# **Detection of Grooming Behaviours with an Acceleration Data** Logger in a Captive Northern Fur Seal (*Callorhinus ursinus*)

Takashi Iwata,<sup>1</sup> Shiroh Yonezaki,<sup>2</sup> Kaoru Kohyama,<sup>3</sup> and Yoko Mitani<sup>4</sup>

<sup>1</sup>Department of Polar Science, The Graduate University for Advanced Studies,

10-3 Midori-cho, Tachikawa, Tokyo 190-8518, Japan

<sup>2</sup>National Research Institute of Far Seas Fisheries, Fisheries Research Agency, 2-12-4 Fukuura,

Kanazawa, Yokohama, Kanagawa 236-8648, Japan

<sup>3</sup>Izu Mito Sea Paradise, 3-1 Uchiuranagahama, Numazu, Shizuoka 410-0295, Japan

<sup>4</sup>Field Science Center for Northern Biosphere, Hokkaido University, 3-1-1 Minato-cho,

Hakodate, Hokkaido 048-8611, Japan

E-mail: yo\_mitani@fsc.hokudai.ac.jp

Current address for Takashi Iwata: International Coastal Research Center, Atmosphere and Ocean Research Institute,

The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa City, Chiba Prefecture, 277-8564, Japan

## Abstract

Northern fur seals (Callorhinus ursinus) continue to dive and forage during foraging trips in cold water. Although their dense fur may prevent a decrease in body temperature, they must spend considerable time grooming to maintain a layer of trapped air in their fur. This study examined grooming and shaking behaviours, which are high-energy cost movements, using an acceleration data logger to accurately estimate the energy budget of these aquatic mammals. The authors examined the consistency between the behavioural records obtained using an animal-borne acceleration data logger and video observations of a captive northern fur seal. Grooming behaviour was defined as rubbing the body with its flippers with rolling that was occasionally associated with shaking. Grooming behaviour was detected by low-frequency components of lateral and dorsoventral acceleration resulting from rolling and high-frequency components of lateral acceleration resulting from rubbing and shaking. These observations show that the grooming and shaking behaviours of northern fur seals can be accurately detected using an acceleration data logger. We suggest that the energy budgets of free-ranging northern fur seals can be more accurately estimated using an index of energy costs and benefits captured using an acceleration data logger.

**Key Words:** acceleration data logger, grooming behaviour, northern fur seal, *Callorhinus ursinus*, energy cost

#### Introduction

Fur is advantageous for insulation and buoyancy in aquatic mammals (Fish et al., 2002). However, fur is easily fouled and can be compressed in water (Costa & Kooyman, 1982; Kruuk & Balharry, 1990). Grooming behaviour restores the air layer in the fur and is necessary to ensure insulation in furred mammals living in aquatic environments. This has been confirmed and studied by direct observation in aquatic mammals such as pinnipeds and sea otters (Liwanag, 2010). These animals rub the fur with their hands or pectoral flippers during grooming while rolling on the surface of the water and sometimes shaking their bodies to remove water contained in the fur to prevent it from compressing and fouling (Fish et al., 2002).

Northern fur seals (Callorhinus ursinus) are a top predator in the North Pacific Ocean (Gentry & Kooyman, 1986). Northern fur seals have one of the thickest fur coats of any mammal, following the aquatic and semi-aquatic mustelids such as the sea otter (Enhydra lutris) and the North American river otter (Lontra canadensis) (Scheffer, 1964; Liwanag et al., 2012). The skin temperature of adult fur seals is maintained higher than that of ambient water or air, indicating that the fur of these animals serves an important insulation function (Irving et al., 1962). Therefore, grooming during a foraging trip is essential. Previous studies of captive northern fur seals using openflow respirometry have shown that the grooming behaviour resulted in significant increases in metabolic rate relative to rest (Liwanag, 2010). Other studies have reported that 16% of each day is spent grooming in the captive Guadalupe fur seal (Arctocephalus townsendi) (Feldman & Parrott,

1996), and 9% of the day is spent grooming in free-ranging sea otters (Yeates et al., 2007).

The proportion of time spent on grooming was considered high in these studies. Detecting and monitoring grooming behaviour are important to estimate the energy budgets of free-ranging northern fur seals. When direct observations are impossible, animal-borne data loggers have been used to assess the behaviour of aquatic mammals (Le Boeuf et al., 1988). Although many studies have investigated the diving behaviour of free-ranging northern fur seals (Goebel et al., 1991; Ponganis et al., 1992; Sterling & Ream, 2004; Kuhn et al., 2010), there is little information about grooming in these seals in the ocean. For example, Insley et al. (2007) used acoustic data loggers to measure the behavioural activity budget during a foraging trip and showed active surface time defined as irregular non-dive-related movements while the northern fur seal was at the surface, evidenced by multiple noisy events such as rhythmic rubbing-like sounds and broadband signals in the acoustic record; however, grooming behaviour was not identified. Thus, a new technique is required to examine the detailed movements of animals under natural conditions. The acceleration data logger has been used to measure propulsion stroke, porpoising, and pitch angle of diving marine animals (Yoda et al., 2001; Sato et al., 2003; Watanabe et al., 2004, 2012). In this study, we examined consistency between behavioural records obtained from an animal-borne acceleration data logger and video observations of a captive northern fur seal to detect grooming behaviour.

## Methods

The experiments were conducted at the Izu Mito Sea Paradise in Shizuoka, Japan, in October 2008 with a captive northern fur seal (length: 106 cm, body mass: 26 kg) that arrived at the aquarium 1.5 y ago. The instrument was attached between the scapulae on the dorsal fur along the spine using quick-setting epoxy while the seal was physically restrained or sedated using a sedative (Horizon, Astellas, Tokyo, Japan) and anaesthetic (Zoletil100, Virbac Laboratories, Carros CEDEX, France). The seal was released into a pool (length: 6 to 10 m; width: 22 m; depth: 4 m; volume: 600 tons) after recovery from anaesthesia. The acceleration data logger (diameter  $\times$  length: 26  $\times$  174 mm; weight in air: 135 g; 3MPD3GT, Little Leonardo Ltd, Tokyo, Japan) recorded the diving depth, temperature, swimming speed, three axes of magnetic field intensity at 1 Hz, and three axes of acceleration (longitudinal, lateral, and dorsoventral) at 16 Hz (Figure 1). Swimming behaviour of the northern fur seal was recorded using three digital video cameras (SDR-S300, Panasonic, Osaka, Japan; IXY-DV-M5, Canon, Tokyo, Japan; HDR-HC3, Sony Corporation, Tokyo, Japan), while acceleration data using the data logger was collected. The data logger was recovered after the experiments.

The authors analysed the depth and acceleration data using *IGOR Pro*, Version 6.0 (WaveMetrics,



Figure 1. Schematic diagram showing the directions of surge (dotted arrow), sway (black arrow), and heave (grey arrow) axes of the data logger attached to the back of a northern fur seal

Inc., Lake Oswego, OR) and Ethographer (Sakamoto et al., 2009), which is plug-in software in IGOR. Grooming was defined as both rolling on the surface of the water and rubbing the fur with the flippers following Liwanag (2010). If the depth was  $\leq 0.5$  m, it was classified as a *surface* behaviour. Using software IFDL (IGOR Filtering Design Laboratory [IFDL], WaveMetrics, Inc., USA), the three axes of acceleration data measured by the logger were broken into a static component related to the orientation of the animal with respect to gravity and a dynamic component imposed by specific movements such as walking and swimming (Yoda et al., 2001; Sato et al., 2003; Watanabe et al., 2012). For example, a static component of longitudinal acceleration is used to distinguish a posture of a penguin such as standing (ca. 9.8 m/s<sup>2</sup>) and lying (ca. 0 m/s<sup>2</sup>). And standing on land and walking can be distinguished using a dynamic component of accelerations because the large lateral swings of walking penguins affect the acceleration pattern recorded by loggers (Yoda et al., 2001).

Rolling was defined as the movement of the northern fur seal around its longitudinal axis. A rolling cycle lasted 1.5 to 10 s (Figure 2). Therefore, low-frequency (< 0.6 Hz), gravity-based acceleration in the lateral and dorsoventral directions was used to detect rolling on the surface. We used spectral analysis and k-mean clustering in *Ethographer* (Sakamoto et al., 2009) to derive the long-period (1.5 to 10 s) oscillations resulting from rolling activity. If a long-period oscillation was detected from both lateral and dorsoventral acceleration axes by the k-means cluster every second, the activity was categorised as *rolling*. And if *rolling* was classified during *surface*, we called it *surface rolling*.

When rubbing, the northern fur seal rolled to its side and moved the upper pectoral flipper side to side to rub the fur 1 to 3 times/s. These pectoral flipper movements were detected from highfrequency components ( $\geq 0.6$  Hz) of dorsoventral acceleration. After extracting the high-frequency components, the remaining peaks and troughs were considered to be the oscillating motion of pectoral *flipper movement* if the gap between the positive peak and neighbouring negative peak  $> 1.0 \text{ m/s}^2$  was within a 0.5-s window (Figure 2). And when *flipper movement* was detected during surface rolling, we called it surface rolling-F. A northern fur seal uses its flipper to rub its fur; however, strokes during rolling without rubbing were also detected using this definition. Thus, rubbing could not be distinguished from stroking. To solve this problem, we used high-frequency components (> 3 Hz) of lateral acceleration. During rubbing, high-frequency components of lateral acceleration showed larger amplitudes

(Figure 2b). If the maximum absolute amplitude of the high-frequency components of lateral acceleration in a 1-s window was >  $1.5 \text{ m/s}^2$ , the activity was categorised as *grooming-associated*. A major source of these high-frequency components was from the northern fur seal scrubbing its fur and skin near where the data logger was attached. In contrast, the amplitude of high-frequency components during rolling without rubbing was lower (Figure 2a). *Grooming* behaviours identified from the logger data during the depth data were classified as *surface rolling* with *grooming-associated* activities.

Shaking activity could also be detected from high-frequency components, and the amplitude was much higher than that of rubbing. *Shaking* was defined as the peaks and troughs with absolute values >  $20 \text{ m/s}^2$  occurring more than two times within 1 s using the high-frequency components of the lateral acceleration data.

### Results

Surface rolling behaviours were observed during the video observations at 11 surface phases, and ten of them are associated with grooming. One surface rolling event without grooming occurred just after we added a live Japanese jack mackerel (*Trachurus japonicus*) to the tank to monitor foraging behaviour (Iwata et al., 2009), but the northern fur seal failed to catch the fish because it escaped under the slope. In the video, the seal rolled with its head down and looked for the fish on the surface after a chasing dive.

From the logger data, *surface rolling* was found in 13 surface phases. All of the *surface rolling* included *flipper movement*; therefore, they were classified as *surface rolling-F*. Ten of these behaviours were the same as the surface phases, including the grooming behaviour in the video observations. One case was a surface phase when the northern fur seal rolled without rubbing, which was described above. In the other two cases, *surface rolling-F* behaviour was detected when the seal turned with its side down while stroking just before it submerged.

*Grooming* behaviour from the logger data was detected from 11 surface phases. Ten of these were the same surface phase as the grooming behaviour observed during video observations. In one other case, only shaking with no rubbing was observed.

Shaking was recorded eight times, all of which were at exactly the same times as the video observations. Shaking duration, cycle, and frequency were  $1.6 \pm 0.3$  s (0.8 to 1.8 s),  $10.9 \pm 2.1$  cycles (6 to 13 cycles), and  $7.1 \pm 0.7$  Hz (5.5 to 7.7 Hz), respectively.







Figure 3. An example of the results classification for the shaking behaviour (arrow) as observed on video. The vertical axes are in  $m/s^2$ .

### Discussion

The results of the current study show that grooming behaviour can be detected from an acceleration data logger placed on the back of a northern fur seal. Grooming behaviour was detected in the video observations by the depth data ( $\leq 0.5$  m), the low-frequency (< 0.6 Hz) components of lateral and dorsoventral acceleration, and the highfrequency (> 3 Hz) components of lateral acceleration when grooming behaviour was defined as rubbing motions with a rolling movement. The high-frequency components of lateral acceleration data were considered because of the subtle motion of the skin during scrubbing.

Shaking is very important because water is removed from the fur to dry the animal (Dickerson et al., 2012). Therefore, shaking the head may be effective to dry the neck and head fur above the sea surface. The frequency of acceleration during shaking was 7 Hz; therefore, recording accelerations at 16 Hz may have been a lower limit in detecting this behaviour. The number of shaking bouts in the lateral acceleration data was exactly the same as that in the video observation data. In a previous study, the authors examined matches between the acceleration records obtained from an animal-borne data logger and video observations of prey captured by a captive northern fur seal (Iwata et al., 2009). However, some prey-capture events were not detected accurately because they can be very complex movements. In comparison, grooming and shaking behaviours were accurately detected in this study because these two behaviours are simpler movements. When we observed free-ranging northern fur seals in the ocean, grooming and shaking behaviours were rarely different from those of a northern fur seal under captive conditions (Iwata & Mitani, unpub. data). Therefore, we suggest that the grooming behaviour study methods utilizing acceleration data of the northern fur seal used here, although it was only one animal, could be adapted to detect grooming behaviour and shaking in free-ranging northern fur seals.

Grooming behaviour in furred aquatic mammals could have two purposes: (1) restoring the effectiveness of insulation and (2) serving to counteract heat loss in cold water by increased heat production (Liwanag, 2010). Therefore, aquatic mammals must groom to prevent fouling and compression of the fur, although the energy cost of grooming is high for aquatic mammals (Williams, 1989; Yeates et al., 2007; Liwanag, 2010). Shaking is thought to be a movement to keep the fur clean. Some acceleration data logger studies have detected detailed movements such as stroking, high-frequency body movements (e.g., porpoising), and events associated with prey capture (e.g., sudden turns and lunge) in free-ranging aquatic animals (Yoda et al., 2001; Sato et al., 2003; Kokubun et al., 2011; Iwata et al., 2012). These movements provide crucial information to quantitatively estimate animal energy budgets. In addition to these movements, grooming behaviour must be detected to accurately estimate energy budgets in furred, freeranging aquatic animals because the energy cost of grooming is high. We detected shaking as an intense, high-frequency movement, which is considered to have a higher energy cost than grooming because the shaking acceleration data were of a high amplitude compared with grooming acceleration data. Using our methods, the energy budgets of the free-ranging northern fur seals could be more accurately estimated using an index of energy cost (grooming, shaking, and stroke) and benefit (prey-capture event).

#### Acknowledgments

We would like to thank the staff at Izu Mito Sea Paradise where the experiment was conducted, and we thank A. Takahashi for lending data loggers. Y. Yamamoto, M. Iwasaki, and K. Hirano provided valuable field assistance. This study was conducted under the fur seal research permit issued by the Ministry of Agriculture, Forestry and Fisheries, Japan. All procedures and management for the northern fur seal were in accordance with the Code of Ethics of the Japanese Association of Zoos and Aquariums. This study was carried out as a part of the International Fisheries Resources Survey Promotion Program supported by Fisheries Agency, Japan. This study was financially supported in part by JSPS Research Fellowship for Young Scientists (18-5512).

#### Literature Cited

- Costa, D. P., & Kooyman, G. L. (1982). Oxygenconsumption, thermoregulation, and the effect of fur oiling and washing on the sea otter, *Enhydra lutris*. *Canadian Journal of Zoology*, 60(11), 2761-2767. http://dx.doi.org/10.1139/z82-354
- Dickerson, A. K., Mills, Z. G., & Hu, D. L. (2012). Wet mammals shake at tuned frequencies to dry. *Journal of the Royal Society Interface*, 9, 3208-3218. http://dx.doi. org/10.1098/rsif.2012.0429
- Feldman, H. N., & Parrott, K. M. (1996). Grooming in a captive Guadalupe fur seal. *Marine Mammal Science*, 12(1), 147-153. http://dx.doi.org/10.1111/j.1748-7692.1996.tb00313.x

- Fish, F. E., Smelstoys, J., Baudinette, R. V., & Reynolds, P. S. (2002). Fur doesn't fly, it floats: Buoyancy of hair in semi-aquatic mammals. *Aquatic Mammals*, 28(2), 103-112.
- Gentry, R. L., & Kooyman, G. L. (1986). Fur seals: Maternal strategies on land and at sea. Princeton, NJ: Princeton University Press.
- Goebel, M. E., Bengtson, J. L., Delong, R. L., Gentry, R. L., & Loughlin, T. R. (1991). Diving patterns and foraging locations of female northern fur seals. *Fishery Bulletin*, 89, 171-179.
- Insley, S. J., Robson, B. W., Yack, T., Ream, R. R., & Burgess, W. C. (2007). Acoustic determination of activity and flipper stroke rate in foraging northern fur seal females. *Endangered Species Research*, 3(7), 1-9.
- Irving, L., Peyton, L., Bahn, C., & Peterson, R. (1962). Regulation of temperature in fur seals. *Physiological Zoology*, 35(4), 275-284.
- Iwata, T., Mitani, Y., Yonezaki, S., Kohyama, K., & Takahashi, A. (2009). Validation of acceleration records to monitor swimming and prey capture behavior in the captive northern fur seal. *Nippon Suisan Gakkaishi*, 75(6), 989-994. [In Japanese with English abstract]. http://dx.doi.org/10.2331/suisan.75.989
- Iwata, T., Sakamoto, K. Q., Takahashi, A., Edwards, E. W. J., Staniland, I. J., Trathan, P. N., & Naito, Y. (2012). Using a mandible accelerometer to study finescale foraging behavior of free-ranging Antarctic fur seals. *Marine Mammal Science*, 28(2), 345-357. http:// dx.doi.org/10.1111/j.1748-7692.2011.00482.x
- Kokubun, N., Kim, J. H., Shin, H. C., Naito, Y., & Takahashi, A. (2011). Penguin head movement detected using small accelerometers: A proxy of prey encounter rate. *Journal of Experimental Biology*, 214(22), 3760-3767. http://dx.doi.org/10.1242/jeb.058263
- Kruuk, H., & Balharry, D. (1990). Effects of sea-water on thermal insulation of the otter, *Lutra lutra. Journal of Zoology*, 220(3), 405-415. http://dx.doi.org/10.1111/j. 1469-7998.1990.tb04315.x
- Kuhn, C. E., Tremblay, Y., Ream, R. R., & Gelatt, T. S. (2010). Coupling GPS tracking with dive behavior to examine the relationship between foraging strategy and fine-scale movements of northern fur seals. *Endangered Species Research*, *12*(2), 125-139. http://dx.doi.org/10.3354/esr00297
- Le Boeuf, B. J., Costa, D. P., Huntley, A. C., & Feldkamp, S. D. (1988). Continuous, deep diving in female northern elephant seals, *Mirounga angustirostris. Canadian Journal of Zoology*, 66(2), 446-458. http://dx.doi.org/ 10.1139/z88-064
- Liwanag, H. E. M. (2010). Energetic costs and thermoregulation in northern fur seal (*Callorhinus ursinus*) pups: The importance of behavioral strategies for thermal balance in furred marine mammals. *Physiological and Biochemical Zoology*, 83(6), 898-910. http://dx.doi.org/ 10.1086/656426
- Liwanag, H. E. M., Berta, A., Costa, D. P., Abney, M., & Williams, T. M. (2012). Morphological and thermal properties of mammalian insulation: The evolution of

fur for aquatic living. *Biological Journal of Linnean Society*, *106*(4), 926-939. http://dx.doi.org/10.1111/j. 1095-8312.2012.01900.x

- Ponganis, P. J., Gentry, R. L., Ponganis, E. P., & Ponganis, K. V. (1992). Analysis of swim velocities during deep and shallow dives of 2 northern fur seals, *Callorhinus ursinus. Marine Mammal Science*, 8(1), 69-75. http:// dx.doi.org/10.1111/j.1748-7692.1992.tb00126.x
- Sakamoto, K. Q., Sato, K., Ishizuka, M., Watanuki, Y., Takahashi, A., Daunt, F., & Wanless, S. (2009). Can ethograms be automatically generated using body acceleration data from free-ranging birds? *PLOS ONE*, 4, 1-12. http://dx.doi.org/10.1371/journal.pone.0005379
- Sato, K., Mitani, Y., Cameron, M. F., Siniff, D. B., & Naito, Y. (2003). Factors affecting stroking patterns and body angle in diving Weddell seals under natural conditions. *Journal of Experimental Biology*, 206(9), 1461-1470. http://dx.doi.org/10.1242/jeb.00265
- Scheffer, V. B. (1964). Hair patterns in seals (pinnipedia). Journal of Morphology, 115(2), 291-303. http://dx.doi. org/10.1002/jmor.1051150211
- Sterling, J. T., & Ream, R. R. (2004). At-sea behavior of juvenile male northern fur seals (*Callorhinus ursinus*). *Canadian Journal of Zoology*, 82(10), 1621-1637. http:// dx.doi.org/10.1139/z04-136
- Watanabe, S., Sato, K., & Ponganis, P. J. (2012). Activity time budget during foraging trips of emperor penguins. *PLOS ONE*, 7, e50357. http://dx.doi.org/10.1371/journal. pone.0050357
- Watanabe, Y., Baranov, E. A., Sato, K., Naito, Y., & Miyazaki, N. (2004). Foraging tactics of Baikal seals differ between day and night. *Marine Ecology Progress Series*, 279, 283-289. http://dx.doi.org/10.3354/meps279283
- Williams, T. M. (1989). Swimming by sea otters: Adaptations for low energetic cost locomotion. *Journal of Comparative Physiology A*, 164(6), 815-824. http://dx.doi.org/10.1007/ BF00616753
- Yeates, L. C., Williams, T. M., & Fink, T. L. (2007). Diving and foraging energetics of the smallest marine mammal, the sea otter (*Enhydra lutris*). *Journal of Experimental Biology*, 210(11), 1960-1970. http://dx.doi.org/10.1242/ jeb.02767
- Yoda, K., Naito, Y., Sato, K., Takahashi, A., Nishikawa, J., Ropert-Coudert, Y., . . . Le Maho, Y. (2001). A new technique for monitoring the behaviour of free-ranging Adelie penguins. *Journal of Experimental Biology*, 204(4), 685-690.