

LIMB COORDINATIONS DURING LOCOMOTION IN CATS AND DOGS

Zofia AFELT and Stefan KASICKI

Department of Neurophysiology, Nencki Institute of Experimental Biology
Warsaw, Poland

Abstract. The relations among swing, stance and step durations for the fore and hind limbs were investigated. Registration of the swing and stance phases was performed by the opening and closing of an electrical circuit as the cat moved along the conductive pathway. In the walking animal, longer swing and shorter stance durations for hind limbs, in comparison with the fore limbs, were observed. However, during trotting phases, these differences were insignificant. The correlations between swing and stance durations were found for both fore and hind limbs. As the walking animal moved faster, swing and stance durations became shorter.

INTRODUCTION

Naturalists have described the cycle of limb movements characteristic of a wide variety of tetrapod mammals moving at various speeds (5, 10). Although the over-all visual impression of a pattern (e.g., walk, trot, gallop) is fairly clear, very little information is available concerning the physiological mechanism of these rhythmic movements (3), despite the analysis of two principal areas of the problem. The study of the mechanisms of locomotor movement of a limb has been based primarily on measurements of angles at joints as well as the length and activity of muscles during the gait (4, 6, 9, 15). The relations between various brain stem structures and particular components of the locomotor act have been largely investigated, although the mechanisms of limb coordinations have been investigated in only a few experiments (1, 13, 18-20).

In general, the locomotor movement of a vertebrate limb can be defined (i) in anatomical terms (flexion, extension, rotation, adduction, abduction) or (ii) on the basis of the duration for which each limb is on or off the ground (i.e., the supporting function of a limb). Still and moving photography have been used to identify relationships between the swing and stance phases of the step cycles of different limbs and 12 types of gaits have been distinguished (5, 10–12, 14). However, the automatic determination of the footfall formulae of a gait is still an unsolved problem.

The aim of this study was to determine the relations between the pattern of limbs movements and the changes of swing, stance and step durations during locomotion in cats and dogs. The contact between paw and platform for each of the four limbs was examined simultaneously.

MATERIAL AND METHODS

The locomotion of 7 adult cats weighing 4 to 5.5 kg and 2 adult dogs weighing 8 to 10 kg was investigated. The animals were encouraged with offers of meat to walk or run along a pathway (3.5 m long and 0.5 m wide), which was open on one or two sides and was either suspended freely or supported 1 m above the floor. One run through the pathway was considered as a trial. The pathway was made of a special conductive rubber and the animals wore "shoes" made of thin, conductive material, but insulated on the inside. These shoes were kept in place with glue and held with rubber bonds (Fig. 1). During the preliminary training the animals were adapted to the experimental conditions.

A current of 1.5 v was applied to each shoe during the experiment via a thin gauge lead, so that an electric circuit was successively opened and closed for each paw, as the animal moved on the conductive pathway (Fig. 1). It was therefore possible to register the swing (open circuit) and stance (closed circuit) phases for all four limbs simultaneously (on-off registration). The voltage changes were recorded with a Mingograph (Elema-Schoenander). The precision of the on-off records was limited by the paper travel speed of the recorder, but was correct within 10 msec. Both shod and unshod animals were filmed as they moved, at film speeds of 32 or 48 frames per second. Accordingly, the film records were correct within 20 or 30 msec respectively.

In dogs EMG registration was performed simultaneously with the on-off registration. The external electrodes were stuck above the gastrocnemius muscle and anterior tibial muscle from both hind limbs.

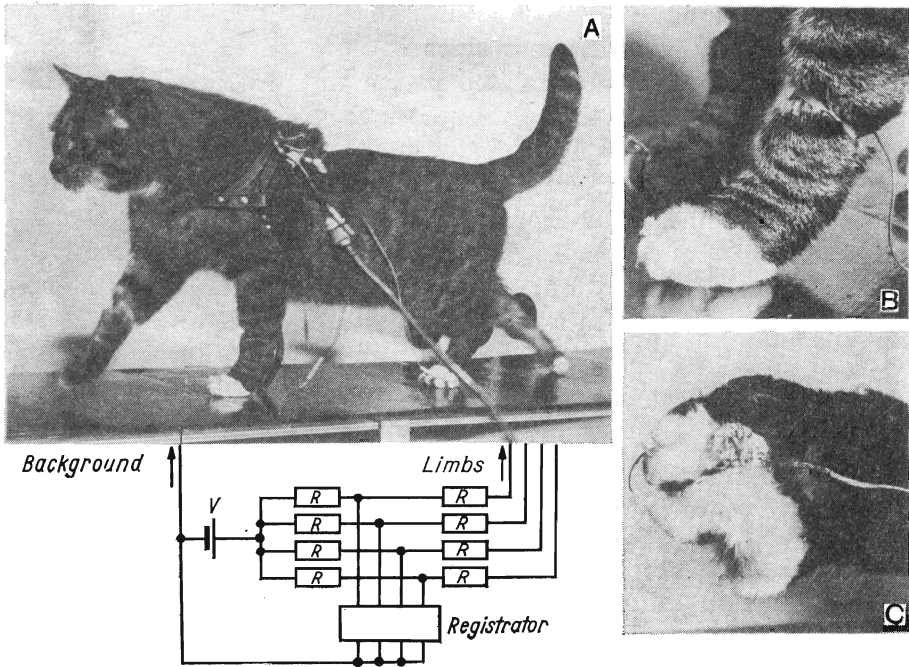


Fig. 1. Scheme of on-off registration arrangement (A) and the paw shoed (B and C).

A typical record of on-off registration is shown in Fig. 2. The period of constant voltage (x) corresponds to the swing phase, and that of lowered voltage (y) corresponds to the stance phase, so that swing and

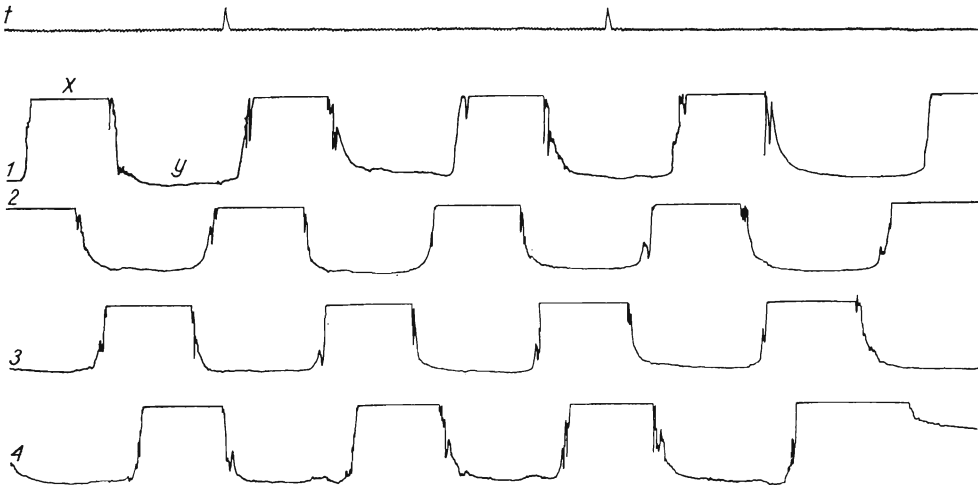


Fig. 2. Records of on-off registration (cat), x , swing phase, y , stance phase, 1, left fore limb, 2, left hind limb, 3, right hind limb, 4, right fore limb, t , time scale 1 sec.

stance durations were directly measured. Start and stop of the progression (i.e., the first and last steps in each trial) were disregarded.

The film pictures were analyzed in the way described in the literature since the 19th century. The particular steps were divided into periods in which the supporting patterns was constant. The sequence of limb movements and the patterns of supporting limbs were plotted on the common schema. Thus the numerical formulae were made, and the numerical formulae from the on-off records were read directly. The double registered trials were examined separately for film and on-off registration and subsequently compared.

RESULTS

For each animal 50 to 70 trials obtained from 3 or 4 experimental situations were evaluated: 30-50 trials with on-off registration, 10 trials with on-off registration during filming and 10 trials with filming unshoed animals. The locomotion of freely moving or shoed animals did not differ, which was confirmed by the comparison of filmed trials. The trials examined were classified according to the numerical formulae as a walk, trot or a gallop. All these gaits will be discussed involving one animal, but the description is appropriate for all animals.

The walk. A walking cat moved at a rate of 1 to 4 km/hr, executing 12 to 6 strides. As the animal moved slower, more strides were performed. The numerical formulae of the walking animal were 4-3-2-3-4-3-2-3 or 3-2-3-2-3-2-3-2 (Fig. 3AB).

The swing and stance phases of the fore and hind limbs were different if the step duration was longer than 550 msec (Fig. 4). The swing and stance duration of the fore limbs were within the range of 200 to 320 msec and 200 to 740 msec, respectively. For hind limbs, they were within 200-370 msec and 200-700 msec, respectively.

When the swing duration of hind limbs was longer, the stance duration was shorter, so the step durations of fore and hind limbs were always the same. As the animal moved faster, the step duration was shorter, and the difference between fore and hind limbs was reduced.

For both fore and hind limbs the swing and stance durations were correlated ($r = 0.85$ or 0.92 , respectively), but the formulae describing these relations were different, since for fore limbs we obtained.

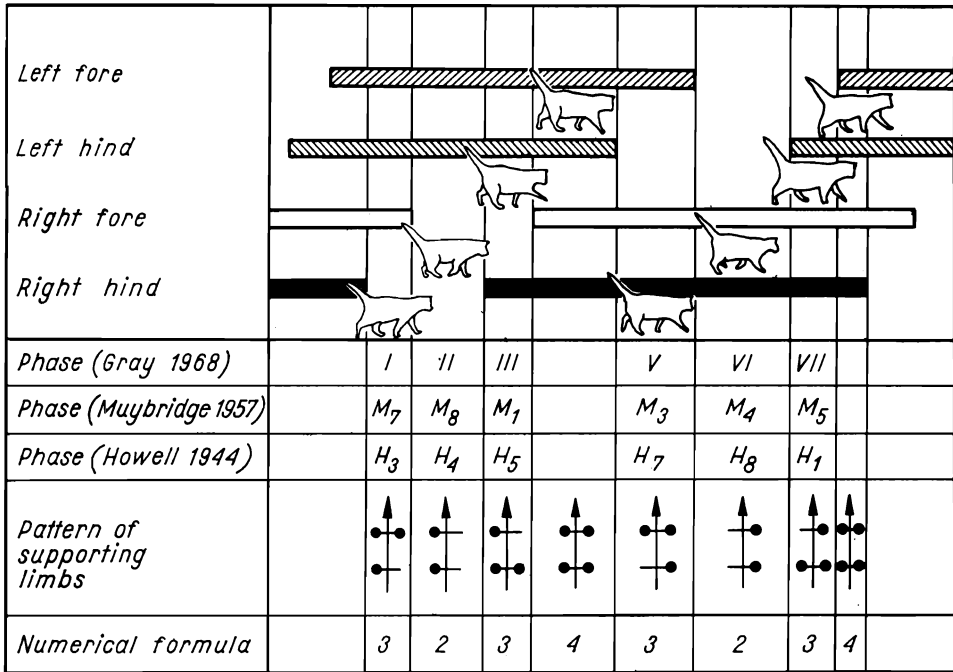
$$x = 0.2y + 160$$

and for the hind limbs

$$x = 0.4y + 120$$

(x — swing, y — stance durations in msec).

A



B

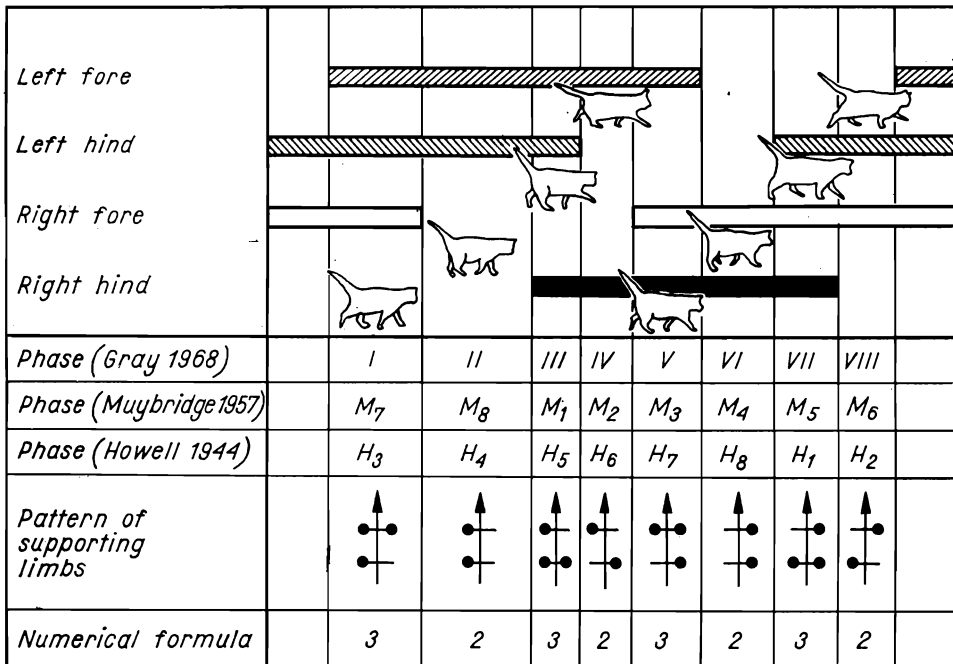


Fig. 3. Records from cinematograph data showing pattern of supporting limbs and numerical formulae (cat). A, amble-like walk, B, normal walk.

When the cat moved at 3.5 to 4 km/hr, it was difficult to differentiate between walking or trotting. In this range of speed a walk turned into trot and sometimes two limbs, on the one side, were still walking, while on the other side trotted.

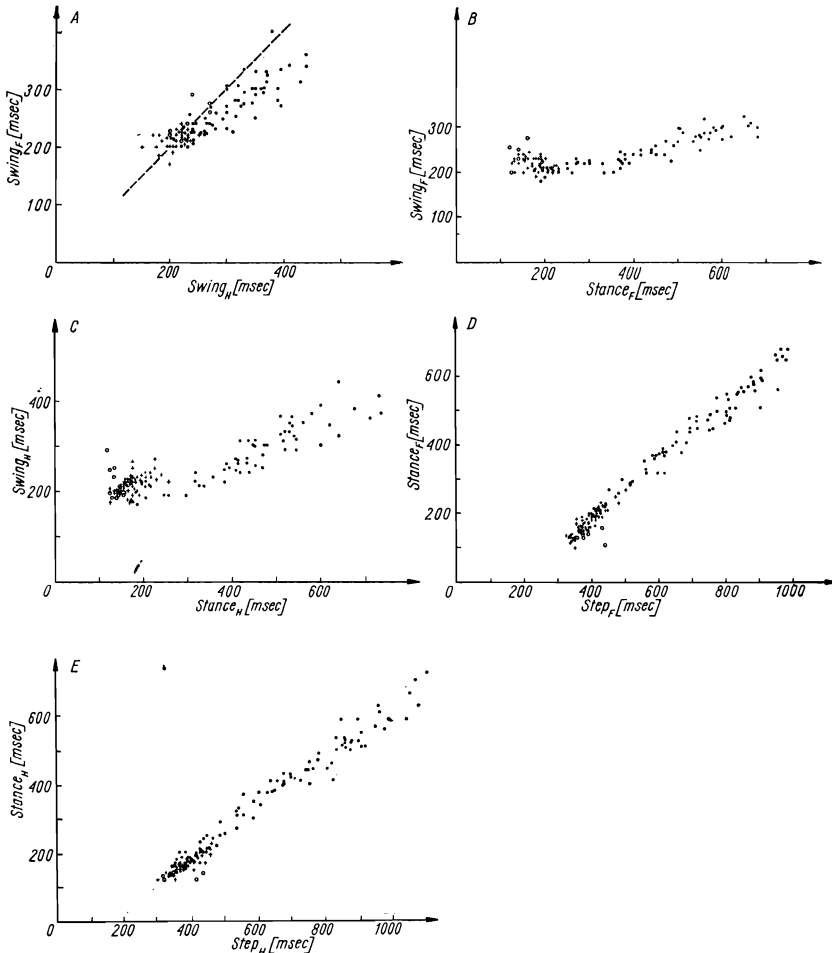


Fig. 4. Relations between: *A*, swing phases for fore and hind limbs; *B*, swing and stance phases for fore limb; *C*, swing and stance phases for hind limb; *D*, stance phase and step for the fore limb; *E*, stance phase and step for the hind limb. Each point correspond with one step of left side limbs in cat. The full circles, walk; the crosses, trot; and the open circles, gallop.

The trot. The speed of the trotting animal varied from 3.5 to 8 km/hr. The animal realized 7 to 4 strides described by the numerical formulae 2-1-0-1-2-1-0-1 or 2-0-2-0.

The swing and stance durations for fore limbs were within the range of 200 to 240 msec and 130 to 230 msec, and for hind limbs within the range of 180 to 250 msec and 130 to 230 msec, respectively. The swing and stance durations were almost the same for both fore and hind limbs, but when the cat trotted very quickly (7 to 8 km/hr), there was a tendency to lengthen the swing duration of the fore limbs and to shorten of the hind limbs. The stance duration was the same for both fore and hind limbs.

The animals started to trot by either turning a walk into a trot or right from the beginning of a trial. Sometimes very quickly trotting animals passed to a gallop, but did not change the speed (about 8 km/hr).

The gallop. The galloping cat moved at a speed 8 km/hr. Since the pathway was short, we did not observed clear gallopping. However, sometimes animals started to spring to what was very similar to a gallop, and 1-2 strides in such trials could be classified as a gallop.

Galloping was seldom observed, so the data were not of sufficient quantity to warrant complete examination. However, we can state that the stance duration was within the range of 120 to 140 msec (Fig. 4). The swing duration changed from 180 to 300 msec, and the longest swing durations were observed when an animal changed from a trot to a gallop.

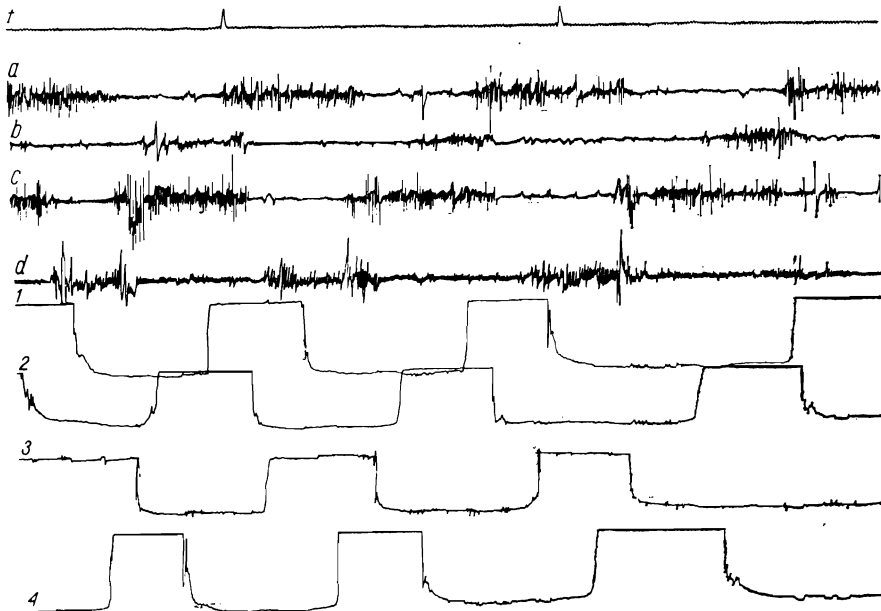


Fig. 5. Record of on-off and EMG registration (dog): *a*, right gastrocnemius muscle; *b*, right anterior tibial muscle; *c*, left gastrocnemius muscle; *d*, left anterior tibial muscle. Other denotations as in Fig. 2.

EMG in walk. The electrical activity of gastrocnemius muscle and anterior tibial muscle compared with the phases of the step is represented in Fig. 5. A typical response of gastrocnemius muscle occurred 50 msec before the contact between the hind limb and platform. The activity of the muscle was still evident during the E₂ component of the stance phase, however the decline of its magnitude was visible in the beginning of the E₃. No activity of gastrocnemius muscle was observed 100 msec before lifting up of the limb. The bursts of activity of anterior tibial muscle were obtained in various allotments of time of the swing phase.

DISCUSSION

The main reason to introduce the on-off registration was to have an objective method to define if the limb is in the swing or the stance phase. This method allows the simultaneous registration of the sequence of all four limbs. The analysis of the data is not complicated, the swing and stance durations may be registered in several ways, such as a tape recorder, and later elaborated by computer. However, the registration of contact of the limb with the background does not exactly corresponds with the phase of supporting the animal by this leg, because before the animal lifts up the leg, it does not support the body. All the disturbances caused by this method (i.e., tactile stimulation by shoes, wires, unusual situation for the animal) can be reduced by preliminary training.

In the dogs the stance and step durations were correlated to the animal's speed. The faster the dog moved, the shorter were stance and step durations. No differences between stance and step durations were observed for the fore and hind limbs (2). The swing phase duration in the dogs was almost constant, about 260 msec at the speed 3–10 km/hr (17).

In the cats, the ratio between the step durations for the fore and hind limbs was also 1 : 1, which is rather obvious. The swing durations in the cat (speed 1.0–4 km/hr) were different for the fore and hind limbs and changed from 200 to 320 or 370 msec respectively. For both fore and hind limbs the high correlation between either swing or stance and step durations was observed. Thus, acceleration was connected not only with the shortening of stance and step durations, but also swing duration. It is easy to notice the differences in the relations between swing and stance phases for fore and hind limbs (see 7, 8). So, these differences suggest different mechanisms for controlling of movements of fore and hind limbs during walking.

The durations of various supporting patterns differed in particular trials, which may possibly be connected with subtle differences in the

speed of the animal. Nevertheless the observed patterns could be described as an amble-like walk (4-3-2-3-4-3-2-3) or normal walk (3-2-3-2-3-2-3-2), trot (2-1-0-1-2-1-0-1) or 2-0-2-0) or gallop (2-1-0-1-2-1-0-1). But because of overlapping excessive speeds of different gaits (e.g., 3.5-4 km/hr for walk and trot) one should be very careful defining the kind of gait according to the speed only.

Thus, the relations between EMG activity of gastrocnemius muscle and anterior tibial muscle and the step phases are in accordance with Engberg's data (4).

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Zofia AFELT and Stefan KASICKI, Department of Neurophysiology, Nencki Institute of Experimental Biology, Pasteura 3, 02-093 Warsaw, Poland.