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Finding the balance: the effect of the position of external devices on little penguins

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Abstract: Many studies on the foraging behaviour of penguins rely on data collected with back-mounted data recorders, which can greatly affect the drag of swimming birds. In recent years, the size of devices has been minimised to reduce drag. In addition, devices have been positioned on the lower back of penguins to reduce the effect of the flow separation caused by the device on the penguin's body. Nevertheless, a device placed on the lower back of penguins is further away from the centre of gravity which may make balancing and swimming difficult. In this study, we used accelerometers to measure and test quantitatively whether the heaving and surging acceleration (as a measure of imbalance) of penguins swimming through a winding channel was different when an external accelerometer was positioned on the lower back compared to the middle of the back (closer to the centre of gravity).

Heaving acceleration was different only for two of the seven penguins when a device was placed on the lower back rather than the middle of the back. While the difference was statistically significant, it was too small (less than 1 m/s^2) to indicate a difference in the swimming behaviour. Although surging acceleration was consistently different in all seven penguins, we suspect this measurement indicated differences in acceleration between two parts of the body (tail and middle back) rather than an effect in balance. Overall, it seems that the balance of little penguins is not greatly affect by positioning of a device. Nevertheless, further experiments with free-ranging penguins are needed to evaluate fully whether the positioning of a device can affect balance of a penguin swimming on the water surface or its buoyancy when diving in the water.

key words: little penguins, balance, external devices, swimming, accelerometers, power analysis

Introduction

Early bio-logging research on the diving ecology and physiology of aquatic vertebrates brought substantial advances to our knowledge of the underwater habits of animals. However, researchers who conducted these studies may not have been fully aware of the artefacts caused by such instruments. Subsequently, researchers realised factors, such as an increase in drag, could substantially influence diving abilities of birds. Attempts were made to reduce drag by making the devices more hydrodynamic and finding the best position on the birds for their attachment (Bannasch *et al.*, 1994). Minimizing the size and frontal surface area of the device was believed to be the most crucial factor to obtain the closest natural diving behaviour in penguins at sea (Culik *et al*., 1994). Currently, 'best practice' suggests that devices should be attached to the lower back of the subjects, where the flow separation caused by the device should have less effect on the penguin's body (Culik *et al*., 1994).

Observations of captive little penguins (*Eudyptula minor*) carrying devices on their backs showed that penguins appeared imbalanced, heaving strongly from side to side while on the surface of the water (Healy *et al*., 2004). These authors suggested that the lower back might not be the best attachment site for penguins since it appeared to affect their balance, probably because it was further from the centre of gravity. Despite its potential importance, balance has been virtually ignored in studies of marine animals fitted with external devices. Recent development of small devices that can measure acceleration at different planes has made it possible to examine factors, such as heaving and surging acceleration (Ropert-Coudert *et al*., 2004). In this study, we used accelerometers to evaluate quantitatively whether the position of the device affects the balance of female little penguins on the surface of water. Here, penguins swam through a winding channel with accelerometers placed on either the lower or middle part of their backs. We hypothesised that penguins with devices on their lower back would be imbalanced and that their heaving acceleration (both the mean and variance) on the surface of the water would be higher than when the devices were placed on the middle of the backs.

Methods

Selection and acclimatisation of penguins

Seven adult female little penguins were captured at Phillip Island (38˚15´S, 145˚30´E), Australia, during the non-breeding stage (austral winter 2003). Birds weighed on average 990 g (range 900–1140 g). Females were chosen because they are believed to be less distressed by captivity than males (Marg Healy, pers. comm.). The penguins were kept in the Phillip Island Nature Park's wildlife rehabilitation facility. They were acclimatised for three days before the experiment, used in the experiment for one day, and released two days later. The penguins were hand-fed twice a day and after each feeding they were allowed to swim in the pool for two hours. All penguins gained on average $8 \pm 3\%$ of their initial body weight while in captivity.

Experimental protocol

Penguins had an accelerometer attached to their lower or middle back using PVC tape (tesa, Germany) (Wilson *et al*., 1997). The tape enabled the accelerometer to be attached securely and later to be removed quickly (less than 2 min) without damaging the feathers of the birds. Each device was placed centrally on the back of the penguin and always orientated in the same position (*i.e.* head to tail). The device was either positioned in the middle of the back or the lower back (Bilo and Nachtigall, 1980; Culik *et al*., 1994). Once equipped with a device, a penguin was placed into a pool and swam through to the end of a winding channel (Fig. 1). The channel was used to encourage penguins to turn right and left in order to measure changes in the heaving acceleration. The channel was one metre wide, four metres long and 0.5 metres deep (Fig. 1). To have a visual archival record of its behaviour, each penguin was filmed with a digital video-camera (Handycam, Sony Ltd., 24 frames/s) swimming

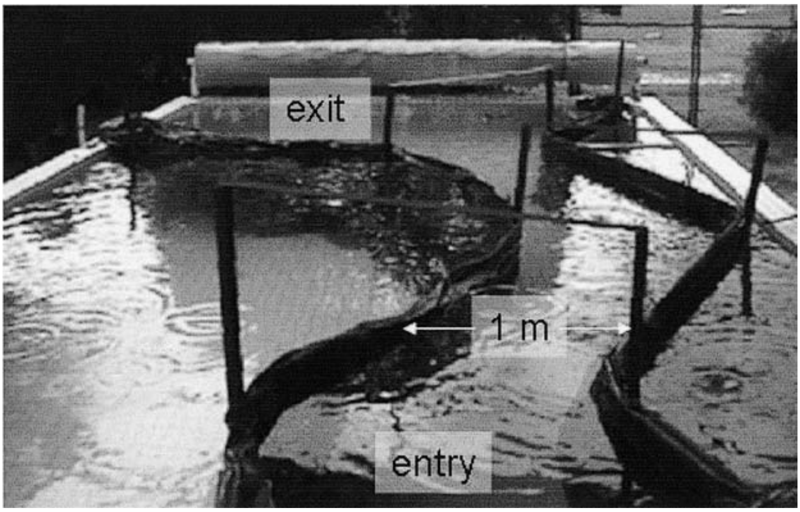

Fig. 1. The winding channel through which the little penguins swam during the experiment.

through the channel. Each bird was captured at the end of its swim, the data logger was removed and the bird was put in a quiet holding area until it was selected again. Penguins swam through the channel four times, twice with the accelerometer positioned on the middle of their back and twice with it positioned on their lower back. The order of the penguins and the position of the accelerometer were chosen randomly.

Accelerometer and parameters

The heaving acceleration of each penguin was recorded using miniaturized, cylindrical, four-channel data loggers or accelerometers (M190-D2GT, 12 bit resolution, 54×15 mm, 20 g including batteries, Little Leonardo, Tokyo, Japan). Each device simultaneously monitored acceleration (16 Hz) and depth (1 Hz). The units contained a tilt sensor capable of measuring both dynamic acceleration (*e.g.* vibration) and static acceleration (*e.g.* gravity, see Ropert-Coudert *et al.*, 2004 for technical details). The absolute accuracy for the depth sensor was 0.1 m. In our study, acceleration was measured along two axes: heaving acceleration measured across the body axis and the surging acceleration measured along the longitudinal body axis of the birds (Fig. 2). The sensor's output was in mV and converted into m/s^2 [surging $=0.002*y(\mathrm{mV})-3.98$ and heaving $=0.002*x(\mathrm{mV})-3.66$, coefficient of correlation $=0.99$ in both accelerations].

Penguins swam at or below the surface of the water to negotiate the bends of the channel, but only surface data were used in the analyses because we were measuring balance in the air and not buoyancy underwater (Fig. 3). These periods were identified using the depth recorder (*i.e.* depth $=0$ to 0.1 m) and the synchronised video images.

The curvature of the back of the penguins differed on average by $31.2\pm2°(n=4)$ between the middle and the lower positions. Hence, the acceleration values from the loggers were offset from the vertical and horizontal axes by 31.2°. To correct for this difference in curvature, the acceleration values from the lower position were multiplied by the cosine of

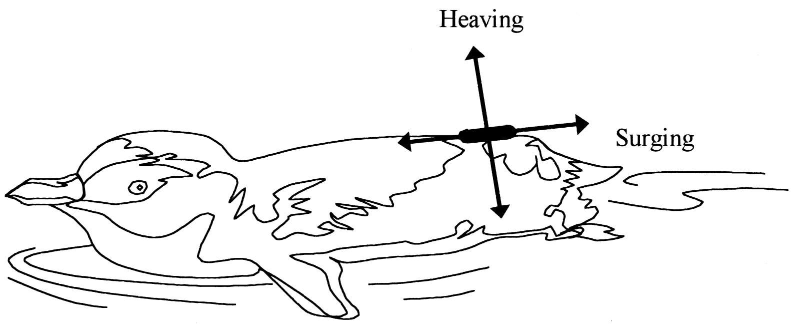

Fig. 2. Penguin showing the two axes of acceleration data, surging along the spine axis and heaving acceleration measured across the spine axis.

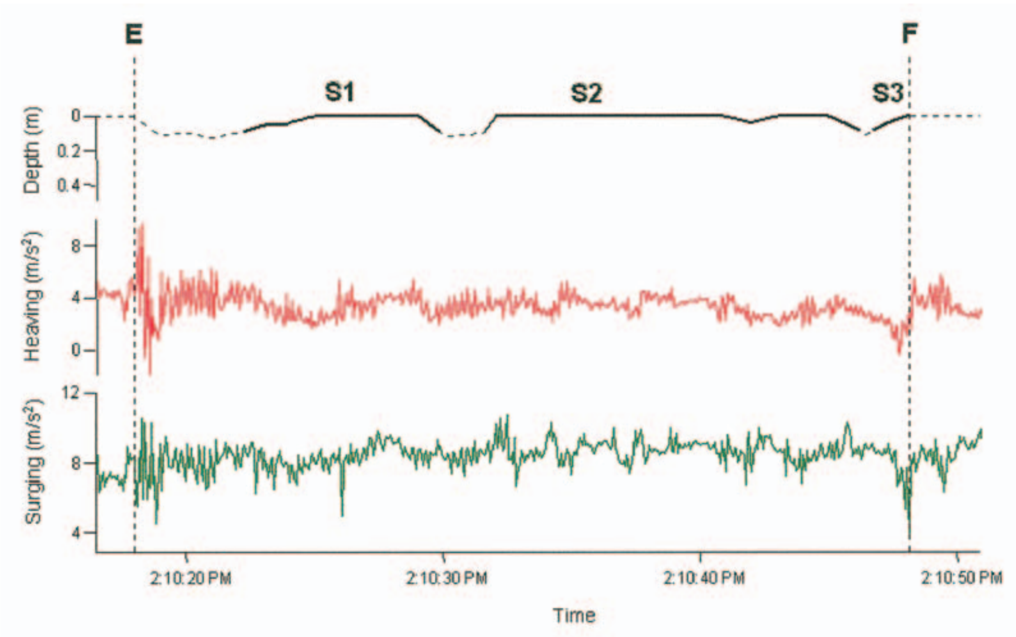

Fig. 3. Depth (black dotted line) and acceleration signals (heaving in red and surging in green) recorded by the accelerometer during a short swimming of a little penguin through the channel in the experimental pool. E denotes entry in the pool; F denotes the end of the Channel. S1 to S3 (black solid lines) are the surface data points used in the analysis.

31.2° to give the corrected vertical and horizontal acceleration.

Statistics

The mean and variance of the heaving and surging acceleration were calculated from the surface data and analysed using analysis of variance. Each analysis had two orthogonal factors: "penguin" which was a random factor with seven levels and "position" which was a fixed factor with two levels, lower or middle back. There were two replicate runs for each penguin with the accelerometer positioned on the lower or middle back ($n=2$). This design provides an efficient and relatively powerful test of the effects of position of the device for each penguin. Variances were tested for homogeneity using Cochran's C-test. Planned comparisons were to test the stated hypothesis (Underwood, 1997; Quinn and Keough, 2002) and power calculations were done using Systat 10 (Systat® software, SPSS Inc., Chicago, USA).

Results

We collected 16150 records of seven penguins with the device on the middle (7457 records) and the lower back (8693 records) positions. Penguins spent 94% of time on the surface. The position of the data loggers affected the acceleration of two of the little penguins that had lower heaving acceleration with the loggers positioned on their lower back than on the middle of their back (position × penguin, $F_{6,14}=9.87$, $p=0.0002$, Fig. 4a). The other five penguins, however, showed no difference in the heaving acceleration with regard to the position of the logger. The heaving acceleration for each penguin was highly consistent between runs (Fig. 4a), resulting in very powerful statistical tests for differences in the movement of the penguins (*i.e.* >99% to detect a 10% difference in the means). There were no differences between the variance of the heaving acceleration of all but one penguin with the loggers positioned on their lower or middle back (position × penguin, $F_{6,14}=3.01$, $P=0.042$).

The surging acceleration of penguins was significantly different with a device placed on the lower or middle back (position, $F_{1,6}=105$, $P=0.0001$, Fig 4b). All penguins showed greater surging acceleration with a device mounted on their lower back compared to the middle of the back (Fig. 4b). There was, however, no difference in the variance of surging between the two positions (position, $F_{1,6}=0.24$, $P=0.64$).

Discussion

Using accelerometers, we quantified the heaving and surging acceleration of little penguins with the device attached either to their lower or middle back. Based on previous visual observations of little penguins carrying devices (Healy *et al*., 2004), we expected that penguins with accelerometers on their lower backs would heave more than those with accelerometers attached to the middle of their backs. This difference would occur because the device is closer to the centre of gravity of the penguin when it is positioned in the middle of the back, presumably making it easier for the penguins to balance and swim efficiently on the surface.

Our results showed that the heaving acceleration of most penguins (five out of seven) was not affected by the position of the device. Thus, for at least two penguins, the position of the device influenced the swimming of the penguins as they showed a lower heaving acceleration with a device positioned on their lower back. However, while the difference was statistically significant, it was too small (less than 1 m/s) to indicate a difference in the swimming behaviour. The variation between middle and lower back in these two penguins probably resulted from a difference in the orientation of the logger.

In contrast, we did not expect that surging acceleration would be affected with the devices in different positions when penguins negotiated the bends of the winding channel

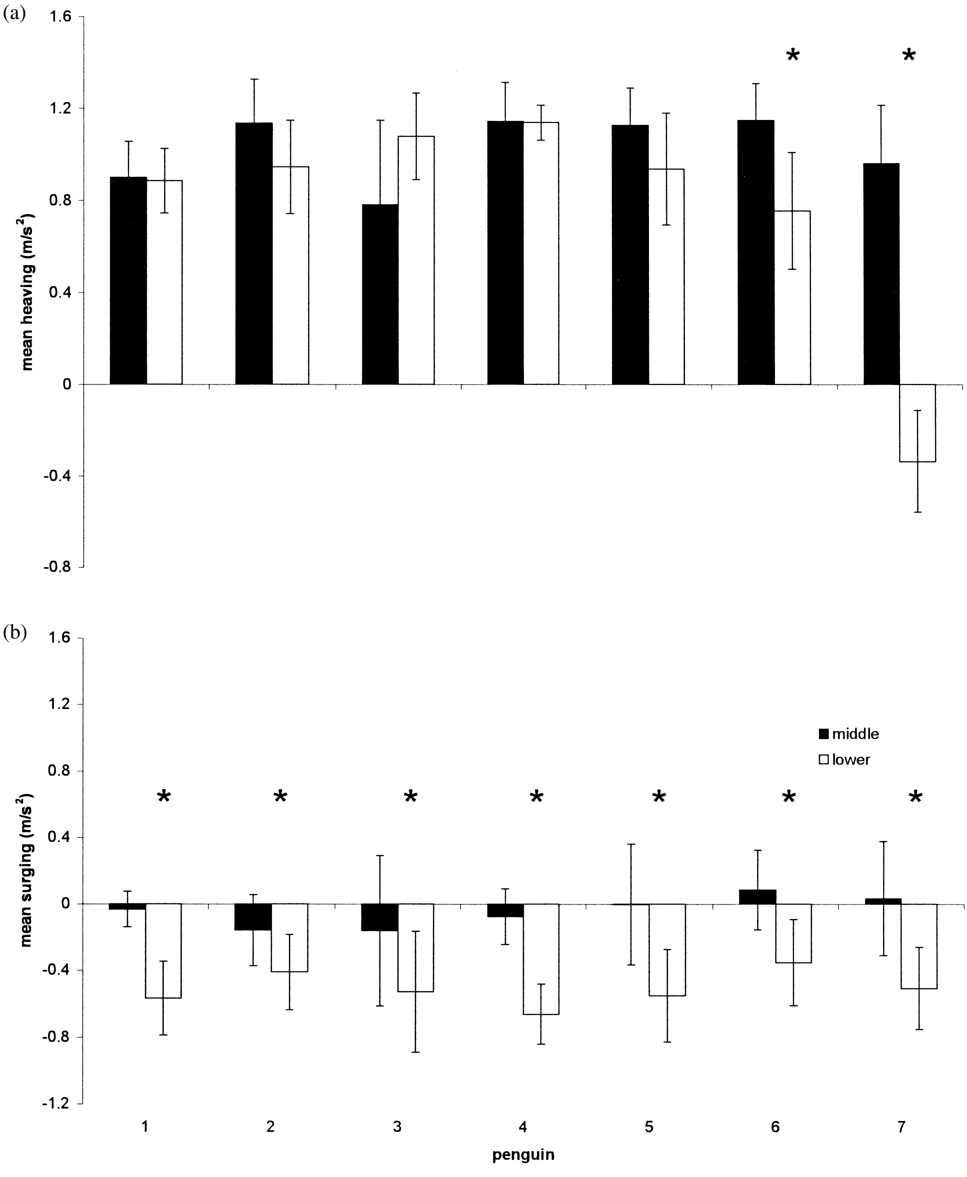

Fig. 4. Acceleration of little penguins with data loggers positioned on their lower or middle backs. a) Heaving acceleration and b) surging acceleration. The acceleration was measured as they swam through a channel with an accelerometer attached to their back in either of two positions, middle (black bars) and lower (clear bars). Surging was significantly different in all penguins between the positions and heaving was significantly different in two penguins (see text for explanation). * indicates significant difference between positions.

used in this study. Surprisingly, the surging of all of the penguins was consistently greater with a device positioned on the lower back than on its middle. A possible explanation is that different sections of the penguins' backs move independently, so our results may indicate differences in acceleration between two parts of the body rather than an effect in balance. Our experiment was not designed to address this confounding factor so we do not have data to disprove this alternative explanation. Hence, future experiments are necessary to test hypotheses on such alternative explanations.

We did not observe any visual indication of a change in tilting behaviour. This is in contrast to the results of Healy *et al.* (2004) and may have been caused by differences in the frontal surface area of the devices and/or in the level of the penguins' fitness. The accelerometer used in this study was 10% heavier but had 38% less volume than the time-depth recorders (TDR) used by Healy *et al.* (2004). The frontal surface area of the accelerometer was smaller than the TDR, being equivalent to 3.4% and 4.9%, respectively, of the cross-sectional area of a little penguin (Lovvorn *et al.*, 2001). The size of the accelerometer, therefore, may have been too small to affect the balance of all penguins. Alternatively, the muscle tone of the penguins may have been responsible for the differences in the results between the two studies. Healy *et al.* (2004) used rehabilitated penguins that had been treated for 20 to 30 days prior to the experiment. After a long period of inactivity, birds may lose muscle mass and strength rapidly as has been shown in eared grebes (*Podiceps nigricollis*). These birds can loose up to 50% of their muscle mass during periods of inactivity in the spring migration stopover (Gaunt *et al.*, 1990). There is direct evidence that atrophied muscles are weaker (Josephson, 1975) potentially making rehabilitated penguins more sensitive to the position of the devices. In this study, healthy penguins were held in captivity for a short period, which probably did not affect their fitness, enabling them to adjust their balance even though the devices were fitted away from their centre of gravity. In summary, it seems that the balance of little penguins are not greatly affect by positioning of a device as long the device is small and fitted on healthy penguins.

This experiment tested specific hypotheses about whether the position of external devices can affect the balance of little penguins while at the water surface. In the field, diving and manoeuvrability may be affected by the positioning of devices. A change in manoeuvrability has been reported for another marine diver, the sea lion *Zalophus californianus* (Fish *et al.*, 2003). When diving instruments attached to their backs, penguins' performance can be affected by changes in the centre of buoyancy, which does not necessarily coincide with the centre of gravity (Lovvorn *et al.*, 2001). Small changes in angle of attack of the body not detectable to the naked eye could cause large variations in lift of the body fuselage (Lovvorn *et al.*, 2001). Further experiments with free-ranging penguins are needed to evaluate the most appropriate positioning of external devices to avoid artefacts in such studies.

The careful experimental design and subsequent power of our analyses enabled us to argue confidently that there was no difference in the heaving acceleration of most penguins in relation to the position of the device. There was little difference in the heaving acceleration of the penguins between replicate runs through the channel. This indicated that the statistical analyses were very powerful (*i.e.* close to 1). The great power of our analyses indicates that we are unlikely to have made a Type II error, that is, to find that there was no effect when there actually was one. Power calculations are a useful tool for evaluating whether non-significant effects are likely to be real, and should be used routinely in such cases (Quinn and Keough, 2002).

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