Biomechanics of head-bobbing in pigeons

Nikolaus F. Troje, Kate Bobyn, Andres M. Kroker, Qingguo Li

BIO MOTION LAB
www.biomotionlab.ca

NSERC CRSNG

Queen's UNIVERSITY

INTRODUCTION

About 40% of all bird species show a peculiar head-motion during locomotion: While the body moves at relatively constant velocity, the head is kept stable in space during a short ***hold phase*** and is then moved quickly into a new position during the ***thrust phase***.

A number of different functions have been proposed:

- Stabilization of the retinal image during the hold phase → may facilitate image processing and the detection of stationary and moving objects
- Enhancement of optic flow during the thrust phase → may facilitate motion parallax based computations
- Biomechanical functions: energy transfer over the gait cycle

Recent work has described head-bobbing mainly as an optokinetic response [1-3]. Here we look at potential biomechanical advantages.

Hypothesis

- In birds with delicate, poorly muscled legs, the positive work normally exerted by the trailing leg during push-off is done by the much stronger neck muscles.
- Head-bobbing can provide a mechanism to transfer the negative work of the weight-accepting leading leg to the trailing leg which requires it in terms of positive work during push-off.

Approach

The proposed mechanism only works if the head-bobbing is conducted

- phase locked to the gait cycle,
- at a very specific phase with respect to the gait cycle

To verify whether this is the case

- We measure horizontal ground reaction forces (GRF) and use them to predict the theoretically optimal phase of head-bobbing and the energetic gain it can provide.
- We also use 3D motion capture technology to assess kinematic data from head and body to determine the actual phase and potential gain of head-bobbing.

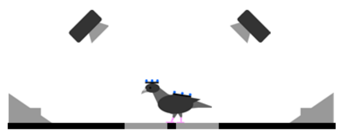
REFERENCES

1. Friedman, M. B. (1975) Visual control of head movements during avian locomotion. Nature 55:67-69.
2. Frost, B. J. (1978) The optokinetic basis of head-bobbing in pigeons. Journal of Experimental Biology
3. Maurice, M., Gioanni, H. Abourachid, A. (2006) Journal of Experimental Biology 209:292-301.
4. Donelan, J. M., Kram, R., Kuo, A. D. (2002) Simultaneous positive and negative external mechanical work in human walking. Journal of Biomechanics 35:117-224.

METHOD

Training

Pigeon were moderately starved and trained to walk back and forth between two feeders that provided alternating access to food. Four different birds were used for this study. A total of 40 head-bobbing cycles were analyzed.



Kinematic data

360 Hz motion capture of four markers attached to the body and four markers attached to the head.

Kinetic data

Two force plates were inserted into the ground plate. Ground reaction forces (GRF) were recorded and stored synchronously with the kinematic data.

Data analysis

Time series of mocap data were parsed into individual head-bobbing cycles and the ones that contained a complete GRF measurement of one foot were used.

The work based on horizontal GRFs was computed assuming that energy can not be transferred from one leg to the other and cannot be stored for later retrieval [4].

$$P = \int |F_{GRF}|\, dv$$

Head motion as a spring-mass system

m = 18g : mass of the head

f : head bobbing frequency obtained from kinematic data

s : amplitude of head displacement relative to body

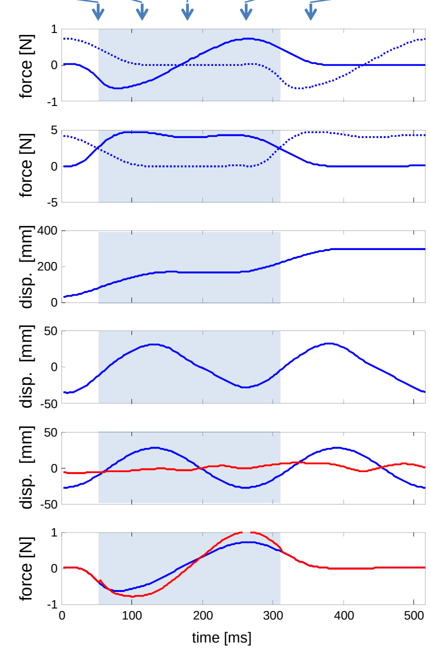
k : spring constant of the system $\quad k = 4\pi^2 f^2 m$

$$F_{HB}(t) = ks\sin(2\pi ft + \varphi)$$

In order to estimate work without head-bobbing, we base it on the measured GRFs minus the head-bobbing induced forces.

$$P_{\sim HB} = \int |F_{GRF} - F_{HB}|\, dv$$

RESULTS



One (out of n=40) example

a. *Solid line: Horizontal GRF during one full gait cycle. The first negative peak indicates the negative work exerted when the leading foot first contacts the ground. The following positive peak indicates the positive work which is the same foot (now the trailing one) exerts during push-off. Dotted line: Copy of the same function shifted 180 degrees indicating the forces exerted by the other foot.*

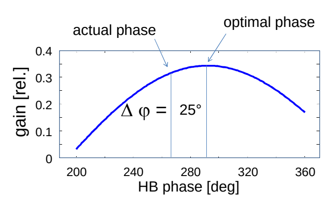
b. *Same as (a) but for vertical GRF. Here and in the other plots, the shaded area indicates the half of the gait cycle during which weight is predominantly on that foot.*

c. *Kinematics of head-bobbing. The sloped thrust phase alternates with the constant hold phase.*

d. *Head motion relative to the body. During the thrust phase the head moves quickly forward. During the hold phase the constant negative velocity accounts for the forward motion of the body.*

e. *Blue: Least-square fit of a sinusoidal function to model the head motion depicted in (d). Red: Residual. Assuming that neck and head function as a spring-mass system, the forces attributed to this system also vary sinusoidally.*

f. *Blue: Measured horizontal GRF copied from (a). Red: Ground reaction forces obtained by subtracting from the measured GRF the forces attributable to head-bobbing from (e). The area between the two curves is the energetic gain potentially achieved.*



Is the actual head-bobbing phase optimal?

In this example, the actual phase deviates from the optimal one by 25 deg. The reduction in gain (Δφ) from 34 to 31.5% is very small, though.

n=40		gain	opt. gain	Δφ
	mean	.266	.288	18
	std	.104	.113	17

SUMMARY

- Head bobbing provides a potential mechanism to reducing negative work during heel strike and positive work during push-off.
- Whether birds use that mechanism, we don't know. However, it is in accordance with the fact that head-bobbing is phase locked to the gait cycle and that its phase optimally supports that mechanism.
- If used, it reduces work by ~25%.
- Even if the neck-head system is not able to store and transfer energy, it would take the load of producing the required forces away from the legs and to the much stronger neck.

Contact: troje@queensu.ca Queen's University, Kingston, Ontario, Canada