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SHORT NOTE

Measuring the influence of unmanned aerial vehicles on Adélie penguins

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Abstract Unmanned aerial vehicles (UAVs) have become a useful tool in polar research. While their performance is already proven, little is known about their impact on wildlife. To assess the disturbance caused on the penguins, flights with a UAV were conducted over an Adélie penguin (*Pygoscelis adeliae*) colony. Vertical and horizontal flights were performed between 10 and 50 m in altitude. Penguins' reactions were video-recorded, and the behavioural response was used to indicate the level of disturbance. During any flight mode, disturbance increased immediately after takeoff and remained elevated at all altitudes between 20 and 50 m. When the UAV descended below 20 m, the disturbance increased further with almost all individuals being vigilant. Only at these low altitudes, vertical flights caused an even higher level of disturbance than horizontal ones. Repetitions of horizontal overflights showed no short-term habituation occurring. Since the results are only valid for the specific UAV model used, we recommend a more extensive approach with different UAV specifications. As the highest flight altitudes already caused detectable but not subjectively visible responses, we also recommend to regard subjective impressions of disturbance with caution.

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Introduction

In the Antarctic region, as well as in the rest of the world, the use of unmanned aerial vehicles (UAVs) has recently experienced a fast increase. The purposes for its use include scientific research, professional film and photo productions, tourism, and private use by members of Antarctic stations. As the technology of UAVs is developing quickly, these devices are becoming more reliable and affordable. Hence, a further increase in this use is to be expected. The sensitivity of wildlife to disturbances caused by an approaching UAV should be considered when developing guidelines for the use of this technology. Penguins of the genus *Pygoscelis* are common in the Maritime Antarctic and have already been the subject of UAV-based scientific research (Mustafa et al. 2014; Goebel et al. 2015).

The use of UAVs in animal research is a rather young topic. Thus, studies about the impact of such vehicles on animals are lacking. Vas et al. (2015) investigated the reactions of birds, namely mallards (*Anas platyrhynchos*), greater flamingos (*Phoenicopterus roseus*) and common greenshanks (*Tringa nebularia*), to approaching UAVs (quadrocopters) in detail and were often able to approach birds within 4 m without escape reactions. Other studies which successfully used UAVs for bird mapping purposes reported only limited impact by subjective impression (Sarda-Palomera et al. 2012; Grenzdörffer 2013; Hanson et al. 2014; Goebel et al. 2015; Ratcliffe et al. 2015; Weissensteiner et al. 2015). Nevertheless, there is a lack of detailed experiments about the impact of UAVs on birds.

Because the use of UAVs is of special interest in remote and hard to access areas such as polar regions, studies of the effects on the local fauna are particularly important. Not much is known about the behavioural and physiological responses of penguins to close UAV flights. Goebel et al. (2015) performed acoustic measurements, revealing that the noise generated by their UAV at 30 m was lost in the background noise of a chinstrap penguin (*Pygoscelis antarctica*) colony.

Addressing the need for further studies on this topic, we investigated Adélie penguins' responses to the use of a microcopter. Based on such experiments, guidelines for using UAVs could be formulated to prevent extensive disturbance of penguin colonies. Müller-Schwarze and Müller-Schwarze (1977) have shown that Adélie penguins ignore predators like skuas, if the predators are flying more than 14 m above ground level (a.g.l.). The same group reported that the size of an object flying over the animals has more influence on their reaction than the shape. Since the UAV has approximately the same dimension as a skua, a similar reaction would be expected.

The Adélie penguin has the richest repertoire of behavioural displays of all penguins (Jouventin 1982) and, thus, is the most studied of all penguin species (see, e.g., Levick 1914; Spurr 1975). In recent years, more modern methods such as heart-rate measurements (Pfeiffer 2005; Schuster 2010) and hormonal analyses (Fowler 1999) became more important and replaced time-consuming and subjective behavioural studies. Nevertheless, behaviour remains an important indicator for many studies investigating stress and disturbance of penguins, often associated with human presence (e.g. Culik et al. (1990) or Schuster (2010) for Adélie penguins, or Walker et al. (2006) for Magellanic penguins (*Spheniscus magellanicus*)). Based on those studies, behavioural analysis was chosen for our study as the sufficient and least invasive method.

Methods

Study site

The study was conducted on Ardley Island, South Shetland Islands, Maritime Antarctic (Online Resource 1) during the breeding season 2014/2015. The island hosts a colony of Adélie (*P. adeliae*), gentoo (*P. papua*) and chinstrap Penguins (Braun et al. 2012). Ardley Island is designated as Antarctic Specially Protected Area No. 150, and a permit for the conduction of this study was issued by the responsible German authority. For observing the influence of UAV flight operations, two breeding groups of Adélie penguins were selected. While group A was situated at a fossil beach terrace about 10 m above sea level (a.s.l.) and 130 m from the coastline, group B was located at a plateau about 30 m a.s.l. and 160 m from the shore (Online Resource 1). Group A consisted of 34 Adélie and 18 gentoo penguin nests of which 6–8 Adélie nests were analysed; group B contained 348 Adélie and 136 gentoo penguin nests of which 7–10 Adélie nests were analysed. The number of analysed individuals varied depending on their visibility.

The weather conditions in the region are often characterized by strong gusts of wind, influencing the flight performance and noise level of the microcopter. Thus, the short time average wind speed on the ground was measured using a hand-held anemometer (Silva® ADC Wind).

UAV specifications

An Octocopter MK ARF Okto XL (HiSystems) was used for this study. The octocopter had a total weight of 3.5 kg (incl. batteries) in flight configuration. The maximum size of the microcopter is 73 × 73 × 36 cm, and it emits a noise level of 70 dB at a distance of 5 m (pers. com. HiSystems). Following Brown (2008), the noise level decreases by 6 dB while doubling the distance from the source. Therefore, the noise level at 40 m distance is presumed to be 52 dB. However, the actual noise level at any distance varies due to weather influences, terrain and the position and flight direction of the UAV. These fluctuations were not measured in the study. Equipped with a GPS and an inertial measurement units (IMU), it has the ability of autonomous flight. This capability was used for the experimental flight schemes (Fig. 1) of the experiment to ensure a precise repetition of the experiment setting while conducting the different runs in terms of positioning and flying speed. During the flights, the UAV was not equipped with any camera or sensor.

Flight schemes

To simulate different types of flight operations, three general flight modes were applied: a horizontal flight, a vertical flight and habituation flights (Fig. 1). The former two flight modes were performed above group A only. UAV takeoff occurred 50 m from group A, since Vas et al. (2015) showed that this distance is adequate to avoid reactions in other bird species. The UAV then ascended to a 50 m flight altitude while travelling to the starting point. This altitude was chosen because in other studies it did not cause a response in the penguins (Müller-Schwarze and Müller-Schwarze 1977; Goebel et al. 2015). The starting point of the vertical flight (Fig. 1b) was at 50 m above the target breeding group, moving downwards to an altitude of 10 m. The horizontal flight scheme (Fig. 1a) also started at 50 m above ground level, but was laterally displaced.

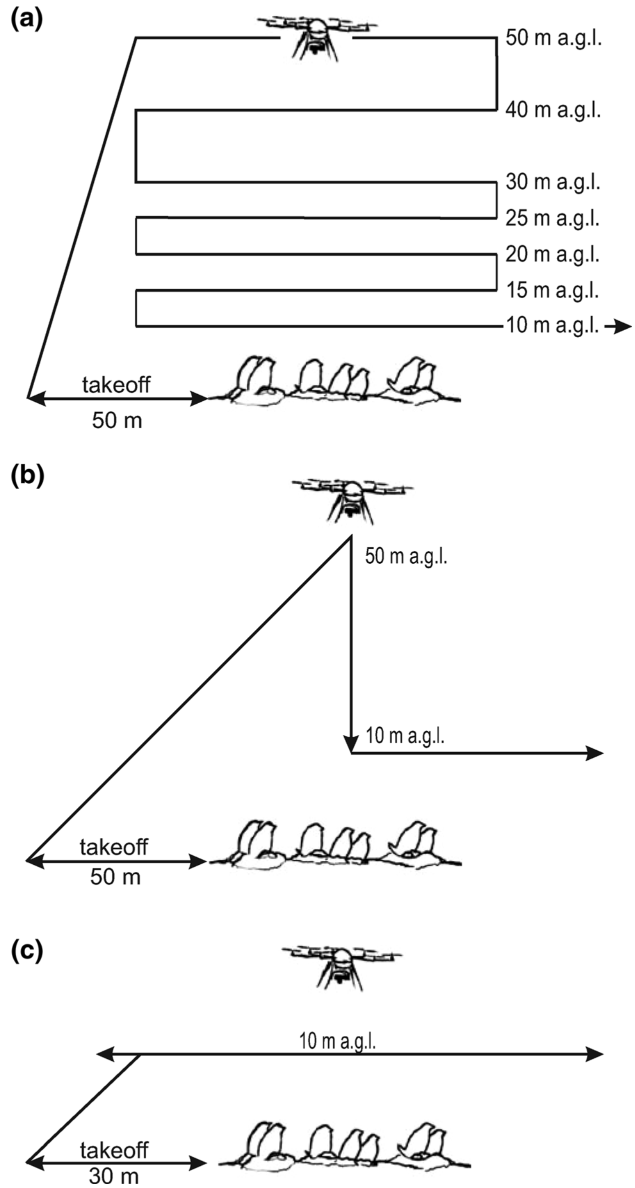

Fig. 1 The design and flight altitudes above ground level (a.g.l.) of the three different flight schemes performed during the experiments: **a** horizontal flight, **b** vertical flight, **c** habituation flight. Horizontal and vertical flights were performed above breeding group A (34 *Pygoscelis adeliae*, 18 *P. papua* nests), habituation flights above breeding group B (348 *P. adeliae*, 136 *P. papua* nests; for location within colony see Online Resource 1)

Repeated horizontal flights occurred along 80 m transects at altitudes of 50, 40, 30, 25, 20, 15 and 10 m above the targeted breeding group. Horizontal flights lasted 178–246 s, and vertical flights lasted 49–77 s. On each of the three test dates (11/23/2014, 01/02/2015, 01/17/2015), horizontal and vertical flight schemes were applied alternately with two repetitions, respectively. Additional flights were conducted to test for short-term habituation in group B. On one test date (11/14/2014), two sessions of 10 m high horizontal flights were completed, with the first session containing 10 flyovers and the second containing 17 (Fig. 1c). Takeoff occurred 30 m from group B, and turning points were 55 m apart. These flights lasted 253 and 351 s. The time between the two flights lasted about 15 min, until the penguin behaviour appeared to reach 'normal' levels. Before every takeoff on flight days 1 and 3, penguin behaviour was recorded for a control period of 8–129 s. During this time, the environmental conditions and set-up were comparable to the flight periods, but the UAV was not airborne.

Behavioural analysis

During all flights, videos of the focal individuals were recorded using a standard camera (Panasonic® LUMIX G5®). The video material was analysed using CowLog 2.0 Software (Hänninen and Pastell 2009). Adélie penguin behaviour was observed on the basis of the ethogram given in Schuster (2010). For each visible individual, behavioural measurements were recorded each second. Behaviour subsequently was classified into five general groups: comfort, resting, vigilance, agonistic and escape. Comfort behaviour comprised all sorts of comfort movements such as stretching and shaking as well as cleaning and preening movements and breeding behaviour (e.g. mutual displays, nest, egg or chick manipulation). Resting behaviour was mainly sleeping in prone or upright positions, only interrupted by behavioural events such as yawning or small comfort movements. A penguin was recorded as vigilant if its eyes were open and movements of the head indicated attention to the surrounding events. Agonistic behaviour comprised aggressive behaviour against the UAV as well as against other penguins. No difference was made between light agonistic behaviours like bill-to-axilla movements or pointing and stronger ones like gaping or even biting. Agonistic behaviours between two penguins were interpreted as signs of disturbance as well, because UAV-induced disturbance can lead to higher internal disquietness in the breeding group and thus cause a higher frequency of aggressive behaviour between neighbours. The last class, escape behaviour, describes the strongest reaction to disturbance, in which the individual is forced to leave its nest, thus leaving its egg or chick unprotected.

During the experiments, it was impossible to exclude that disturbance factors besides the UAV such as from predators flying close to the colony occurred. If predators or other penguins approached the breeding group during observations and caused visible responses, the experiment was stopped, and the material was not used. As a result of the experiment setup, the UAV pilot and cameraman had to stand within a viewing distance of circa 15 m from the penguins and therefore caused some disturbance, which was minimized by being very quiet and only making slow movements.

As usual for behavioural analyses, one has to keep in mind that interpreting the behaviour will always have some lack of objectivity. This was minimized by defining clear patterns of differences between the various kinds of behaviour. Due to the attempt to keep behaviour interpretations objective, it was not possible to analyse changes in the intensity of behaviours, and therefore, only frequencies and durations were observed.

Statistics

To assess disturbance, penguin reactions were grouped into *disturbed* and *undisturbed* with the first comprising vigilance, escape and agonistic behaviour, the latter resting and comfort behaviour. For each horizontal flight series, the mean proportion of disturbed individuals per altitude per flight was calculated. For vertical flights, the continuous descent altitudes were grouped into categories with a range of 10 m (10–19.9 m, 20–29.9 m, etc.), and the mean proportion of disturbed individuals per altitude category per flight was calculated. As the pre-takeoff and transfer periods were similar in both flight modes (Fig. 1), they were pooled and used in both analyses. A binomial generalized linear mixed model (Bates et al. 2014) with wind speed and flight altitude as fixed factors and running flight number nested in flight day as random factors was used to test for the influences on disturbance level. This analysis was conducted in R (R Core Team 2014). Further univariate analyses were performed in IBM® SPSS® Statistics 22. Graphs were created using SigmaPlot© 13.0, and maps were made in ESRI® ArcGIS® 10.1.

Results

The binomial GLMM showed that in both horizontal and vertical flights altitude had a significant impact ($p < 0.001$) on disturbance levels. Neither wind speed ($p = 0.274$, 0.144, respectively) nor the wind speed altitude interaction ($p = 0.954$, 0.874, respectively) had an effect.

Since only altitude influenced the disturbance in both flight modes, a one-way ANOVA of the different flight altitudes was calculated to be able to test for within-factor differences. Disturbance levels were logit-transformed and violation of the independence-of-samples prerequisite had to be accepted for the ANOVA. Variances were homogenous in both flight modes (Levene test, horizontal $L = 0.386$, $p = 0.925$, $N = 93$; vertical $L = 0.861$, $p = 0.512$, $N = 66$) allowing for the F after R–E–G–W post hoc test to find homogeneous subsets.

At the 0.05 significance level, horizontal flights showed three distinct subsets of mean disturbance levels (Fig. 2). The low level before takeoff increased with transfer flight to the target penguin group. During the flight scheme, this intermediate disturbance level was maintained until an overflight altitude of 20 m. The last overflights of the scheme at 15 and 10 m increased the disturbance to a high level.

A similar pattern was found in response to vertical flights. The low disturbance level before takeoff increased (Fig. 2) during transfer flights to the focal penguin group. This was sustained until the UAV had lowered to the 20–30 m class. The 10–20 m class showed a further increase in disturbance level with mostly almost all individuals reacting. The calculation of the level of disturbance through the uncategorized vertical flight altitudes (running mean) shows a rapid increase below ca. 20 m (Online Resource 2) and thus confirms the above finding.

A comparison of horizontal and vertical flights revealed no difference when the flight levels above 20 m were compared (Mann–Whitney-$U = 732.0$, $p = 0.148$, $N = 72$); however, if just the horizontal altitudes of 10 and 15 m and the vertical class of 10–20 m were considered, the disturbance was higher in vertical flights (Mann–Whitney-$U = 133.0$, $p = 0.006$, $N = 27$).

During short-term repetition flights, the birds showed no habituation. No correlation between the mean disturbance level and the flight repetition number was detected (Spearman rho $= -0.244$, $p = 0.22$, $N = 27$). During the second flight with more repetitions, a decreasing disturbance trend after the 13th overflight seemed to occur. Not enough flights in the course of the season were performed to be able to reliably assess long-term habituation effects or sensitivity changes with season progress.

Discussion

The results show that there is indeed a visible reaction of penguins to UAVs flying above their colony. This reaction increases with lower altitudes. Short-term habituation did not occur, and the flight mode (horizontal or vertical) had an impact on the disturbance level at altitudes below 20 m. The level of disturbance caused by a microcopter in our experiments is considerable in contrast to previous studies on birds (Hanson et al. 2014; Goebel et al. 2015; Vas et al. 2015), even such on nesting birds (Sarda-Palomera et al. 2012). Since the disturbance level during transfer was already significantly different from the reaction under pre-takeoff conditions, it seems likely that a takeoff distance of 50 m is not sufficient to avoid disturbance in Adélie penguins. It is possible that this impact lasted into the

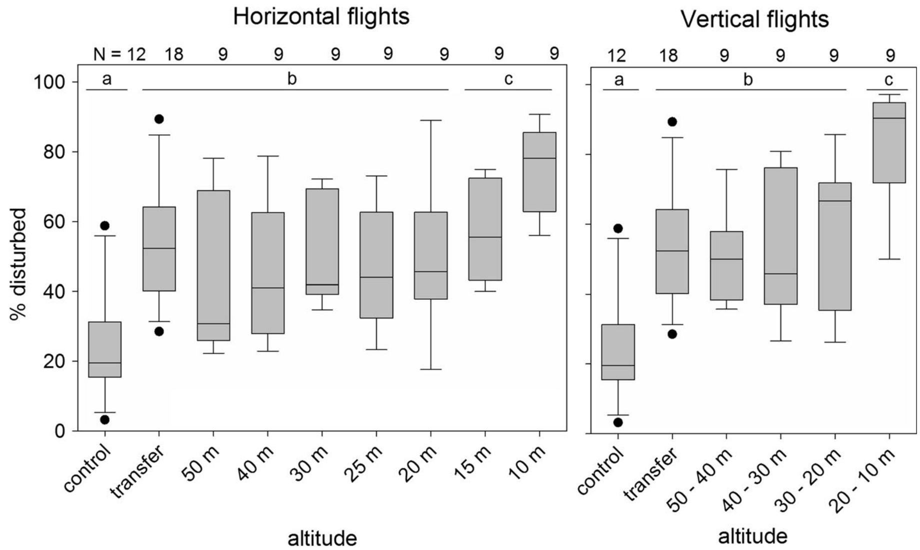

Fig. 2 Disturbance effects of horizontal and vertical unmanned aerial vehicle flights over the group of 6–8 analysed Adélie penguins. Shown is the proportion of disturbed penguins (i.e. showing vigilance, escape or agonistic behaviour) before takeoff (control), during transfer from takeoff to the nest group and at the different investigated flight altitudes. Control and transfer data were pooled for both flight modes. Every flight contributes one data point. Before takeoff disturbance is always significantly (0.05 significance level) lower *a* than in all other tested flight situations. At the 10 and 15 m (*horizontal*) and 10–20 m (*vertical*) level *c* disturbance is significantly higher than during other altitudes *b* of the respective flight mode

beginning of the flight schemes, as disturbance levels at high altitudes were comparable to those during transfer.

Despite results showing that average wind speed did not affect disturbance levels, gusty wind conditions at the study site may have had an influence. As all the flights were based on a GPS track, the UAV had to reach each waypoint in the track, which took a longer time and produced more noise if there were gusts. Hanson et al. (2014) documented a slight reaction to UAV flyovers on lekking greater sage-grouse (*Centrocercus urophasianus*) when the UAV motor speed was increased to obtain a higher flight altitude. Also the flight velocity and time needed for takeoff varied with different wind conditions. It was also subjectively observed by field personnel that the sound volume of the UAV is higher during vertical movements than horizontal ones. This possibly contributes to the higher disturbance by vertical than horizontal flights found at altitudes below 20 m. Another factor causing this result can be explained by a methodological constraint. The main indication of vigilant behaviours was the movement of the head. In vertical flights, the UAV moves at the penguin from above, which necessarily causes head movements in vigilance behaviours. In horizontal flights, the UAV moves towards the penguin from a lateral position. Depending on the position of the penguin, this may cause no or only small head movements, even in a vigilant bird. Moving vertically, the UAV continuously gets closer to the penguin, while horizontal movements depart from the individual after passing and thus generate decreasing attention. The detected increased sensitivity to vertical approaches is in line with the results of Vas et al. (2015). This indicates that there is a higher disturbance by vertical flights as they may mimic a predatory bird attack.

Penguins' reactions towards the UAV and natural predators (Müller-Schwarze and Müller-Schwarze 1977) are both comparable: below an altitude of 20 m, the disturbance increased significantly compared to higher flyovers. At higher altitudes up to at least 50 m, UAV flights still cause reactions in contrast to natural predators. It remains unclear whether this lack of reaction towards higher flying predators observed by Müller-Schwarze and Müller-Schwarze (1977) is only due to the methodological difference (i.e. subjective impression). Flying predators move almost silently, whereas a UAV creates a noticeable level of noise. By responding to this unknown sound penguins could thus still become vigilant towards the UAV at altitudes above 20 m.

Attention should be paid to the fact that all tests were conducted by one specific octocopter. Generalizations to other models that differ in size or noise should be made cautiously. Furthermore, our analyses were exclusively based on behavioural observations, but animals can already be stressed before behavioural evidence becomes visible (Wilson et al. 1991; Ditmer et al. 2015). Thus, we recommend extending disturbance experiments with UAVs. It would be important to compare the results to similar experiments conducted with UAV models of different size and noise levels. A synchronous recording of the UAV's sound volume at the focal penguins is desirable. The experimental set-up should further be extended to flights in higher altitudes and with higher takeoff distance, to determine the boundary where disturbance exceeds the pre-takeoff-level. Finally, to increase the objectivity and sensitivity of results, the use of biologging (Ditmer et al. 2015) and/or heart-rate-measuring equipment such as artificial eggs (Schuster 2010) is recommended for future studies.

Conclusion

The use of UAVs is rapidly increasing, even in the Antarctic. Nevertheless, little is known about the impact of UAV operations on bird colonies, and distance guidelines do not exist yet as they do for pedestrians or manned aircraft. Our study shows that flying an octocopter creates noticeable responses in Adélie penguins even from 50 m away. Thus, studies that investigate disturbance effects are urgently needed to establish UAV regulations and prevent negative effects of UAV use on bird colonies.

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Compliance with ethical standards

Ethical approval All applicable international, national and/or institutional guidelines for the care and use of animals were followed.

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