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Using an omnidirectional video logger to observe the underwater life of marine animals: Humpback whale resting behaviour

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ABSTRACT

Animal-borne video loggers are powerful tools for investigating animal behaviour because they directly record immediate and extended peripheral animal activities; however, typical video loggers capture only a limited area on one side of an animal being monitored owing to their narrow field of view. Here, we investigated the resting behaviour of humpback whales using an animal-borne omnidirectional video camera combined with a behavioural data logger. In the video logger footage, two non-tagged resting individuals, which did not spread their flippers or move their flukes, were observed above a tagged animal, representing an apparent bout of group resting. During the video logger recording, the swim speed was relatively slow (0.75 m s^{-1}), and the tagged animal made only a few strokes of very low amplitude during drift diving. We report the drift dives as resting behaviour specific to baleen whales as same as seals, sperm whales and loggerhead turtles. Overall, our study shows that an omnidirectional video logger is a valuable tool for interpreting animal ecology with improved accuracy owing to its ability to record a wide field of view.

1. Introduction

Over the past 30 years, animal-borne recording devices were increasingly utilised in animal ecology studies, especially for marine animals that direct observations are rarely possible (Hays et al., 2016). For instance, depth and swim speed sensors, global positioning system receivers, and tri-axial acceleration monitors that deduce animal motion and posture were used to investigate the foraging behaviour of various marine mammals (Boyd et al., 1999; Goldbogen et al., 2006; Horsburgh et al., 2008; Iwata et al., 2015). In addition, migration and diving physiology were investigated using satellite transmitters, acoustic telemetry, heart-rate sensors, and blood-sampling devices (Goldbogen et al., 2019; Hazen et al., 2012; Hussey et al., 2015; McDonald and Ponganis, 2014; Ponganis et al., 2011).

Video loggers are powerful tools for the direct observation and comprehension of animal behaviour since they capture images of the surrounding environment of a focal animal (Davis et al., 1999; Goldbogen et al., 2013; Hooker et al., 2002); however, typical video loggers can only provide footage of a limited area on one side of an animal being recorded owing to their narrow angle of view. A previous study on humpback whales (*Megaptera novaeangliae*) using animal-borne camera loggers showed that the presence or absence of direct competitors feeding on the same prey affected the foraging behaviour of a tagged whale (Akiyama et al., 2019). Specifically, the feeding duration of the tagged animal was shorter in the presence of other individuals (Akiyama et al., 2019). Nevertheless, the presence of competitors could not be confirmed outside the narrow viewing angle of the video logger. Thus, a camera with a wider angle of view could more effectively record various parameters in the prey environment, such as density; distribution; and the presence or absence of co-operators, predators, and/or inter/intra-specific competitors.

The humpback whale is a cosmopolitan species of baleen whale (Clapham and Mead, 1999), and their behaviour, especially foraging behaviour, has been investigated extensively using animal-borne data loggers (Friedlaender et al., 2016; Goldbogen et al., 2008; Tyson et al., 2012; Ware et al., 2014; Witteveen et al., 2008). The foraging behaviour

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of rorqual baleen whales can be identified using particular signal patterns of swim speed and acceleration data (Goldbogen et al., 2006). However, only a few studies have investigated the resting behaviour of baleen whales since it is difficult to identify resting behaviour from only behavioural data. This is because resting and slow transiting traits are similar to each other, and share characteristics with less active motion and slow swim speed (Friedlaender et al., 2014; Tyson et al., 2012). Furthermore, the behaviour of individuals surrounding an animal with an attached wide-view video logger can be more easily observed than that of a tagged animal. If video data loggers record the resting behaviour of other animals in the vicinity of a tagged animal, and behavioural data loggers simultaneously record the inactive behaviour of the tagged animal (little or no motion data from an accelerometer and very slow swimming speed data from a speed sensor), the behaviour of the tagged animal may also be defined as resting. Thus, data obtained from the behavioural data logger can be corroborated by data from the wide-angle video logger and vice versa.

Acquiring information on the resting behaviour of animals is necessary to understand their ecology. Although resting is essential for animals, they must employ a predator avoidance strategy since the predation risk is higher during that time (Lima et al., 2005). Furthermore, resting time represents only a small percentage of their time budget (Siegel, 2005), because increased resting time decreases the amount of time allocated towards other behaviours (i.e., foraging). Short resting bouts probably contribute to minimising predation risk, observing conspecific behaviours, and looking after calves. Studies on the resting behaviour of captive toothed whales showed that they employ unihemispheric sleep, whereby one of the cerebral hemispheres is awake while the other is asleep (Mukhametov et al., 1977; Sekiguchi and Kohshima, 2003). By employing unihemispheric sleep, animals avoid obstacles and breathe voluntarily during sleep at sea (Rattenborg et al., 2000; Siegel, 2005). Miller et al. (2008) suggested that wild sperm whales employ unihemispheric sleep on or close to the sea surface and bihemispheric sleep during drift dives. Although tag data showed that Bryde's whales (*Balaenoptera brydei*) rest at night (Izadi et al., 2018), knowledge of the resting behaviour of baleen whales remains limited, especially by direct observation.

Here, we report the resting behaviour of humpback whales using an animal-borne omnidirectional video logger with a 270° underwater angle of view. We also report the swim speed and tri-axial acceleration characteristics during resting using a behavioural data logger and examine the consistency between the behavioural data logger and video logger records.

2. Materials & methods

2.1. Fieldwork

Field surveys were conducted in January 2016, off the coast of Vengsoya, Norway. The underwater behaviour of a single humpback whale was measured using bio-logging. We carefully approached the whale on board a 6 m boat and attached a suction-cup tag using a 6 m carbon fibre pole (Aoki et al., 2015; Baird, 1998; Johnson and Tyack, 2003). The tag included a behavioural data logger (ORI400-PD3GTC; diameter × length: 16 × 74 mm; 29 g mass in the air; Little Leonardo, Tokyo, Japan), an omnidirectional video camera (DVL-THETA, length × width × height: 136 × 42 × 23 mm; 118 g mass in air, Little Leonardo Ltd., Tokyo, Japan), a very high frequency (VHF) transmitter (Advanced Telemetry Systems, USA), and a satellite transmitter (SPOT5; Wildlife Computers, USA). The ORI400-PD3GTC logger records diving depth, temperature, conductivity, and swim speed at 1 Hz as well as surge, heave, and sway accelerations at 20 Hz. The DVL-THETA omnidirectional camera records 15 frames per second with a 360° field-of-view on land and an approximately 270° field-of-view underwater. The camera is composed of two lenses with a 180° field-of-view on each side on land, and distortion needs to be corrected for when measuring object distances and sizes. Some modules of the DVL-THETA video camera were provided by RICOH, while Little Leonardo engineered the waterproofing using epoxy glue. The tag was naturally detached after several hours. The data loggers were retrieved using ARGOS satellite telemetry to locate the general area of the floating tag along with VHF transmitter signals to determine the precise location for tag recovery. Fieldwork in Norway was carried out under a permit issued by the Norwegian Food Health Authority (FOTS ID 8165).

2.2. Analysis of behavioural data

We analysed depth, speed, and acceleration data using IGOR Pro version 6.0 (WaveMetrics, Portland, OR, USA). As measured by power spectral density, the fluke stroke of the tagged whale was detected as the dominant cycle frequency of the longitudinal acceleration data. The calculations showed a dominant cycle frequency of approximately 0.14 Hz. Dynamic acceleration signals higher than 0.13 Hz were separated from the raw acceleration data using a high-pass filter. Small noises caused by the high-frequency vibration of the tag were eliminated using a 0.5 Hz low-pass filter. Peaks of dynamic acceleration were represented fluke strokes when their absolute amplitudes were greater than a threshold determined at 0.15 m s^{-2} by visual inspection (Sato et al., 2003a). Swim speed was recorded as the number of rotations per second of an external propeller and was converted to swim speed (m s^{-1}) as previously described (Sato et al., 2003a). Swim speeds slower than the stall speed of 0.2 m s^{-1} were not included in the analysis. Diving was defined as spending longer than 10 s continuously at a depth greater than 5 m. During submerging deeper than 5 m, only a few seconds are considered as breathing and not diving time.

3. Results

Approximately 11 h of behavioural data (1112–2204 h, on 26 January 2016) and approximately 1 h of video footage data (1229–1347 h) were obtained from loggers attached to a humpback whale. As shown in Fig. 1a, there was a distinct change in the activity of the tagged whale at 1619 h. Before this time, the animal exhibited inactive behaviour with a relatively low mean stroke rate during diving (0.5 ± 0.8 per min) and slow mean swimming speed during drift diving (0.95 ± 0.29 m s^{-1}). After 1619 h, the mean stroke rate during diving was higher (1.9 ± 0.8 per min), the mean swimming speed during diving was faster (1.7 ± 0.23 m s^{-1}), and the pitch angle oscillation was larger (Fig. 1a). The video logger recorded for 1 h while the whale was inactive.

3.1. Inactive dives

In the 1 h period during which the video logger successfully recorded the footage, a total of 20 inactive dives were recorded by the behavioural data logger (Fig. 1b). The mean dive depth (± standard deviation; SD) of the inactive dives was 11 ± 4 m, with a maximum value of 19 m, whereas the mean dive duration was 95 ± 67 s, with a maximum value of 272 s (n = 20 dives). During the inactive dives, the swim speed was 0.75 ± 0.21 m s^{-1} (n = 20 dives). During the inactive dives, the swim speed was the highest at the beginning of the descent phase, gradually decreased towards the end, and then increased slightly towards the end of the approximately 5 m ascent phase (Fig. 1c).

3.2. Stroke signals

Stroke signals during the inactive dives of the tagged animal were documented nine times in the video recording period. The tagged animal was probably slightly positive buoyant throughout the dive because it ascended without making any strokes or with strokes of very low amplitude. The swim speed of the animal slightly increased towards the end of the ascent, which could be attributed to a change in buoyancy.

Two individuals were observed above the tagged animal throughout

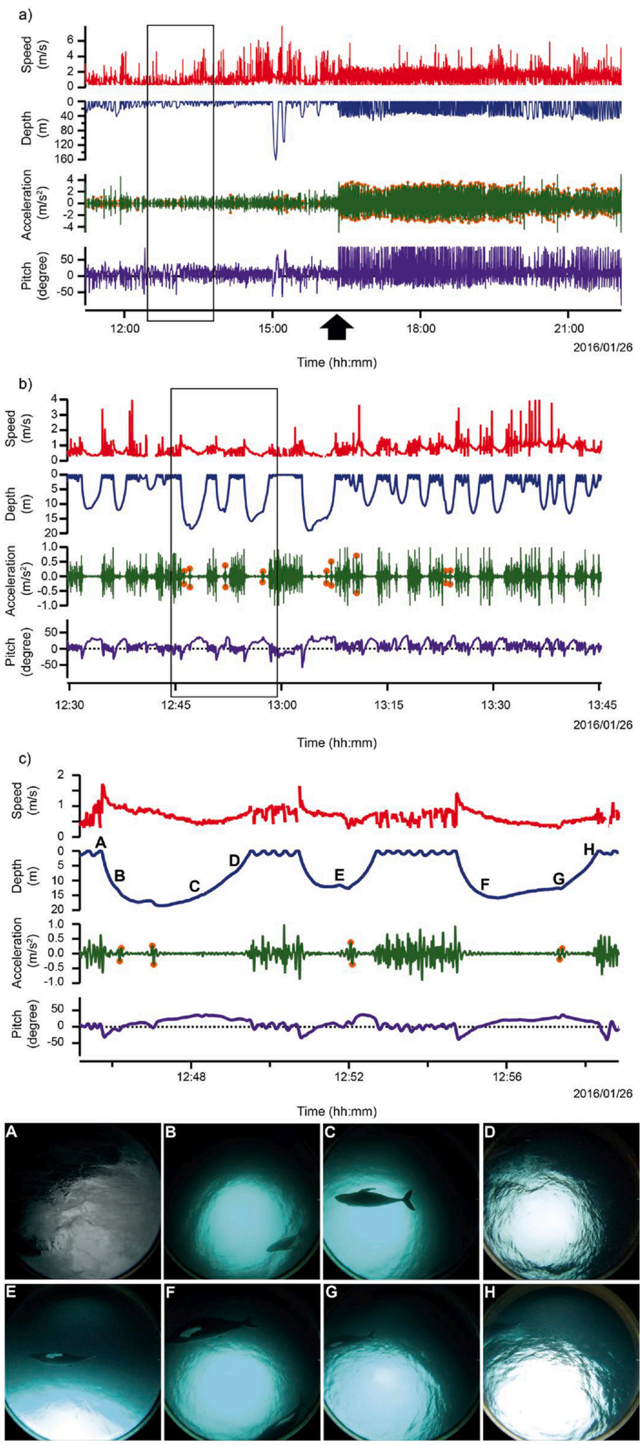

Fig. 1. Time series records of swim speed, depth, high-frequency components of longitudinal acceleration, and pitch angle as obtained from the behavioural data logger. The orange dots on the dynamic acceleration graph indicate fluke strokes. a) Records for the entire tagged period (11 h). Black arrow indicates 1619 h before which the tagged whale exhibited inactive behaviour and after which exhibited active behaviour. The black-outlined rectangular segment shows the entire period of video logger recording; b) Enlarged record of the black-outlined rectangular segment from a). All dives are resting. Few stroke signals with very low amplitude are shown; c) Three drift dives (A–D, E, and F–H) from the enlarged record of the black-outlined rectangle segment in b) and video images. A–H on the depth graph correspond to those on the video images. Image A shows water splashing at the beginning of the dive. Images B–H are completely stable and show drifting non-tagged animals.

the video recording (Fig. 2 and Movie 1). The two animals maintained a stable horizontal posture and drifted; they did not spread their flippers and did not move their flukes, except when resting near the surface. The video logger footage was completely stable for 31 min, which was the total time the whales spent underwater. The tagged animal also drifted during video recording since the two non-tagged animals were seen to be drifting, yet remained within the frame of the video logger, and the footage was stable. The tagged animal probably stroked once to dive deeper because a stroke signal occurred at a depth of less than 5 m (Fig. 1c). There were a few stroke signals (0–2 times) with minor changes in the pitch angle (–35 to +36°) during the dive (Fig. 1c). The video logger showed that another animal that accompanied the tagged whale stroked near or on the surface (Movie 1). The vertical distance between the tagged animal and other animals was 0–17 m, as estimated by the depth data when another individual was on the surface.

4. Discussion

Using the omnidirectional video logger, we recorded underwater footage of a humpback whale drift diving with only gentle movements, and we documented the characteristics of its resting behaviour. Specifically, the whale stroked to dive at less than 5 m depth during inactive rest, then descended inertly to a maximum depth of 19 m, and finally ascended using positive buoyancy with very gentle movements of the pectoral flippers or fluke (Fig. 1). Humpback whales rest while maintaining a horizontal position, which were similar behaviour to humpback whales and other baleen whales in previous studies (Schuler et al., 2019; Torres et al., 2018). The dynamic behaviour observed after 1619 h could represent foraging behaviour, as concluded by the fast swim speed, high stroke rate, and substantial change in pitch angle (Akiyama et al., 2019; Cade et al., 2016). In the same area, killer whales (*Orcinus orca*) that appear are not predators of humpback whales since they target fish species (Jourdain and Vongraven, 2017); therefore, humpback whales do not show any predator avoidance behaviour.

Previous studies on seals showed that drift dives during resting are characterised by few or no stroke signals and slow swim speed (Mitani et al., 2010; Watanabe et al., 2015). Sperm whales (*Physeter macrocephalus*) rest while maintaining a vertical posture during drift dives and float horizontally on the surface (Miller et al., 2008). A cruising speed of 1.45 m s^{-1} at the descent or ascent phase of a dive has previously been reported for humpback whales (Watanabe et al., 2011); however, in the present study, the swim speed of a tagged whale throughout the video recording was slower (0.75 m s^{-1}) than that previously reported. In the present study, the drift dives of humpback whales were considered to be resting behaviour because they displayed similar characteristics to the resting behaviours documented in previous studies (Mitani et al., 2010; Watanabe et al., 2015), such as no or few strokes and slow swim speed throughout diving.

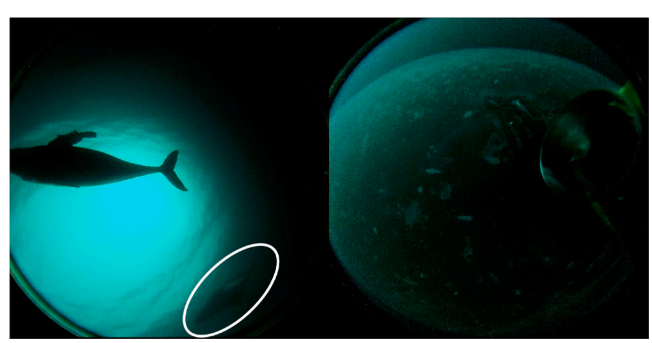

Fig. 2. Image from the omnidirectional video logger attached to a humpback whale. The left slide shows two humpback whales, one of which is indicated by a white ellipse. The right slide shows the back of the tagged animal and the behavioural data loggers.

Since the research area was a foraging ground and the research period was the last phase of feeding, the tagged humpback whale probably had a high energy reserve (Aoki et al., 2021) and kept air in their lung and, consequently, exhibited positive buoyancy. The resting and drift diving behaviour of humpback whales, especially in the ascent phase, is similar to the resting behaviour of loggerhead turtles (*Caretta caretta*), which involves a gradual ascent phase with nearly neutral buoyancy (Minamikawa et al., 2000). A previous study showed that humpback whales rested by logging on the surface (Friedlaender et al., 2013; Schuler et al., 2019), while no other reports of drift diving as a resting behaviour in baleen whales have been found. We considered that the animals probably choose the type of resting behaviour depending on sea conditions, their body conditions, and/or other factors, such as buoyancy (Narazaki et al., 2018).

A previous study used an animal-borne still camera logger that recorded backward footages and described the teaching-like behaviour of Weddell seals (*Leptonychotes weddellii*) during which the mother swims together with its pup (Sato et al., 2003b). However, a deeper understanding could be attained using a camera with a wider angle of view that records other behaviours, such as mating and teaching-like behaviour during foraging. In humpback whales, the patch residence time in a single dive is shorter when animals encountered competitors, as shown using behavioural and video loggers (Akiyama et al., 2019). However, these data were not sufficient to verify the presence or absence of other individuals owing to the narrow angle of view of the video logger. Body contact of long-finned pilot whales (*Globicephala melas*) has been reported using animal-borne still-image camera loggers (Aoki et al., 2013) and revealed that pilot whales proffer their right/left flipper to rub others; however, this behaviour could be more clearly recorded if a camera with a wider angle of view was used to display the frequency of body contact between tagged and untagged animals. In our study, the omnidirectional camera recorded a wide area of the tagged animal's environment, identifying two other animals during rest at a shallower depth than the tagged animal (Fig. 2). The use of cameras with a wide angle of view contributes towards deepening our understanding of marine animal behaviour by recording the surrounding environment and revealing the presence or absence of competitors of the same or other species during foraging, the prey distribution, and any intraspecific interactions.

5. Conclusions

The present study showed the underwater resting behaviour of humpback whales based on data from a single whale, where behaviour was inferred from video data of companion whales, and behavioural data was revealed in the same tagged whale. Omnidirectional video loggers are powerful tools that may aid in elucidating social behaviours in animals, such as positional relationships among individuals, time spent with other individuals, and body contact frequency. From a technical perspective, omnidirectional video loggers increase the number of observed animals as they record the behaviour of multiple companion animals surrounding a tagged individual. Furthermore, the omnidirectional video monitors the habitat area and collects information related to the occurring conditions, such as the distribution of marine organisms and the state of artificial debris. Overall, cameras with wider angles of view, such as omnidirectional video loggers, could become a valuable tool for observing and understanding marine animal ecology, combining information about animal behaviour and the surrounding environment.

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CRediT authorship contribution statement

Takashi Iwata: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Visualization, Writing - original draft, Writing - review & editing. **Martin Biuw:** Data curation, Investigation, Writing - review & editing. **Kagari Aoki:** Funding acquisition, Methodology, Writing - review & editing. **Patrick James O'Malley Miller:** Data curation, Funding acquisition, Investigation, Project administration, Supervision, Writing - review & editing. **Katsufumi Sato:** Funding acquisition, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare no competing or financial interests.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.beproc.2021.104369.

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