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Relationship between masticatory rhythm, body mass and mandibular morphology in primates

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ABSTRACT

Objective: It has been proposed that rhythmic movements such as locomotion and respiration have a period proportional to body mass$^{1/4}$. Mastication basically consists of rhythmic alternation of jaw-closing and jaw-opening movements. We studied the relation between masticatory rhythm and body mass in primates, and masticatory rhythm and mandible morphology.

Methods: We measured the chewing cycle duration (CCD), mandibular length, mandible height, mandible width and distance from the condylar process of mandible to the centre of gravity of the mandible. Body mass was quoted from the literature.

Results: The CCD is related to mandible morphology and was found to be proportional to body mass$^{1/6}$.

Conclusion: These findings suggest that masticatory rhythm is correlated with body mass and mandibular morphology, and that scaling rate of masticatory rhythm to body mass is slower than for the other rhythms.

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1. Introduction

Locomotion and respiration are rhythmic movements that are controlled by the spinal cord and medulla respectively. A clear relation has been found between stride frequency of mammals during locomotion and body mass (M_b).[1–3] At identical speeds, the stride frequency of locomotion decreases as body mass increases. Moreover, the respiratory frequency decreases as M_b increases.[3] These studies suggest that locomotion and respiration are proportional to $M_b^{1/4}$.

Mastication involves rhythmic alternation of jaw-closing and jaw-opening movements accompanied by coordinated movements of the tongue, cheeks and lips. Mastication, like locomotion and respiration, is programmed mainly in the neural structure within the brainstem known as the central pattern generator.[4,5] The central pattern generator receives inputs from sensory receptors in the lips, oral mucosa, jaw-closing muscles and periodontal ligaments around the roots of the teeth, and the final motor commands are sent by the central pattern generator.[4,6] Although the duration of a complete mastication sequence, and the parameters of the individual masticatory cycles, vary with food type, the masticatory rhythm produced by the central pattern generator is fixed within individual animals[7] and within species.[8–12] It has been found that the masticatory frequency decreases as

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M_b increases.[13–19] Small mammals have a shorter chewing cycle duration (CCD) than larger mammals. The slope of the regression line was different in these studies, however.[13–19] This difference might be due to differences in the method of measuring CCD, or differences in the size and hardness of foods given to the test animals. Also, genetic differences between subpopulations of species in different experiments might be responsible. It has been reported that differences in hardness and stickiness of food influences the CCD[20,21] and that bite size has an effect on the number of chewing cycles and the periodic time of the chewing sequence.[22–25] Consequently, it remains unclear whether the exponent of the CCD is the same as locomotion and respiration.

Various factors of mandible morphology have been proposed as the reason for differences in masticatory rhythm: mandibular mass, mandibular length (L_m), taken together with the gravity-driven pendulum model and the length of the jaw closing muscles.[13,17] The CCD has been found to increase with L_m.[13,15,17] Measuring of mandibular morphology has not been made sufficiently, however.

In the present study, the CCD was found not to be affected by food properties. We also measured L_m, mandibular ramus height (H_m) and mandibular width (W_m), and the distance from the condylar process (CP) to the centre of gravity of mandible (CGM). Our aim was to determine whether the relation between the CCD and body mass is the same as for locomotion and respiration. We also investigated the relationship between masticatory rhythm and mandible morphology.

2. Materials and methods

2.1. Animals

Healthy mature primates were chosen as subjects, as they are closely related to humans and their feeding behaviour is similar to each other. Exclusion criteria included the presence of periodontal disease and more than one missing tooth. The experiments were performed on 3 families (Cercopithedae, Cebidae, Hominoidae), and a total of 12 species (Tables 1 and 2). Body mass was taken from the literature.[26]

2.2. Measurements of mandible morphology

For these measurements we used skeletal remains of primates in the Japan Monkey Centre, Primate Research Institute, Kyoto

Table 1 – Body mass and chewing cycle duration.

Families	Species	Number	Body mass (g)	Chewing cycle duration (ms)	
				Mean	S.E.
Cercopithedae	*Miopithecus talapoin*	2	1013	245.5	5.0
	Macaca sinica	3	3850	277.2	1.7
	Macaca fuscata	3	14,500	322.3	33.5
	Papio hamadryas	3	12,000	292.8	15.9
	Mandrillus sphinx	3	11,500	281.5	10.5
Cebidae	*Saimiri sciureus*	3	852	212.2	7.4
	Cebus apella	3	3050	249.4	9.7
	Ateles belzebuth	4	8832	279.9	6.1
	Ateles geoffroyi	3	7456	219.6	8.9
Hominoidae	*Hylobates lar*	6	6000	288.9	11.2
	Pan troglodytes	4	50,000	412.0	17.8
	Gorilla gorilla	3	169,500	546.1	32.6

Table 2 – Mandible morphology.

Species	Number	Mandibular length (mm)		Mandibular ramus height (mm)		Mandibular width (mm)		CP-CGM (mm)	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Miopithecus talapoin	4	35.8	5.8	20.1	3.1	37.1	4.5	21.4	3.7
Macaca sinica	3	62.0	3.2	35.8	1.8	53.7	2.3	32.7	2.7
Macaca fuscata	3	89.4	10.3	61.0	7.0	78.2	5.8	45.4	5.0
Papio hamadryas	4	112.0	14.4	53.5	7.8	82.4	2.9	57.9	12.0
Mandrillus sphinx	3	137.6	37.2	71.9	19.5	91.3	19.6	85.0	30.3
Saimiri sciureus	3	32.6	1.1	18.7	0.8	31.0	1.0	19.0	1.7
Cebus apella	4	53.1	1.6	34.5	3.3	48.8	4.4	29.0	2.8
Ateles belzebuth	2	65.6	2.4	45.3	6.0	60.9	2.3	40.5	0.7
Ateles geoffroyi	4	63.7	2.7	39.9	4.6	54.9	4.0	36.9	2.1
Hylobates lar	4	64.3	6.4	31.5	4.2	54.0	3.3	33.7	3.0
Pan troglodytes	1	129.3		77.3		113.0		81.0	
Gorilla gorilla	2	158.6	9.1	123.1	3.3	137.7	2.4	98.2	14.4

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