STUDIES ON THE KINETO-ADAPTATION

(I. On the Index of Limb Bones and the Locomotion in some Frogs)

By

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General Introduction

We can see at the same time the adaptive character and the hereditary one in the living body. Although in many cases it is difficult to distinguish this from that, it is generally said that in animals adaptive characters are found in the locomotive organ, and in plants they are found in the nutritive organ.

In higher animals, limbs and wings are the typical locomotive organs, and, as it was said, they show adaptive characters in general. Accordingly, there must exist a close relationship between these locomotive organs and the locomotion type of animals. Therefore, it would be very interesting to investigate this relationship, in the related animals which live in different environments and have different habits. Especially, the investigation of the relationship concerning the relative sizes of limbs and wings, the mutual sizes in their long bones or segments, namely, the index, on the one side and the locomotion type of animals, on the other, is important from both the standpoints of morphology and of oecology. Davenport (1933) made clear the relationship between the crural index and the locomotion type in mammals. Shimizu and Suzuki (1943) studied the index of limb bones in *Triton*, and further the author (1947) investigated the relative growth of bones in the albino rat, and also at the same time studied the development of the index of limb bones. And the author also investigated, the effect of the abnormal behavior on the growth of bones of the operated albino rat whose lower arm, when newly born, is cut off at the elbow joint without damaging the humerus. Now the author would call all the studies such as above-mentioned, "Studies on the kineto-adaptation". Such investigation of the operated albino rat as was said is "Studies on the Kineto-adaptation through Experiments".

I wish to continue the study "On the Kineto-adaptation" hereafter, but I live in the inconvenient environment to take advantage of the literature

concerned, and I sincerely hope that the reports would instruct me on the literatures.

I. On the Index of Limb Bones and the Locomotion in some Frogs.*

Introduction

As we all know, the Anura is very popular animal and we can easily collect some species of them with different locomotive types. Namely, they are *Bufo* which is inactive in both locomotions, jumping and swimming, *Rana nigromaculata* which is skilful in both locomotions and *Rana temporaria* which is a good jumper, etc.

The author investigated the relation between the mutuality on size of fore and hind limb bones, and of homologous bones of both limbs, the index of two long bones of them, on one side, and the locomotion type, on the other.

And I obtained some results, so I will report here about them. Here I am thankful to Mr. Takao Higuchi and Mr. Kazuo Iwamoto who are the students of the Shinshū Univ., to whom I owe in collecting the materials.

Materials and Methods

Frogs taken in this study are all adult; their species names and numbers are given in Table 1.

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* 1. The summary of this study was reported at the 22nd General Meeting of the Zool. Soci. of Japan, in Hiroshima, 12 October 1951.

2. "Studies on the Kineto-adaptation II. On the Relationship between the Relative Sizes of the Locomotive Organ and the Locomotion in some Insects of Orthoptera" was issued on Bull. Fac. Edu. Shinshū Univ., No. 2, March, 1952.

Table 1. Notes on Materials

	Species Name	N	Collecting Place
Arcifera	*Bufo vulgaris formosus*	♂ ♀ 16	Tokyo
	Hyla arborea japonica Guenther	♂17 ♀28 45	Matsumoto, Nagano Pref.
Firmistorna	*Rana japonica Guenther*	♂ ♀ 14	Katsuta, Ibaraki Pref.
	R. nigromaculata	♂20 ♀11 31	Hirooka, Higashichikuma, Nagano Pref.
	R. rugosa Shlegel	♂ 9 ♀22 31	〃
	R. catesbeiana Shaw	♀ 3	Katsuta, Ibaraki: Shimosuwa, Nagano Pref.
	R. temporaria ornativentris	♂ 1 ♀ 3 4	Matsukawa, Kitaazumi, Nagano Pref.

In the investigation, frogs are not divided by the sex. Of Bull frogs and *R. temporaria*, their numbers are very few, compared with the others, and as to the results, I put this point into consideration.

Investigated indices are as follows; the indices as to indicate the mutuality of size of fore and hind limbs and of homologous bones of both limbs are the intermembral index, the index of radio-ulna to tibio-fibula and the index of humerus to femur, the indices as to indicate the mutuality of long bones of limbs are the brachial index and the crural index. The lengths of bones were measured with the caliper at the longest part, and the lengths of radio-ulna+humerus and tibio-fibula+femur are taken as those of fore and hind limbs, respectively. Indices are shown with percentage in all cases.

Indices can be objectively indicated clear as above-stated, but the type and force of the locomotion cannot be done so. Therefore, the forces of jumping and swimming were subjectively judged by their environments and habits.

The difference of indices by the species was tested by the confidence of intervals as follows. Namely, first, the sample mean and the unbiased estimate of variance of indices were calculated in each species. The sample mean $\bar{x}$, and the unbiased estimate of variance u^2 are given by the following formulae; here x_i is the sample value and N is the size of sample:

$$\bar{x}=\frac{1}{N}\sum_{i=1}^{N}x_i \qquad u^2=\frac{1}{N-1}\left(\sum_{i=1}^{N}x_i^2-N\bar{x}^2\right).$$

Based on these values the confidence of intervals of the population mean (m) is determined as follows;

$$\bar{x}-\Delta \leq m \leq \bar{x}+\Delta$$

here $\Delta=\frac{t.u}{\sqrt{N}}$, t is Student t in the level of significance 1%.

In the above method the confidence of intervals is calculated in each species; for instance, in two species, in the case of sample means are $\bar{x}_1$, $\bar{x}_2$, and the confidence of intervals are $\bar{x}_1 \pm \Delta_1$, $\bar{x}_2 \pm \Delta_2$, if these ranges do not overlap each other, the difference of $\bar{x}_1$ and $\bar{x}_2$ is significant, and if they do it is insignificant.

Results and Discussion

Results are given in Table 2, Fig. 1 and 2.

Indices of homologous bones of the fore and hind limbs.

1. The intermembral index (fore limb/hind limb×100)

As is shown in Table 2, this index is smaller than 100 in all species, in other words the fore limb is shorter than the hind one in the length. In *B. vulgaris* this index is 78.6, and is remarkably high, compared with the

Table 2. Statistic values on the index of the limb bone in Some Anura.

Species Name	N	intermembral index			humerus/femur		
		$\bar{x}$	$\bar{x}\pm\Delta$	Mi.~Ma.	$\bar{x}$	$\bar{x}\pm\Delta$	Mi.~Ma.
B. vulgaris	16(♂, ♀)	78.6	78.6 ± 3.16 75.44~81.76	73.8~82.5	88.0	88.0 ± 3.22 84.78~91.22	82.6~93.0
H. arborea japonica	45 { ♂17 ♀28	50.5	50.5 ± 1.28 49.22~51.78	48.5~53.9	59.0	59.0 ± 0.99 58.01~59.99	55.8~62.8
R. japonica	14(♂, ♀)	44.2	44.2 ± 2.81 41.39~47.01	41.7~48.1	57.3	57.3 ± 2.95 54.35~60.25	53.6~61.9
R. temporaria ornativentris	4 { ♂ 1 ♀ 3	44.4			56.3		
R. rugosa	31 { ♂ 9 ♀22	48.2	48.2 ± 1.61 46.59~49.81	45.8~50.5	60.2	60.2 ± 0.91 59.29~61.11	57.5~63.3
R. catesbeiana	3 (♀)	47.2			58.7		
R. nigromaculata	31 { ♂20 ♀11	53.2	53.2 ± 1.38 51.82~54.58	47.9~56.4	64.0	64.0 ± 1.71 62.29~65.71	59.7~69.5

others. Except *B. vulgaris*, this index is 53.2 in *R. nigromaculata*, and is the highest and that is 44.2 in *R. japonica* and is the lowest. And between these two, the other species are in a line in descending order, as follows: *H. arborea*, *R. rugosa*, *R. catesbeiana* and *R. temporaria*. This will make it clear that in this index there is no remarkable difference by species, with the exception of *B.* vulgaris. And further it is clear that in this index, the difference is insignificant in many species. Therefore, based on this index frogs will be divided into the following two groups: *Bufo* and the others. Namely, in *Bufo* the fore limb reaches about 80% of the hind limb, but in others the fore limb is about half of the hind limb, and the relative length of the fore limb is very short compared with that of *Bufo*.

2. The index of radio-ulna to tibio-fibula: the index of humerus to femur.

As it is cle r from Fig. 1., these indices are essentially in accord with the above intermembral index about the relation among species. This accordance is natural result from the fact that, as already stated, the length of fore and hind limbs is humerus+radio-ulna and femur+tibio-fibula, respectively.

The differences that exist between these indices are:

i. The index value is higher in the index of humerus to femur, generally. Namely, in *B. vulgaris*, though the index of humerus to femur is 10% higher

(under the level of significance 1%)

radio-ulna/tibio-fibula			brachial index			Crural index		
$\bar{x}$	$\bar{x}\pm\Delta$	Mi.~Ma.	$\bar{x}$	$\bar{x}\pm\Delta$	Mi.~Ma.	$\bar{x}$	$\bar{x}\pm\Delta$	Mi.~Ma.
68.5	68.5 ± 2.56 65.94~71.06	64.2~72.5	71.2	71.2 ± 3.84 67.36~75.04	58.8~75.9	92.2	92.2 ± 3.44 88.76~ 95.64	88.0~ 94.8
42.1	42.1 ± 1.31 40.43~43.86	39.1~45.1	70.9	70.9 ± 1.80 69.10~72.70	66.1~78.1	99.3	99.3 ± 1.55 97.75~100.85	94.8~102.5
33.0	33.0 ± 2.28 30.72~35.28	30.4~35.3	68.4	68.4 ± 2.72 65.68~71.12	62.7~74.4	118.2	118.2 ± 2.39 115.81~120.59	115.9~122.5
34.0			68.8			113.6		
37.3	37.3 ± 1.08 36.22~38.38	35.2~39.0	67.6	67.6 ± 0.75 66.85~68.35	64.9~71.0	108.9	108.9 ± 1.95 106.95~110.85	103.0~114.0
36.1			64.1			103.3		
42.7	42.7 ± 1.40 41.30~44.10	39.2~45.4	67.9	67.9 ± 1.88 66.02~69.78	62.8~74.5	101.5	101.5 ± 2.15 99.35~103.65	97.4~104.9

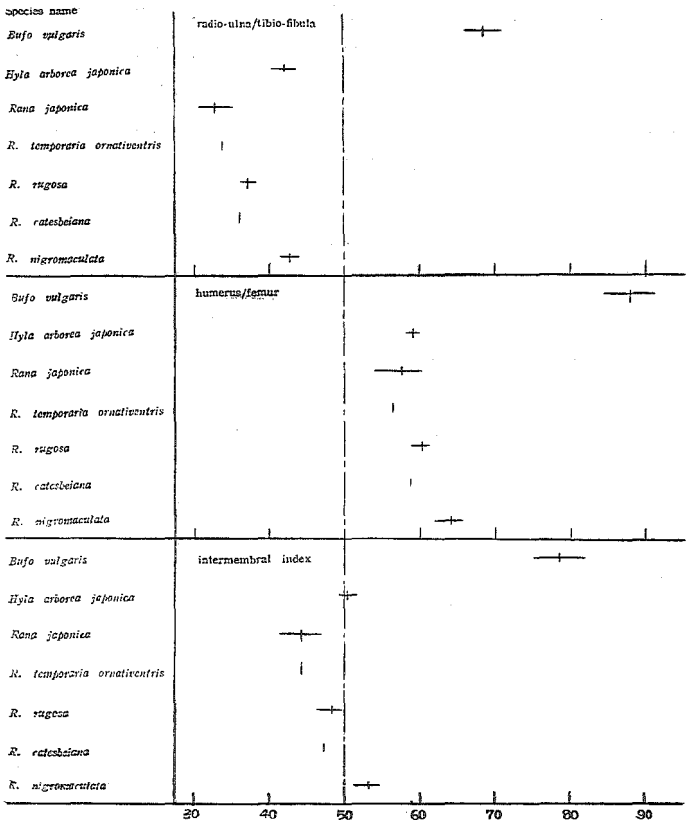

Fig. 1. The confidence of interval in the index of the mutual homologous bones of the fore and hind limbs ($\bar{x} \pm \Delta$). The sample mean is indicated with the short line.

than the intermembral index, on the contrary, the index of radio-ulna to tibio-fibula is 10% lower than that. In the others, too on this point they are principally in accord with *Bufo*: that is to say, the index of humerus to femur is 60% and 10% higher than the intermembral index, and the index of radio-ulna to tibio-fibula is lower than that, but in the latter the difference by the species considerably remarkable, compared with the former.

ii. By the index of humerus to femur, frogs are divided into two groups as was in the case of the intermembral index, but in the index of radio-ulna to tibio-fibula, frogs are divided into three groups: *Bufo*: *H. arborea*, *R. nigromaculata* and *R. rugosa*, *R. catesbeiana*, *R. temporaria*, *R. japonica*.

Indices of two long bones of the fore and hind limbs.

1. The brachial index (radio-ulna/humerus×100)

In *R. catesbeiana*, this index is 64.1 and is the lowest, in *B. vulgaris* that is 71.2, the highest of all. Accordingly, of this index the difference between

the lowest and the highest is merely 7.1. And from the index value, it is said that radio-ulna is slightly longer than $^1/_2$ of humerus, in all species.

Further, seeing $m \pm \Delta$ in Fig. 2, we find the surprising fact. Namely, the sample mean of this index shows a little difference by the species, but this difference cannot be significant. In other words, this fact means that this index has no close relation to the locomotion of frogs.

2. The crural index (tibio-fibula/femur×100)

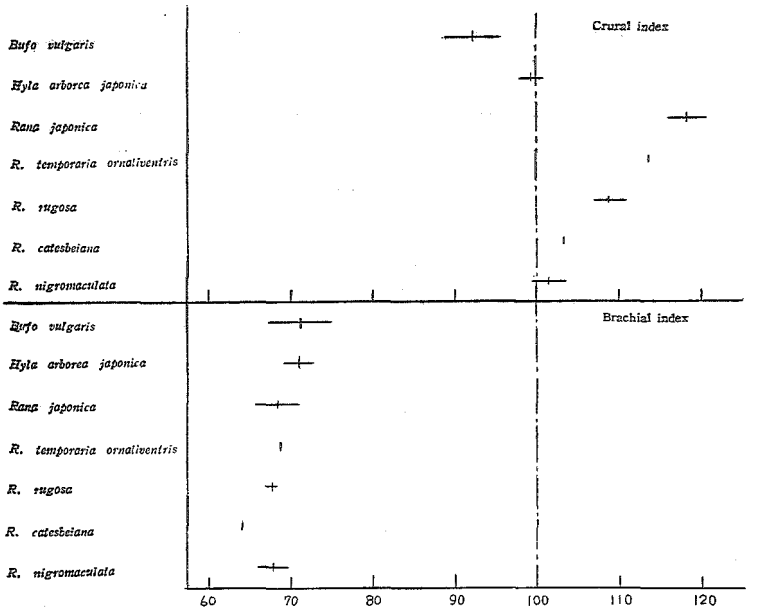

Fig. 2. The confidence of interval in the index of two long bones of the fore and hind limbs ($\bar{x} \pm \Delta$). The sample mean is indicated with the short line.

We can see in Table 2 that this index, in *R. japonica* is 118.2 and is the highest, and in *B. vulgaris* that is 92.2, the lowest of all; between these two other species are in line as follows, in descending order: *R. temporaria*, *R. rugosa*, *R. catesbeiana*, *R. nigromaculata* and *H. arborea*. But as it is clear from Fig. 2, it is difficult to make grouping of species in a boundary line. But through the qualitative difference of this index, frogs can be divided into the following three groups. That is in *Bufo*, whose index is the lowest of all, tibio-fibula is a little over 90% of femur; accordingly, the former is a little shorter than the latter, then in *Hyla*, *R. nigromaculata* and *R. catesbeiana* they are about in equal length in both, and in other species tibio-fibula are longer than femur, especially in *R. japonica* whose index is the highest, tibio-fibula reaches to 120% of femur in the length. It must be

said to be interesting and to notice that this grouping is in accord with the afore-said index of radio-ulna to tibio-fibula, but the order by the index value is different. Namely, though in the index of homologous bones of fore and hind limbs, the index is the lowest in *R. japonica*, and is the highest in *Bufo*, but in the crural index this order is inverted, and the highest in *R. japonica* and is the lowest in *Bufo*.

The above indices of the limb bones show a fair difference by species with the exception of the brachial index. Next, I will consider this difference by the species in the relation with the locomotion type and the environment of frogs.

In adult *Bufo*, its relation to water being not so intimate, its chance of swimming is less, and it is unskilfull and inactive in jumping. Therefore, in *Bufo*, both locomotions of swimming and of jumping are inactive, and in a word, it will be said, that the locomotion is slow and blunt in this species. And the body type in *Bufo* is massive. In *R. japonica* and *R. temporaria* the relation to water is alike as in *Bufo*, but there is the following difference between them; the body type is smart and jumping is skilful in the latter. In *Hyla*, *R. nigromaculata*, *R. rugosa* and *R. catesbeiana*, the body type is as like as in the above two species of genus *Rana*, and in these four species there are common characteristics in the environment and locomotion type. Namely, they all live in water and moist places, and are skilful in both locomotions of jumping and of swimming. It may be said that *Hyla* and *R. rugosa* are inactive in their locomotion, compared with *R. nigromaculata* and *R. catesbeiana*, but this is doubtful as far as the consideration of the difference of the body size between them is concerned.

From this, it may be said that the locomotion type of frogs studied here will be divided into the following three groups:

Bufo: unskilful in swimming and jumping, and are stupid in its motion.

Hyla, *R. nigromaculata*, *R. rugosa*, *R. catesbeiana*: skilful in both of swimming and jumping. To say the least of it, they oftner swim and jump.

R. japonica, *R. temporaria*: skilful in jumping, to say the least of it they seldom swim.

These three groupings of frogs are in accord with grouping through the index above-stated. Accordingly, the relation between the index and locomotion type is as follows:

Through the intermembral index and index of humerus to femur, frogs are divided into two groups; these indices are high in the stupid *Bufo* and are

low in the others, especially these are the lowest in *R. japonica* and *R. temporaria* which are good jumpers. In *Triton* (*Urodera*) (Shimizu and Suzuki, '43), the intermembral index reaches to 104~114, and is remarkably higher than *Bufo* (*Anura*), *Triton* cannot jump. Therefore, it is said that the short fore limb relative to hind one and short humerus relative to femur, are profitable in jumping. But, through the index of distal bones of the fore and hind limbs that is the index of homologous bones, frogs are divided into the following three groups: *Bufo: Hyla, R. nigromaculata: R. japonica, R. temporaria, R. rugosa, R. catesbeiana.* This discrepancy in grouping is unaccountable.

In the brachial index, there is no significant difference by the species. This is nothing but that this index has no close relation with the locomotion of frogs. In both locomotions of jumping and of swimming, frogs do not use the fore limbs so much as the hind ones. It may be said that the above result is due to this fact. In *Triton*, this index is only 46~59, and is so low, compared with that in *Anura*.

The crural index is remarkably high in *R. japonica* which is the good jumper, as compared with others, while this index is very low in *Bufo* which is stupid and those of *Hyla, R. nigromaculata, R. rugosa* which are skilful in both locomotions of swimming and of jumping lie between these extremities. Davenport ('33) reported that this index is the highest in jumpers, compared with those of the other locomotion type in mammals. Therefore, it is common in *Anura* and mammal that the relative length of tibio-fibula to femur is longer in jumpers than the animals in other locomotion type. In Triton, this index and the brachial index are nearly equal, and it is 45~53, but this is very low, as compared with the crural index of Anura. It is interesting to consider this difference from the standpoint of the locomotion type.

As is clear in Table 1, *Bufo* and *Hyla* belong to the same suborder *Arcifera*, and the others belong to genus *Rana* (suborder *Firmisterna*) from the viewpoint of taxonomy. As clear from afore-said results, the classification of the frogs taken in this study through the index does not accord with that of taxonomy, and *Hyla* belongs to *Rana* rather than *Bufo*. Namely, through the index, the frogs taken in this study are divided into two groups; *Bufo* and the others. It is considered that this may be the result of the adaptive character due to the environment and locomotive obligation.

Summary

Here the author's investigation into the relationship between the index of limb bones and locomotion in some frogs (ref. Table 1), brings the following results:

1. The intermembral index (Table 2, Fig. 1): Through this index frogs are divided into the two groups; *Bufo* and the others. The index of the former is about 80, the highest of all, and those of the latter are about 50. It is said, therefore, the length of the fore limb to that of the hind one gains the most in the inactive frogs such as *Bufo*.

2. The index of humerus to femur (Table 2, Fig. 1): On grouping and values of this index, it is essentially in accord with the index above, but this index is about 10% higher than that in all species.

3. The index of radio-ulna to tibio-fibula (Table 2, Fig. 1): This index is essentially in accord with the above indices, too. But in this index in the grouping differs from the above-stated indices. Namely, it is as follows, descending order; *Bufo vulgaris* (68.5): *Hyla arborea, Rana nigromaculata* (about 42): *R. rugosa, R. japonica, R. temporaria, R. catesbeiana* (about 35). This discrepancy in grouping is unaccountable.

4. The brachial index (Table 2, Fig. 2): For this index, it shows about 70 in all species, indicating insignificant difference by the species. In other words, this index has not much to do with the locomotion of frogs. It may be said that this is due to the fact that frogs do not use the fore limb so much in the locomotion.

5. The crural index (Table 2, Fig. 2): Through this index, frogs are divided into three groups: in *Bufo* this is the lowest, and tibio-fibula is shorter than femur just slightly; in *H. arborea, R. nigromaculata* and *R. catesbeiana* tibio-fibula is nearly equal with femur in length; in *R. rugosa, R. japonica* and *R. temporaria* tibio-fibula is longer than femur. In this index the order of *Bufo* and *R. japonica* is in the reverse with the above-stated intermembral index, accordingly it may be said that in the good jumper such as *R. japonica*, tibio-fidula is longer than femur.

6. Of the frogs taken in this study, *Bufo* and *Hyla* belong to the same suborder *Arcifera*, and the others to genus *Rana* (suborder *Firmisterna*) from the viewpoint of taxonomy. But from the above-stated index *Hyla* belongs to *Rana* rather than *Bufo*. It is considered that the factual difference of the grouping in taxonomy and index may result from adaptation due to the environment and locomotive obligation.

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