

## CINEMATOGRAPHIC AND ELECTROMYOGRAPHIC ANALYSIS OF VERTICAL STANDING JUMP IN THE DOG

By MIKIHICO TOKURIKI

*Department of Animal Management and Hygiene, Faculty of Agriculture,  
University of Tokyo*

(Received 24 January 1979)

### SUMMARY

The electromyograms of 37 skeletal muscles were obtained using the bipolar wire electrode method in the vertical standing jump of a dog. Their electromyographic patterns were analyzed in conjunction with cinematographic films. Co-contraction of muscles of the extremities was observed during take-off and landing. Electromyograms also revealed that the forelimbs were accelerated against the body just after take-off and that the fore quarters transferred the centre of gravity of the body in a much more complicated movement than the hind quarters. In the floating phase, the muscles of the lower extremities had no activity, apart from some proximal ones. That the muscles of the four extremities exhibited their activity just before landing indicates that the activity may have been controlled by a central programme. In the vertical standing jump, the dog brings the centre of gravity of the body near to the kicking or landing paws by skillful movement of the axial skeleton. Cinematography revealed that, in the leaping gallop gait, the dog makes a similar movement of its axial skeleton.

### INTRODUCTION

The dog performs three gaits in locomotion: walk, trot and gallop. Tokuriki (1973 *a*, *b*, 1974) analysed these gaits in treadmill locomotion from an electromyographical point of view. Gallop on the treadmill, however, is slower (180 m/min) than full-speed or leaping gallop, which a dog performs in the open. It is difficult to analyse the leaping gallop electromyographically, although Muybridge (1887) and Hildebrand (1959, 1961) investigated this gait cinematographically. It is assumed, however, that the leaping gallop consists of successive jumps. The vertical standing jump may serve as a model for the leaping gallop, although its direction is quite different.

Jumping is a specific behaviour. A dog often performs successive long jumps when it begins to gallop abruptly from standing. Alexander (1974) showed that the gastrocnemius and plantaris muscles behave, in take-off for jumping, essentially as passive elastic bodies. He indicated that the stress which acted in limb bones and muscles was likely to be greater when an animal was accelerating in jumping than when it was running at constant speed. The electromyographic analysis of jumping may also make clear the degree of muscle co-ordination during a state of maximum contraction.

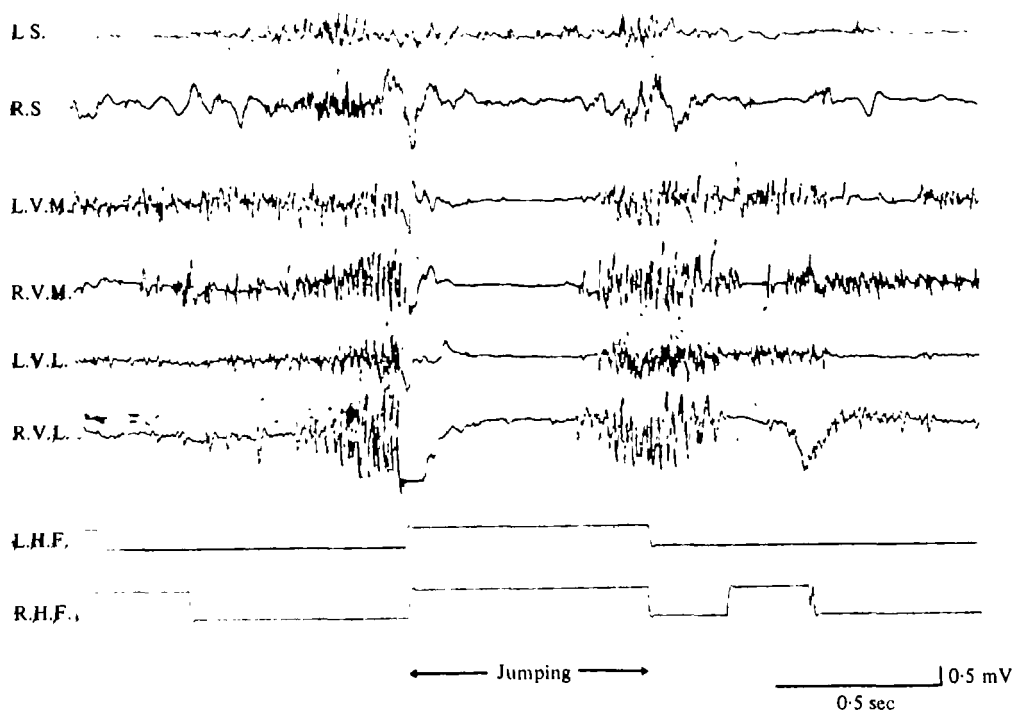


Fig. 1. Electromyogram of hind limb muscles and their swing-stance phase in vertical standing jump. Switches attached to the soles of the hind feet make the stance phase (lower line) and the swing one (upper line). L. S.; Left semitendinosus; R. S.; right semitendinosus; L. V. M.; left vastus medialis; R. V. M.; right vastus medialis; L. V. L.; left vastus lateralis; R. V. L.; right vastus lateralis; L. H. F.; left hind foot; R. H. F.; right hind foot.

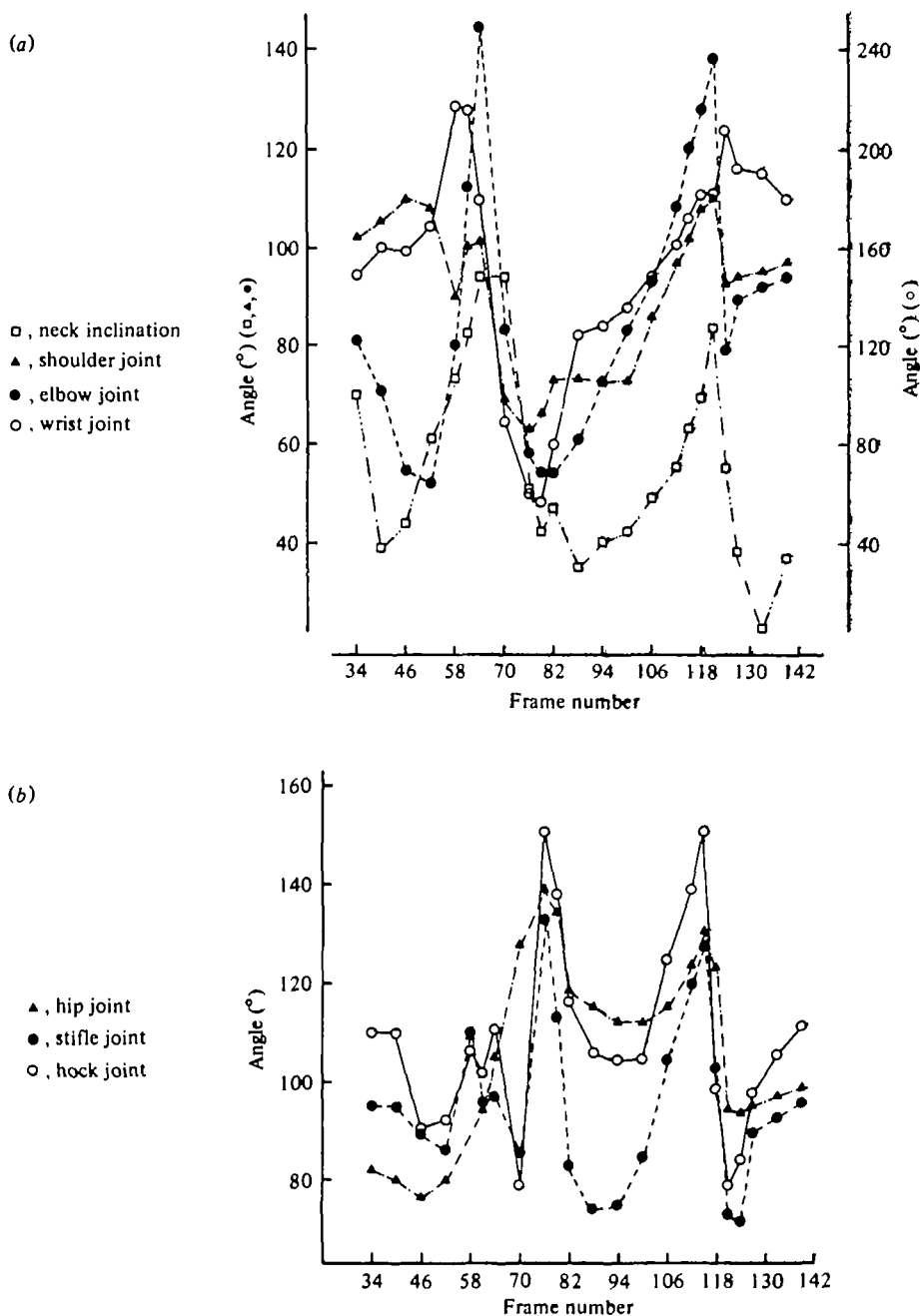
#### MATERIALS AND METHODS

A 4-year-old female mongrel 17 kg in weight and 43 cm in height at the withers with no locomotor deficiency was trained to perform the vertical standing jump.

Bipolar wire electrodes made of  $120\mu\text{m}$  enamel copper wire were put into the middle of each of 37 skeletal muscles by means of a 27-gauge hypodermic needle. An insulated enamel portion 0.5 cm in length at the distal tip was bared with concentrated sulphuric acid and bent back sharply against the needle shaft 0.5 cm in length. The interval between electrodes which seemed to cause little pain was 2 cm. The electrodes were, without anaesthesia, injected into the muscles of a dog standing on the treadmill.

Thirteen dogs were used for the experimenter's training for electrode insertion in the 37 muscles. The electrode wires were inserted into objective muscles of these dogs standing on the floor, and electrode placement was checked by dissection of these animals.

The electromyogram (EMG) of the caput longum of the triceps brachii muscle was always recorded simultaneously with that of the muscles of the neck and fore quarters. The EMG of the vastus lateralis muscle was obtained with that of the muscles of the hind quarters. The left and right muscle activity of each muscle was always recorded



**Fig. 2.** Changes in angle calculated from an enlarged 16-mm film. (a) The neck and the joints of the forelimbs. (b) The joints of the hind limbs. The neck inclination is measured against the horizontal line and the joint angles measured on the flexing side. The frame numbers are the same as shown in Fig. 5. Film speed is 64 frames per second.

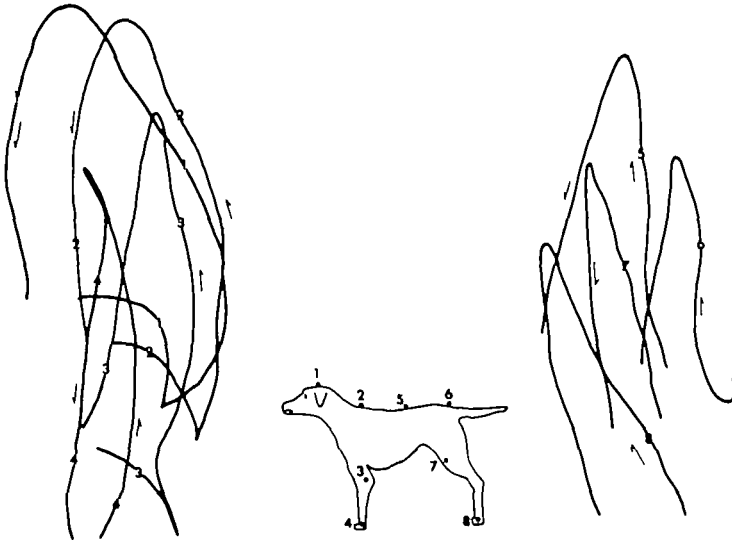


Fig. 3. Loci of cyclogram of eight points at the centre of joints and several points of the body. These points are located on the basis of original data. Loci of fore quarters and hind quarters are depicted separately. (1) Head. (2) Withers. (3) Elbow joint. (4) Metacarpo-phalangeal joint. (5) Centre of the back. (6) Root of the tail. (7) Stifle joint. (8) Metatarso-phalangeal joint.

at the same time. The EMG activity of each muscle was graded in the following manner: nil (o), negligible ( $\pm$ ), slight (+), moderate ( $\#$ ) and marked ( $\#\#$ ) (Basmajian, 1974).

The dog was often equipped with switches attached to the soles with adhesive tape. Each switch was made of two 5 by 4 cm metal pieces facing each other and formed a part of the relay circuit. It was turned on when the sole touched the ground. There was little difference in the EMG of each muscle between jumping with and without the switches attached, although the dog could jump higher without the switches attached.

An oscillograph was used for amplifying and recording the electrical activity of the muscles. It was a nine-channel electroencephalograph, San-ei Sokki Model EG-900, equipped with an ink-writing recording system.

The time constant of the amplifiers was 0.001 s. The action potentials of six muscles were recorded simultaneously with the turning on and off of the two switches set on the left and right feet. Jumping was repeated six to seven times.

Fig. 1 shows the original records of EMG and switches which make the stance phase (a lower line) and the swing phase (an upper line) clear. 16-mm motion pictures of the jumps were taken at a velocity of 64 frames per second (fps) from a front, lateral and back viewpoint. Sequential frames throughout a jump were enlarged and printed. Fig. 2 was prepared from enlarged pictures to show changes in the neck inclination and joints in jumping. The neck inclination was measured to the horizontal line. The angles of the joints were gauged on the flexing side.

The cyclogram of jump was recorded with 1.5 V light bulbs attached to eight points at the centre of movement in the joints and at several points over the whole body (Fig. 3).

To compare jumping with the leaping gallop, cinematographic pictures were taken at 64 fps from a lateral viewpoint of the same dog, galloping at full speed in the open.

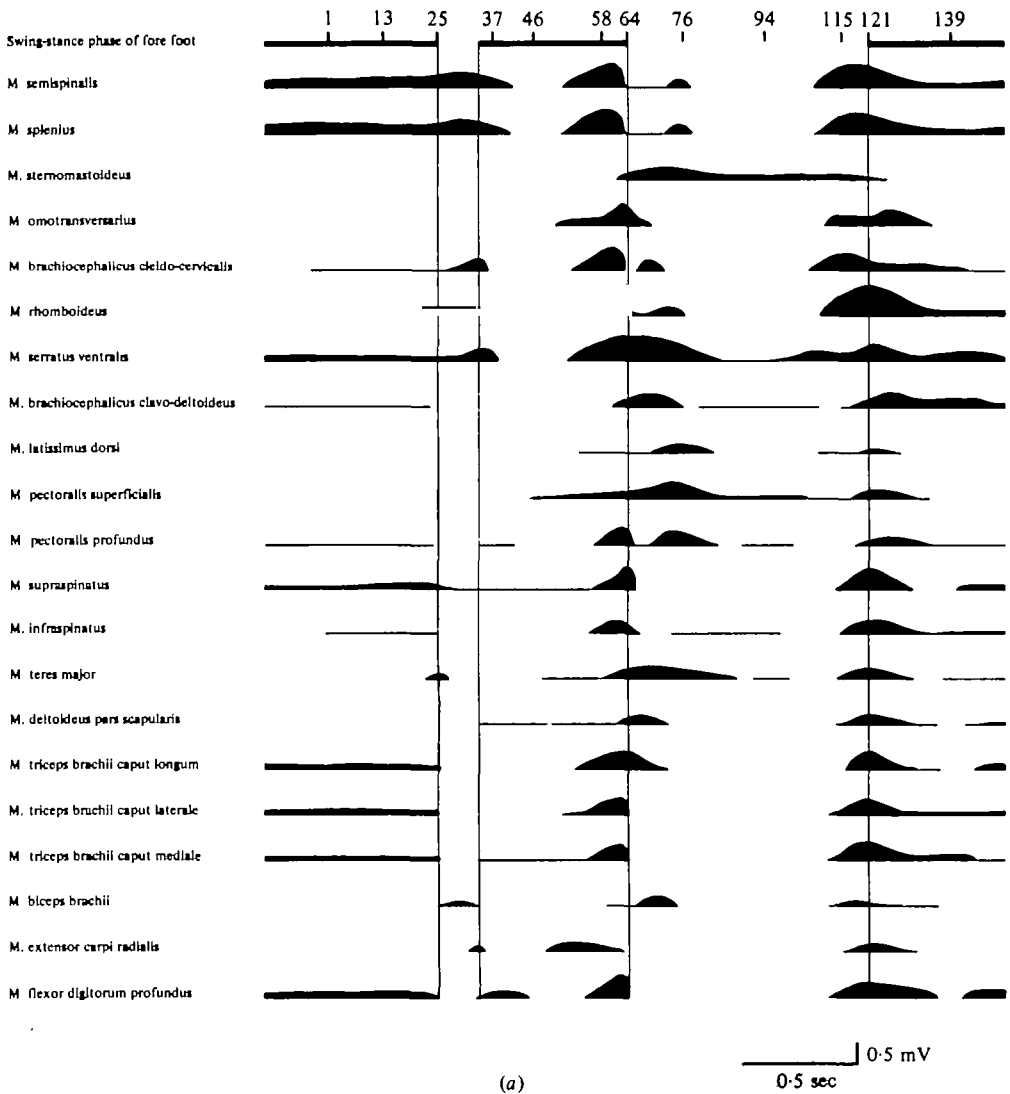


Fig. 4. Schematically summarized patterns of muscle activity in vertical standing jump. (a) The muscle activity of the fore quarters. (b) The muscle activity of the hind quarters. The solid bar indicates the stance phase and the blank bar the swing phase. The numbers over the bar are the same as shown as in Fig. 5.

**RESULTS**

The dog did not make a sudden leap from the standing posture. It performed a series of preparatory motions before floating. The 16-mm motion picture and cyclogram revealed that every jump with these preparatory motions was almost always identical. Muscle action potentials during the jumping were remarkably reproducible. Naturally, the dog sometimes performed a relatively low or twisting jump, but data on such jumps were omitted. The dog leaped to a height of about 140 cm (measured at head level) and landed about 20 cm forward from the place of take-off.

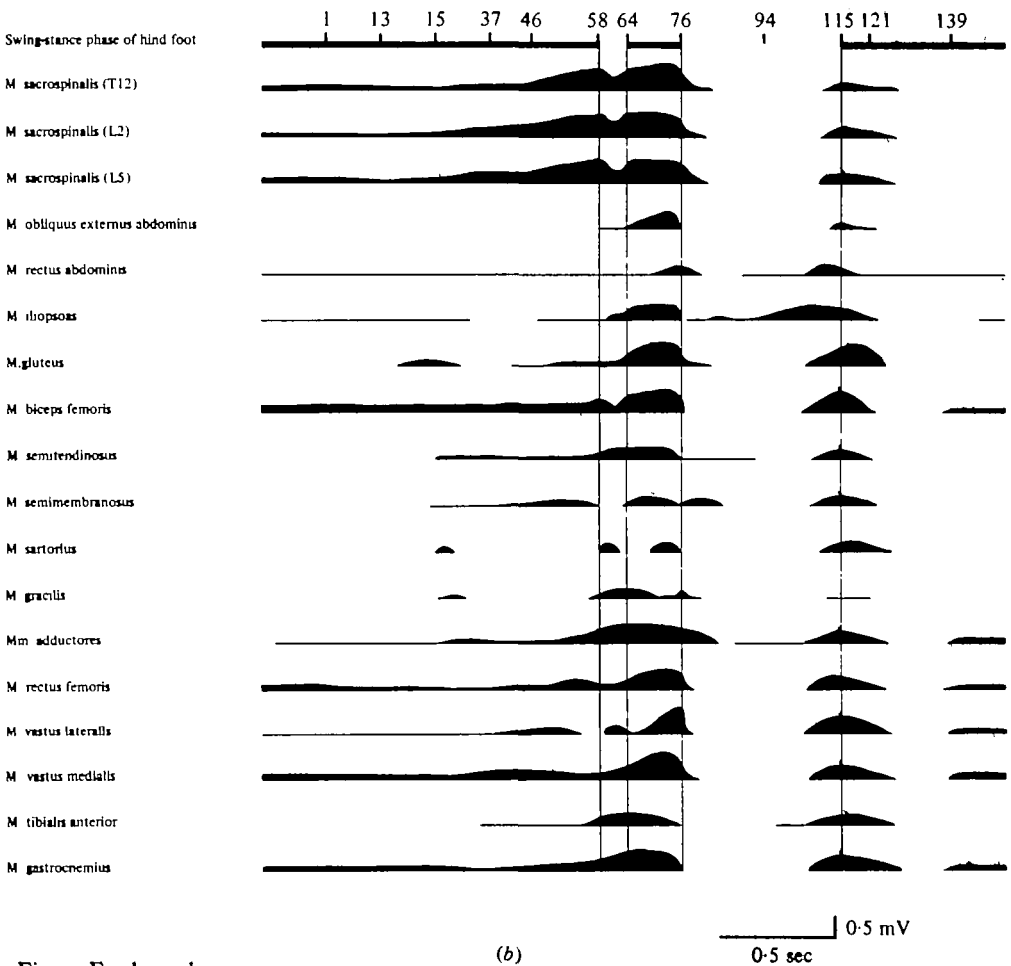


Fig. 4. For legend see p. 275.

Fig. 4 is a schematic presentation of electromyographic activity of each muscle which was constructed from the original records.

Fig. 5 shows the tracing of selected prints of successive pictures taken at 64 fps. The number below the drawing indicates the frame number, which was chosen because of an important inflexion point of motion. The following explanation is given under the heading of the frame numbers shown in Fig. 5.

#### Nos. 1-13

The head and neck are extended on command. The dog watches the experimenter's face.

#### Nos. 13-25.

The forelimbs are going to swing forward. The epaxial muscles continue their slight activity. The hind limbs, if not already side by side, will step to become parallel with each other.

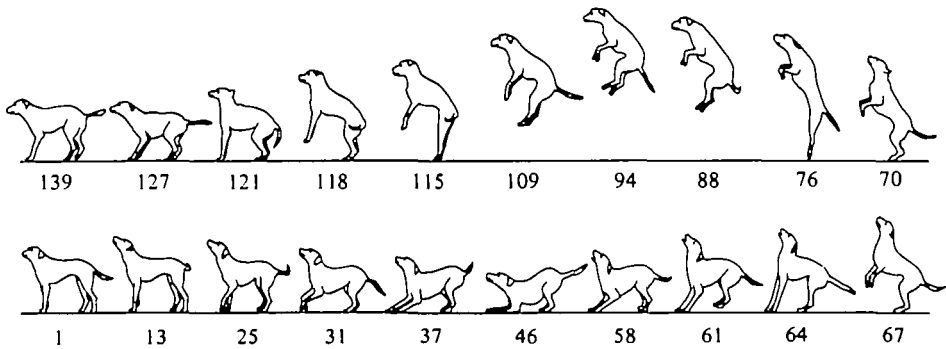


Fig. 5. Tracing from the enlarged 16-mm film of vertical standing jump. The serial numbers below the drawings mean the numbers of selected frames taken at a velocity of 64 frames per second.

#### Nos. 25-37

The forelimbs swing forward. The strength of contraction of many muscles of the forelimbs changes. The whole body, especially the fore quarters, is sinking.

#### Nos. 37-46

The elbow joints are flexed to touch the ground. The head and neck are stretched forward. In this position, the forelimb muscles, apart from the rhomboideus and flexor digitorum profundus, show little activity. In the hind limbs, on the other hand, the hamstrings, adductores, quadriceps femoris, and gastrocnemius muscles present a negligible or slight activity to fix the intermediate position of the hind limb joints.

#### Nos. 46-58

The head and neck again perform dorsiflexion rapidly. The cervical epaxial muscles exhibit their activity earlier than the elbow extensor muscles to indicate that the dorsiflexion of the neck precedes the elbow extension. Fig. 2(a) also shows that the neck changes earlier in inclination than the elbow joint. The rhomboideus and serratus ventralis muscles which connect the scapula with the body also increase earlier in activity than the triceps brachii muscle. The sacrospinalis muscle increases in activity in accordance with the neck extension. Almost all the muscles of the forelimbs increase in activity in these phases.

#### Nos. 58-64

Almost all the muscles of the forelimbs develop their activity up until the forelimbs take off. When the forelimbs are kicking the ground, both hind limbs often step in forward. As a result, a relatively heavy load is imposed on the forelimbs and the hind paws are allowed to come near the centre of gravity of the body. Many muscles of the hind limbs amplify their activity in the second half of the stepping stage. The neck is erected in the upper-backward direction in accordance with the course of kicking of the forelimbs. The epaxial neck muscles decrease in activity before the take-off of the forelimbs. The over-extended carpal joints begin to be flexed again. The fore paws kick front-downward (Fig. 3 (4)).

## Nos. 64-70

The head and neck are stretched first in an upward and backward direction and then in a front and upward direction (Fig. 3 (1)). The sternomastoideus and cleido-cervicalis muscles have moderate activity. As soon as the forelimbs leave the ground, their joints are flexed actively by the omotransversarius, clavo-delhoideus, teres major, deltoideus scapularis, and biceps brachii muscles. After the forelimbs take off, the hip joints continue to extend (Fig. 2*b*), because the trunk is going to assume an upright position. The stifle and hock joints are flexed transiently (Fig. 2*b*), although the extensor muscles are active (eccentric contraction).

## Nos. 70-76

The neck continues to be stretched in a front and upward direction (Fig. 3 (1)). The epaxial neck muscles and some upper-forelimb muscles develop activity when the hind paws kick off the ground. Many hind limb muscles increase in activity for about 0.2 s and decrease just before take-off. The activity of such flexor muscles as the iliopsoas, the sartorius and the tibialis anterior disappears just before the hind limbs take off.

## Nos. 76-88

The head and neck which have been stretched forward against the trunk return to the usual position in this stage. The neck maintains an inclination of about 40 degrees (Fig. 2*a*). The cyclogram shows that the lumbar point of the back is raised vertically, although the hind limbs kick the ground in a back-downward direction (Fig. 3 (5, 8)). The muscles of the forelimbs seem to be released from tension in the floating phase, because these limbs begin to be extended to take an unsymmetrical position. The serratus ventralis, clavo-delhoideus, pectorales, infraspinatus and teres major muscles have intermittent activity. The sternomastoideus muscle has slight activity throughout the swing phase. As soon as the hind limbs take off, almost all the hind limb muscles stop or decrease the activity. The adductores muscles maintain moderate activity after take-off.

## Nos. 88-109

The dog attains the highest point in the picture bearing frame number 94. The neck inclination becomes steep gradually (Fig. 2*a*), although the head position undergoes little change. Although the tips of the toes of the forelimbs point in a vertical direction, the elbow and the carpal joints are extended rapidly with little activity of the extensor muscles (Fig. 2*a*). The joints of the hind limbs also begin to be extended with little change in activity of the extensor muscles (Fig. 2*b*). The left and right hind limbs take a symmetrical position now that the body is falling.

## Nos. 109-115

The hind limbs are brought close together, parallel to each other. The neck begins to be flexed dorsally. The sacrospinalis muscle, in contrast to its activity at take-off, shows only slight activity. The epaxial neck muscles and almost all the hind limb muscles increase in activity about 150 mm seconds before the hind paws touch the ground. At the moment when the hind paws touch the ground, all the hind limb



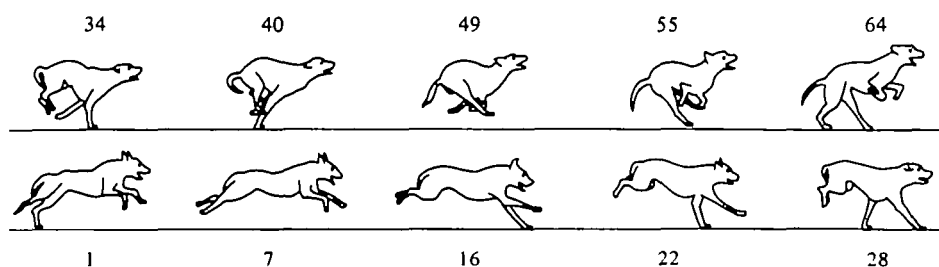


Fig. 6. Tracing from the enlarged 16-mm film of leaping gallop. The serial numbers below or over the drawings show the number of selected frames taken at a velocity of 64 frames per second.

muscles, except the gracilis muscles, have moderate or marked activity. The rhomboideus and serratus ventralis muscles also increase in activity to fix the forelimbs against the impulse of landing of the hind limbs. The stifle joints are extended to nearly the same angles as at the time of take-off, although the axial skeleton takes a different position (Fig. 2*b*).

#### Nos. 115-121

The neck increases in inclination (Fig. 2*a*). The epaxial neck muscles have marked activity. The joints of the forelimbs are extended farther after the hind limbs land on the ground. Almost all the forelimb muscles start their activity about 150 mm seconds before landing of the fore paws. The activity of the hind limb muscles decreases as soon as the hind paws touch the ground, and ceases about 0.2 s after landing.

#### Nos. 121-139

The neck takes a perpendicular direction and the head a rather upward direction when the fore paws land on the ground. Changes in the position of the head before and after landing, however, are much less remarkable than those of the neck. The forelimb muscles show a moderate or marked activity before and after landing of the fore paws, apart from the latissimus dorsi, pectorales, biceps brachii and extensor carpi radialis muscles. The hip, stifle and hock joints are extended after flexion with little muscle activity. The neck which is extended in a vertical direction at the time of landing is transferred to a down-forward direction. The shoulder and elbow joints are flexed rapidly (Fig. 2*a*). All the forelimb muscles wane in activity after landing, although some of them do not cease activity.

Fig. 6 shows leaping gallop which is copied from the selected prints of successive pictures from a lateral view taken at 64 fps. The dog flexes and extends the spine at the time of leaping gallop. This resembles the 'inch-worm' motion, which Hildebrand (1959, 1961) described in galloping of the cheetah. The trunk is extended when the leading hind limb leaves the ground (Fig. 6 (1, 7)). The back line of the neck is maintained at the same level as that of the lumbar part. The trunk begins to be flexed when the trailing forefoot strikes the ground (Fig. 6 (16, 22)). The head and neck are extended at the time of landing of the leading forelimb (Fig. 6 (28)). The trunk is considerably flexed when the leading forelimb leaves the ground (Fig. 6 (40)). The

dorsiflexion of the neck and the ventriflexion of the trunk reach a climax at the time when the trailing hind paw touches the ground (Fig. 6 (55)). Then the neck and trunk are again stretched forward (Fig. 6 (64)).

#### DISCUSSION

It is of interest to note that jumping seems to be led by the head and neck which are stretched upward before the joints of the forelimbs begin to be extended. The same phenomenon is seen in the dog at the time of transfer from trotting to galloping. The dog flexes the head and neck dorsally to a large extent at this time. The dorsiflexion of the head and neck decreases their moment about the fore paws. The reaction of the head and neck to be accelerated upward gives such a heavy load on the forelimbs that it induces a strong muscle contraction.

The flexor muscles of the forelimbs, such as the pars scapularis of the deltoideus and the biceps brachii muscles, resume the activity after take-off of these limbs. The caput longum of the triceps brachii muscle, the flexor of the shoulder joint, continues the activity throughout the time of take-off (Fig. 4 *a*). This is because each joint is actively flexed to obtain the upward acceleration of the fore feet against the trunk. The serratus ventralis muscle acts strongly to fix the fulcra of the forelimbs at this time.

The neck and trunk, after the take-off of the forelimbs, are also stretched against the hind paws to acquire their upward acceleration. These reactions give a big load to the hind limbs, which can use this load to perform a strong thrust.

In each joint of the hind limbs the activity of the flexor muscles coincides with that of the extensor muscles and comes to an end just before take-off in a vertical standing jump (Fig. 4). This co-contraction is such that the simultaneous contraction of both agonists and antagonists with a supremacy of the former produces a visible motion (Basmajian, 1974). This co-contraction may be necessary to acquire the strongest thrust, but Kamon (1971) did not observe the co-contraction of the tibialis anterior and the gastrocnemius muscle in human beings at the time of vertical jumping. This may be caused by the difference between the digitigrade and the plantigrade. The co-contraction has not clearly been observed in walk, trot or slow gallop, although the activity of some flexor muscles overlaps that of some extensor ones (Tokuriki, 1973 *a, b*, 1974). It may be used in such locomotion to give rapid acceleration, as in the abrupt transfer from standing to galloping. The co-contraction also occurs in the muscles of the fore limbs at the time of landing.

The forelimbs are flexed actively in the air. The hind limbs also seem to be flexed not only by the passive contraction of the stretched flexors but also by the active contraction of such muscles as the iliopsoas and semitendinosus (Fig. 4). All the four limbs remain flexed at the time of soaring (Fig. 5 (76–88)). When the dog comes down, each limb begins to be stretched, although the extensor muscles show little activity. This is the labyrinthine reflex.

The posture of the body in the air seems relaxed (Fig. 5 (88–94)), although some upper-arm muscles, such as the serratus and pectorales, and the adductores muscles are active (Fig. 4). It is interesting to note that the pectorales muscles of the forelimbs and the adductores muscles of the hind limbs, the muscle to have adduct action, are active in the floating phase. The adduction of the four limbs may be necessary to keep the body in the air.

It may be natural that the epaxial neck muscles have no activity in the floating phase, although the head and neck take the same position as those in standing. It is not necessary for these muscles to support the head and neck against gravity. It is of interest to note that the position of the head and neck seems to be maintained by the sternomastoideus muscle, a non-epaxial one, which has no activity in standing. It is, however, difficult to speculate about the action of the head and neck in the air, as the postures in floating may be controlled by complicated control mechanisms such as the tonic neck reflex, the labyrinthine reflex and the optical control.

The muscles of the hind limbs display their activity just before landing (Fig. 4). This indicates that their activity may be controlled by the central programme (Engberg & Lundberg, 1969). The extensors, just after landing, may also depend on the co-activation of the alpha and gamma systems, since they show a dynamic stretch and present an eccentric contraction (Shik, Orlovskii & Severin, 1966; Goslow, Reinding & Stuart, 1973).

The neck takes a perpendicular direction and the head a rather upward direction when the fore paws land on the ground (Fig. 5 (121)). In this condition the centre of gravity of the head and neck moves backward, which decreases the moment of these regions about the fore paws. These changes serve for the stabilization of the neck and the prevention of the head and neck from descending against the reaction of the fore paws striking the ground. It is of interest to note that the longitudinal axis of the neck parallels to that of the forelimb at the time of landing of the fore paws. In leaving the ground, the same phenomenon is observed (Fig. 5 (64)). (In this case the neck takes an upper-backward direction, because the forelimbs point in the same direction.) In the course of leaping gallop the longitudinal axis of the neck and the leading forelimb takes the same direction at the time of take-off of this forelimb (Fig. 6 (40)). This suggests that a strong neural linkage may exist between the neck and the forelimbs.

After landing, the dog extends all the joints of the hind limbs with little muscle activity and those of the forelimbs with muscle activity (Fig. 4). When the hind limbs are going to be extended, the forelimbs, after landing on the ground, are flexed with the flexion of the head and neck. The centre of gravity of the body moves forward and downward. Thus, the hind quarters may be raised on the fulcra of the fore paws. The hind limbs may be extended only with a passive extension which is produced by the elastic force of the extensor muscles stretched by a strong flexion. On the other hand, when the forelimbs are going to be extended, their muscles must be active to extend every joint, since the centre of gravity of the body is shifted forward. In landing, the head position changes less than the neck position (Fig. 5 (115-127)). This may indicate the importance of optical control in landing.

The cyclogram (Fig. 3) and the EMG pattern (Fig. 4) show that the fore quarters have a complicated movement for transferring the centre of gravity of the body. The hind quarters, however, have a simple action to push up the body vertically. The resultant of the ground reaction of the forelimbs and that of the hind legs is in a vertical direction.

The observation that the EMG activity pattern of the fore quarters, unlike that of the hind quarters, is very complicated was also made in walking, trotting and galloping of the dog (Tokuriki, 1973 *a, b*, 1974). This suggests that, in jumping, the forelimb has an important role as a balancer and that the hind limb is important as a propeller.

Successive axial movements in jumping and galloping take place in the following manner. The head and neck are extended forward. The vertical line drawn from the centre of gravity of the body approaches the fore paws (Figs. 5 (37-46) and 6 (22-28)). The head and neck are rapidly moved upperbackward. The trunk is flexed. The hind legs step in before the take-off of the fore paws (Fig. 5 (58-64)). In galloping, the dorsiflexion of the neck is not so steep because of the difference in jumping direction. The longitudinal direction of the forelimbs and neck in galloping is the same as in jumping, before the take-off of the fore paws (Fig. 6 (40)). The trunk is flexed when the hind limb touches the ground (Fig. 6 (55)). Before the hind limbs kick off the ground, the neck and trunk are rapidly extended (Figs. 5 (67-76) and 6 (64-1)). The movement of the axial skeleton changes its form in vertical standing jump in the same way as in leaping gallop. As a result, the centre of gravity of the body approaches the kicking or landing paws.

In both the vertical standing jump and leaping gallop, to enable the extremities to do powerful kicking, the centre of gravity of the body moves near the kicking or landing paw with the skillful movement of the axial skeleton. It is concluded that the present analysis of the vertical standing jump may be applied to the elucidation of leaping gallop, although the direction of kicking in the vertical standing jump is different from that in leaping gallop.

The author thanks Dr S. Nomura for valuable advice and Dr H. Sawazaki for a critical review of this manuscript.

#### REFERENCES

- ALEXANDER, R. McN. (1974). The mechanics of jumping by a dog (*Canis familiaris*). *J. Zool., Lond.* **173**, 549-573.
- BASMAJIAN, J. V. (1974). *Muscles Alive*, 156 p. Baltimore: Williams & Wilkins Company.
- ENGBERG, I. & LUNDBERG, A. (1969). An electromyographic analysis of muscular activity in the hind-limb of the cat during unrestrained locomotion. *Acta physiol. scand.* **75**, 614-630.
- GOSLOW, G. E. Jr, REINKING, R. M. & STUART, E. G. (1973). Physiological extent, range and rate of muscle stretch for soleus, medial gastrocnemius and tibialis anterior in the cat. *Pflügers Arch. ges. Physiol.* **341**, 77-86.
- HILDEBRAND, M. (1959). Motions of the running cheetah and horse, *J. Mammal.* **40**, 481-495.
- HILDEBRAND, M. (1961). Further studies on locomotion of the cheetah. *J. Mammal.* **42**, 84-91.
- KAMON, E. (1971). Electromyographic kinesiology of jumping. *Archs phys. Med. Rehabil.* **52**, 152-157.
- MUYBRIDGE, E. (1887). *Animals in Motion*, pp. 49-57. New York: Dover Publications (reprinted in 1957).
- SHIK, M. L., ORLOVSKII, G. N. & SEVERIN, F. V. (1966). Organization of locomotor synergism. *Biophysics* II, 1011-1019.
- TOKURIKI, M. (1973a). Electromyographic and joint-mechanical studies in quadrupedal locomotion. I. *Walk. Jap. J. vet. Sci.* **35**, 433-446.
- TOKURIKI, M. (1973b). Electromyographic and joint-mechanical studies in quadrupedal locomotion. II. *Trot. Jap. J. vet. Sci.* **35**, 525-533.
- TOKURIKI, M. (1974). Electromyographic and joint-mechanical studies in quadrupedal locomotion. III. *Gallop. Jap. J. vet. Sci.* **36**, 121-132.