Biologia Futura

https://akademiai.com/loi/019

Ground force kinetic adaptations associated with canine boots

Kathleen Shorter and Wendy Brown

Canine and Equine Research Group, Faculty of Science, Agriculture, Business and Law, University of New England, Armidale, NSW, Australia

DOI: 10.1556/019.70.2019.16

Original Article

Cite this article: Shorter K, Brown W. 2019. Ground force kinetic adaptations associated with canine boots. *Biol. Fut. 70*, 128–133.

Received: 2 February 2019
Accepted: 16 May 2019

Keywords:
dog, footwear, biomechanics, gait, locomotion, injury

Introduction: Dog boots are being utilized to improve performance and welfare of dogs exposed to a range of adverse conditions; however, there is a lack of empirical evidence establishing the impact of these on gait characteristics. The aim of this research was to quantify alterations to ground force kinetics associated with the introduction of canine boots. *Methods:* Six clinically sound beagles were analyzed on two separate occasions using a cross-over study design to enable randomization between barefoot and shod conditions. During each session, dogs were trotted by an experienced handler over an AMTI force plate sampling at 1,000 Hz to quantify stance time, peak vertical force, peak vertical instantaneous loading rate, and vertical impulse. *Results:* Although there was no significant difference found between footwear conditions for stance time, peak vertical force, and vertical impulse, peak vertical instantaneous loading rate was significantly greater in shod when compared to barefoot. *Discussion:* Findings suggest that while canine boots may provide environmental protection, increases in loading rate are indicative of alterations in foot strike that may result in overloading of musculoskeletal structures. Therefore, caution must be taken when introducing footwear to ensure an adequate adjustment period.

INTRODUCTION

Footpad-related injuries are among the most commonly reported injuries in both working dog (Duhaime et al., 1998; Fox et al., 2008; Gordon, 2012; Slensky et al., 2004; Takara & Harrell, 2014) and sporting dog (Cullen et al., 2013; Lafuente & Whyle, 2018) populations. Within military working dogs in combat zones, 21% of non-combat-related injuries were associated with soft tissue trauma, with footpad or paw injuries (32%), the most commonly involved site, which was attributed to working on hot, rough surfaces (Takara & Harrell, 2014). The incidence of footpad-related injuries reported in search and rescue dogs also varied according to the terrain and environmental conditions where the dogs were deployed (Duhaime et al., 1998; Fox et al., 2008; Gordon, 2012; Slensky et al., 2004).

Footpad injuries include localized lacerations, abrasions and punctures to the area but may also extend to involving surrounding musculoskeletal structures resulting in lameness. The presentation of such injuries reflects the function of the footpads to not only provide protection from adverse environmental conditions but also to dissipate both shear and compressive forces associated with weight-bearing activities.

Protective footwear, such as dog boots, is intended to reduce the incidence of footpad-related injuries. Dog boots are commonly utilized within service dog industries where dogs are exposed to a variety of environmental stressors while undertaking their working roles. However, the use of protective footwear within these industries does not seem to be universally or consistently applied, and this may be partially due to an absence of robust scientific findings to inform these practices. Non-significant reductions in the incidence of cuts and abrasions have been associated with the wearing of paw protection within search and rescue (Slensky et al., 2004). Anecdotally, however, military-working dog handlers have reported impaired performance due to a lack of tolerance (Takara & Harrell, 2014); while the Federal Emergency Management Agency identified that dog boots are rarely utilized due to impairing sensation and traction both of which are critical in the performance for search and rescue dogs (Wong & Robinson, 2004); and dog boots were used sparingly in military-working dogs on deployment in Kuwait, due to concerns about the boots preventing heat dissipation (Toffoli & Rolfe, 2006). It appears that none of these issues have been subjected to scientific research and

Author for correspondence:
Kathleen Shorter
e-mail: kshorter@une.edu.au

evidence-based guidelines regarding the appropriate method of introduction to and subsequent utilization of protective footwear for canines are lacking.

Kinetic gait analysis provides an objective method of non-invasively quantifying external forces exerted during locomotion. Force platforms incorporate sensing elements (either strain-gauges or piezoelectric sensors) that quantify ground reaction forces based on the understanding of Newton's third law of motion; whereby when a dog steps onto the plate, the force recorded in Newtons (N) is equal and opposite in magnitude to that imparted. Primarily within canine-based research, force plate analysis has focused on reporting forces within the vertical and anterior–posterior direction in respect to the force–time curve during ground contact. In particular, canine research has reported variables such as peak force, impulse, and loading rates when investigating the kinetics associated with clinical presentations such as lameness (Fanchon & Grandjean, 2007). Fanchon and Grandjean (2007) established that vertical force variables demonstrated greater accuracy, in particular, peak vertical force and the peak vertical instantaneous loading rate in identifying hind limb lameness, where Abdelhadi et al. (2013) identified that such variables were also sensitive to compensatory load redistribution mechanisms associated with induced forelimb lameness within beagles.

As the field of canine science matures, there is an increasing tendency to apply the rigors of science to all aspects of canine management. As the presentation of footpad-related injuries not only results in the primary presentation of localized pain and discomfort but may also progress to lameness resulting in impaired function and performance, the efficacy of preventative measures such as protective footwear needs to be objectively quantified. The aim of this research was to quantify alterations to ground force kinetics associated with the introduction of canine boots. As the immediate introduction of protective footwear is visually observed to result in altered tactile behavior within dogs (Wong & Robinson, 2004), it was hypothesized that this would manifest through altered ground force kinetics that may impair the function of the footpads to dissipate forces associated with weight-bearing activities.

MATERIALS AND METHODS

Six privately owned, purebred beagles, three males and three females (mass: 13.28 ± 0.48 kg), participated in this study with the written consent of their owner and were analyzed on two separate occasions using a cross-over study design to enable randomization between barefoot and shod conditions. Males and females were matched for age; the oldest pair being 6 years, then 3.5 years, and the youngest pair 1.3 ± 0.3 years. All participating dogs demonstrated no visible signs of lameness and were considered clinically healthy based on observations from their owner with no documented history of orthopedic disease. Testing sessions were 8.3 ± 1.4 days apart.

For the shod condition, dog boots were simulated through the application of a 2-mm ethylene-vinyl acetate (EVA) pad (Briggate Medical Company, VIC, Australia) secured using Equus cohesive bandage (Equus, Nar Nar Goon North, VIC, Australia). In contrast to commercially available boots, this approach facilitated a customized fit for each dog that replicated the shock absorptive properties associated with boots. The EVA pads were first cut to the shape of the dog's footpads and then secured with cohesive bandage up to the hock, as shown in Fig. 1. Prior to data collection, each dog was walked on a lead for several minutes to habituate to the sensation of the boots, until the gait appeared normal, based on visual observation by the researchers.

All testing was conducted within the Exercise and Sports Science Laboratory at the University of New England enabling ground force kinetics to be collected at 1,000 Hz using an AMTI force plate (AMTI, MA, USA) imbedded within a 20-m walkway. All data were collected through Qualisys Track Manager Version 2.9 (Gothenburg, Sweden) to enable synchronization of the ground force kinetics with a Qualisys Oqus 300+ camera sampling at 100 Hz positioned perpendicular to the direction of movement to facilitate the visual identification of footfalls during subsequent data analysis.

Following habituation with both the laboratory and protocols, dogs were trotted over the force plate by a single, experienced handler at a self-preferred pace. Within each session, six trials of each functional step were recorded for subsequent analysis. A valid trial was defined by the

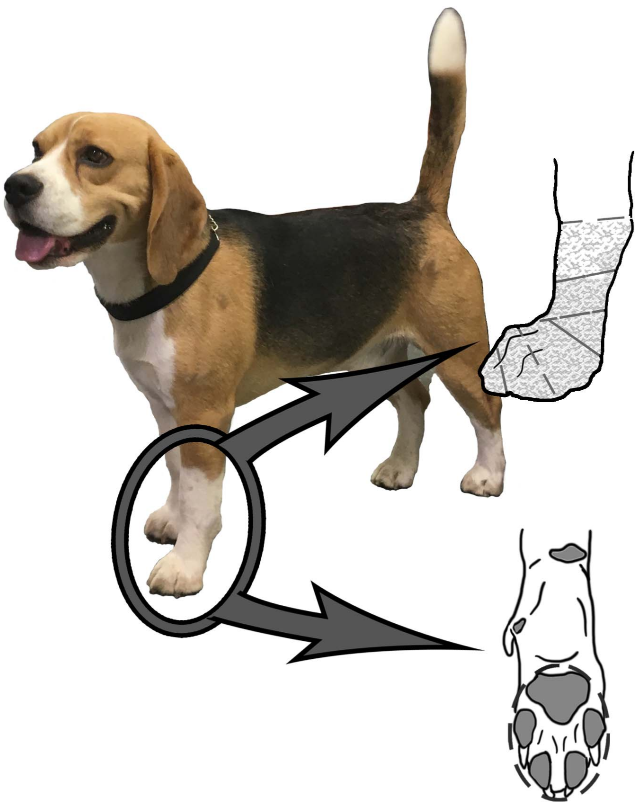


Fig. 1. Customized boots were created by securing EVA pads to the soles of dogs' feet with cohesive bandage. The dotted line in the bottom image outlines the area covered by the cushioning EVA pads. The upper figure illustrates the position of the bandage. EVA: ethylene-vinyl acetate

complete ipsilateral fore- and hind strike over the force plate whereby the dog was also observed to maintain a steady-state, linear gait pattern with the handler maintaining a loose leash throughout the trial.

Ground force kinetic data were exported and subsequently analyzed within Visual3D Version 5 (C-motion, Rockville, USA) whereby the following variables were investigated: stance time (s), peak vertical force (N), peak vertical instantaneous loading rate ($N.s^{-1}$), and vertical impulse (N.s), summarized in Fig. 2. For the purpose of this study, only the vertical component of the ground reaction force was chosen for analysis. Stance time was defined as the duration during which vertical force exceeded 20 N. Peak vertical instantaneous loading rate was defined as the maximal instantaneous value calculated from the first derivative of the vertical force–time curve, whereas vertical impulse was calculated as the area under the vertical force–time curve during the entire stance phase using the trapezoid rule.

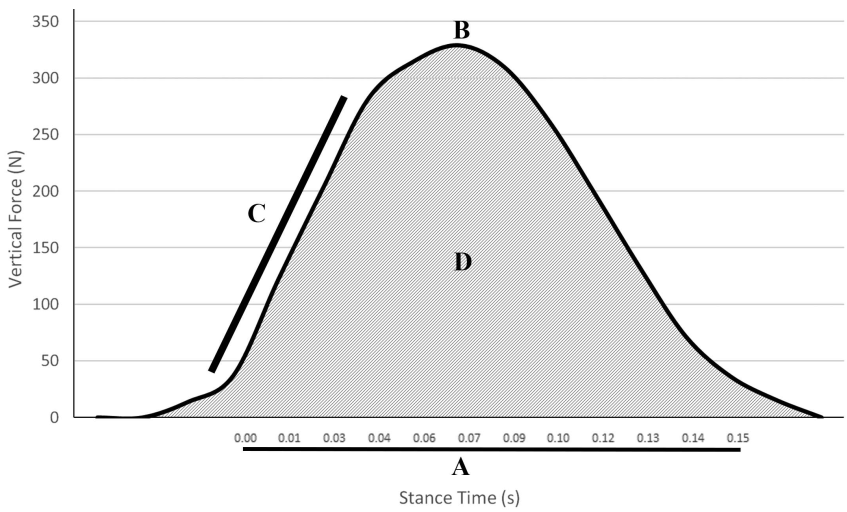
To establish the influence of footwear, as data did not meet assumptions of normality, non-parametric analysis of each variable was conducted using Wilcoxon signed-ranked tests ($p < .05$) within SPSS Version 24 (IBM Corporation, NY, USA). Effect size (ES) was calculated by dividing the absolute test statistic (Z) by the square root of the number of pairs and classified using Cohen's classification system (Cohen, 1988).

RESULTS

A representative force–time curve for one dog between footwear conditions is shown in Fig. 3. No significant difference ($p > .05$) was found between footwear conditions for stance time, peak vertical force, and vertical impulse (Table 1). Peak vertical instantaneous loading rate was significantly greater ($Z = -2.201$, $p = .028$) in shod ($17{,}125.017 \pm 3{,}511.747$ $N.s^{-1}$) when compared to barefoot ($11{,}670.877 \pm 1{,}175.993$ $N.s^{-1}$) with a large ES (ES = 0.64) noted.

DISCUSSION

The aim of this research was to quantify alterations to ground force kinetics associated with the introduction of canine boots. While findings initially indicate that the impact of protective footwear is minimal based on peak vertical force, vertical impulse, and stance time, the significant 47% increase in peak vertical instantaneous loading rate suggests to take caution. In particular, although the use of dog boots may improve animal welfare through environmental protection, the increase in peak vertical loading rate is suggestive of an alteration in foot strike, which may result in the subsequent overloading of surrounding musculoskeletal structures. Future research using larger numbers of dogs



Label	Variable	Definition
A	Stance time (s)	The duration of time during the functional step where both paws were in contact with the force plate identified when vertical force was greater than 20 N
B	Peak vertical force (N)	The maximal vertical force observed during the functional step
C	Peak vertical instantaneous loading rate ($N.s^{-1}$)	Representative of the rate of loading observed by the steepness of the curve, the maximal, instantaneous value is calculated from the first derivative of the vertical force-time curve
D	Vertical impulse (N.s)	The area under the vertical force-time curve during the functional step using the trapezoid rule and considered to be representative of the load

Fig. 2. Summary of the ground force kinetic variables used in this study

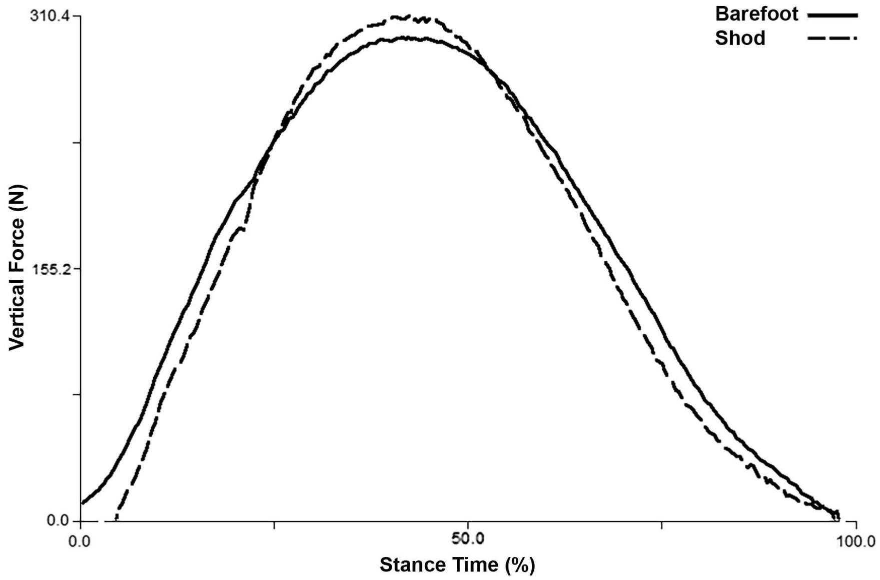


Fig. 3. Representative vertical force–time curve between footwear conditions for one dog

Table 1. Ground reaction force kinetics (mean ± *SD*) associated with footwear conditions

Variable	Condition	Mean ± *SD*	*p*	ES
Stance time (s)	Barefoot	0.146 ± 0.011	.345	0.27
	Shod	0.150 ± 0.010		
Peak vertical force (N)	Barefoot	303.827 ± 13.804	.463	0.21
	Shod	297.671 ± 24.139		
Peak vertical instantaneous loading rate ($N.s^{-1}$)	Barefoot	11,670.877 ± 1,175.993	**.028**	0.64
	Shod	17,125.017 ± 3,511.747		
Vertical impulse (N.s)	Barefoot	22.569 ± 1.028	.753	0.09
	Shod	22.367 ± 10.965		

Note. Bold value represents statistically significant result ($p < .05$). *SD*: standard deviation; ES: effect size.

and multiple breeds is warranted to confirm whether the results of this study are applicable to dogs generally. Further research under field conditions, despite logistically challenging, would also be beneficial for broader interpretation.

The high incidence of footpad-related injuries experienced by dogs engaged in working and sporting activities supports the need for proactive prevention and management of such occurrences. Beyond the initial impact of localized pain and discomfort, footpad injuries may progress to lameness resulting in impaired function and performance, and, when combined with occupational demands associated with repetitive limb loading, may lead to the development of degenerative conditions such as osteoarthritis, the leading reason for euthanasia within military-working dogs (Moore et al., 2001).

Findings suggest that while canine footwear may provide some inherent protection from the environment, the ability of boots to improve force dissipation associated with weight-bearing activities is questionable. The utilization of force platform-derived variables within this research was based on their reported sensitivity in identifying alterations to gait in the presence of lameness (Fanchon & Grandjean, 2007); however, no significant difference between footwear conditions was noted within this research. In contrast, Abdelhadi et al. (2013) identified induced forelimb lameness resulted in an increase in both peak vertical force and vertical impulse to the contralateral hind limb, whereas Griffon et al. (1994) observed an increase in peak vertical force affecting the contralateral forelimb. Therefore, while such variables have been noted for their sensitivity in identifying lameness, the inability for these to identify a change in footwear condition within this study may be in part due to the introduction of footwear affecting all limbs. In particular, rather than resulting in a compensatory redistribution of force, canine footwear may instead place an increased demand on surrounding musculoskeletal structures to aid in the dissipation of ground reaction forces. This supposition is supported by the significant increase in peak vertical loading rate, which is acknowledged to be influenced by the associated foot-strike pattern and position of the lower-limb within bipedal gait.

Although force platforms quantify the ground force kinetics associated with movement, when used in isolation, this methodology fails to quantify compensatory changes to movement/technique that may occur. Within bipeda gait analysis, the impact of footwear has been the focus of numerous research studies with habitually barefoot runners typically landing on the forefoot, whereas habitually shod runners adopt a predominately rearfoot strike resulting in higher rates and magnitudes of loading that may contribute to an increased injury risk (Lieberman et al., 2010). Using a combination of 3D video and force platform analysis, Hashish et al. (2016) quantified compensatory adaptions associated with runners acutely transitioning from shod to barefoot running and found that runners who maintained a rearfoot strike were associated with a 108% increase in loading rate, whereas those who adopted a forefoot strike demonstrated a 41% reduction. The reduction in loading associated with forefoot striking was accompanied by a concomitant change in ankle angle (Hashish et al., 2016), while the change toward a forefoot strike was also noted to result in alterations in lower extremity muscle activity (Shih et al., 2013). As forefoot striking is associated with lowering loading rates, such findings from bipedal gait analysis emphasize that it may not be the presence of footwear in canines that directly aid in dissipating impact forces due to their cushioning properties but rather that a change in foot strike pattern may possess greater potential in either the prevention or exacerbation of injuries associated with loading. Future research should aim to quantify associated changes in foot strike to provide greater clarity surrounding the true impact that footwear may impart.

CONCLUSION FOR FUTURE BIOLOGY

Although there is currently no uniformity in the application of dog boots, undoubtedly there are situations where the use of protective footwear is likely to afford benefits in reducing footpad-related injuries. When deliberating the potential advantages and disadvantages, the impact on gait is an additional factor that warrants consideration, but the importance of this has largely been overlooked. Using kinetic gait analysis, our research demonstrated a significant alteration in canine gait associated with wearing footwear. The methodology proved sensitive enough to determine differences in foot strike between shod and barefoot conditions, even though dogs were tested after a short habituation period when no visible difference in gait was evident to the observers. Given the propensity for footpad injuries in dogs and that foot protection is commonly utilized across a range of working, sporting, and service dogs, further research is needed to provide scientific evidence to develop best-practice guidelines surrounding the use of footwear in dogs. Based on our findings, we advise caution when introducing footwear and recommend an adequate habituation period. More research is needed to identify optimum habituation regimens and to determine the most appropriate style of footwear for different breeds of dogs in different working roles.

Acknowledgments: The authors would like to thank Shirley Fraser (Dandangadale beagles) for allowing her dogs to participate in this research and Caleb Lawman for his assistance with data collection.

Ethical Statement: Authority to conduct this research was obtained from the University of New England Animal Ethics Committee (AEC16-093).

Funding Statement: This research was conducted using in-kind support within the University of New England and did not receive any external funds.

Competing Interests: The authors declare no competing interests.

Authors' Contributions: KS conceptualized the experiment, analyzed the data, and interpreted the results. KS and WB designed the experiment, acquired the data, and wrote the manuscript.

REFERENCES

Abdelhadi, J., Wefstaedt, P., Galindo-Zamora, V., Anders, A., Nolte, I., Schilling, N. (2013) Load redistribution in walking and trotting beagles with induced forelimb lameness. *AJVR 74*(1), 34–39.

Cohen, J. (1988) *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Cullen, K., Dickey, J., Bent, L., Thomason, J., Moëns, N. (2013) Internet-based survey of the nature and perceived causes of injury to dogs participating in agility training and competition events. *JAVMA 243*(7), 1010–1018.

Duhaime, R., Norden, D., Corso, B., Mallonee, S., Salman, M. (1998) Injuries and illnesses in working dogs used during the disaster response after the bombing in Oklahoma City. *JAVMA 212*(8), 1202–1207.

Fanchon, L., Grandjean, D. (2007) Accuracy of asymmetry indices of ground reaction forces for diagnosis of hind limb lameness in dogs. *AJVR 68*(10), 1089–1094.

Fox, P., Puschner, B., Ebel, J. (2008) Assessment of acute injuries, exposure to environmental toxins, and five-year health surveillance of New York Police Department working dogs following the September 11, 2001, World Trade Center terrorist attack. *JAVMA 233*(1), 48–59.

Gordon, L. (2012) Injuries and illnesses among urban search-and-rescue dogs deployed to Haiti following the January 12, 2010, earthquake. *JAVMA 240*(4), 396–403.

Griffon, D., McLaughlin, R., Roush, J. (1994) Vertical ground reaction force redistribution during experimentally induced shoulder lameness in dogs. *Vet. Comp. Orthop. Traumatol. 7*(4), 154–157.

Hashish, R., Samarawickrame, S., Powers, C., Salem, G. (2016) Lower limb dynamics vary in shod runners who acutely transition to barefoot running. *J. Biomech. 49*, 284–288.

Lafuente, P., Whyle, C. (2018) A retrospective survey of injuries occurring in dogs and handlers participating in canicross. *Vet. Comp. Orthop. Traumatol. 31*(5), 332–338.

Lieberman, D., Venkadesan, M., Werbel, W., Daoud, A., D'Andrea, S., Davis, I., Mang'Eni, R., Pitsiladis, Y. (2010) Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature 463*, 531–535.

Moore, G., Burkman, K., Carter, M., Peterson, M. (2001) Causes of death or reasons for euthanasia in military working dogs: 927 cases (1993–1996). *JAVMA 219*(2), 209–214.

Slensky, K., Drobatz, K., Downend, A., Otto, C. (2004) Deployment morbidity among search-and-rescue dogs used after the September 11, 2001, terrorist attacks. *JAVMA 225*(6), 868–873.

Shih, Y., Lin, K.-L., Shiang, T.-Y. (2013) Is the foot striking pattern more important than barefoot or shod conditions in running? *Gait Posture 38*(3), 490–494.

Takara, M., Harrell, K. (2014) Noncombat-related injuries or illnesses incurred by military working dogs in a combat zone. *JAVMA 245*(10), 1124–1128.

Toffoli, C. A., Rolfe, D. A. (2006) Challenges to military working dog management and care in the Kuwait theatre of operation. *Mil. Med. 171*(10), 1002–1005.

Wong, J., Robinson, C. (2004) Urban search and rescue technology needs: identification of needs. Document no. 207771. Federal Emergency Management Agency and the National Institute of Justice.