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SUB-ICE FORAGING BEHAVIOR OF EMPEROR PENGUINS

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Summary

Emperor penguins (*Aptenodytes forsteri*) were equipped with a remote underwater video camera, the Crittercam, to evaluate sub-ice foraging behavior while the birds dived from an isolated dive hole. Three birds dived and foraged successfully for 1 h periods after being trained to wear and to dive with a harness for camera attachment. Video and depth profile recordings revealed that emperor penguins travel at shallow depths (<50 m), ascend to the undersurface of the ice to feed on fish, and descend back to depth to return to the exit hole. Although the mean durations of dives of individual birds with the Crittercam were 21–35 % shorter than the diving durations of these same birds without the camera, the dive profiles in both situations were similar, thus demonstrating a similar foraging strategy in birds diving without the camera. Despite shorter diving durations with the camera, the penguins were still successful at prey capture in 80 % of 91 dives greater than 1 min in duration. Prey included the sub-ice fish *Pagothenia borchgrevinki*. Hunting ascents (from depth to within 5 m of the surface) occurred in 85 % of dives, ranged from zero to three per dive, and were associated with successful prey capture in 77 % of 128 ascents. Occasionally, several fish were captured during a single ascent. These observations and this application of video technology create a model for further physiological and behavioral studies of foraging, and also emphasize the potential importance of shallow dives as sources of food intake for emperor penguins during foraging trips to sea.

Key words: *Aptenodytes forsteri*, camera, dive, emperor penguin, foraging behaviour, *Pagothenia borchgrevinki*, video recording.

Introduction

The isolated dive hole paradigm has been the primary model for investigating the diving physiology of emperor penguins (*Aptenodytes forsteri*). Heart rate responses, swimming velocities and metabolic rates have all been examined (Kooyman et al., 1992; K. A. Nagy, G. L. Kooyman and P. J. Ponganis, in preparation). Most importantly, this is the only situation in which the aerobic dive limit of an avian diver has been determined with post-dive lactate measurements (Ponganis et al., 1997). Although food intake during the daily diving activity of these birds has been inferred from increases in body mass and guano deposition (K. A. Nagy, G. L. Kooyman and P. J. Ponganis, in preparation; Ponganis et al., 1997), very little is known about the foraging strategy and feeding behavior of the penguins under the ice. To evaluate this diving behavior better and to identify prey items, we trained birds to wear a harness and dive with a National Geographic Crittercam camera attached.

Materials and methods

Emperor penguins *Aptenodytes forsteri* (Gray) captured on the sea ice of McMurdo Sound, Antarctica, were maintained in a corral at a sea ice camp (Ponganis et al., 1997) for 2 months prior to release. They foraged daily beneath the sea ice through two isolated dive holes. Three birds (25–26 kg in body mass) were trained to wear a harness, to which a National Geographic Crittercam underwater video camera (1 kg, neutral buoyancy, 9 cm in diameter, 25 cm in length; Marshall, 1998) was attached for 1 h periods (Fig. 1). The housing also contained a depth transducer and microprocessor recorder (500 m depth range, 0.3 m sensitivity, 2 s sampling rate). At other times, birds dived with only a smaller time/depth recorder (Mk5, Wildlife Computers, Redmond, WA, USA; 50 g, 3.5 cm×1 cm×8 cm; 750 m depth range, 3 m accuracy, 2 s sampling rate) glued to their back (Kooyman et al., 1992).

The training program consisted of 3–4 daily sessions of 1 h. First, a penguin was accustomed to wear and to dive with the harness alone. Progressively larger and heavier ‘dummy’ cameras were then attached to the harness each day until the bird was diving with one the size of the Crittercam.

The harness was constructed of 2.5 and 5 cm wide nylon straps with quick-release plastic buckles (Fig. 1). The camera was attached with hose clamps to a 21 cm×10 cm center back strap on the harness. A 3 cm×12 cm Velcro patch, glued with

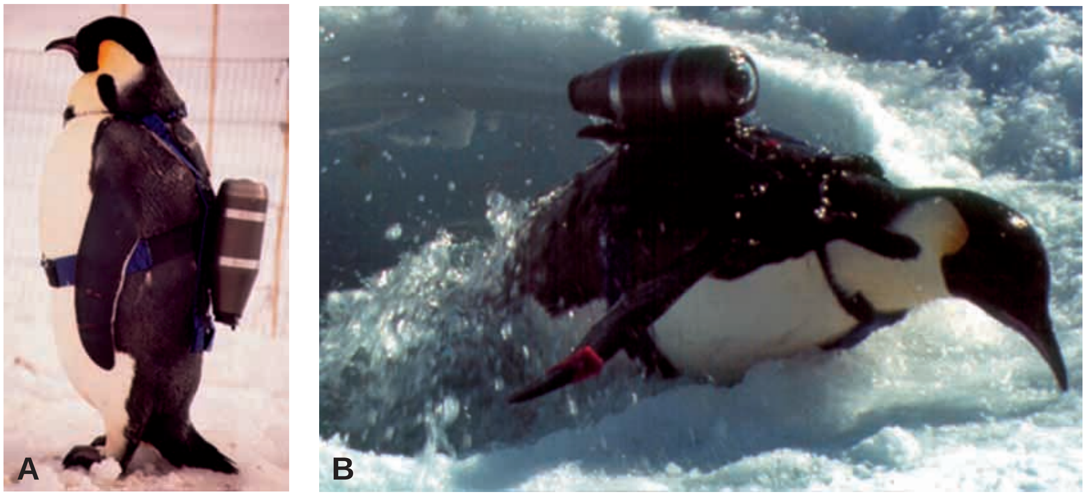

Fig. 1. The camera attached to an emperor penguin. (A) The harness consisted of abdominal and shoulder straps, a midline chest strap and a central back strap to which the Crittercam camera was attached. (B). Exit of an emperor penguin from a dive hole. The camera weight is distributed to the shoulders and to the mid-back Velcro patch.

Loctite 412 cyanoacrylate glue to feathers in the mid-back region, attached to Velcro on the underside of the center back strap. This reduced wobble of the camera on the swimming bird. The weight and ‘pull’ of the camera were distributed to both the shoulder straps and the Velcro attachment on the back.

Dive analysis and graphics were performed with Excel and Origin software. Mean values ± standard errors of the mean are presented. The results of *t*-tests were assumed to be significant at $P<0.05$.

Results

The three penguins dived and successfully foraged while they were equipped with the Crittercam. The mean diving duration of 110 dives lasting more than 1 min for the three birds with the camera was 4.2±0.1 min. More than 75 % of dives clustered between 3 and 6 min in duration (Fig. 2), with most dives in the 3 to 4 min histogram bin. The longest dives of each of the birds were 6.6, 6.9 and 7.9 min. The mean durations of dives of individual birds with the Crittercam were 21–35 % shorter than the mean values of the same birds without the camera. In 88 dives of these birds, when equipped with only a time/depth recorder, mean diving duration was 6.0±0.2 min, significantly longer than when wearing the camera.

A review of video and time/depth recordings from the Crittercam revealed that, under these conditions, emperor penguins travel alone at shallow depths, ascend to the undersurface of the sea ice to feed on fish, and descend back to depth before returning to the exit hole (Figs 3, 4). A review of time/depth recordings, comparing these three penguins with eight other birds equipped with conventional time/depth recorders alone, revealed similar dive profiles and, thus, the same foraging strategy in birds diving without the camera. Maximum depths of dives both with and without the camera were less than 50 m.

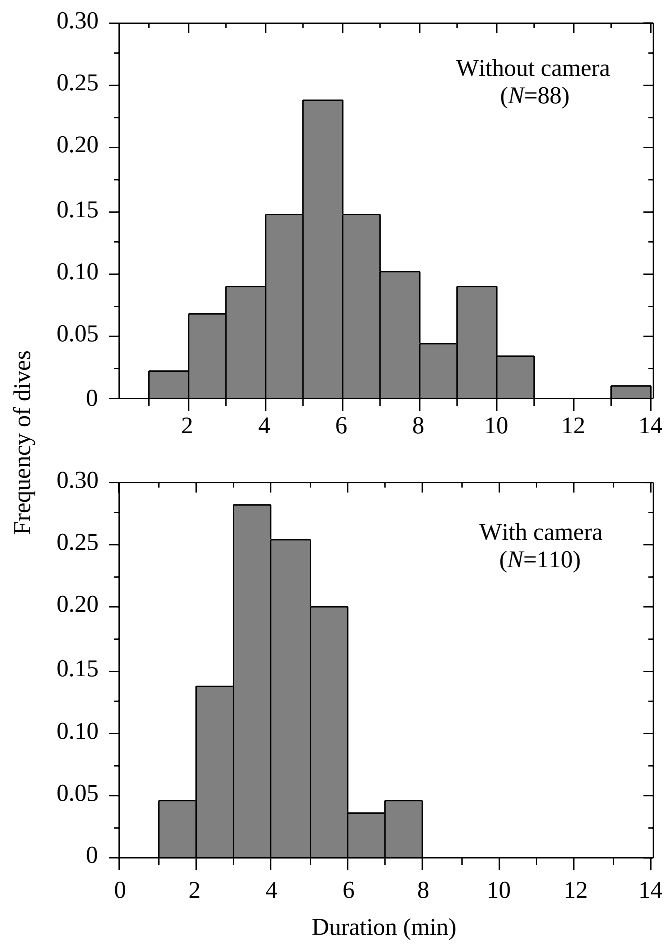

Fig. 2. The distribution of diving durations of three emperor penguins with and without the camera. Mean diving duration of birds with the camera (4.2±0.1 min) was significantly ($P<0.05$) shorter than that of those without the camera (6.0±0.2 min) (means ± S.E.M.).

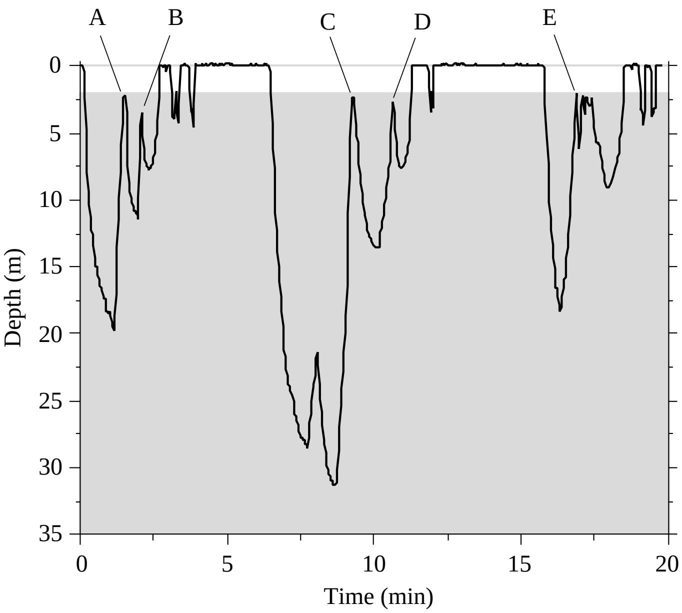

Fig. 3. A 20 min depth profile of three long dives (sea ice thickness 2 m). Points A–E indicate hunting ascents; B was unsuccessful; A, C and D each resulted in one fish capture, and E in four.

Despite shorter diving durations with the camera, the penguins were still successful at prey capture in 80 % of 91 dives lasting longer than 1 min. Poor video quality prevented video analysis in 19 dives. Video images revealed the primary prey item to be the sub-ice fish *Pagothenia borchgrevinki*. Hunting ascents (defined as non-exit ascents from depth to within 5 m of the surface) occurred in 85 % of dives, ranged from zero to three per dive and were associated with successful prey capture in 77 % of 128 ascents. Occasionally, several sub-ice fish were captured during a single ascent.

Discussion

This study reports the first use of a remote video camera to record feeding behavior in a freely diving penguin. Although the camera (>10 % of the estimated cross-sectional area of the bird and approximately 4 % of its body mass) and harness undoubtedly increased drag and contributed to shorter diving durations (Wilson et al., 1986), judicious selection and training of penguins allowed them to carry this device and still to forage successfully under sea ice. Similar dive profiles with and without the camera have now documented a common diving behavior in this well-studied physiological model. The adaptability of the birds to this experimental manipulation and future miniaturization of video recorders will create new possibilities for further physiological and behavioral studies.

The sub-ice foraging strategy of these birds appears to be one of solo travel and search at depth, with ascents to hunt and capture fish under the ice. When within the camera image, the fish are usually swimming into, or are already in, the platelet ice layer. At the time of capture, the fish are usually motionless with their head and much, but not all, of their body buried in the platelet ice layer. The high foraging success rate of birds equipped with the Crittercam, and past observations of daily and seasonal weight gains of emperor penguins at the experimental dive hole (K. A. Nagy, G. L. Kooyman and P. J. Ponganis, in preparation), suggest that this mode of hunting is quite efficient. One bird, equipped with only a time/depth recorder in the current study, gained 1.4 kg after just four dives.

Fig. 4. An emperor penguin approaches, captures and engulfs a fish in the platelet ice layer at the undersurface of the sea ice.

These observations also suggest that shallow dives can represent an important source of food intake for emperor penguins. It is notable that 30–60 % of dives during foraging trips to sea are to less than 50 m in depth (Kirkwood and Robertson, 1997; Kooyman and Kooyman, 1995). Although fish and squid captured during deep (100–500 m) dives of emperor penguins are major prey items from October to December (Cherel and Kooyman, 1998; Kirkwood and Robertson, 1997), reports of *Pagothenia* and krill as significant components of stomach content analyses suggest that shallow dives are also important (Cherel and Kooyman, 1998; Kirkwood and Robertson, 1997; Offredo and Ridoux, 1986). This is especially so in late winter (August/September) (Kirkwood and Robertson, 1997).

Despite the size of the Crittercam and the shorter diving durations of birds with the camera, our application of video technology has now elucidated a common diving/foraging behavior of emperor penguins in this experimental dive hole model. Such knowledge will benefit the interpretation of physiological data, lead to further behavioral studies and potentially provide a better understanding of diving behavior at sea.

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