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Testing the minimum approach distance guidelines for incubating Royal penguins *Eudyptes schlegeli*

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Abstract

Minimum approach distance guidelines are common tools to maintain a buffer between breeding seabirds and human activity, with the goal of mitigating potentially harmful impacts from these interactions. We employed an experimental design to measure the heart rate and behaviour of Royal penguins on Macquarie Island, Australia, in response to a single pedestrian visit using the current recommended approach distance of 5 m for visitors. Penguins showed increased heart rate (1.23 times average resting heart rate) and vigilance (six-fold increase), suggested to be a precursor to a flight or fight response, however, no penguins fled their nests. These responses were significantly greater than observed during Subantarctic skua overflights, suggesting incubating Royal penguins viewed a single pedestrian at 5 m as a greater threat than a predator overflight. Single persons using the current minimum approach guideline when visiting incubating Royal penguins appear unlikely to elicit responses considered greater than minor or transitory, consistent with activities that are considered acceptable by current management arrangements on Macquarie Island. However, applying this guideline requires caution because the cumulative impacts of visitation are unknown and greater responses may occur with larger group sizes or during different breeding phases. We consider minimum approach distance guidelines should be based on the separation distance necessary to allow animals to undertake normal activity, rather than on the distance people can approach wildlife before the animals flee.

Keywords: *Eudyptes schlegeli*; Royal penguins; Human disturbance; Visitor management; Minimum approach distance; Heart rate; Behaviour

1. Introduction

Minimum approach distance guidelines, or set-back distances, are often used by natural resource managers as a proactive measure to mitigate potentially harmful effects of human activity near seabird and waterbird colonies (Erwin, 1989; Claridge, 1997; Rodgers and Smith, 1997; Booth and Bio, 2001). Examples of their application include tourist behaviour guidelines (International Association of Antarctica Tour Operators, 2003), aircraft overflight distances (Australian Antarctic Division, 2000), boat approach guidelines (Rodgers and Schwikert, 2002), and guidelines for petroleum industry activities (Scobie and Faminow, 2000). To be most effective, minimum approach distance guidelines should be based on empirical evidence of responses to human activity, as opposed to anecdotal information (Claridge, 1997; Booth and Bio, 2001). This empirical evidence is ideally derived from manipulative experiments, which can reveal specific responses elicited by specific stimuli, appropriately cater for the variation in seabird and waterbird responses to human activity that are known to exist (Fernández-Juricic et al., 2002; Blumstein et al., 2003), and allow rapid and accurate development of guidelines.

Penguin colonies are popular wildlife tourist destinations, particularly in many subantarctic and Antarctic locations, where tourism has been steadily increasing

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since the 1980s (International Association of Antarctica Tour Operators, 2005). It has generally been thought that penguins breeding in Antarctica and the subantarctic were robust to pedestrian visitation, however this assumption has been challenged in recent times (Müller-Schwarze, 1984; Culik and Wilson, 1991). Several studies have now quantified the effects of human visitation on penguins, with results varying widely. Demonstrated behavioural and physiological effects have been reported in some studies (Culik et al., 1990; Wilson et al., 1991; Giese, 1998; Fowler, 1999) but not in others (Nimon et al., 1995; but also see Culik and Wilson, 1995). In addition, reduced reproductive performance has been documented (Woehler et al., 1994; Giese, 1996; McClung et al., 2004), but not consistently (Yorio and Boersma, 1992; Cobley and Shears, 1999; Patterson et al., 2003). From these studies, it appears that species-specific responses operate with other factors, such as breeding phase, further influencing results (Culik and Wilson, 1995; Claridge, 1997; Yorio et al., 2001). Moreover, these results highlight that long-term fitness consequences of visitation to penguins are possible, suggesting that cautionary measures to manage human visitation near penguin colonies may, in some cases, be warranted.

Royal penguins *Eudyptes schlegeli* are endemic to Macquarie Island (54° 30′S 158° 57′E) and are subject to human activity from the Australian Antarctic Program, management programs from the Tasmanian Parks and Wildlife Service and commercial tourism. Royal penguins are frequently subject to pedestrian visits, with Australian Antarctic Program and Tasmanian Parks and Wildlife Service personnel commonly traversing the island using routes located near breeding colonies. In addition, one colony, located at Sandy Bay (54° 32′S 158° 55′E), is specifically targeted for commercial tourist visits. Most visitors, irrespective of their purpose for being on the island, seek close interactions with penguins, and a 5 m minimum approach distance guideline is recommended as providing a suitable buffer between breeding penguins and people (Tasmanian Parks and Wildlife Service, 2003a), similar to that used on other subantarctic and Antarctic locations by tourism operators (International Association of Antarctica Tour Operators, 2003) and Antarctic Treaty nations (Antarctica New Zealand, 2000; Umweltbundesant, 2002). The 5 m minimum approach distance is often applied as a blanket guideline, applicable to all penguin species during all stages of their breeding and moult, however, the suitability of this guideline has not been empirically tested for penguins breeding on Macquarie Island. A previous study on Royal penguins found that investigator activity did not influence within-season breeding success (Hull and Wilson, 1996), however, these results do not transfer easily to information about the effects of the current 5 m guideline for pedestrian visitation.

Reviewing the minimum approach distance guidelines is cited as a management and research priority for Macquarie Island (Tasmanian Parks and Wildlife Service, 2003b). To address this, we conducted controlled approach experiments to record behaviour and heart rate from incubating Royal penguins before, during and after exposure to pedestrian approaches to 5 m. In addition, responses to naturally occurring stimuli, including conspecifics and Subantarctic skuas *Catharacta skua lonnbergi* were recorded, to allow comparisons with responses to the human approach stimulus. The overall aim of this study was to assess the suitability of the 5 m minimum approach guideline for incubating Royal penguins, and to consider implications for management of human–penguin interactions for both tourism and government operations on Macquarie Island.

2. Methods

2.1. Field procedures and study design

Field work on Macquarie Island was conducted between Green Gorge (54° 37.9′S 158° 53.9′E) and Red River (54° 36.5′S 158° 54.5′E), from 28 October to 17 November 2001. Only edge-nesting penguins were selected for experiments, as these individuals were exposed to the greatest potential disturbance from pedestrians. This selection of penguins also controlled for the influence of nest location within the colony (Tenaza, 1971). Only single incubating birds were selected (i.e. no partner was present) to eliminate the possibility of partners influencing the responses of focal birds. Penguins were approached between the hours of 12:00 and 18:00, and during specific weather windows, whereby wind <25 knots (measured at 2 m above ground level using a Speedtech Instruments Weathermate©) and precipitation was ⩽light, based on Australian Bureau of Meteorology definitions (Bureau of Meteorology, 2001). No other human visitation to these colonies occurred leading up to and during experiments. All colonies were situated between tall tussock grassland *Poa foliosa* and pebbled beaches (Selkirk et al., 1989).

2.1.1. Behaviour and heart rate

Behaviour was recorded on Hi-8 video cameras operated from a remote observation post out of view of focal penguins. Heart rate was concurrently recorded via artificial eggs (Giese et al., 1999). For the duration of the experiment (2 h), real eggs were placed in a field incubator and then replaced in original nests. Prior to the placement of the artificial egg, 30 min of behaviour was recorded (i.e. pre-egg placement period), during which the penguin had no exposure to humans (Table 1). The period of time between placing eggs and commencing the pedestrian approach was 100 ± 5 SD minutes.

Table 1
Pedestrian approach sequence

Phase	Description	Duration
Pre-egg placement	No people present	30 min
Break	No people present	80 min
Pre-approach	No people present	21 min
Approach	Walking from 30 to 5 m at 1 m/s towards the focal bird	25–35 s
Approach	Standing at 5 m from focal bird	60 s
Approach	Crouching at 5 m from focal bird	60 s
Approach	Standing and retreating at 1 m/s along original route	25–35 s
Post-approach	No people present	15 min

2.1.2. Pedestrian approach

The pedestrian approach experiment followed a before (pre-approach), during (approach) and after (post-approach) repeated measures design. The same protocol was strictly followed for each approach. Table 1 outlines the approach procedures used, and the duration of recording for each phase of approaches. Post-approach recordings were split into 5×3 min segments in order to more accurately determine when behaviour returned to pre-approach levels. No humans were visible to the focal penguins during pre-approach and post-approach periods.

For each approach, the pedestrian wore a red jacket to give consistent visual stimuli to the focal penguins. Penguins were approached from 30 to 5 m, with each 5 m interval identified to investigate the distance category at which focal birds first became alert.

To assess whether using artificial eggs influenced subsequent results, two controls were used. To determine if artificial eggs influenced the normal behaviour of individual penguins prior to the pedestrian stimulus, pre-egg placement behaviour was compared to their pre-approach behaviour. To determine if artificial eggs subsequently predisposed focal penguins to respond differently to the pedestrian stimulus, we recorded the distance at which one neighbouring incubating penguin per focal bird (less than 0.5 m away from focal bird) first became alert to the pedestrian stimulus, and compared this to the focal penguins.

To provide comparisons of responses to natural stimuli and pedestrian approaches, opportunistic measurements of behaviour and heart rate were made in the presence of agonistic interactions with conspecifics walking past the nest, and during Subantarctic skua overflights lower than 15 m above the focal penguin nest. All such recordings occurred during the pre-approach.

2.2. Analyses

Behaviour was collected from 26 penguins and analysed using the behavioural software *The Observer 5.0* (Noldus Information Technology, 2002). Behaviours were classified as states or events (after Altman, 1974), and measured as a proportion of observed time or the frequency of occurrence per minute, respectively. State behaviours included resting, maintenance and posture. Resting consisted of time spent motionless or undertaking comfort events (described below). Maintenance included all related nest or body maintenance activities (classified separately as preening and nesting), and display comprised all related activities from bowing to head swinging (Warham, 1971, 1975). Posture was recorded as either the time spent standing off the egg, or crouching or lying with the egg covered. Comfort, vigilance and aggression were scored as frequency of occurrence per minute. Comfort behaviours included yawning, defecating and stretching (after Smith, 1970). Vigilant behaviours comprised looking, turning the head from 0° to 180° from a forward facing position, and neck extensions. Agonistic acts comprised reaching towards the offender with the bill, or striking with the bill (Smith, 1970; Warham, 1971; Jouventin, 1982). In addition, we scored behavioural events previously suggested to be responses to human activity, or associated with displacement activity, including: head shaking, swallowing, raising flippers and wing shivering (after Smith, 1970; Warham, 1971; Jouventin, 1982).

Heart rate was expressed as beats per minute and established from minimum time periods of 15 s, regardless of behaviour. Resting heart rates were established from pre-approach recordings by counting beats per minute only during periods of rest, following behavioural definitions above, from minimum time periods of 15 s.

To accommodate the relatively transitory events of some of the natural stimuli to which penguins were exposed, we standardised the timescale of comparisons between pedestrian and natural stimuli, by analysing vigilance, aggression and heart rate responses during the first 15 s following exposure to each stimulus. During the approach, the first 15 s once the approacher arrived at 5 m was used.

2.2.1. Statistical analyses

Paired *t*-tests were used to compare penguin behaviour before and after placement of artificial eggs (pre-egg placement vs. pre-approach), and for comparisons between pedestrian and natural stimuli, for which individual differences between treatments met normality assumptions (Zar, 1996). Statistical power analyses were applied to the former, where the effect sizes of interest were a 50% and 20% change in behaviour. Bonferroni corrections ($P = 0.017$) were applied to results for comparing responses between natural and pedestrian stimuli. A chi-squared analysis was used to compare the distance focal and neighbouring penguins first became alert. The first distance category (30 m) was excluded from analyses as no responses were recorded from this distance. To determine if particular behaviours could be reliable predictors of a physiological response, heart rate from the approach was broken into 5 s intervals and then correlated with other labile behaviours over the same time frame using non-parametric Spearman's rank order correlations, given behaviours often did not fit a normal distribution (Quinn and Keough, 2002). Lag sequential analyses (Noldus Information Technology, 2002) were used to determine the number of times bill-shaking, swallowing, wing shivering and flipper raising occurred with other behaviours, to determine associations between behaviours and to ascertain if these could be reliable indicators of response to human activity.

To compare behaviour and heart rate before, during and after the approach, a series of mixed model analyses were used. In addition, to determine if both resting heart rate and heart rate were stable prior to conducting the approach, resting heart rate and heart rate from the pre-approach period were sub-sampled into six consecutive 3 min periods and compared over time using mixed model analyses.

For all mixed models, experiment phase (pre-approach/approach/post-approach one through four) was treated as a fixed factor, with penguins specified as subjects within the covariance structure for the repeated component of analyses. Prior to fixed effects testing, selection of appropriate covariance structures were undertaken using Akaike Information Criterion (AIC), Schwarz's Bayesian Criterion (BIC) and Chi-Square tests of comparisons of −2 Log Likelihoods, following Brown and Prescott (1999). Satterthwaite's approximation for degrees of freedom were used, with fixed effects testing using Wald's *F*-tests and least squares means (Littell et al., 1996). Following significant *F*-tests ($p < 0.05$), contrasts were performed with the null hypotheses that approach and post-approach values were not different from those recorded in the pre-approach, and assessed with *t*-tests based on least squares means results for fixed effects.

For those variables that satisfied assumptions of normality, Residual Maximum Likelihood (REML) techniques were used in linear mixed models. For those variables that did not satisfy assumptions of normality, e.g. behaviours that occurred more rarely during the experiments resulting in skewed distributions, data were treated as binary responses for the presence or absence of the behaviour. Analyses were undertaken using Generalised Linear Mixed Models (GLMM) (McCullagh and Nelder, 1989) and pseudo-likelihood measures of estimation (Wolfinger and O'Connell, 1993; Littell et al., 1996). For the Generalised Linear Mixed Model analyses, data from the 21 min of pre-approach were split into 7×3 min segments (however still treated as one factor level) to allow appropriate comparison to each 3 min period during approach and post-approach periods. For Generalised Linear Mixed Model analyses Bernoulli error distributions and logit link functions were specified, with a dispersion parameter fitted (Littell et al., 1996).

Where necessary for parametric statistics, percentage data were arcsine transformed or continuous data $\log(x + 1)$ transformed prior to testing, to meet relevant assumptions (Zar, 1996). For testing, $\alpha = 0.05$.

Mixed model analyses were undertaken using the PROC MIXED procedure in SAS, with a GLIMMIX macro for binary response variables, following Littell et al. (1996) and Brown and Prescott (1999). All other statistical analyses were carried out using SPSS v.11 and GPower.

3. Results

3.1. Effects of artificial eggs on behaviour

There was no statistical difference in the behaviour of individual penguins before and 80 min after artificial eggs were introduced into their nests ($p > 0.05$). These results had a high (>80%) power to detect a 50% change in behaviour, but due to individual variation, had a low power to detect a more subtle (20%) change in behaviour (Fig. 1). Nevertheless, these results suggest that using artificial eggs did not alter the behaviour of focal penguins in the absence of human stimuli.

The distance at which focal and neighbouring Royal penguins first displayed vigilant activity was not statistically different ($x^2 = 1.963$, df = 4, $P = 0.743$), suggesting that placing artificial eggs did not alter the subsequent behaviour of focal penguins when approached. By the

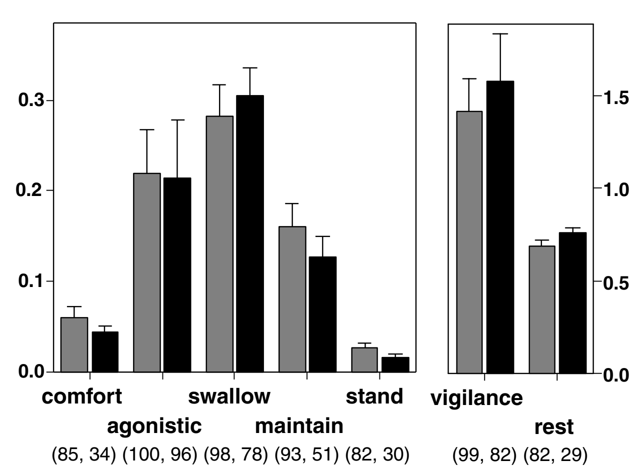

Fig. 1. Mean ± SE Royal penguin behaviour, [percentage time spent (maintenance activity, standing, resting) and acts per minute (comfort, agonistic, vigilance activity and swallowing)] before (light bars) and 80 min after (dark bars) placement of artificial egg to record heart rate. Figures in parentheses below are power to detect a 50% and 20% change in effect size from *t*-tests, respectively.

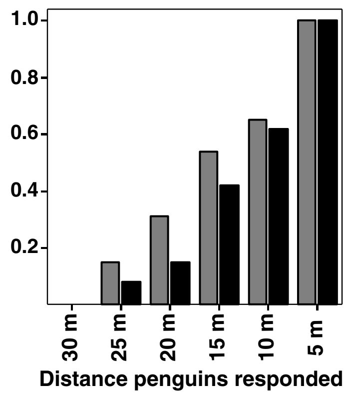

Fig. 2. The cumulative proportion of the distance at which Royal penguins first became vigilant during the approach (focal penguins light bars, neighbour penguins dark bars).

time the approacher was 5 m from the nest, 100% of focal and neighbouring penguins sampled ($n = 54$) had responded to the approacher, with 65% from each group responding at the 10 m approach distance (Fig. 2).

3.2. Establishing resting heart rate

Royal penguin heart rate and resting heart rate did not significantly vary during the 6×3 min pre-approach sub-sampled periods ($F_{5,66.2} = 0.69$, $P = 0.635$, $F_{5,102} = 1.35$, $P = 0.250$, respectively), however, there were significant differences in heart rate and resting heart rate between penguins ($F_{24,14} = 68.3$, $P < 0.001$, $F_{24,102} = 246.28$, $P < 0.001$, respectively).

3.3. Effects of approach on heart rate and behaviour

When approached, Royal penguin heart rate was 23% higher than that recorded during the pre-approach ($t_{23.1} = -6.97$, $P < 0.001$, Fig. 3(a)), and levels of vigilance were 600% greater ($t_{25} = -9.98$, $P < 0.001$, Table 2 and Fig. 3(b)). Heart rate and vigilance peaked when the pedestrian reached 5 m, at 1.7 times resting heart rate and 20.9 acts/minute, respectively. The percentage of time penguins spent resting also significantly decreased and comfort levels significantly increased when the pedestrian was at 5 m ($t_{25} = 8.56$, $P < 0.001$; $t_{315} = -3.79$, $P < 0.001$, respectively, Fig. 3(c) and (d)). During the approach, vigilance was the most labile behaviour recorded, with the mean frequency of vigilance acts/minute showing a significant positive relationship with mean beats per minute, expressed as a function of resting heart rate ($r_s = 0.758$, $n = 35$, $P < 0.001$) (Fig. 4(a) and (b)). During the approach, penguins responded to any movement by the pedestrian, with heart rate and vigilance increasing when approached, during the subtle movement of crouching and when the pedestrian stood to leave (Fig. 4(a) and (b)).

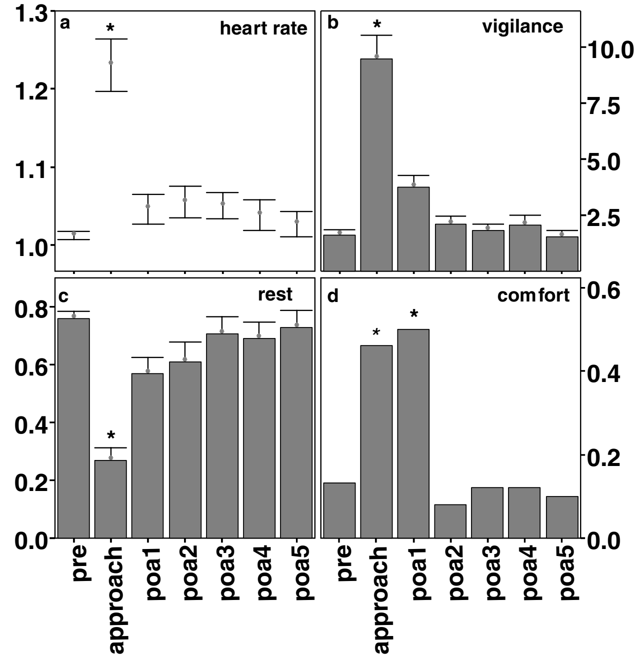

Fig. 3. (a)–(d) Mean ± SE Royal penguin heart rate as a function of individual resting heart rate (a), vigilant acts/minute (b), percentage time spent resting (c), and proportion penguins performing comfort acts (d). Stars indicate experiment phases significantly different from pre-approach.

Egg exposure due to standing was recorded during every experiment phase, primarily associated with comfort and maintenance activity (Fig. 5). Full body stretches, the only comfort behaviour recorded in association with egg exposure, were a ritualised behaviour lasting 3.2 ± 0.8 SD seconds ($n = 37$ events recorded across all experiment phases). During maintenance behaviour, standing and exposing the egg was primarily associated with preening (particularly when penguins would preen their backs), with mean time of egg exposure being 19.2 ± 13.6 SD seconds ($n = 48$ events recorded across all experiment phases).

During the approach, the proportion of penguins observed standing and exposing eggs was greater than observed prior to the approach, although this difference was not significant ($F_{6,315} = 1.68$, $P = 0.125$, Table 2). Egg exposure associated with vigilant behaviour was only recorded during approaches (4 penguins recorded standing, 15% of penguins sampled, Fig. 5).

For the 3 min immediately following the approach heart rates were comparable to those recorded prior to approaches, however vigilance levels remained significantly elevated ($t_{25} = -4.62$, $P < 0.001$, Fig. 3(b)). Following approaches, we observed a trend whereby more penguins stood, associated with increased comfort levels and greater numbers of penguins performing maintenance, although only comfort levels were significantly different to pre-approach levels ($t_{315} = -4.12$, $P < 0.001$, Table 2 and Fig. 3(d)). From 4–15 min following the

Table 2
Fixed effects results for mixed model analyses of Royal penguin heart rate and behaviour

Response	
Heart rate (beats per minute)	$F_{6,20.1} = 13.40$, $\mathbf{P < 0.001}$
Vigilant acts/minute	$F_{6,23.8} = 37.83$, $\mathbf{P < 0.001}$
Percentage time spent resting	$F_{6,21.2} = 31.23$, $\mathbf{P < 0.001}$
Proportion penguins standing off egg	$F_{6,315} = 1.68$, $P = 0.125$
Proportion penguins performing comfort acts	$F_{6,315} = 5.30$, $\mathbf{P < 0.001}$
Proportion penguins performing maintenance activity	$F_{6,258} = 0.69$, $P = 0.656$
Proportion penguins performing agonistic acts	$F_{6,292} = 0.72$, $P = 0.632$
Proportion penguins performing swallowing acts	$F_{6,315} = 0.94$, $P = 0.468$

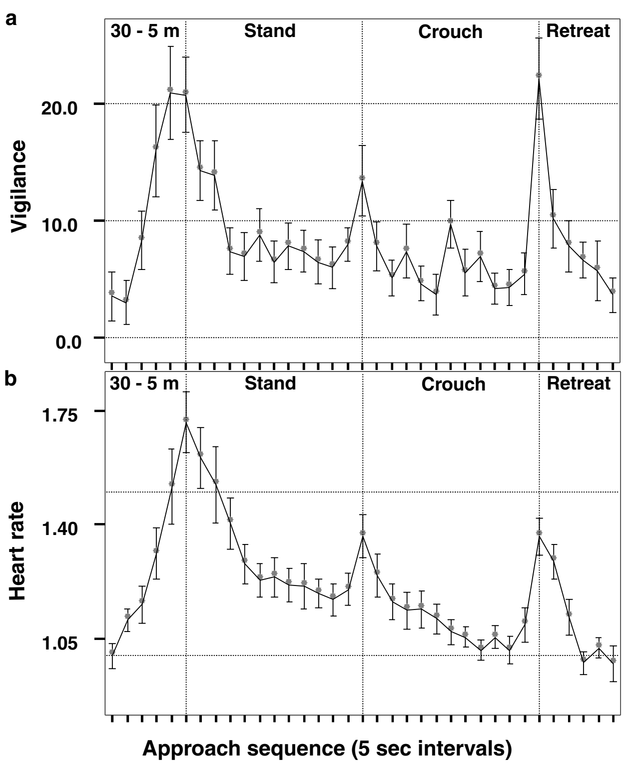

Fig. 4. (a)–(b) Mean ± SE vigilance (a) and heart rate (b) per 5 s during the approach sequence ($n = 26$ for vigilance, $n = 20$–22 for beats per minute).

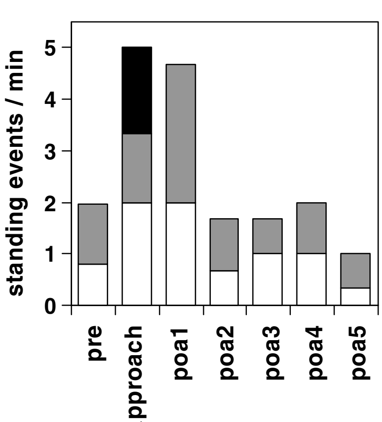

Fig. 5. Number of standing events recorded per minute for comfort (clear bars), maintenance (light bars) and vigilant activity (dark bars).

approach, behaviour and heart rate were not significantly different to that recorded from the pre-approach period.

3.4. Behaviours previously associated with disturbance events

During analyses, particular attention was paid to behaviours that have been previously associated with disturbance in penguins. Wing shivering was recorded from only one penguin (4% of sampled penguins), and flipper raising from four penguins (15% of sampled penguins). Both behaviours were associated with agonistic and vigilant activities.

During the pre-approach, 19 out of 26 penguins displayed bill-shaking, with a total of 65 events recorded. Swallowing followed bill-shaking events in 63 (97%) of these events. Maintenance activity preceded 58%, and vigilant or agonistic activity 26%, of bill-shaking events, respectively. Swallowing events were recorded from all penguins, with a total of 162 swallowing events recorded. Of the 99 swallowing events not associated with bill-shaking, 43% followed maintenance activity, and 40% followed vigilant or agonistic activity. There was no significant difference in numbers of penguins swallowing during the experiment sequence.

3.5. Comparison of responses to natural stimuli versus human stimuli

The three different stimuli penguins were exposed to elicited three characteristically different responses. All three responses involved elevated heart rate above resting heart rates (Fig. 6(a)–(c)), however, heart rate during human approach was significantly greater than that recorded during skua overflights ($t_{14} = 7.34$, $P < 0.001$) or agonistic interactions with conspecifics ($t_{14} = 5.93$, $P < 0.001$). Skua overflights and human approaches both elicited increased levels of vigilance, however, significantly greater responses were recorded during human approaches ($t_{14} = 3.75$, $P = 0.002$). Responding to a conspecific elicited a markedly different behavioural response, as it primarily involved agonistic acts, which were not recorded during human approaches or skua overflights.

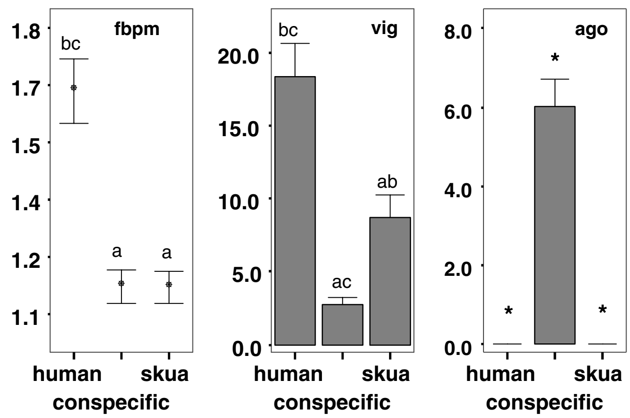

Fig. 6. Mean ± SE of beats per minute as a function of individual resting heart rate (fbpm), vigilant acts/minute (vig) and agonistic acts/minute (ago) during approacher standing at 5 m ($n = 26$), agonistic interactions with a conspecific ($n = 15$) and skua overflights ($n = 15$). Letters indicate statistical difference. Stars indicate no statistical testing done as no agonistic responses were recorded during human approaches or skua overflights.

4. Discussion

4.1. Royal penguin heart rate and behaviour in the absence of people

We found no difference in behaviour before and after egg placement and no difference in the distance of first response between penguins that received artificial eggs and those that did not, suggesting that the methodology we used did not adversely influence subsequent results. Further, during our control (pre-approach) period, heart rate and resting heart rate did not vary over time, suggesting that heart rate had stabilised before approach experiments commenced.

In the absence of human activity, Royal penguins spent the majority of their time resting, interspersed with bouts of maintenance activity and low levels of vigilance and comfort activity. These results are consistent with those recorded for this and other crested penguin species during incubation (Smith, 1970, 1974; Warham, 1971, 1975; Haftorn, 1986).

We recorded a wide range in resting heart rates of individual Royal penguins. Intra-species variation in physiological parameters are well known amongst vertebrates (Spicer and Gaston, 1999), with penguin resting heart rates demonstrated to vary within and between individuals based on factors such as sex and body condition (Froget et al., 2001; Green et al., 2001). The variation we observed may have been a consequence of some intrinsic factor not measured. The variation in Royal penguin resting heart rate reported here (78.3 ± 3.0 SE, $n = 25$) was within the range for resting heart rate reported in previous studies on the morphometrically similar Macaroni penguin *Eudyptes chrysolophus*, however, mean resting heart rate for Royal penguins was slightly lower [early breeding Macaroni females 85.4 ± 4.4 SE $n = 9$ and male 96.6 ± 2.3 SE $n = 9$ (Green et al., 2001) and brooding/crèching females 101.4 ± 5.3, $n = 30$ (Green et al., 2002)]. The peak heart rates recorded during this study (1.7 times resting heart rate during first 15 s of pedestrian standing at 5 m, maximum recorded from an individual was 2.36) were within the physiological capability previously recorded for Macaroni penguins during diving activity [275 beats per minute – Green et al. (2003), equalling approximately 2.8 and 3.2 times resting heart rate of male and female Macaroni penguins, respectively, using resting heart rate from Green et al. (2001); and 2.7 times resting heart rate using brooding/crèching females from Green et al. (2003)].

4.2. Royal Penguin responses to pedestrian approaches

Several authors have suggested that humans may represent ‘pseudo’ predators for wildlife, eliciting a flight or fight response comparable to those displayed when animals are subject to natural predators (Frid and Dill, 2002; Beale and Monaghan, 2004a). This suggests that breeding penguins would be expected to adjust responses relative to the perceived threat each stimulus represented, ultimately balancing survivorship against the current breeding attempt in deciding whether to flee (Ydenberg and Dill, 1986). In fleeing the nest, penguins would have reached a decision where the perceived risk of staying on the nest represented a threat to their own survival that outweighed the benefits of continuing to breed. During our study, no penguin abandoned its nest, suggesting that a single person approaching the nest to 5 m did not represent a sufficient threat to warrant sacrificing the current breeding attempt. Rather, we observed a short-term, stress response to the experimental stimulus, defined as an interruption to homeostasis by a perceived threat (Moberg, 2000; Romero, 2004). This response was comparable to other studies on seabirds investigating similar stimuli (Culik et al., 1990; Wilson et al., 1991; Giese, 1998; Weimerskirch et al., 2002; de Villiers et al., 2005). The response we recorded from Royal penguins is likely to be a precursor to a flight or fight response, particularly evident through heightened vigilance activity, increased heart rates and the occurrence of standing events associated with vigilance (only observed during approaches), suggesting a level of behavioural and physiological preparedness, should a more extreme response be warranted, similar to that described in other studies (Stout and Schwab, 1980).

During this study pedestrian approaches elicited significantly greater physiological and vigilant responses from Royal penguins than did skua overflights, similar to results in Adélie penguins *Pygoscelis adeliae* (Wilson et al., 1991; Giese, 1998). This may have been a consequence of the brevity of the skua overflight, however we sought to control this by standardising the time-frame measured (15 s) from the skua, conspecific and human stimuli. Measuring heart rate and behaviour in response to skuas walking near focal penguins may have been a more appropriate comparison, however, skua overflights still provide a valid and useful index of responses of penguins to naturally occurring disturbance stimuli. Nevertheless, results suggest that Royal penguins perceived a single person approaching to 5 m as a greater threat than a skua overflight, possibly a consequence of the relative familiarity with the stimulus of the skua. Given Royal penguins would have considerable experience with skua overflights, penguin responses to this stimulus would be expected to reflect a balance between maintaining vigilance toward a known predator, and minimising energy expenditure toward a stimulus that is frequent and familiar. By contrast, given their relative unfamiliarity with pedestrians, penguins may assess this stimulus as warranting an elevated response. Habituation to human stimuli has been reported from penguin colonies exposed to frequent visitation (Yorio and Boersma, 1992; Fowler, 1999; Holmes, unpublished data). However, as habituation requires exposure to a consistent and frequent stimulus (Mazur, 1998), this mechanism is unlikely to operate at Royal penguin colonies on Macquarie Island because human visitation (by tourists and Australian Antarctic Program expeditioners) is infrequent and visitor group size inconsistent.

We found that the magnitude of increase in Royal penguin heart rate recorded during pedestrian approaches differed to that from similar studies on other species. Increases of 1.5 and 1.6 times resting heart rate have been reported for Adélie penguins (Culik et al., 1990; Giese, 1998). In contrast, Nimon et al. (1995) found, on average, no increase in Gentoo penguin heart rate when birds were approached to 3 m, however, in a critique of this study, Culik and Wilson (1995) pointed out that Gentoo penguin peak heart rate values of 1.2 times resting heart rate were recorded in the presence of visitors. It is unclear if the relative familiarity of penguins in Nimon et al.'s (1995) study played a role in the lower responses they reported, given that this work was conducted at a colony (Cuverville Island) with a history of high visitation (International Association of Antarctica Tour Operators, 2005). Penguin heart rate values from Nimon et al.'s (1995) previous work on Adélie penguins were suggested to be influenced by the methodologies used (i.e. prior capture and handling) (Nimon et al., 1995). We could detect no effect of our method for recording heart rate on subsequent results.

Several previous studies have demonstrated how visitor behaviour (e.g. approach type, walking speed, angle of approach) can influence seabird responses (Burger and Gochfield, 1981; Wilson et al., 1991; Giese, 1998; Martin et al., 2004; Fernández-Juricic et al., 2005). We found that Royal penguins responded to even subtle movements by a visitor, such as crouching, highlighting the need for people visiting penguins to move slowly and avoid sudden movements when near breeding colonies.

4.3. Using behaviour to predict responses

In this study we quantified a number of behaviours previously thought to be associated with responses to human activity. Information of this kind is valuable to managers and can be used as a self-guiding resource for visitors to monitor their own impact while visiting penguins.

Displacement activity is commonly referred to as a response to human activity or disturbance events (Jouventin, 1982), through the presence of 'irrelevant' behaviours (Kortmulder, 1998). In penguins this has been reported to include preening (in *Aptenodytes* sp.) and bill-shaking activity (Jouventin, 1982). During this study there was evidence of Royal penguins performing displacement activity, through significantly greater numbers of birds performing comfort activities during and after the approach, and increased numbers of penguins undertaking maintenance activity following the approach.

Bill-shaking and swallowing in penguins and other seabirds are likely to operate as functional behaviours (e.g. to remove excess sodium chloride from the bill) but are also suggested to be displacement behaviours (Jouventin, 1982). Other authors have further suggested that bill-shaking may also be a consequence of increased stress hormones in Adélie penguins (Ainley, 1974), and Giese (1998) reported significantly higher rates of bill-shaking when penguins were approached to 5 m by a single person. During the pre-approach period in this study, 58% of bill-shaking events followed maintenance activity and 26% after vigilant or agonistic activity. Swallowing occurred after 97% of all bill-shaking events, and when occurring independently of bill-shaking, also followed maintenance, vigilance and agonistic behaviours in similar proportions to bill-shaking. However, no significant change was recorded in the proportion of penguins swallowing when approached, suggesting this behaviour would be less reliable as an indicator of response to human activity in incubating Royal penguins.

We found that vigilant activities (i.e. heading-turning and neck extensions) were a strong predictor of heart rate during pedestrian visitation, in contrast with studies on Adélie penguins, where physiological responses often pre-empted behavioural response (Wilson et al., 1991; Giese, 1998). This result suggests that people near Royal penguins can gauge the effects of their visit on both penguin behaviour and heart rate by observing vigilance behaviour. Flipper raising and wing shivering, previously suggested to be responses to humans (Warham, 1975; Jouventin, 1982), proved less reliable as indicators of physiological response in incubating Royal penguins.

4.4. Management implications

For managers of human–wildlife interactions, developing minimum approach guidelines requires consideration of not just biological effects but social expectations (Moscardo, 2001; Finkler and Higham, 2004; Valentine et al., 2004), legal requirements and management objectives (Claridge, 1997; Council of Managers of National Antarctic Programs, 1999). The role of studies such as ours is to contribute biological information as the basis for minimum approach distance guidelines that reduce the likelihood of unacceptable impacts occurring during human-wildlife interactions.

A key component in developing minimum approach distance guidelines is defining a threshold of acceptable impact, that is, what response is considered acceptable when approaching wildlife, and what responses are to be avoided. Within the Macquarie Island draft management plan, activities are generally not allowable when they are likely to exceed minor or transitory impacts (Tasmanian Parks and Wildlife Service, 2003b; p. 52 and 175). However, this plan offers no strict definition of what is meant by minor or transitory in this context. This terminology and concept is similar to that used for environmental impact assessments in Annex I of the Protocol on Environmental Protection to the Antarctic Treaty (the Madrid Protocol) (Council of Managers of National Antarctic Programs, 1999; Kriwoken and Rootes, 2000; Cohen, 2002). Despite ambiguities in the interpretation of what constitutes a minor or transitory impact, and the absence of clear definitions in the Madrid Protocol (Redgwell, 1994; Vicuña, 1996), practical application of these definitions requires assessment of each activity on a case by case basis (Cohen, 2002). The significance of potential impacts can then be determined through consideration of factors including the direct, indirect and cumulative effects of the activity (Council of Managers of National Antarctic Programs, 1999).

For people visiting penguins in the subantarctic and Antarctic, the most unambiguous examples of direct impacts to individual animals that are likely to exceed minor or transitory would be mortality or an abandoned breeding attempt. However, these represent relatively gross responses to visitation. Not only do managers often wish to ensure there is minimal chance of such extreme responses occurring, it is also possible that significant effects on key parameters such as breeding success can occur even when gross responses, such as fleeing the nest, are not a part of an animal's immediate response to pedestrian activity (Giese, 1996; Beale and Monaghan, 2004a). Consequently, minimum approach distance guidelines that allow minor or transitory impacts may not reliably prevent deleterious longer-term effects, as these responses may contribute to the proximate mechanisms of more significant harmful impacts for some animals. Frequency of visitation would also influence the consequences of short-term responses such as these, and should be integrated into management decisions about suitable minimum approach distances.

During our study we observed neither nest abandonment nor associated mortality, and the physiological and behavioural responses we observed returned to pre-approach values immediately following the approach, or within 3 min of the approach. Strict interpretation of these results would suggest that using the minimum approach distance guideline of 5 m when visiting incubating Royal penguins would not exceed minor or transitory impacts. However, it would be prudent to exercise caution given the specific nature of our study, and uncertainty as to the cumulative or long-term impacts of visitation. During this study we deliberately employed a low intensity stimulus to identify the minimum responses likely to occur during pedestrian visitation to Royal penguins, and conducted our work over one breeding phase only. Seabird responses to human activity have been found to increase with visitor group size (Geist et al., 2005; Holmes, unpublished data) and vary with stage in the breeding cycle (Wilson et al., 1991). Further, because penguins are subject to greater energetic pressure during years of poor food availability, as they have to travel further for less food (Davis and Renner, 2003), human activity is thought to have greater implications during these times (but see Gill et al., 2001; Beale and Monaghan, 2004b). A further important factor influencing response is that of breeding status. Among some species, non-breeding penguins are known to approach a stationary pedestrian stimulus, suggesting that detrimental effects are unlikely, and that a level of curiosity is evident. These responses can misrepresent those of breeding animals who may find such interactions stressful. Finally, habituation is a confounding factor that may influence responses (Dunlop, 1996; Cobley et al., 2000). The responses of penguins subject to high levels of human activity on a regular basis may not necessarily be similar to those subject to low levels infrequently. We therefore believe our results should not be interpreted to suggest that human visitation, in any form other than that we examined here, does not effect breeding Royal penguins.

An alternative, more conservative, approach to managing the impacts of human visitation on wildlife is to aim to prevent all visible effects to animals. The Australian Antarctic Division minimum approach distance guidelines, for example, aim to ensure visitors have less than minor or transitory impacts on breeding wildlife. These guidelines provide a buffer zone between people and wildlife that allows animals to undertake normal activity, as opposed to reflecting the distance people can approach animals before the animal makes a decision to flee. Under the Australian Antarctic Division guidelines applicable to the federally managed Australian Antarctic Territories, and subantarctic Heard and McDonald Islands, pedestrian visitors to breeding penguins are required to maintain a 30 m distance from the birds (50 m from breeding Emperor penguins) (Australian Antarctic Division, 2004). These guidelines are also recommended to Australian Antarctic Program expeditioners on Macquarie Island, however the Tasmanian Parks and Wildlife Service guideline of 5 m takes precedence because this island is managed by the Tasmanian State Government. The approach of the Australian Antarctic Division aims to be consistent with the lowest definition of impact under the Madrid Protocol (less than minor or transitory impacts), and is also consistent with the precautionary principle inherent in the Madrid Protocol (Redgwell, 1994; Rothwell, 1996; Rothwell and Davis, 1997; Scott, 2001). This is an important consideration given the cumulative or long-term effects of the minor or transitory responses caused by closer approaches are unknown.

Our results and those of other studies (Giese, 1998) indicate that maintaining a distance of 30 m from breeding penguins is a conservative approach that is unlikely to cause even minor or transitory responses. During this study, we found that incubating Royal penguins did not respond either behaviourally or physiologically when pedestrians were 30 m from the nest, suggesting that visitor guidelines based on a minimum separation distance of 30 m would provide greater certainty that visitors do not cause detrimental impacts than the current guideline of 5 m. However, unlike many parts of the Antarctic continent, this distance may be logistically impractical at Macquarie Island and other subantarctic locations because of the nature of the terrain. If closer approaches cannot be avoided, it should be remembered that closer approach distances will result in greater likelihood of penguins responding, and greater intensity of individual responses. We support the conservative approach based on preventing any visible response of wildlife to visitors. This requires visitors to Antarctica to be educated on the range of normal wildlife behaviour, to recognise disturbance responses when they occur and to know to retreat quietly when they see animals responding to their presence.

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