Cooperation Research Center for Biomechanics
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Biomechanical analysis of the kinematics of different dog harnesses
- Research report -

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Abstract

The aim of the study is to determine, using 3D motion capture, how the usage of different harnesses changes the dog's walking kinematics compared to free (unleashed) movements. Due to limited capture volume, a part of the trial was carried out using a treadmill. The difference between compulsive speed and natural walking limits the study. To eliminate this limitation, a few steps of ground walks were also recorded in each test case. The motion was assessed using distance type and angular gait parameters (step width, step height, step length, stride length, spinal and limbic joint angles). The study involved five dogs previously trained for treadmill walking. Test cases were defined for every combination of the following factors: with different harnesses and without harness, with and without leash, treadmill and ground walk. Gait parameters were calculated from the 3D coordinates of anatomical points, recorded by an optical motion capture system. The walking kinematics of the dogs significantly differed between treadmill walk and ground walk. Probably, the reason for this is the switch between different movement types (walk and trot) between the forced speed on the treadmill and self-selected speed on the ground. The usage of different harnesses compared to gait without harness does not influence gait kinematics as none of the studied gait parameters indicated significant deviations. In case of retracted leashes, the changes in gait kinematics is similar for each harness. Due to the pull of the leash the dog changes to a slower gait pattern (from trot to walk) on the ground. On the treadmill at unchanged constrained walking speed, the pull of the leash does not alter significantly the gait pattern in any of the studied harnesses. Consequently, the wearing of the different harnesses - either without leash or with retracted leash – does not influence the dog's walking kinematics; only the changes of willingly chosen natural walking patterns at different speeds (walk, trot) influence gait kinematics, but this is a trained behavior of dogs in response to the retraction force expressed by their owner.

Introduction

The aim of the study is to determine, using 3D motion capture, how the usage of different harnesses changes the dog's walking kinematics compared to free (unleashed) movements. Study methods are based on relevant literature. There are studies available where dog kinematics is analyzed in 2D only in the sagittal plane[1]. The walk of a dog can be analyzed in kinetic and kinematic perspectives[2–4], e.g. muscular activity can be studied using EMG[5]. During kinematics motion analysis, the gait pattern of the dog is analyzed, which can be more effectively conducted using 3D motion capture[6,7]. In the present study, 3D kinematics motion analysis was also performed using the most widely applied marker sets from the literature[8].

Methods

Dogs studied

Five healthy dogs participated in the study, whose data is summarized in Table 1. The dogs were trained in the previous weeks to be able to naturally walk on treadmills.

Table 1. Dogs studied

Number	Breed	Weight (kg)
1	Cane Corso	50
2	Bullterrier	26
3	Bullterrier	16
4	Yorkshire terrier	3
5	Beagle-labrador mixed breed	26

Harnesses studied

The following three harness types were studied, manufactured by Julius-K9®:

- K9®
- Duo-Flex®
- IDC®

The motion analysis of one of the dogs (nr. 5) was also conducted using a third party harness. The results are included in Supplementary material 2, but being the only sample the third party harness was not analyzed statistically.
The studied harnesses were custom made, to not include light-reflexive materials, which could influence motion capture measurements.

Measurement procedure

The test cases, that were studied, included walk without harness, walk while wearing the harness and walk in the harnesses while retracted by leash. During the treadmill walk (Figure 1) the owner of the dog was squatting in front of the treadmill and periodically praised the dog with treats to maintain a continuous walk on the treadmill. The processed parts of the trial are continuous homogeneous sections after and before feeding the dog. During ground trials, the dog was walking through the room straight to its owner on the other side of the room, who was calling the dog. The test cases were performed for both treadmill and ground walk.

Figure 1. Gait analysis on treadmill

Measurement of gait kinematics

Gait kinematics was measured using an 18 camera OptiTrack Flex13 motion capture system (NaturalPoint, Corvallis, Oregon, USA). Infra reflexive markers were placed on certain anatomical points of the dogs according to Hogy[8] as seen in Figure 2. On the thoracic limbs, markers were placed over the distal lateral aspect of the fifth metacarpal bone, the ulnar styloid process, the lateral epicondyle of the humerus, the greater tubercle of the humerus, and the dorsal aspect of the scapular spine. On the pelvic limbs, markers were placed over the distal lateral aspect of the fifth metatarsal bone, the lateral malleolus of the fibula, the lateral femoral condyle, the greater trochanter of the femur, and the iliac crest. On the spine, markers were placed over the sacral apex, the dorsal spinous process of vertebra L7, the dorsal spinous process of vertebra T13, the dorsal spinous process of T1, and the occipital protuberance. The markers were fixed on the dogs using kinesio tape. Each of the participating dogs were short-haired, thus their hair did not influence marker placement and unnecessary marker movement.

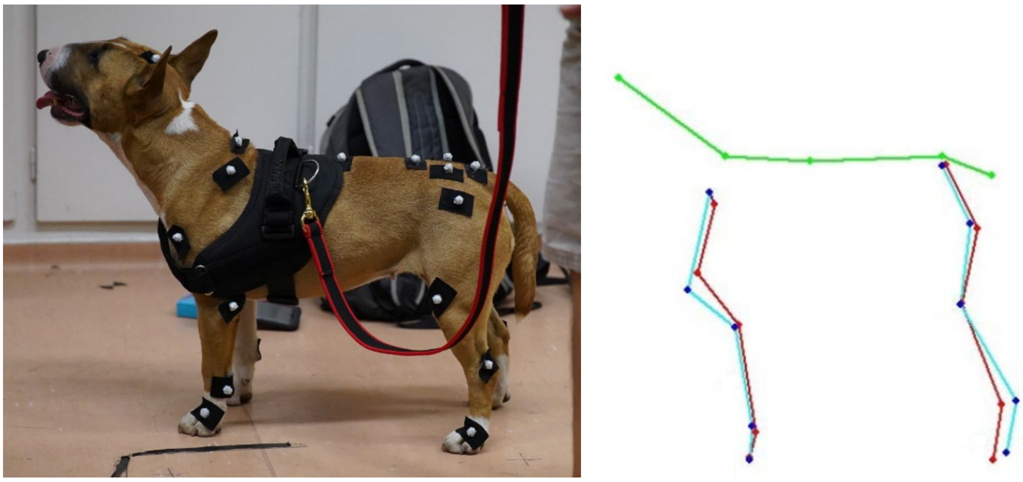

Figure 2. Marker placement on the dog and corresponding kinematics model based on the literature[8]

Gait parameters calculated

Angular gait parameters are shown in Figure 3 in the sagittal (a) and horizontal (b) planes. Angular parameters defined on limbs are normalized to the gait cycles of the corresponding legs and averaged for each homogeneous gait cycle. Spinal angles are normalized for the gait cycles of a chosen limb. This does not influence the range of motion parameters.
The following distance type parameters were also calculated:

- step length,
- stride length,
- step width of the thoracic limbs,
- step width of the pelvic limbs,
- step height of the thoracic limbs (how high the paws are elevated),
- step height of the pelvic limbs.

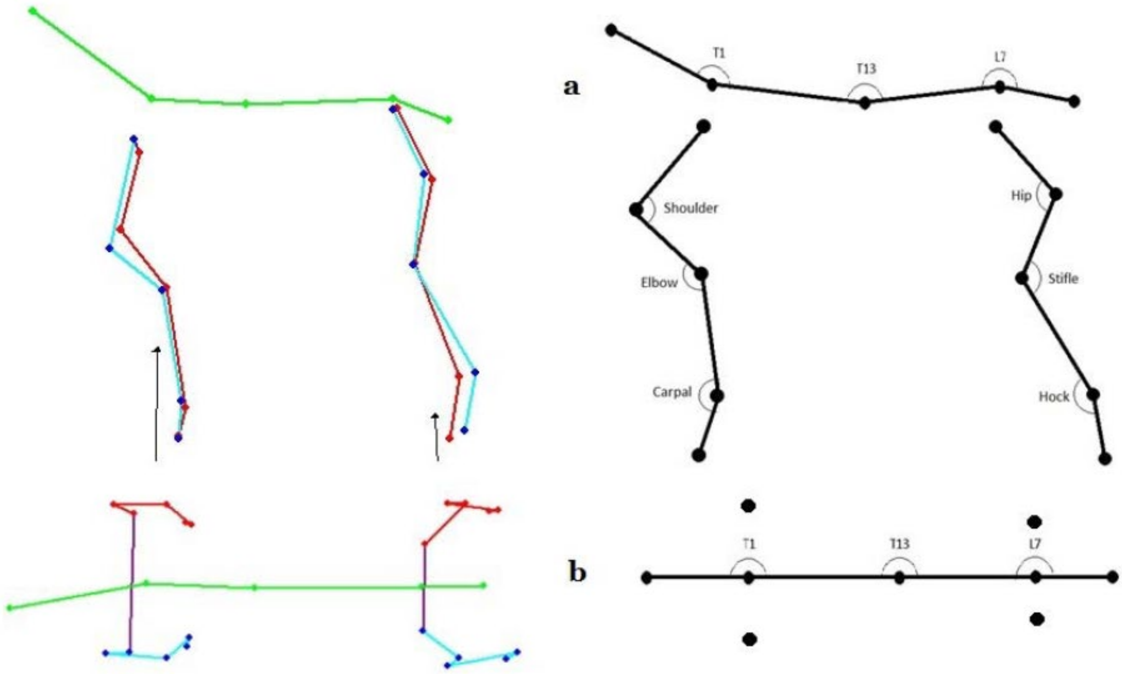

Figure 3. Angular gait parameters (a. sagittal plane, b. horizontal plane)[8]

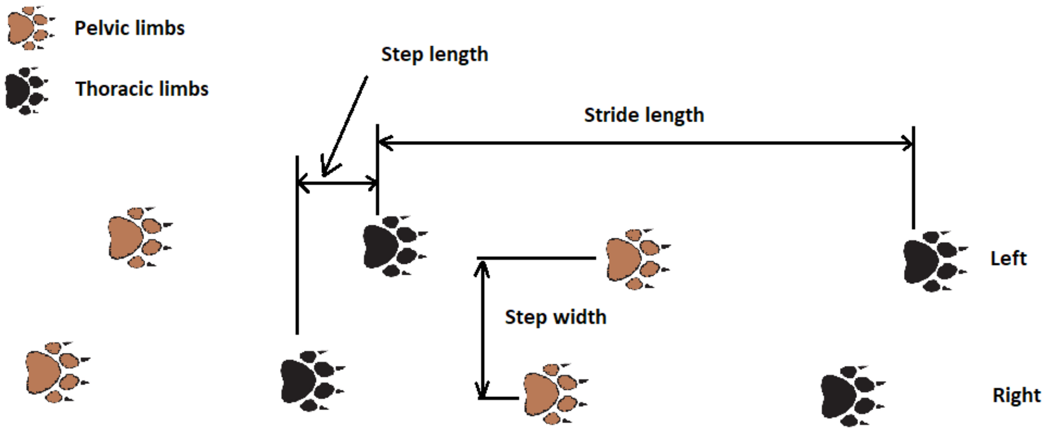

Figure 4. Distance type gait parameters

Measuring the pulling force of the leash

During the trials with a retracting leash, the force of the leash was measured using a load cell. The load cell at the end of the leash was sampled by an HX711 analogue-digital converter at 10 Hz and forwarded to the measurement program running on a computer using an ATmega328 microcontroller through a serial port. The synchronization between the load cell and the mocap system was carried out using an infra LED, operated by the microcontroller. Thus, the starting frame of the force measurement can be identified in the mocap software. When studying the pulling force of the dogs on the leash, the average force was normalized with the body weight of the dog, representing how much weight the dog would pull relative to its own bodyweight.

Statistical comparison

The time function of joint angles is identified for each gait cycle. Individual cycles and average and 95% confidence intervals are displayed in the supplementary material. Statistical comparison is based on distance type parameters.

Statistical analysis was carried out using multivariate and univariate variance analysis (ANOVA). Multivariate ANOVA determines whether, considering all parameters studied (distance type gait parameters), the test cases studied significantly differ from each other or not. Univariate ANOVA determines whether, considering a chosen parameter, the test cases studied significantly differ from each other or not. Further analysis of the pairwise comparisons identifies which test cases differ significantly. The level of significance was set to $p = 0.05$ with a 95% confidence interval. This means that a significant difference exists when $p < 0.05$ and this significant difference is 95% certain.

Results and discussion

Comparison of gait pattern between treadmill and ground walk

In the comparison of gait parameters during treadmill and ground walk, the comparison factor was the use of treadmill versus ground. We compared the measurements obtained from the tests where the dogs did not wear a harness. The comparison (supplementary file 3) shows significant deviations in stride length (p=0.013), step length (p=0.016), and step width of the thoracic limbs (p=0.009) and pelvic limbs (p=0.004). On the other hand, step height shows significant differences in the thoracic limbs (p=0.03) but not in the pelvic limbs (p=0.144). Significant deviations of the parameters are obviously the result of the different walking speeds. On the treadmill, dogs walk at a predefined walking speed, their pattern can be identified as walk or amble. On the ground, the mostly applied gait type was trot. Thus the effect of the harnesses is compared separately for ground walk and treadmill walk.

Comparison of different harnesses based on treadmill trials

Statistical results are detailed in Supplementary file 4. The multivariate ANOVA based on the distance type parameters does not indicate significant differences between the walking patterns for the different harnesses and walking without a harness on the treadmill (p=0.939). Univariate test results show no significant difference, either (p≥0.361). Pairwise comparisons show no significant difference in case of any harness compared to the walk without a harness (p≥0.408).

Comparison of different harnesses during ground walk

Results of the statistical comparison are detailed in Supplementary material 5. The multivariate ANOVA based on distance type parameters does not indicate significant differences between the walking patterns for the different harnesses and walking without a harness during ground walk (p=0.891). Univariate test results show no significant differences either (p≥0.441). Pairwise comparisons show no significant differences compared to walk without a harness on the ground (p≥0.144).

Treadmill walking using retracting leash

Results of the statistical comparison are detailed in Supplementary material 6. Neither the multivariate nor the univariate ANOVA shows significant differences in the gait pattern between pulling the dog back with a leash and walking without a harness in treadmill trials. In the pairwise comparisons, the step width of the pelvic limbs was reduced: in case of the IDC® harness < 2cm and significant (p=0.01); in case of the Duo-Flex® harness, the average reduction was 2.2 cm and not significant (p=0.052); in case of the K9® harness it was 2.3 cm and not significant (p=0.94). The suspected cause of the reduction in pelvic step width is the more efficient force exertion against the pulling leash, as this could not be observed in the walks without a leash. Other distance type parameters such as step length and stride length did not change as the dogs had to maintain a constant speed in order not to fall down from the treadmill. Step height parameters did not show significant deviations either. The average measured body weight normalized leash force was 0.105 ± 0.033.

Ground walking using retracting leash

Results of the statistical comparison are detailed in Supplementary material 7. For ground walk with retracting leash, the multivariate ANOVA did not, while univariate ANOVA indicated significant reductions in many gait parameters compared to ground walk without leash: stride length (p<0.001), step length (p<0.001), and step width of the pelvic limbs (p=0.028) were equally reduced significantly. The pairwise comparison indicated similar deviations compared to the walk without a harness, while it indicated no significant difference between the walks with a retracting leash in the different harnesses. The suspected cause of the deviations is the reduction in speed of the trotting dog due to the reaction to retracting leash. They are trained to slow down on the pulling of the leash. Most dogs in the study switched from trot to walk or pace, except the Yorkshire terrier which was the smallest dog and trotted in both conditions. The average measured body weight normalized leash force was 0.151 ± 0.059. It can be observed that during ground walking the dogs exert a one and a half time larger pulling force compared to treadmill walking, while they switch to a slower gait type.

Conclusion

Although, the walking patterns of dogs are different during treadmill and ground walking, this is a result of switching between natural gait types that suit different speeds (walk, trot). Wearing the harnesses, does not alter the gait patterns, which could be statistically observed using the gait parameters studied. When applying retraction force by leash to the harnesses, the change in walking type is adapted similarly in case of each dog and harness. This is clearer in ground walk, where the dogs change walk types as a learned behavior to respond to the owner's will exerted by the leash. On the treadmill with the same forced speed, the retracting leash did not change the gait of the dogs, wearing a harness significantly.

Supplementary material:

1. Original research plan, and processing software specification (JULIUS_K9_MOGI_jarasvizsgalo_szoftver_specifikacio.pdf)
2. Calculated gait parameters in tabular form (results.xlsx)
3. Statistical comparison without harness between ground and treadmill walking (stat_ground-treadmill.pdf)
4. Statistical comparison of different harnesses on treadmill (stat_treadmill.pdf)
5. Statistical comparison of different harnesses on ground (stat_ground.pdf)
6. Statistical comparison of different harnesses on treadmill with retracting leash (stat_treadmill_leash.pdf)
7. Statistical comparison of different harnesses on ground with retracting leash (stat_ground_leash.pdf)
8. Processed measurement files (csv, and pdf files with calculated parameters) compressed file

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