

Analysis of the Musculoskeletal Load Generated when a Small Dog Walks on a Slippery Floor*

Shijian Li, Daisuke Chugo, Satoshi Muramatsu, Sho Yokota, Jin-Hua She, Hiroshi Hashimoto, Uemura Takashi, Hiroaki Kamishina, Yoshiharu Hata, Takayuki Yamada and Takahiro Uchida

Abstract— The objective of this paper is to identify the stresses placed on the musculoskeletal system when small dogs walk on floors with low friction coefficients. In many households, and small dogs in particular are often kept indoors. According to veterinary experience, it is known that small dogs kept indoors that walk with their lower limbs slipping cause a great deal of stress on the musculoskeletal system, and that the incidence of joint disease in the lower limbs of such small dogs is high. In this study, we measured the body movements of small dogs walking on slippery floors using a three-dimensional motion capture system and force plate system. Furthermore, by inputting these measurements into the musculoskeletal simulation model we have developed to simulate the musculoskeletal system of dogs, we derived the load on the musculoskeletal system of small dogs on slippery and non-slippery floors. As a result, it was identified that walking on a slippery floor causes a strong load on the lower limb muscles of small dogs.

I. INTRODUCTION

Many dogs are kept as pets, and in particular, the number of households with small dogs kept indoors is increasing [1]. Generally, when people keep dogs indoors, they tend to choose wooden floors in consideration of ease of cleaning. However, when small dogs walk on wooden floors, their lower limbs easily slip. Dogs are animals that naturally live on ground with sufficient friction, so slipping on wooden floors can cause stress to their bodies.

Small dogs can suffer from joint disease (herniated discs etc) in their lower limbs as they get older, and if the condition is serious, it can make walking difficult [2]. The only way to treat this joint disease is with rehabilitation by a physiotherapist [3,4], so it can be hard on the dog and its owner.

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Shijian Li and Daisuke Chugo are with Graduate School of Science and Technology, Kwansai Gakuin University, Sanda, Hyogo 6691330 Japan (corresponding author to provide phone: +81-79-565-7043; fax: +81-79-565-7043; e-mail: {lishijian, chugo}@chugolab.com).

Satoshi Muramatsu is with School of Information Science and Technology, Tokai University, Hiratsuka, Kanagawa 2591292 Japan. (e-mail: muramatsu@tokai.ac.jp).

Sho Yokota is with Faculty of Science and Engineering, Toyo University, Kawagoe, Saitama 3508585 Japan. (e-mail: s-yokota@toyo.jp).

Jun-Hua She is with School of Engineering, Tokyo University of Technology, Hachioji, Tokyo 1920982 Japan. (e-mail: she@stf.teu.ac.jp).

Hiroshi Hashimoto is with Master Program of Innovation for Design and Engineering, Advanced Institute of Industrial Technology, Shinagawa, Tokyo 1400011 Japan. (e-mail: hashimoto@aait.ac.jp).

Uemura Takashi and Hiroaki Kamishina are with KyotoAR Animal Advanced Medical Center, Kuse, Kyoto 6130034 Japan. (e-mail: {NeuroRehab723, kamishina}@kyotoar.com).

Yoshiharu Hata, Takayuki Yamada and Takahiro Uchida are with Rinrei Co., Ltd., Chuo, Tokyo 1040061 Japan. (e-mail: {hata.y, yamada.ta, uchida.t}@rinrei.co.jp)

Therefore, it is important for them to prevent their dog from suffering from joint disease in its lower limbs.

On the other hand, it is known from veterinary experience that small dogs kept indoors suffer from joint diseases in their lower limbs more frequently [5]. Therefore, we have previously developed a flooring coating material that increases the coefficient of friction on slippery indoor floors, reducing the risk of small dogs slipping when walking [6]. Using the coating material, we investigated the effect on the posture of small dogs when walking. On the other hand, there has been no research to quantitatively identify the load that the slipping of the lower limbs during walking places on the musculoskeletal system of dogs.

Therefore, we have developed a simulation model that approximates the musculoskeletal system of dogs [7], and have analyzed the impact of slipping of the lower limbs on the musculoskeletal system of dogs [8,9]. As a result, it was found that the stress on the musculoskeletal system of dogs is increased by the slipping of the lower limbs. However, the dogs that were the subject of analysis in these studies were medium-sized or large dogs that are usually kept outdoors, and therefore they tend to be heavy. Therefore, it was difficult to discuss the effects of slips that occur when dogs walk on wooden floors, as their lower limbs do not slip easily even on wooden floors.

The objective of this study is to quantitatively evaluate the effect of the coefficient of friction of flooring on the musculoskeletal system of dogs when they walk on flooring, with a particular focus on small dogs that are often kept indoors. To do this, small dogs such as Chihuahuas were recorded as they walked on a floor that had been made less slippery by applying a coating agent, and on a floor that was slippery, using a three-dimensional motion capture system and force plate system. Next, a musculoskeletal model of the dog was created, applying the physical parameters of each test dog, such as weight and body length, and by inputting the measurement data into the model, the force exerted by the dog's muscles during walking was identified through simulation, and the impact of a slippery floor on the dog's walking was considered.

II. MUSCULOSKELETAL MODEL OF A SMALL DOG

In recent years, many researchers have been using the musculoskeletal simulator OpenSim to analyze human movement [10]. We have also been using the musculoskeletal simulator OpenSim to conduct research on human movement analysis [11,12].

In this study, we have made use of this knowledge to develop a musculoskeletal model of a small dog, which is often

kept indoors. In the previous study, a musculoskeletal model of a large dog, the greyhound, was developed [13]. Based on this musculoskeletal model, we obtained the opinions of veterinarians and reflected the characteristics of the musculoskeletal system of small dogs in this musculoskeletal model [7-9]. Fig. 1 shows a full-body diagram of the developed musculoskeletal model of a small dog, and Fig. 2 shows a detailed diagram of the lower limbs. Table 1 shows the muscles that make up the lower limb model.

In this paper, we analyzed the gaits of three small dogs and one medium-sized dog, as shown in Fig. 5 and Table 3. In these analyses, we applied the body parameters of each dog, such as height and weight, to this musculoskeletal model.

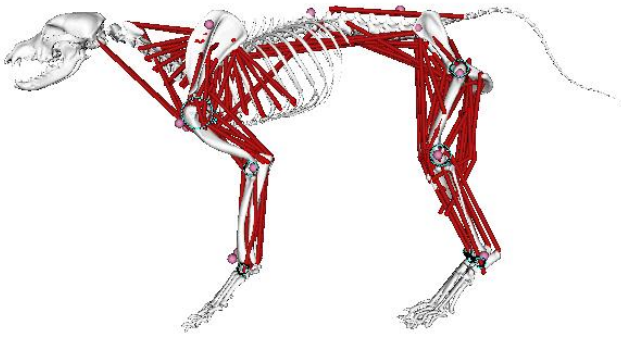


Figure 1. Musculoskeletal model of a small dog.

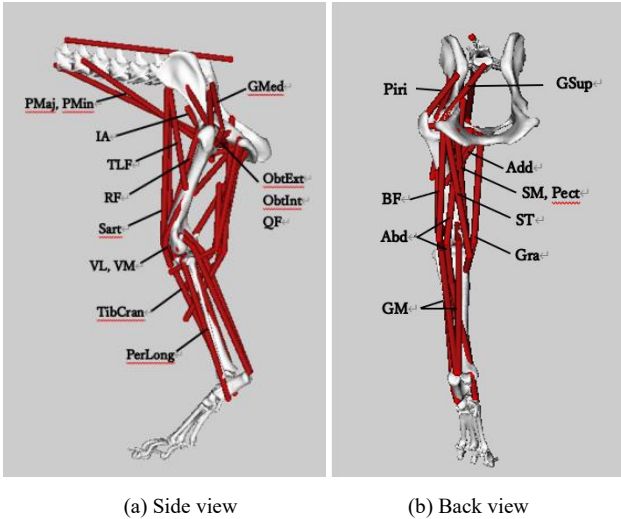


Figure 2. Detail of lower limb section of a small dog musculoskeletal model.

III. MEASURING A SMALL DOG'S WALKING MOTION

A. Experimental Setup

We measured the movement of the body and the force with which the lower limbs kicked the ground when we made small dogs walk on a floor made of flooring material. The flooring material used was one that is widely used in Japan (USUI-TA manufactured by Panasonic Corp.). We prepared two pieces of this flooring material, and coated one of them with the coating materials we had developed (manufactured by Rinrei Co. Ltd. [6]). The flooring material with the coating material applied and the flooring material without the coating material applied

TABLE I. MUSCLES OF A LOWER LIMB DOG MODEL.

| Abbreviation | Muscular Name | The way muscles work |
|----------------|-----------------------|---|
| <i>GMed</i> | Gluteus medius | Extension and abduction of the hip joint. Internal rotation of the hind limb. |
| <i>GInt</i> | Gluteus profundus | |
| <i>GSup</i> | Gluteus superficialis | External rotation of the hip joint. Abduction of the limb. |
| <i>ObtExt</i> | Obturator externus | External rotation of the hind limb. |
| <i>ObtInt</i> | Obturator internus | Abduction of the hindlimb at the hip joint. |
| <i>Add</i> | Adductoren | Hind limb adduction. |
| <i>Abd</i> | Abductor cruris | Hind limb abduction. |
| <i>Pect</i> | Pectineus | Hind limb adduction. |
| <i>Piri</i> | Piriformis | External rotation of the hip joint. |
| <i>Sart</i> | Sartorius | Flexion of the hip joint. Flexion of the knee joint . |
| <i>VL</i> | Vastus lateralis | Extension of the knee joint. |
| <i>VM</i> | Vastus medialis | |
| <i>RF</i> | Rectus femoris | Extension of the knee joint. Flexion of the hip joint. |
| <i>TFL</i> | Tensor fascia lata | Tension of the lateral thigh fascia. Extension of the knee joint. Flexion of the hip joint. |
| <i>IA</i> | Iliacus | Hip flexion, external rotation. |
| <i>QF</i> | Quadratus femoris | Extension of the hip joint. External rotation of the hind limb. |
| <i>Gra</i> | Gracilis | Hind limb adduction, knee joint flexion. Extension of hip and tarsal joints. |
| <i>ST</i> | Semitendinosus | Extension of the hip joint, flexion of the knee joint and extension of the tarsal joint. |
| <i>SM</i> | Semimembranosus | Extension of the hip joint . Flexion and extension of the knee joint. |
| <i>BF</i> | Biceps femoris | Extension of the hip, knee and tarsal joints. Flexion of the knee joint. |
| <i>GM</i> | Gemelli muscles | Extension of the tarsal joints. Flexion of the knee joint. |
| <i>TibCran</i> | Tibialis cranialis | Flexion of the tarsometatarsal joint. External rotation of the foot. (turning the foot plantar surface inwards) |
| <i>PerLong</i> | Peroneus longus | Flexion of the tarsal joint. Internal rotation of the foot. (turning the foot plantar surface outwards). |

are shown in Fig. 3, and the friction coefficients of these are shown in Table 2.

The body movements of small dogs were measured using a three-dimensional motion capture system. If the motion capture markers were attached directly to the dogs, it would be difficult to obtain accurate measurements because the markers would move due to the dogs' body hair. Therefore, in this study, the dogs were fitted with clothes that were suited to their body size, and the markers were attached to the clothes. A force plate device for dogs was used to measure the force with which the lower limbs of small dogs kicked off the ground. The measurement surface of the force plate device was also covered with flooring material for the experiment, so that the test dogs could walk on the force plate without feeling any discomfort. The experimental environment is shown in Fig. 4.

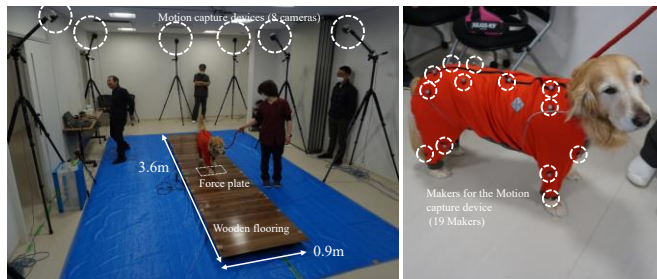
All experiments on the test dogs were executed under the supervision of a veterinarian in accordance with the ethical guidelines of Kyoto AR Animal Advanced Medical Center.



(a) With coating material (b) Without coating material
Figure 3. Flooring material used in the experiment.

TABLE II. THE FRICTION COEFFICIENTS OF FLOORING MATERIALS

| | With coating material | Without coating material |
|---------------------------------------|-----------------------|--------------------------|
| <i>coefficient of static friction</i> | 0.506 | 0.295 |



(a) Experimental environment (b) Markers attached to the dog
Figure 4. Experimental Setup.

B. Subjects

In this study, the walking motions of four test dogs were measured. Three of the dogs were small dogs kept indoors in Japan. In addition, the walking motions of one medium-sized dog were also measured for comparison with the results of the experiment. Each test dog is shown in Fig. 5, and the physical data for each test dog is shown in Table 3.

TABLE III. BODY PARAMETERS OF TEST DOGS

| <i>Subject</i> | A | B | C | D | |
|--------------------|--------------------|--------|--------|-----------------|------|
| <i>Name</i> | TOTO | QOO | MARU | KUERU | |
| <i>Type</i> | Poodle | Poodle | Poodle | German Shepherd | |
| <i>Sex</i> | M | M | M | M | |
| <i>Age</i> | 10 | 9 | 2 | 1 | |
| <i>Weight [kg]</i> | 3.0 | 3.0 | 5.0 | 38.2 | |
| <i>Length [m]</i> | <i>Body length</i> | 0.26 | 0.23 | 0.31 | 0.60 |
| | <i>Body height</i> | 0.28 | 0.30 | 0.29 | 0.63 |
| | <i>Femur</i> | 0.10 | 0.13 | 0.10 | 0.25 |
| | <i>Tibia</i> | 0.08 | 0.11 | 0.09 | 0.20 |
| | <i>Hock</i> | 0.07 | 0.07 | 0.08 | 0.12 |
| | <i>Metatarsus</i> | 0.06 | 0.07 | 0.07 | 0.09 |

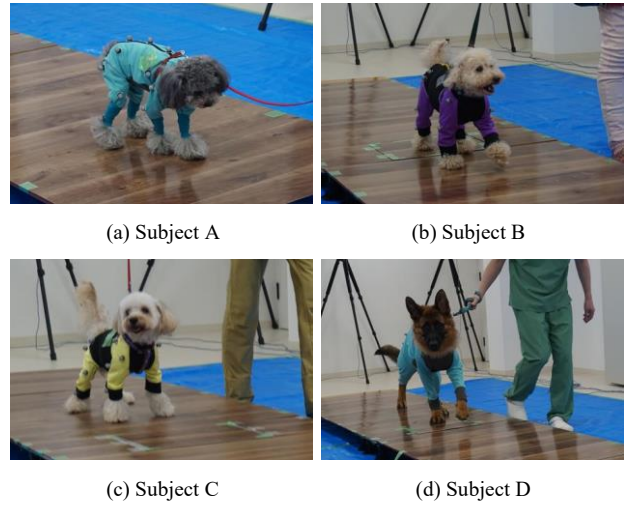


Figure 5. Test dogs.

C. Experimental Results

The results of the experiment are shown in Figs. 6 to 16. As shown in Figs 6 and 7, the subject A walked on the wooden floor. When the floor had a coating material, subject A trotted, and when it did not, the subject A walked normally.

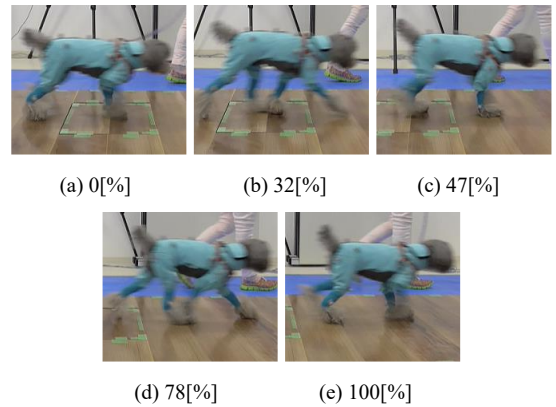


Figure 6. Changes in the posture of subject A walking on the floor with our coating material. One step from (a) to (e), where the supporting leg and the swinging leg cross, is defined as 100%. (b) indicates when the leg is on the ground, (c) indicates when the leg is kicking the ground with maximum force, and (d) indicates when the leg is off the ground. In the following, this paper will classify the gait of dogs in the same way.

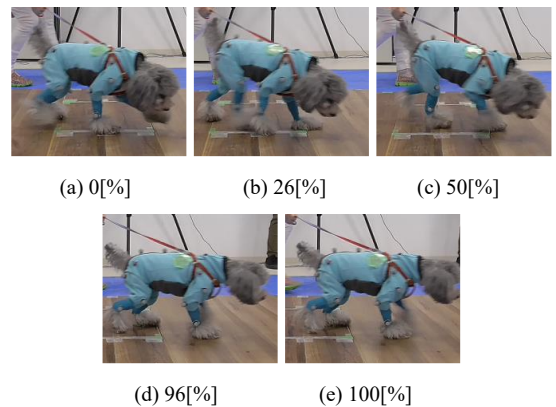


Figure 7. Changes in the posture of subject A walking on the floor without our coating material.

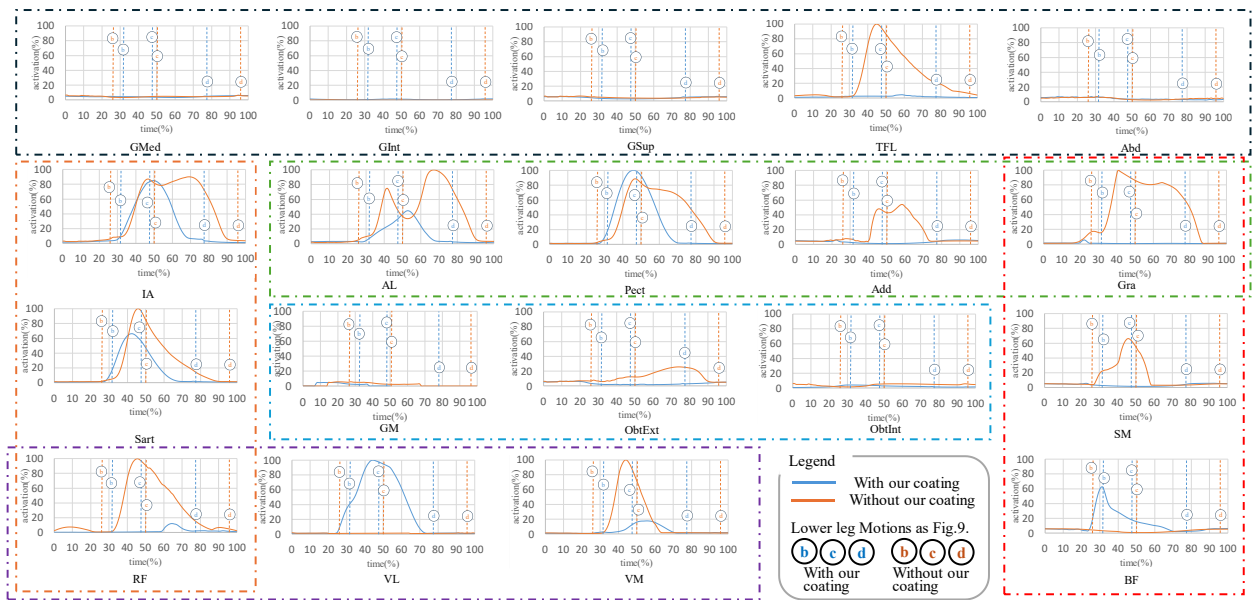


Figure 8. Muscle exertion in the lower limbs derived from the simulation (Subject A).

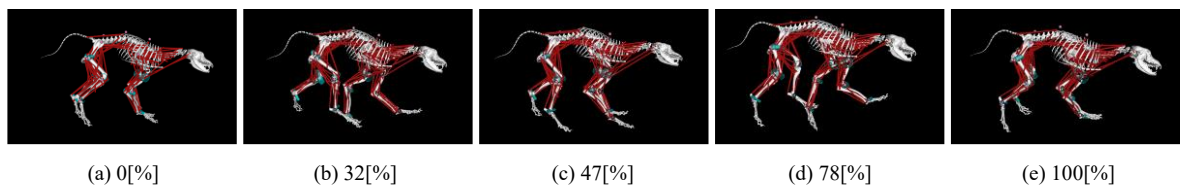


Figure 9. Changes in the posture of subject A walking on the floor with our coating material.

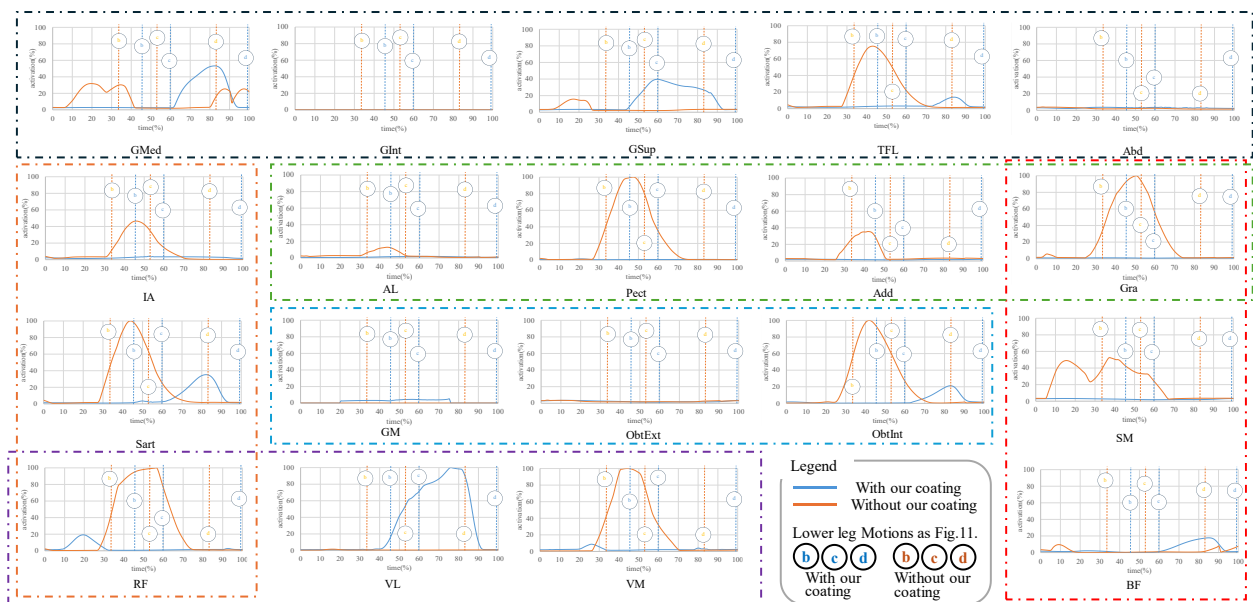


Figure 10. Muscle exertion in the lower limbs derived from the simulation (Subject B).

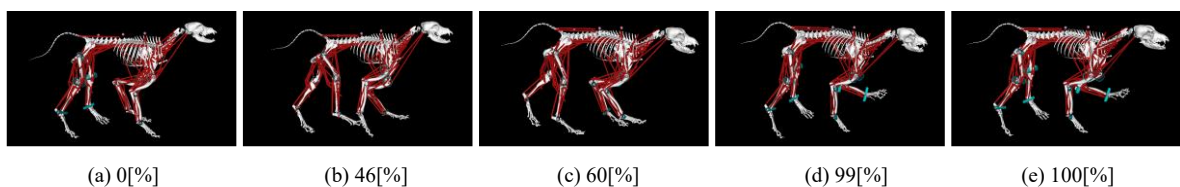


Figure 11. Changes in the posture of subject B walking on the floor with our coating material.

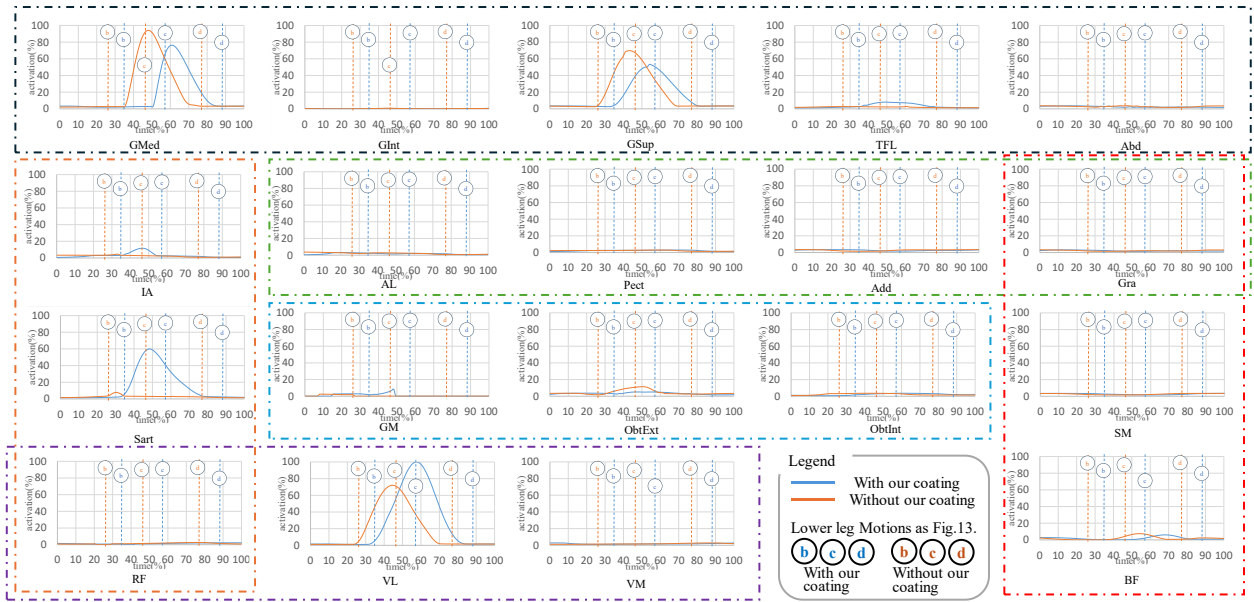


Figure 12. Muscle exertion in the lower limbs derived from the simulation (Subject C).

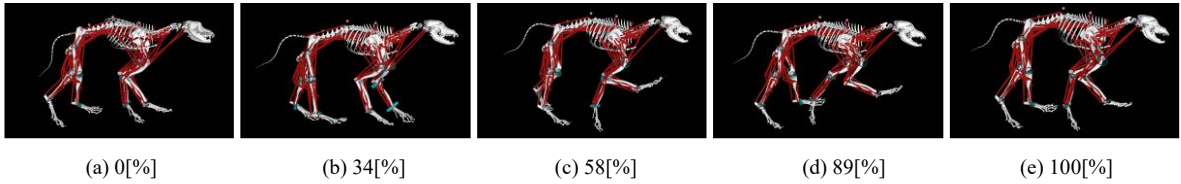


Figure 13. Changes in the posture of subject C walking on the floor with our coating material.

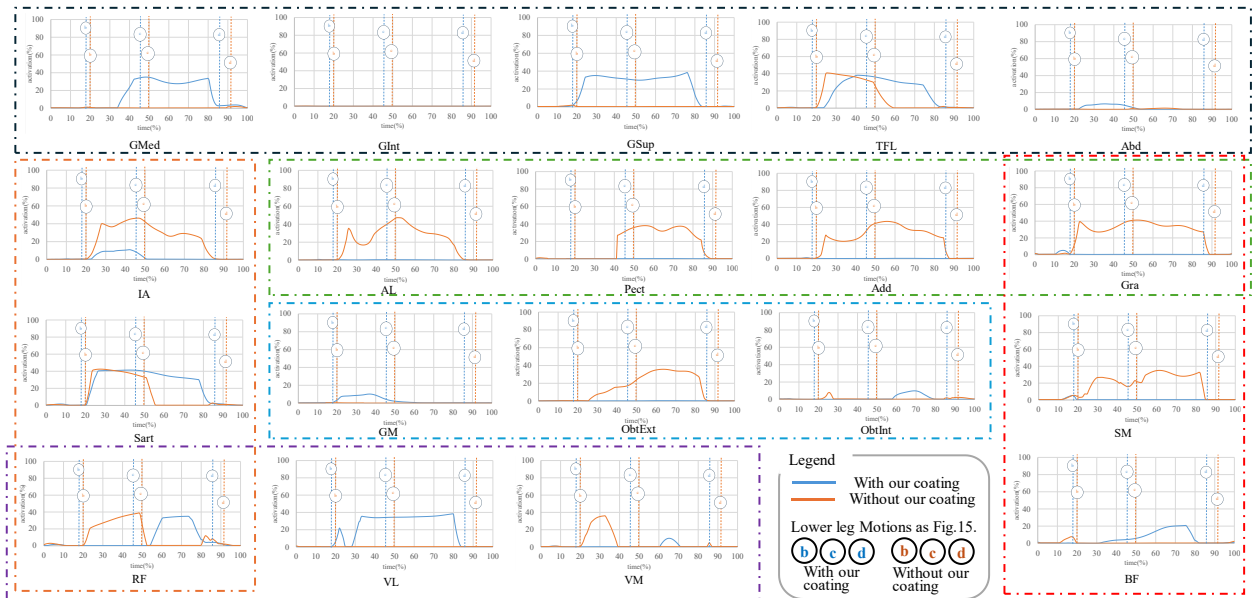


Figure 14. Muscle exertion in the lower limbs derived from the simulation (Subject D).

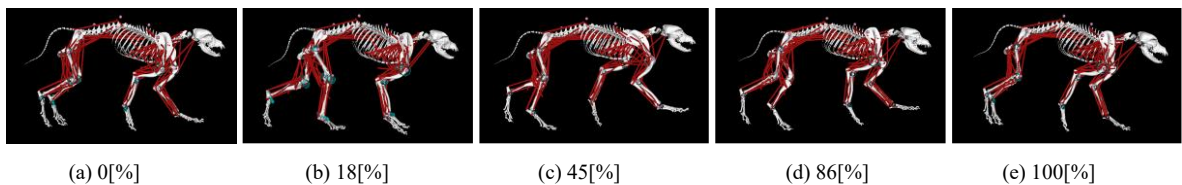


Figure 15. Changes in the posture of subject D walking on the floor with our coating material.

Figs. 8, 10, 12 and 14 show the amount of muscle exertion during walking as calculated by the musculoskeletal simulator, and Figs. 9, 11, 13 and 15 show the posture of the test dogs at the time. Furthermore, Fig. 16 shows the reaction force generated when the test dogs' lower limbs kicked the ground.

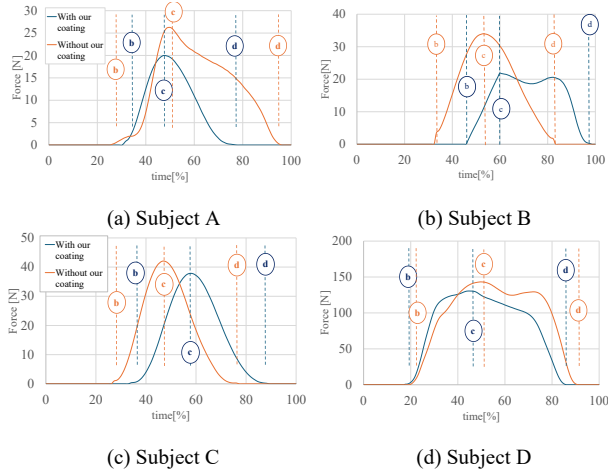


Figure 16. Force plate measurement values.

D. Discussions

From Fig. 16, we can see that the force applied to the force plate when walking changed significantly for test dogs A, B and C on the non-slip and slippery floors, whereas there was no significant change for test dog D. This indicates that the medium-sized dog D, which has a large body weight, is able to obtain the necessary friction force to kick off the floor surface even on a wooden floor, whereas the small, light-weight dogs A, B and C are unable to obtain sufficient friction force on the low friction coefficient of the wooden floor.

Figs. 8, 10 and 12 show the muscle exertion when walking on two floors. These diagrams are divided into frames according to the movement in which the muscles are used. The black frame shows muscles that perform extension of the hip joint, the orange frame shows muscles that perform flexion of the hip joint, the green frame shows muscles that perform adduction of the hip joint, the blue frame shows muscles that perform external rotation of the hip joint, the purple frame shows muscles that perform extension of the knee joint, and the red frame shows the hamstrings.

From Figs. 8, 10 and 12, we can see that the way muscles are used differs between slippery and non-slippery floors, especially in small dogs. For example, in test dogs A and B, the amount of muscle exertion in the hamstrings increased on the slippery floor. The hamstrings play a role in coordinating the movement of the lower limbs to maintain a stable walking cycle, and on a slippery floor, it is thought that the hamstrings work harder to counteract the phenomenon of the lower limbs slipping when they kick off the ground. Some veterinarians have observed that ACL (anterior cruciate ligament) injuries are common in dogs kept indoors [14]. As with the hamstrings, the ACL is a muscle that helps to maintain posture, so ACL injuries are thought to be caused by the hamstrings being overloaded. In addition, we can see that the way muscles are used changes depending on how slippery the floor is, thus we plan to conduct further research on this in the future.

IV. CONCLUSION

In this study, small dogs, which are often kept indoors, were made to walk on a slippery wooden floor, which is commonly used in houses, and on a non-slip wooden floor coated with paint to increase the coefficient of friction. Furthermore, a musculoskeletal simulator was developed to approximate these small dogs, and it was identified how the use of the muscles in the lower limbs of small dogs changed depending on the slipperiness of the floor. As a result, it was identified that the hamstrings, the muscles that adjust posture to enable a certain gait to be repeated during walking, were active on slippery floors. According to veterinarians, there are many cases of dogs kept indoors suffering damage to muscles similar to hamstrings, and it is thought that this may be due to small dogs overusing their hamstrings on slippery indoor floors..

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