Fine scale feeding behavior of Weddell seals measured by mandible accelerometer

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Introduction

The investigation of the feeding behavior is a central topic in studies on the foraging ecology of marine mammals and seabirds. Continuous efforts to observe prey ingestion of marine endotherms yielded several unique techniques. Stomach temperature recorders use the difference between the temperature of ectothermic prey and the stomach temperature of an endothermic predator as a proxy for prey ingestion. This concept was extensively used in seabirds (e.g. Wilson et al. 1992), and seals (e.g. Gales & Renouf 1993, Kuhn & Costa 2006). An alternative approach is based on recordings of the movements of jaws or mandibles when prey is being caught and swallowed. This concept uses strain-gauges, read switches or magnet-hall inter-mandibular angle sensors (IMASEN - Wilson et al. 2002) in seabirds (e.g. Simeone et al. 2003, Takahashi et al. 2004) and seals (e.g. Bornemann et al. 1993, Ploetz et al. 2001, Liebsch et al. 2007).

The “mandible movement method” is non-invasive and potential loss or non-retrieval of instruments uncritical in terms of animal welfare aspects. All techniques, however, are based on archival tags, thus retrieval of the loggers is essential for data access. Handling and deployment of these various types of loggers are often difficult under field conditions, and call for improvement in this respect. Considering the importance of the underlying concept, Naito (2008) proposed a new method based on a miniaturized acceleration data logger to be attached to jaws of marine predators. The new jaw-accelerometer-logger was successfully tested in captive hooded seals, and provided accurate detection of feeding events (Suzuki et al. 2009). The aim of the present study is to examine the feasibility of this method in free ranging Weddell seals.

Materials and methods

The experiments were conducted in early December 2008 at the end of the breeding season. We deployed UME380-D2GT jaw accelerometers (JAM) and digital still image loggers (DSL) on three non-lactating female Weddell seals. The JAMs (15mm diameter, 53mm length, 18g in air; Little Leonard Co., Tokyo, Japan) were glued to hair below the center part of the lower jaws of anesthetized seals using Araldite® epoxy resin and nylon mesh (Fig. 1 middle). We obtained dive depth, environmental temperature and image data (Fig. 1 right) at 1Hz resolution and two way acceleration, heave (*x*) and surge (*y*), at 32Hz over three consecutive days from each of the instrumented seals. Only dives deeper than 0.5m were processed. Processing and analysis of the data is based on Igor Pro software (6.30J; Wave Matrics, OR, USA), Igor Filtering Design Lab. (IFDL; ver.4, WaveMetrics) and Ethographer (Sakamoto et al. 2009). In order to discern feeding events from miscellaneous accelerations e.g. body movements, we applied a 3Hz high pass filter algorithm (Suzuki et al. 2009), and masked out accelerations below 0.3 G level as based on experiments in hooded seals: $4.46 \pm 1.77 m/s^2$; $0.46 \pm 0.18G$ (Suzuki et al. 2009). This threshold is indicative for a steep increase of acceleration noise with low peak amplitude and long lasting duration (> 10s). We compared the acceleration levels of heave (*x*) and surge axes (*y*) in both positive and negative oscillations and found no significant differences between *x* and *y*-axes, though the percentage of undetected events after comparison with visual analysis was lower in *y* (up/down 6.25%) than in *x* (14.58/12.50%). This was in particular true for events with only small amplitudes. In addition, highest values were detected in the *y*-up component, indicating this being the most sensitive detector for mandible movements (Figs. 2, 3).

Results and Discussion

Diving behavior: only one of the instrumented seals dived actively providing a total of 167 dives during two consecutive “nights”. The seal dived from shallow to midwater depths (MAX <79m), see Fig. 4; (bottom depth ~125m). The slight bimodal pattern in the distribution of dive depths indicate a preference for shallow dives < 20m and depths around 70m. The absence of up and down movements during the bottom phases may suggest dive excursions along the underwater contour of the iceberg where the seal was equipped. Given the presence of a cryo-benthic fauna attached to the iceberg as described by Watanabe et al. (2006) for a floating ice shelf, this would plausibly explain the low level of feeding accelerations which are indicative for suction feeding e.g. on small crustaceans.

Jaw acceleration pattern: three acceleration patterns were detected (1) consecutive up- and downward movements with short duration (< 6s), (2) gradual attenuating long lasting patterns with a low peak amplitude, and (3) long lasting patterns with high peak amplitudes. We presumed pattern (1) as indicative for feeding events and (2) for vocal activity. Pattern (3) is yet unknown and was excluded from further analysis.

Feeding behavior: we found 48 feeding events by visual examination in 167 dives (0.29/dive), which is a far lower rate than the 2.8/dive ratio reported by Liebsch et al. 2007 using the IMASEN method (Tab. 1). However, we can not disprove a potential bias by identification errors. The distribution of feeding depths is in congruence with the preferred dive depths at around 70m, suggesting that the seal selected this depth layer due to prey distribution (Fig 4).

Vocal behavior: we found 15 distinctive patterns proposed as vocalization events in the 167 dives (Table 2, Fig. 5). These events were solely observed in shallow water (< 20m). Due to gradual attenuation (fade-out) of the acceleration level, the termination of these events was difficult to detect. Since underwater vocalizations of ice breeding seals are assumed having a mating context, this might explain the comparatively low feeding rate in this study. Gluing JAM on a mandibular side instead of center part of the lower jaw may enhance the sensitivity for feeding events and reduce noise caused by movements of pharyngeal muscles .

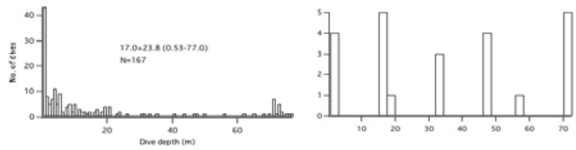

Fig. 4. Distribution of dive depths (left) and depths of feeding events (right). The slight bimodal pattern in dive depths is not reflected in feeding events. Feeding rates were apparently highest in depths at around 15m and 70m.

Fig. 1 (left). Bathymetric chart of the Atka Bay including location of the Neumayer Station (70° 39’S, 08° 15’W). The depth contour inside the bay indicates water depth less then 200 m. The Atka Bay is about 20 km long and wide, marking a permanent indentation in the front of the Ekstrøm Ice Shelf on the coast of Queen Maud Land. The bay is flanked by floating ice shelf cliffs with an ice thickness of about 80 m at the outer ice margin, rising up to 200 m within the first 5 km to the South. Water depths range from 80 m to 250 m. The sea ice of the bay provides a birthing site for numerous Weddell seals, which get access to the water via breathing holes and tidal cracks along the feet of several stranded icebergs and across the bay. The Weddell seal was instrumented at 70° 34.7160' S 8° 5.3940' W (●) in the vicinity of a stranded iceberg on 2008-12-11. The acceleration logger was glued below the center part of the lower jaws (mid photo) and programmed for delayed start (99 h). The camera logger was deployed on the seal’s head, yielding available light images close to surface (right photo). Map cut-out of the bathymetric chart taken from Hinze et al. (1997) AWI Bathymetric Chart of the Weddell Sea, Antarctica (BCWS), Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, doi:10.1594/PANGAEA.708081.

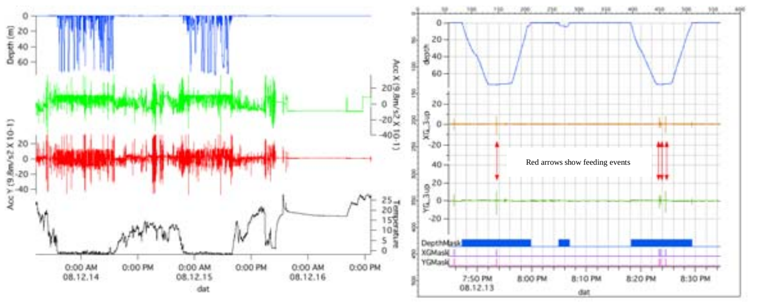

Fig. 2. Data on depth, acceleration x, y and temperature were processed using Igor Pro (upper left). Based on these data high frequency acceleration (>3Hz) was filtered and shallow dives (< 0.5m) and slow accelerations (<0.3G) were masked out using IFDL and Ethographer (see mask column of upper right figure). Red arrows indicate feeding events on x and y axes. “DepthMask”, “XGMask” and “YGmask” columns indicate dive duration exceeding 0.5m depth, and acceleration events on x and y axes exceeding 0.3G level respectively.

Table 2. Wed16 Feeding events summary (No. dives, time, feeding depth, Peak level of feeding acceleration (x10-1G) in

No. of feeding	Dive	Time at dive	Feedng depth	X up	X down	Y up
1	1	19:53:30	72.7	7.7	10.9	10.6
2	2	20:24:00	72.5	6.6	4.2	5.2
3			72.7	3	3.7	6
4			72.3	7.4	8.9	10.5
5	3	21:21:30	72.7	4.2	3.7	7
6	4	21:59:30	18.2	17.4	21.2	20.5
7	5	0:27:05	46.4	10.1	10.7	16.5
9			46.4	6.2	8.9	19.6
10			46.4	15.4	11.6	6.7
11			46.4	20.1	15.2	20.4
12	6	0:41:15	16.4	8.3	10.8	16.3
13	7	0:54:10	56.9	23	23.8	28.3
14	8	1:25:00	2.7	3.5	2.5	
15	9	1:40:00	1.6	4.1	4.2	3.6
16	10	2:25:00	16.7	7.7	8.2	15
17			15.9	10.5	13.4	11.1
18			15.6	3.8	2.9	3.1
19	11	3:57:15	1	10.5	8.9	13.3
20	12	4:42:25	33.7	3.3	2.7	
21			33.7	13.7	14.5	10.4
22			33.7	9.7	7.9	13.6
23	12	4:57:30	15.3	3.7	6.1	
24	14	5:39:00	0.8	13.1	17.8	7.8
25				11.9	6.8	13.6
26	15	22:43:30	17.7	6.8	30.5	41
27			13.3	11.2	7.1	12.4
28	16	23:50	4.1			4.7
29			4	2.9	3	3.2
30			4.6	5.3	3.7	5.3
31			4.9	9	5.6	5.3
32			4.1			4.1
33			4.8	6.3	7.3	8.9
34	17	0:45:00	6.9			3.1
35	18	2:02:45	72.4			7.3
36			72.6			4.5
37	19	2:02:30	1.7	4.7	7	7.5
38			2.2			3.4
39	20	2:53:45	73.4			4.4
40			74.6	4.6	4	2.9
41	21	3:30:00	73	3.1	3.4	4.9
42	22	4:20:30	76.8	3.8	3.5	6.4
43			76.8	4.8	4.5	4.2
44			71.5	4.1	5.7	6
45	23	5:02:40	3.3	3.4	2.6	7.6
46	24	5:33:30	35.3	33.1	30.5	38.8
47	25	6:10:00	65.1	2.4	2.9	3.4
48			64.8	3.9	2.6	8.1
49	26	7:42:25	0.6	22.5	19	20.1

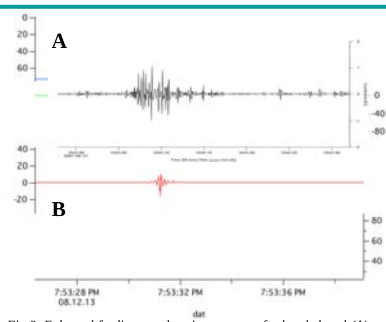

Fig 3. Enlarged feeding acceleration pattern of a hooded seal (A) and a Weddell seal (B - this study). The enlarged acceleration pattern was used to identify feeding events according to the results from analogue jaw acceleration experiments in hooded seals (Suzuki et al. 2009). Feeding accelerations were characterized by quick up and down accelerations of short duration. Three harp seals were fed with herring by “ram” feeding mode. The feeding event in this study occurred in short duration (<1s) which was shorter than feeding events of Weddell seals as reported by Liebsch et al. (2007) with a mean duration of 2.8s (S.D.:3.1) including benthic feeding events. It is likely that the short feeding duration was due to small prey items ingested in “suction feeding mode”. This type of feeding pattern was observed during bottom phases of U-shaped dives in midwater depths. Not any dives to the bottom were observed in this study.

Table 2. Summary of vocalization by Wed16. Accelerations of Y axis were measured at peak value .

No. vocalization	Time	Duration (s)	Depth (m)	Acc level (+)	Acc level (-)
1	20:56:20	10	4.3	5.1	3.5
2	21:42:40	12.3	7.5	8.8	6.3
3	3:30:40	11.3	3.3	5	3.2
4	5:01:15	7.2	8.2	1.6	2.1
5	5:02:25	14.4	9.5	2.2	2
6	21:42:30	8.8	9.9	6.2	4.8
7	21:43:30	9.5	5.5	6.5	5.8
8	22:06:30	10.6	0.8	3.8	3
9	22:16:20	20.1	1.4	7.4	4.4
10	0:45:50	11.8	17.1	2.2	3.1
11	0:47:30	24.5	16.8	11.6	10.5
12	3:52:55	4	1.6	2.8	2.1
13	5:00	18.1	18	8.1	4.1
14	5:01:00	19.5	4.6	14.1	12.5
15	7:37:00	16	0.8	13.7	12.2

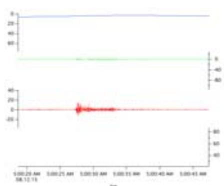

Fig. 5. Distinct patterns of accelerations were sometimes found in shallow dives (<20m), and are considered being a proxy for vocalization.

Conclusions

- The measurement of jaw acceleration is a distinctive proxy for feeding activity in free ranging Weddell seals
- The method is sensitive for small events e.g. caused by suction feeding
- The method is assumed being sensitive for vocal activity
- For documentation of underwater behavior and identification of species of prey and its actual ingestion, jaw acceleration loggers and flash camera loggers should be combined