

Measuring the state of consciousness in a free-living diving sea turtle

Jonathan D.R. Houghton^a, Allen Cedras^b, Andrew E. Myers^{a,c}, Niko Liebsch^a,
Julian D. Metcalfe^d, Jeanne A. Mortimer^{e,f}, Graeme C. Hays^{a,*}

^a Department of Biological Sciences, Institute of Environmental Sustainability, Swansea University, Swansea SA2 8PP, UK

^b Marine Parks Authority, Seychelles

^c Large Pelagics Research Laboratory, University of New Hampshire, Durham, NH 03824, USA

^d Centre for Environment, Fisheries and Aquaculture Science, Lowestoft Laboratory, Pakefield Road, Lowestoft NR33 0HT, UK

^e Department of Zoology, University of Florida, Gainesville, Florida 32611, USA

^f Island Conservation Society, Victoria, Mahe, Seychelles

Abstract

We report on results from two types of data-logger attached to hawksbill turtles (*Eretmochelys coriacea*) in the breeding season at the Seychelles, Indian Ocean. Conventional time–depth recorders (TDRs) showed prolonged bouts of long dives to the seabed, consistent with benthic resting. This behaviour has been widely reported in sea turtles and appears to be a common feature for energy conservation. An Inter-Mandibular Angle Sensor (IMASEN) recorded mouth opening and buccal pumping by one turtle for 2.5 days. Buccal pumping occurred widely while the turtle was submerged, consistent with a function of olfactory sensory perception of the turtle's environment. However, buccal pumping stopped during the middle of long benthic dives consistent with the turtle entering a phase of sleep. It therefore appears that by recording buccal oscillations, it is possible to assess the state of consciousness of turtles allowing the eco-physiology of diving to be more fully explored.

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1. Introduction

Over recent years our understanding of the free-living behaviour of marine vertebrates has been transformed through the use of data-loggers and transmitters that can provide information on various aspects of the behaviour of individuals and their environment (e.g. Sims et al., 2005; Metcalfe et al., 2006). Dive profiles are now routinely measured with time–depth recorders (TDRs) (e.g. Rice and Balazs, 2008-this issue; Ropert-Coudert and Wilson, 2005) some linked to satellite transmitters (Myers et al., 2006). However, depth data is increasingly supplemented by other measurements such as swimming effort (e.g. measured with accelerometers or swim speed recorders); patterns of feeding (e.g. measured with stomach temperature recorders, visual imaging recorders or mouth-opening sensors) (Ropert-Coudert and Wilson, 2005). Information is therefore starting to be gleaned on how animals

partition their time between various activities such as travelling, feeding and breeding (Beck et al., 2003; Fowler et al., 2006). Much recent attention has focussed on patterns of foraging given the central component of feeding in the life history of vertebrates (e.g. Austin et al., 2006; Myers et al., 2006; Watwood et al., 2006). However, some behaviours which may similarly be very important, have received much less attention.

Resting forms a vital component in the time-budget of all vertebrates. For some marine vertebrates, resting may take place on land, such as seals that haulout to rest ashore, making the time spent resting fairly easy to measure by direct observation. However, for other marine vertebrates that do not haul ashore to rest, we can infer that resting presumably takes place at sea, potentially on the sea surface, in mid-water or on the seabed. For example, some whales are thought to sleep at the surface when their behaviour is described as “logging” (Goold, 1999; Lyamin et al., 2000). It has been suggested that some species of seal may rest in mid-water, during which time they may passively drift down or up in the water column depending on their state of buoyancy (Biuw et al., 2003; Page et al., 2005). It

* Corresponding author.

E-mail address: g.hays@swan.ac.uk (G.C. Hays).

is thought that dolphins may be able to sleep while continuing to swim, sometimes keeping one eye open beneath the surface (Lyamin et al., 2004; Sekiguchi et al., 2006). However, it is sometimes difficult to unequivocally resolve the function of dives even when diving animals are directly observed in aquaria (e.g. Lyamin et al., 2006). In such cases direct measurements of an animal's state, for example from electroencephalogram readings, may be needed (Lyamin et al., 2004).

Hard-shelled turtles, both marine and freshwater species, appear to be unusual amongst air-breathing divers in that they typically rest on the bottom, often for extended periods, during demersal stages of their life cycle. For example, dives to the seabed of >30 min have regularly been recorded for green (*Chelonia mydas*) (Hays et al., 2004a), hawksbill (*Eretmochelys imbricata*) (van Dam and Diez, 1996; Storch et al., 2006) and loggerhead (*Caretta caretta*) turtles (Houghton et al., 2002). In winter, when water temperatures are low, dives of over 6 h have been recorded for marine species, while freshwater turtles may sometimes stay submerged for many weeks during winter (see Hochscheid et al., 2005a and references therein). For free-living individuals, resting behaviour has generally been inferred from examination of dive profiles rather than being directly recorded. However, hard-shelled sea turtles show characteristic behaviours when resting, which might be directly recorded allowing their behavioural state to be unequivocally identified. Walker (1959) first noted that while submerged hard-shelled turtles are awake, they have their eyes open (in common with many other vertebrates) and also show continuous rhythmic throat movements termed buccal oscillations (sometimes called gular pumping). Buccal oscillations generate a steady flow of water pass the chemosensory organs and, in essence, the behaviour corresponds with turtles smelling the water, presumably for detection of prey, predators, or other individuals (Manton et al., 1972a,b). Walker (1959) noted that when turtles closed their eyes for extended periods (presumably sleeping) buccal oscillations ceased. In essence, therefore, buccal oscillations seem to give an indication of the state of consciousness for submerged hard-shelled turtles. Recently, Hochscheid et al. (2005b) used a device termed the IMASEN (Inter-Mandibular Angle Sensor) to measure buccal oscillations in captive loggerhead turtles. Buccal oscillations were associated with very small openings of the mouth (Hochscheid et al., 2005b). In line with the visual observations of Walker (1959), Hochscheid et al. (2005b) used an IMASEN to record the cessation of buccal oscillations when loggerhead turtles rested on the bottom of tanks with their eyes closed. Hochscheid et al. (2005b) suggested that IMASENs deployed on free-living animals might be used to

Table 1

Details of successfully instrumented hawksbill turtles

Turtle id	Equipment deployed	Deployment date	Length of dive record	CCL (cm)
2929	TDR	28/10/2004	16 days	80
3089	TDR	30/10/2004	14 days	80
2969	TDR+IMASEN	31/10/2004	15 days	80
2872	TDR	2/11/2004	28 days	90

TDR = time–depth recorder. CCL = curve carapace length (cm).

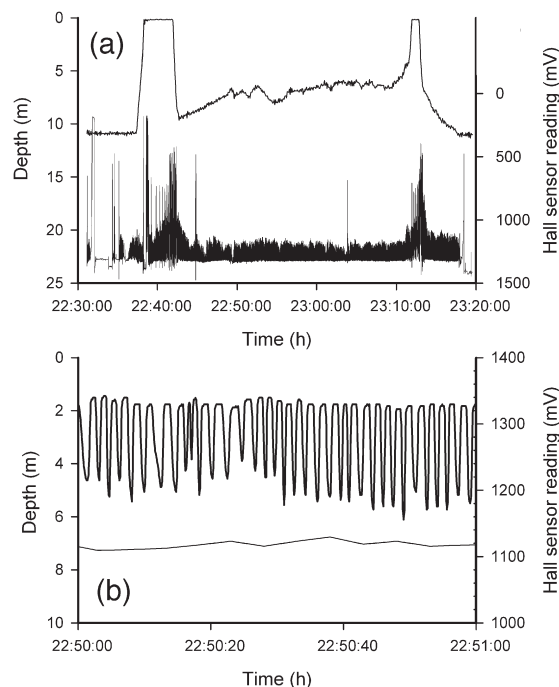


Fig. 1. Typical IMASEN and depth traces from an active dive. Thin line = depth, thick line = Hall sensor readings. Part (a) shows the complete dive, part (b) shows 1 min during the dive. Note variation in depth indicative of turtle activity, with the turtle ascending from about 10 m up to 6 m during the dive. The values recorded by the IMASEN (mV) give a relative measure of mouth gape. When the mouth was closed the Hall sensor and magnet would be closer together giving higher reading (~1300 mV). When the mouth opened, the Hall sensor and magnet would become further apart producing lower values. When at the surface, wide mouth-opening events were recorded. When submerged the trace shows regular small amplitude mouth-opening events.

record the state of consciousness of turtles while on the seabed. To explore this possibility, we deployed an IMASEN on a free-living hawksbill turtle in the interesting interval and recorded the extent of gular pumping along with dive profiles.

2. Materials and methods

We attached an IMASEN (Driesen and Kern, Bad Bramsted, Germany) to a hawksbill turtle that had completed nesting on Curieuse Island Marine National Park in the granitic Seychelles (4°16.827' S; 55°44.462' E). Close (within 5 km) to the island are water depths up to 30 m. The IMASEN (5.5 × 3.4 cm, 27.6 g in air) consists of a Hall sensor, linked to a data-logger, which measures the proximity of a nearby magnet. By positioning the Hall sensor on the upper mandible of the turtle and a neodymium boron magnet on the lower mandible, we recorded when the turtle opened its mouth (see Myers and Hays (2006) for a schematic of attachment). While the raw values (mV) recorded by the IMASEN gave a relative measure of mouth opening, we were unable to convert these values into absolute gape distances (mm) because the turtle re-entered the water before we could complete validation measurements. The IMASEN sampled at 10 Hz and at this sampling frequency the logger memory was filled in 2.5 days.

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