owners are used in this capacity, is warranted to ensure appropriate head and neck positioning occurs throughout WT exercise.

Water depth has a direct impact on GM and LD muscle activity in dogs undertaking walk exercise on a WT. Walking at a depth directly above the tarsal joint results in increased workload for GM and LD. As water height is increased beyond the stifle joint, GM and LD workload reduced. The findings from this study have relevance to hydrotherapy in practice and could be used to alter rehabilitation regimes and fitness programmes to most suit the individual dog and its specific needs.

Conflict of Interest

No conflicts of interest apply to this work.

Acknowledgements

We would like to thank the staff of Cotswold Dog Spa and the owners and their dogs for their willingness to participate in this study.

References

Agostini, V., Ganio, D., Facchin, K., Cane, L., Carneiro, S.M. and Knaflitz, M., 2014. Gait Parameters and Muscle Activation Patterns at 3, 6 and 12 Months After Total Hip Arthroplasty. The Journal of Arthroplasty. 29 (6): 1265-1272.

Alvarez, C.G., Rhodin, M., Bobbert, M.F., Meyer, H., Weishaupt, M.A., Johnston, C. and Weeren, P., 2006. The Effect of Head and Neck Position on the Thoracolumbar Kinematics in the Unridden Horse. Equine Veterinary Journal. 38 (S36): 445-451.

Barnicoat, F. and Wills, A.P., 2016. Effect of Water Depth on Limb Kinematics of the Domestic Dog (Canis Lupus Familiaris) During Underwater Treadmill Exercise. Comparative Exercise Physiology. 12 (4): 199-207.

Breitfuss, K., Franz, M., Peham, C. and Bockstahler, B., 2015. Surface Electromyography of the Vastus Lateralis, Bicep Femoris, and Gluteus Medius in Sounds Dogs During Walking and Specific Physiotherapeutic Exercises. Veterinary Surgery. 44 (5): 588-595.

Borghuis, J., Hof, A.L. and Lemmink, A.P.M., 2008. The importance of sensory-motor control in providing core stability. Implication for measurement and training. Sports Medicine, 38 (11): 893-916.

Brown, S., Stubbs, N. C., Kaiser, L. J., Lavagnino, M. and Clayton, H. M., 2015. Swing phase kinematics of horses trotting over poles. Equine Veterinary Journal. 47 (1): 107–112.

Chowdhury, R.H., Reaz, M.B., Ali, M.A.B.M., Bakar, A.A., Chellappan, K. and Chang, T.G., 2013. Surface electromyography signal processing and classification techniques. Sensors, 13(9): 12431-12466.

Davies, L., 2011. Provision of Canine Hydrotherapy in the UK. Veterinary Record. 168: 465-466.

Deban, S.M., Schilling, N. and Carrier, D.R., 2012. Activity of Extrinsic Limb Muscles in Dogs at Walk, Trot and Gallop. Journal of Experimental Biology. 215 (2): 287-300.

Delsys 2017. Delsys Trigno Manual available at: http://delsys.com/Attachments_pdf/manual/MAN-012-2-7.pdf

De Luca, C.J. 1997. The use of surface electromyography in biomechanics. Journal of Applied Biomechanics. 13(2), pp. 135-163.

De Luca, C.J., Gilmore, L.D., Kuznetsov, M. and Roy, S.H. 2010. Filtering the surface EMG signal: Movement artefact and baseline noise contamination. Journal of Biomechanics. 43: 1573-1579.

Faber, M, Schamhardt, H., Weeren, R.V., Johnston, C., Roepstorff, L. and Barneveld, A.B., 2000. Basic Three-dimensional Kinematics of the Vertebral Column of Horses Walking on a Treadmill. American Journal of Veterinary Research. 61 (4): 399-406.

Fanchon, L. and Grandjean, D., 2009. Habituation of healthy dogs to treadmill trotting: repeatability assessment of vertical ground reaction force. Research in veterinary science, 87(1): 135-139.

Fridlund, A.J. and Cacioppo, J.T., 1986. Guidelines for human electromyographic research. Psychophysiology, 23(5): 567-589.

Garcia, T.C., Sturges, B.K., Stover, S.M., Aoki, K., Liang, J.M., Reinhardt, K.B. and Kapatkin, A.S., 2014. Forelimb Brachial Muscle Activation Patterns Using Surface Electromyography and Their Relationship to Kinematics in Normal Dogs Walking and Trotting. Comparative Exercise Physiology. 10 (1): 13-22.

Goddard, M.A., Burlingame, E., Beggs, A.H., Buj-bello, A., Childers, M.K., Marsh, A.P. and Kelly, V.E., 2014. Gait Characteristics in a Canine Model of X-linked Myotubular Myopathy. Journal of Neurological Sciences. 346 (1): 221-226.

Gommans, L.N., Smid, A.T., Scheltinga, M.R., Brooijmans, F.A., Van Disseldorp, E.M., Van Der Linden, F.T., Meijer, K. and Teijink, J.A. 2016. Altered Joint Kinematics and Increased Electromyographic Muscle Activity During Walking in Patients with Intermittent Claudication. Journal of Vascular Surgery. 63 (3): 664-672.

Groesel, M., Zsoldos, R.R., Kotschwar, A., Gfoehler, M. and Peham, C., 2010. A preliminary model study of the equine back including activity of longissimus dorsi muscle. Equine Veterinary Journal, 42(s38): 401-406.

Halaki, M. and Ginn, K., 2012. Normalization of EMG signals: To normalize or not to normalize and what to normalize to? In Computational intelligence in electromyography analysis-a perspective on current applications and future challenges. Intech.

Hesse, K.L. and Verheyen, K.L.P., 2010. Associations between physiotherapy findings and subsequent diagnosis of pelvic or hind limb fracture in racing Thoroughbreds. Equine veterinary journal, 42(3): 234-239.

Holler, P.J., Brazda, V., Dal-Bianco, B., Lewy, E., Mueller, M.C., Peham, C. and Bockstahler, B.A., 2010. Kinematic motion analysis of the joints of the forelimbs and hind limbs of dogs during walking exercise regimens. American Journal of Veterinary Research, 71(7): 734-740.

Jackson, A., Millis, D., Stevens, M. and Barnett, S., 2002. Joint kinematics during underwater treadmill activity. Proceedings of the second International Symposium on Rehabilitation and Physical Therapy in Veterinary Medicine. 191.

Kaneda, K., Wakabayashi, H., Sato, D. and Nomura, T. (2007) Lower Extremity Muscle Activity During Different Types and Speeds of Underwater Movement. Journal of Physiological Antrhopology. 26 (2), 197-200.

King, M.R., 2016. Principles and Application of Hydrotherapy for Equine Athletes. Veterinary Clinics of North America: Equine Practice, 32(1): 115-126.

King, M.R., Haussler, K.K. Kawcak, C.E., Mcllwraith, C.W. and Reiser, R.F., 2013. Mechanisms of aquatic therapy and its potential use in managing equine osteoarthritis. Equine Veterinary Education, 25(4): 204-209.

Kirkby, K.A. and Lewis, D.D. (2012) Canine Hip Dysplasia: Reviewing the Evidence For Nonsurgical Management. Veterinary Surgery, 41 (1).

Licka, T.F., Peham, C. and Frey, A., (2004). Electromyographic activity of the longissimus dorsi muscles in horses during trotting on a treadmill. American journal of veterinary research, *65*(2), pp.155-158.

Lopez-Rivero, L. and Letelier, A. (2000). Skeletal muscle profile of show jumpers: physiological and pathological considerations. In: Linder, A., ed. Conference on Equine Sports Medicine and Science 2000. Sicily, Italy, May 14-16, 2000. CESMAS, pp. 57- 75.

Marsolais, G.S., Dvorak, G. and Conzemius, M.G., 2002. Effects of postoperative rehabilitation on limb function after cranial cruciate ligament repair in dogs.Journal of the American Veterinary Medical Association. 220 (9): 1325-30.

Marsolais, G.S., McLean, S., Derrick, T. and Conzemius, M.G., 2003. Kinematic analysis of the hind limb during swimming and walking in healthy dogs and dogs with surgically corrected cranial cruciate ligament rupture. Journal of the American Veterinary Medical Association. 222 (6): 739-743.

McGonagle, L. and Taylor, R.A., 2004. History of Canine Rehabilitation. Canine Rehabilitation and Physical Therapy, 1-4.

McGowan, C.M., Golland, L.C., Evans, D.L., Hodgson, D.R. and Rose, R.J., 2002. Effects of Prolonged Training, Overtraining and Detraining on Skeletal Muscle Metabolites and Enzymes. Equine Veterinary Journal. 34 (S34): 257-263.

Mendez-Angulo, J.L., Fishman, A.M., Groschen, D.M., Kieffer, P.J. and Trumble, T.N., 2013. Effect of Water Depth on Amount of Flexion and Extension of Joints of the Distal Aspects of the Limbs in Healthy Horses Walking. American Journal of Veterinary Research. 74 (4): 557-566.

Monk, M.L., Preston, C.A. and McGowan, C.M. 2006. Effects of early intensive postoperative physiotherapy on limb function after tibial plateau leveling osteotomy in dogs with deficiency of the cranial cruciate ligament. American Journal of Veterinary Research. 67 (3): 1-8.

Mooij, M.J.W., Jans, W., Den Heijer, G.J.L., De Pater, M. and Back, W. 2013. Biomechanical Responses of the Back of Riding Horses to Water Treadmill Exercise. The Veterinary Journal. 198: e120-e123.

Musienko, P.E., Deliagina, T.G., Gerasimenko, Y.P., Orlovsky, G.N. and Zelenin, P.V., 2014. Limb and Trunk Mechanisms For Balance Control During Locomotion in Quadrapedals. Journal of Neuroscience. 34 (16): 5704-5716.

Nankervis, K.J., Finney, P. and Launder, L., 2015. Water Depth Modifies Back Kinematics of Horses During Water Treadmill Exercise. Equine Veterinary Journal. 48 (6): 732-736.

Nankervis, K.J., Launder, E.J. and Murray, R.C., 2017. The use of Treadmills within the Rehabilitation of Horses. Journal of Equine Veterinary Science (in press).

Nordander, C., Willner, J., Hansson, G.A., Larsson, B., Unge, J., Granquist, L. and Skerving, S., 2003. Influence of the subcutaneous fat layer, as measured by ultrasound, skinfold calipers and BMI, on the EMG amplitude. European Journal of Applied Physiology 89(6): 514–9.

Payne, R.C., Hutchinson, J.R., Robilliard, J.J., Smith, N.C. and Wilson, A.M., 2005. Functional specialisation of hind limb anatomy in horses (Equus caballus). Journal of Anatomy, 206(6): 557-574.

Ritter, D.A., Nassar, P.N., Fife, M. and Carrier, D.R., 2001. Epaxial muscle function in trotting dogs. Journal of Experimental Biology, 204(17), pp.3053-3064.

Rhodin, M., Alvarez, C.B., Bystrom, A., Johnston, C., Weeren, P.R., Roepstorff, L. and Weishaupt, M.A., 2009. The Effect of Different Head and Neck Positions on the Caudal Back and hind limb Kinematics in the Elite Dressage Horse at Trot. Equine Veterinary Journal. 41 (3): 274-279.

Rhodin, M., Johnston, C., Holm, K.R., Wennerstrand, J. and Drevemo, S., 2005. The Influence of Head and Neck Position on Kinematics of the Back in Riding Horses at the Walk and Trot. Equine Veterinary Journal. 37 (1): 7-11.

Richards, J., Thewlis, D. and Selfe, J., 2008. Chapter 10: Measurement of muscle function and physiological cost In Richards, J. (Eds.) Biomechanics in Clinic and Research. Elsevier: Philadelphia, USA. pp. 129-151.

Robert, C., Audigie, F., Valette, J.P., Pourcelot, P. and Denoix, J.M., 2001. Effects of Treadmill Speed on the Mechanics of the Back in the Trotting Saddlehorse. Equine Veterinary Journal. 33: 154-159.

Robert, C., Valette, J.P., Pourcelot, P., Audigie, F. and Denoix, J.M., (2002). Effects of trotting speed on muscle activity and kinematics in saddlehorses. Equine Veterinary Journal, 34(S34), pp.295-301.

Schilling, N. and Carrier, D.R., 2010. Function of the Epaxial Muscles in Walking, Trotting and Galloping Dogs: Implications For the Evolution of Epaxial Muscle Function in Tetrapods. Journal of Experimental Biology. 213 (9): 1490-1502.

Scott, R., Nankervis, K., Stringer, C., Westcott, K. and Marlin, D., 2010. The Effect of Water Height on Stride Frequency, Stride Length and Heart Rate During Water Treadmill Exercise. Equine Veterinary Journal. 42 (38): 662-664.

St George, L. and Williams, J.M., 2013. Electromyographic Evaluation of Approach Stride, Jump Stride and Intermediate Stride in Selected Superficial Muscles of the Jumping Horse: A Preliminary Study. Comparative Exercise Physiology. 9 (1): 23-32.

Tomlinson, R.,2012. Use of Canine Hydrotherapy as Part of a Rehabilitation Programme. The Veterinary Nurse. 3 (10), 624-629.

Valentin, S. and Zsoldos, R.R., 2016. Surface electromyography in animal biomechanics: A systematic review. Journal of Electromyography and Kinesiology, 28: 167-183.

Waining, M., Young, I.S. and Williams, S.B., 2011. Evaluation of the status of canine hydrotherapy in the UK. Veterinary Record. 168: 407-412.

Webster, E.L., Hudson, P.E. and Channon, S.B., 2014. Comparative functional anatomy of the epaxial musculature of dogs (Canis familiaris) bred for sprinting vs. fighting. Journal of anatomy, 225(3): 317-327.

Wentink, G.H., 1976. The action of the hind limb musculature of the dog in walking. Cells Tissues Organs, 96(1): 70-80.

Williams, J.M., 2017. Electromyography in the Horse: A Useful Technology? Journal of Equine Veterinary Science (in press: DOI: http://dx.doi.org/10.1016/j.jevs.2017.02.005).

Williams, J.M., Gundry, P., Richards, J. and Protheroe, L., 2012. A preliminary evaluation of surface electromyography as a tool to measure Muscle fatigue in the National Hunt racehorse. The Veterinary Nurse, 4(9): 566-572.

Williams, S.B., Wilson, A.M., Rhodes, L., Andrews, J. and Payne, R.C., 2008. Functional anatomy and muscle moment arms of the hind limb of an elite sprinting athlete: the racing greyhound (Canis familiaris). Journal of anatomy, 213(4): 361-372.

Winter, D.A. 2009. Biomechanics and Motor Control of Human Movement (4th Edn). John Wiley & Sons, Hoboken, NJ. pp. 224-277

Zsoldos, R., Kotschwar, A., Kotschwar, A. B., Rodriguez, C., Peham, C. and Licka, T. 2010. Activity of the equine rectus abdominus and oblique external abdominal muscles measured by surface EMG during walk and trot on the treadmill. Equine Veterinary Journal. 42 (38): 523-529.

Table 1. Participant Information

Participant	Breed	Age	Gender	Weight (kg)	Forelimb Length (cm)	Hind limb Length (cm)
Participant 1	Springer Spaniel	3	M	15.5	33	35
Participant 2	Golden Retriever	7	F	29.3	43	47
Participant 3	Weimaraner	6	F	36.2	53	55
Participant 4	Labrador	12	F	30.7	38	40
Participant 5	Labrador	2	F	22.0	39	42
Participant 6	Labrador	4	F	25.0	40	42
Participant 7	Cocker Spaniel	4	M	24.3	42	44

Table 2. Minima (min), maxima (max) and mean with standard deviation (SD) for normalised iEMG estimated workload, reported to 2 decimal places, for gluteus medius (GM) and longissimus dorsi (LD) across all water depths for the cohort

iEMG (% of dry maximum dynamic contraction)			Water Depth			
		Value	1: No submersion	2: Mid-tarsal	3: Between LM and LE	4: Between LE and GT
Gluteus medius	Right	Min iEMG±SD	4.49±7.04%	4.71±5.68%	2.82±3.89%	2.72±2.25%
		Max iEMG±SD	60.16±77.69%	65.46±70.97%	40.07±39.31%	38.63±36.6%
		Mean iEMG±SD	19.88±24.95%	21.97±24.96%	13.06±15.43%	11.99±15.19%
	Left	Min iEMG±SD	18.86±11.58%	20.71±11.78%	16.65±11.7%	16.23±11.29%
		Max iEMG±SD	80.60±42.29%	83.23±29.86%	63.21±24.03%	52.93±27.8%
		Mean iEMG±SD	39.36±14.63%	43.74±12.14%	34.98±14.91%	31.61±15.89%
Longissimus dorsi	Right	Min iEMG±SD	33.17±31.24%	32.08±26.33%	25.01±22.67%	25.99±22.55%
		Max iEMG±SD	40.53±31.25%	45.94±24.7%	33.44±22.29%	33.32±21.57%
		Mean iEMG±SD	35.19±31.42%	37.35±25.7%	27.77±22.27%	26.96±22.25%
	Left	Min iEMG±SD	30.17±20.67%	30.22±21.07%	30.77±20.36%	29.48±20.7%
		Max iEMG±SD	36.31±23.15%	39.49±22.52%	35.04±21.99%	33.19±21.41%
		Mean iEMG±SD	33.61±23.43%	34.09±22.39%	32.16±22.02%	31.41±21.41%

Table 3. Post hoc Wilcoxon Signed Rank results for mean iEMG percentages between water levels for GM and LD (* denotes significant result; revised Bonferroni adjusted alpha: $p<0.01$). iEMG: integrated electromyography; GM: gluteus medius; LD: longissimus dorsi.

Muscle	Depth 1 - Depth 2	Depth 1 - Depth 3	Depth 1 - Depth 4	Depth 2 - Depth 3	Depth 2 - Depth 4	Depth 3 - Depth
Right GM	P=0.013*	P=0.679	P=0.408	P=0.004*	P=0.001*	P=0.679
Left GM	P=0.23	P=0.679	P=0.147	P=0.007*	P=0.0001*	P=0.301
Left LD	P=0.147	P=0.147	P=0.38	P=0.004*	P=0.0001*	P=0.535
Right LD	P=0.147	P=0.214	P=0.023	P=0.007*	P=0.0001*	P=0.301

Table 4. Post hoc Wilcoxon Signed Rank Test for mean MUAP for GM and LD (* denotes significant result; revised Bonferroni adjusted alpha: $p<0.01$). iEMG: integrated electromyography; GM: gluteus medius; LD: longissimus dorsi

Muscle	Depth 1 - Depth 2	Depth 1 - Depth 3	Depth 1 - Depth 4	Depth 2 - Depth 3	Depth 2 - Depth 4	Depth 3 - Depth 4
Right GM	P=0.23	P=0.535	P=0.214	P=0.004*	P=0.0001*	P=0.535
Left GM	P=0.062	P=0.301	P=0.038	P=0.004*	P=0.0001*	P=0.301
Left LD	P=0.098	P=0.0147	P=0.023	P=0.002*	P=0.0001*	P=0.408
Right LD	P=0.098	P=0.408	P=0.038	P=0.013	P=0.0001*	P=0.214

Figure Legends

Figure 1: A: Patient preparation pre-hydrotherapy and B: Sensor locations.

Sensors were applied over the muscle belly of the gluteus medius (GM) and longissimus dorsi (LD) and were secured with duct tape and vet wrap to prevent erroneous movement. GM electrodes were positioned at the midpoint of between the iliac crest and greater trochanter on the left and right side (Breitfuss et al. 2015). LD electrodes were located to the left and right side of L3 vertebrae on the sagittal plane.

Figure 2. Water depths used during study.1) no submersion (depth 1), 2) mid-tarsal (depth 2), 3) between the lateral malleolus and lateral epicondyle (depth 3) and 4) between the lateral epicondyle and greater trochanter (depth 4). Red line represents the water level.

Figure 3: Lateral bending of the spine of dogs during walking on the WT. Red lines show estimated spinal position based on subjective observations.

Figure 1a

Figure 1b

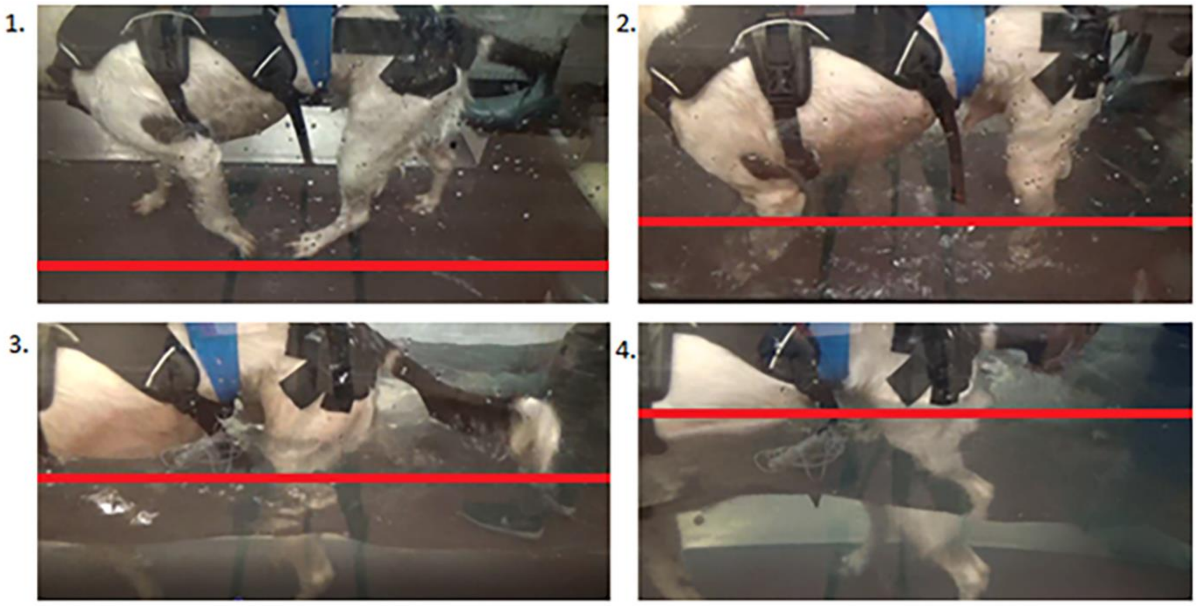

Figure 2

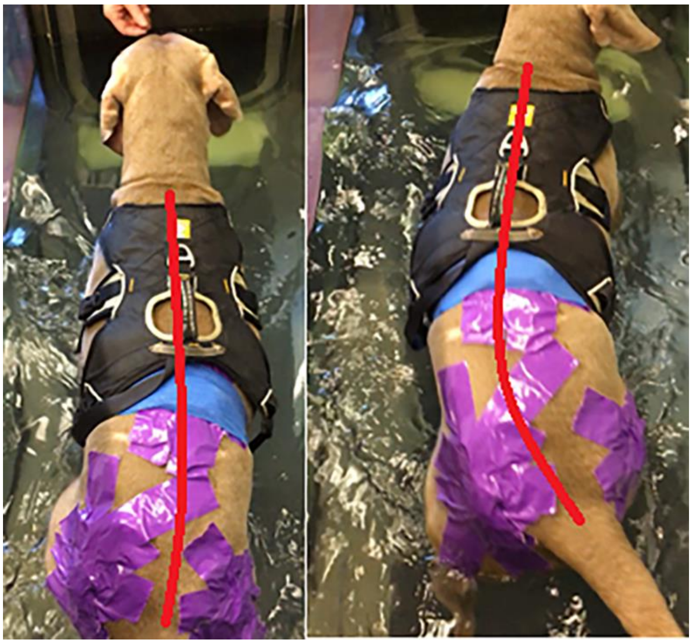

Figure 3