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VARIATION IN STOMACH TEMPERATURE AS INDICATOR OF MEAL SIZE IN HARBOUR SEAL, *PHOCA VITULINA*

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ABSTRACT: To understand the role of the marine mammals as components in foodwebs, it is important to know the composition, frequency and size of their meals. Marine mammals have a core body temperature of about 37°C, and feed mainly on poikilothermic animals. Food intake will therefor lead to a cooling of the stomach, followed by an increased metabolism. Up till now there has been no direct method for measuring the amount of food ingested by free ranging animals. Here we describe the use of a method for remote registration of changes in stomach temperature to quantify meal sizes in captive harbour seals (*Phoca vitulina*). This might serve as a calibration of technology that may also be applied to free ranging seals. The animals were fed a range of meal sizes at various temperatures and individual fish sizes. The time taken to regain initial stomach temperature from minimum temperature (recovery time) was significantly related to both meal size and meal temperature. The time taken from initial temperature to initial temperature again was regained (total time) was also significantly related to both meal size and meal temperature. Recovery time is in this experiment considered the best available indicator of meal size when meal temperature is known.

INTRODUCTION

To understand the role of the marine mammals as components in foodwebs, it is important to know the size of their meals. Different methods (such as isotope-labelled water, changes is seal weight, analysis of faecal and stomach content and energy account in captive seals) have been used to gain this information, all with limitations (Gales & Renouf, 1993). Marine mammals have a core body temperature of about 37°C (Feltz & Fay, 1966), and feed mainly on poikilothermic animals (Bjørge, 1991). Food intake will therefor lead to a cooling of the stomach, followed by an increased metabolism (Markussen *& al.*, 1994). Up till now there has been no direct method for measuring food intake in free ranging marine mammals. Wilson *& al.* (1992) developed equipment that records and stores data on stomach temperature in penguins (*Speniscus demersus*) and albatross (*Diomedea exulans*), and suggested that changes in stomach temperature may be used in estimating the amount of food ingested. Dive profiles have been used to categorise harbour seal (*Phoca vitulina*) behaviour at sea and to identify foraging behaviour and foraging grounds, and feeding in harbour seals has been confirmed by monitoring stomach temperature (Bjørge *& al.*, 1995). Gales & Renouf (1993) have measured changes in stomach temperature in captive harp seals (*Phoca groenlandica*) as a result of intake of food, snow, ice and sea water. In their study, the shortest time taken to regain initial stomach temperature was for intake of water, followed by snow, ice and food.

The aim of this study is to describe the use of stomach temperature to measure meal sizes in captive harbour seals. This method could be used as a calibration of telemetry equipment that may be applied to free ranging seals.

MATERIALS AND METHODS

The seals and the holding facilities

In the experiment we used two adult harbour seals, one 80 kg male ("Totto") and one 65 kg female ("Hercula"). The seals were kept in captivity at the Dept of Biology, University of Oslo. The facility consists of two outdoor tanks, one rectangular (3x8 m, 1.5 m deep) and one circular (2.5 m in diameter, 1.5 m deep), both connected with a dry platform. The tanks were continuously supplied with running freshwater. The seals were normally fed thawed herring (*Clupea harengus*) by hand, and were daily given about 50 mg of vit. A-palmitat as an additional source of vitamin A.

The equipment

Temperature transmitters (produced by SINTEF, Trondheim, Norway) were inserted in a herring fed to the seals by hand. The digestion process released the transmitters quickly into the stomach cavity, where they remained for a maximum of 14 days and were thereafter expelled. The transmitters were calibrated before and after the experiment. The temperature data were transmitted as ultrasonic signals via a hydrophone to a VEMCO VR 60 Ultrasonic Receiver (both produced by VEMCO ltd., Halifax, Canada). The receiver stored the temperature data together with the date and time. During the experiment, the seals were kept in the rectangular tank without access to the dry areas to maintain transmission of data through water to the hydrophone.

Experimental design

The seals were fed a range of meal sizes consisting of herring at various temperatures and individual fish sizes (Table 1). While varying meal size, meal temperature and fish size were kept constant at 11°C and <200 g, respectively. In the experiments with varying meal temperature, meal size were 1.5 kg and fish size were <200 g. While varying fish size, the meal size were 1.5 kg and the meal temperatures were 11°C. The individual herring and the total meal size were weighed to the nearest 5 g, the temperature to the nearest 0.1°C. Recordings of stomach temperatures started about 10 min prior to every meal and continued until well after the temperature returned to and stabilised at the initial temperature. Markussen (1993) found that the time taken from the food was ingested until the faeces started to be expelled ranged from 2 h 35 min to 6 h 15 min. The feeding interval in this experiment was chosen to be 6 h.

Table 1. Number of replicates of every variable in the experiment. The fish categories of <200g and >250g contained fish of sizes 120-200g and 250-350g, respectively.

Seal	Meal size (g)				Meal temperature (°C)			Fish size (g)	
	250	500	1500	3000	3	7	11	<200	>250
"Totto"	6	9	9	6	6	5	9	9	11
"Hercula"	5	6	5	5	6	5	5	5	6

Data analyses and definitions

The temperature data were averaged in intervals of one minute. The initial temperature was defined as the lower limit of the 95% confidence interval of the stomach temperatures before the feedings. The minimum temperature after a meal was defined as the lowest mean temperature in a one minute interval. We tested the correlation between meal size, meal temperature and fish size and the magnitude of the temperature drop; time used to reach minimum stomach temperature (drop time); time taken to regain initial temperature from minimum temperature (recovery time) and time taken from initial temperature to initial temperature again was regained (total time). The effect of different meal sizes, meal temperatures and fish sizes were estimated by linear regression with a 5% error due to chance. Differences between the regression lines were estimated with analysis of variance.

RESULTS

The regression lines for the data from the two seals were significantly different for recovery time against fish temperature, for recovery time against fish size and for total time against meal temperature. The data from the two seals were for that reasons not pooled, but treated as two sets of data.

In general, the stomach temperature profile is as shown in Fig. 5. The stomach temperature dropped up to about 10°C in less than 30 minutes and used up to two hours to regain initial temperature. Some of the stomach temperature profiles had a temperature minimum in addition to the major one obtained by food intake.

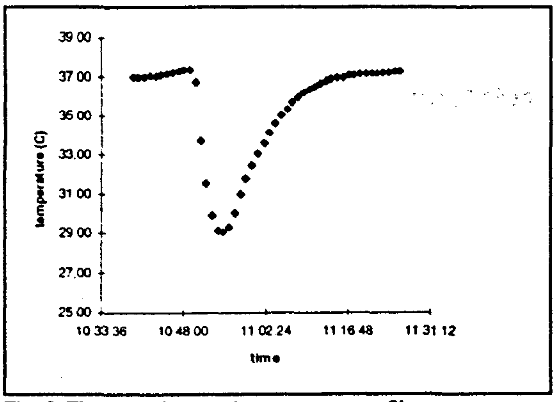

Fig. 5. The general stomach temperature profile

Recovery time

The regression lines for recovery time against fish temperature had both slope and intercept significantly different in the two datasets. The regression line slopes for recovery time against fish size were also significantly different.

The experiment shows that recovery time is a good measurement for meal size, and it also shows a good relation with meal temperature. In both datasets the recovery time was significantly related to both meal size ($p<0.001$, $R^2=0.94$; $p<0.001$, $R^2=0.93$, positive correlation, Fig. 1) and meal temperature ($p<0.001$, $R^2=0.96$; $p<0.001$, $R^2=0.97$, negative correlation, Fig. 2). The recovery time was significantly correlated to fish size in one dataset ($p=0.007$, $R^2=0.58$, positive correlation).

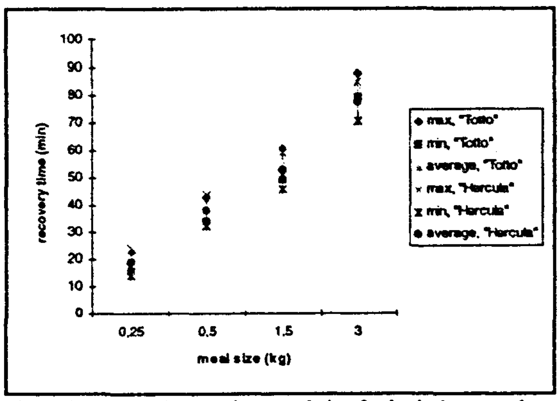

Fig. 1. Recovery time against meal size for both datasets shown as average values and 95% confidence intervals (shown as max. and min. values).

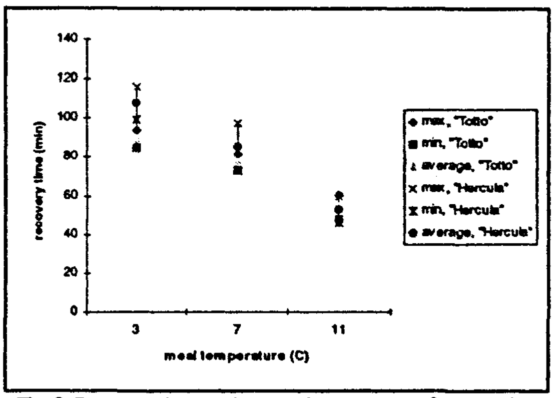

Fig. 2. Recovery time against meal temperature for both datasets shown as average values and 95% confidence intervals (shown as max. and min. values).

Total time

The regression lines for total time against meal temperature was significantly different in the two datsets.

As recovery time, total time a good measurement for both meal size and meal temperature. In both datasets total time was significantly correlated to both meal size ($p<0.001$, $R^2=0.92$; $p<0.001$, $R^2=0.90$, positive correlation, Fig. 3) and meal temperature ($p<0.001$, $R^2=0.73$; $p<0.001$, $R^2=0.96$, negative correlation, Fig. 4). Total time was significantly correlated to fish size in one dataset ($p=0.013$, $R^2=0.50$, positive correlation).

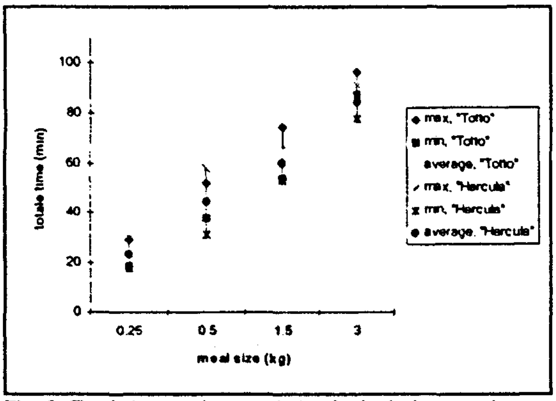

Fig. 3. Total time against meal size for both datasets shown as average values and 95% confidence intervals (shown as max. and min. values).

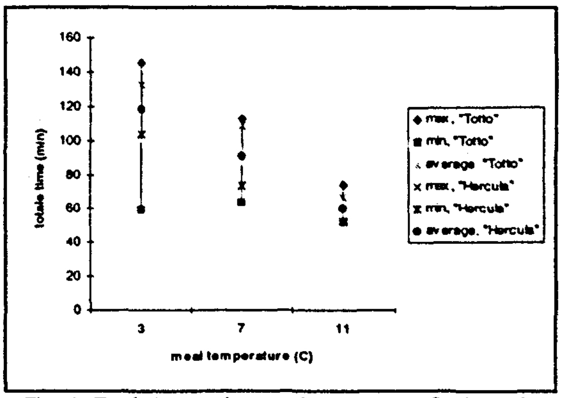

Fig. 4. Total time against meal temperature for both datasets shown as average values and 95% confidence intervals (shown as max. and min. values).

Temperature drop and drop time

Neither of the datasets gave significant correlation between the three variables and the temperature drop. In one of the datasets the drop time vas significantly correlated with both meal size ($p=0.047$, $R^2=0,134$, positive correlation) and fish size ($p=0.035$, $R^2=0.225$, negative correlation), but not fish temperature.

DISCUSSION AND CONCLUSION

This experiment shows that both time taken to regain initial stomach temperature from minimum temperature (recovery time) and time taken from initial temperature to initial temperature again was regained (total time) is good measurements of meal size. This is confirmed by experiments carried out by Gales & Renouf (1993). In our experiments there was no significant correlation between temperature drop and meal size, but one of the seals showed an significant correlation between drop time and meal size. Gales & Renouf (1993) found no relation neither between drop time nor minimum temperature attained and meal size. Our experiment also showed a significant correlation between meal temperature and both recovery time and total time. To use the stomach temperature as indicator of meal size, then, one must know the temperature of the food (i.e. the temperature of the ambient water at the depth where free ranging seals are foraging). Radio tagged harbour seals along the Norwegian coast have indicated that harbour seals feed mainly near or at the bottom (Bjørge *& al.*, 1995). For a specific foraging area, then, the meal temperature may be determined by measuring water temperature at the sea floor.

In the experiment we had two categories of fish sizes. The fish size often varied more within the category than between the two categories, and this may be a reason for the differences in correlations between the variables and the fish size between the two datasets. These variations in fish size, together with a possible variation in orientation of the transmitter in the stomach, may be the explanation for the overall differences in regression lines for the two datasets. Possible variations in meal temperature and the time used feeding the seals is considered as a minimal source of error because the feedings never exceeded more than a few minutes. The feeding by hand minimised bias in estimating the amount of food ingested.

It has been assumed that marine mammals obtain the water needed from the fish ingested (Irving *& al.*, 1935; Tarasoff & Toews, 1972), and that ingestion of cold water would involve a considerable metabolic cost (Wilson & Culik, 1991). Mariposa (salt water drinking) has, however, been observed in captive harbour seals (Renouf & Scott, 199) and harp seals (Gales & Renouf, 1993), in addition to intake of fresh water by captive harp seals (Renouf & Scott, 1991; Gales & Renouf, 1993). In this experiment the seals were fed by hand while keeping their head above the water. This eliminated the water intake along with food intake. But water intake after ingestion of food may have occurred, and this may have resulted in diverging stomach temperature profiles (Fig. 5). Water intake was also observed visually, but never on the tagged seal. The ingestion of water would bias the results using this method on free ranging seals.

The metabolism of the seals is affected by their activity (Davis, 1985; Castellini *& al.*, 1985), by the food ingestion itself (Webster, 1983; Markussen *& al.*, 1994) and with ambient temperature (Irving & Hart, 1957; Bigg, 1981). However, these relationships are not discussed here. The metabolism is also affected by size of the seal (Irving & Hart, 1957), but this experiment does not give any conclusive evidence of any differences between the seals.

Telemetry equipment may be a helpful tool to increase our knowledge about marine mammals and their impact on the marine environment, and it has successfully been used to confirm feeding behaviour in free ranging harbour seals (Bjørge *& al.*, 1995). To use this equipment to quantify meal sizes in free ranging animals, it would need to be calibrated on captive animal. This study is an attempt to describe a way of approaching this problem, and data is available to combine variations in stomach temperature and temperature of the meal to find the size of the food ingested.

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