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Communications

Remotely releasable collar mechanism for medium-sized mammals: an affordable technology to avoid multiple captures

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Collar-mounted monitoring devices for collecting behavioural or positional data (e.g. sound recorders, accelerometers, GPS, VHF) are increasingly used in wildlife research. Although these tools represent an improvement in terms of data quality, they require capturing animals. Using remotely releasable collars allows for reducing the number of captures by half; however, currently this technology is primarily available for large mammals. Here, we present a locking mechanism design that is remotely releasable and light enough (22 g) for medium-sized mammals (>1 kg), can run in low-power mode for years, is reusable directly after recharge, and has a material cost of less than €50. An Android application operates this mechanism over a Bluetooth connection. We developed custom-purpose software for both the locking mechanism and the Android application. We tested two collars equipped with this locking mechanism in field-like conditions on two ring-tailed lemurs *Lemur catta*. The release mechanism has an operational range of 10–50 m and can run in active mode (allowing remote release) for several hours. Implementation of the presented release mechanism for collars on medium-sized mammals provides a low-cost solution to reduce the number of captures. We demonstrate that some low-cost technical improvements of tools used for studying wildlife can have significant effects on reducing the stress experienced by animals during capture. Detailed description of this new mechanism design provides a starting-block for potential adaptations for a broader range of species.

Keywords: animal tracking, bio-logging, captures, collar, mammals, releasable, technology

Over the past twenty years, the number of studies that equipped animals with monitoring devices (e.g. GPS, sound recorders, loggers) has increased exponentially (Kays et al. 2015, Wilson et al. 2015, Fehlmann and King 2016, Hughey et al. 2018). Even though these methods are undoubtedly beneficial for research and conservation by allowing much finer individual-level data acquisition, they usually involve capturing and retaining animals twice: once for mounting the device and once for removing it. These double captures are paradoxical, given that general awareness concerning animal welfare and other ethical concerns at the same time led to the development and promotion of less invasive methods of data collection (Waits and Paetkau 2005, Acevedo-Whitehouse et al. 2010, Mahendiran et al. 2018).

Wild animal captures are widespread practices that are motivated by various research purposes (e.g. ecology, behaviour, genetics or morphology), individual welfare (e.g. snare removal) or conservation goals (e.g. population estimates). This practice implies several risks and costs for the animal. Numerous studies have reported regular cases of injuries or even deaths (Nicholson et al. 2000, Arnemo et al. 2006, Jacques et al. 2009, Spotswood et al. 2012, Cunningham et al. 2015). Injuries and death may be caused mechanically in case of defective equipment or animals struggling with the device, but more often they are associated with direct or indirect effects of anaesthesia (Cunningham et al. 2015). In particular mammals under 20 kg are more susceptible to severe injuries of vital organs and fractures than larger species (West et al. 2014, Cunningham et al. 2015).

Some studies also reported social consequences of captures, including partner or rank changes, forced copulations, fatal attacks (Pelletier et al. 2004, Schütz et al. 2006, Cunningham et al. 2015), or a reduction of activity (Morellet et al. 2009). Additional stress is generated for the animal if these captures are close in time (Arnemo et al. 2006). Hence, there is currently an urgent need for developing alternative solutions, like remotely releasable collars, to limit the number of captures.

A releasable collar system that is either programmable beforehand (time triggered release mechanisms) or controllable from a distance (remote control) could reduce the number of captures associated with equipping animals by half. These mechanisms would diminish the consequences of capture failures for both the animals (fewer individuals that remain with the equipment for an extended period of their life) and the researchers (fewer device losses). Such release systems are commonly sold with GPS devices designed to study large mammals' movements on a long-term basis (Merrill et al. 1998, Matthews et al. 2013). Whereas some studies reported failures, others have described effective usage of this mechanism (Merrill et al. 1998, Matthews et al. 2013). However, such commercial solutions are usually expensive and using them for research purposes requires a substantial budget. The costs saved by reducing the number of captures in large animals may compensate for it, but this is usually not the case for smaller animals. Moreover, equipping smaller animals requires the consideration of additional constraints, such as size and weight restrictions, while current devices designed for larger animals often rely on bulky, heavy and non-reusable squib (explosive) release mechanisms (Chapman and Hamerly 1988, Marshall et al. 2005). There is therefore a clear need for a cheap and open-access solution (Rafiq et al. 2019).

To fill this gap, we designed a lightweight (22 g), easy-to-use, releasable collar mechanism, controllable at a distance through Bluetooth via an easy-to-use Android application (Fig. 1). Moreover, this mechanism is reusable, has a battery life of over a year in standby mode, can run in active mode for several hours, and has a low manufacturing cost (<€50). We tested this releasable collar under field-like conditions on two semi-free ranging ring-tailed lemurs *Lemur catta* housed in the Wild Park Affenwald, Germany. In this paper, we provide a technical description of the prototype and the results of these tests.

Material and methods

Specifications

In the development of this remotely releasable locking mechanism, the following two design factors play a key role: size and weight. Commonly, the rule of the 5% applies, i.e. the mass of a device attached to an animal should not exceed 3–5% of the animal's body mass (Coughlin and van Heezik 2014, Portugal and White 2018). This weight limit determines both the size and battery capacity of the device. The size should be kept minimal to prevent hindrance of the animal, and sufficient battery capacity ensures that the device is self-powered during the entire duration of the behavioural recording, e.g. minutes to hours with vocal recordings and days to months with GPS tracking.

Another important specification is that the locking mechanism should be safe to operate and reusable. The first is self-evident for the safety of both the animal and the operator. Moreover, by making it reusable, not only the ease of use of the device increases but also its functionality. Finally, the ability to operate the device remotely is also

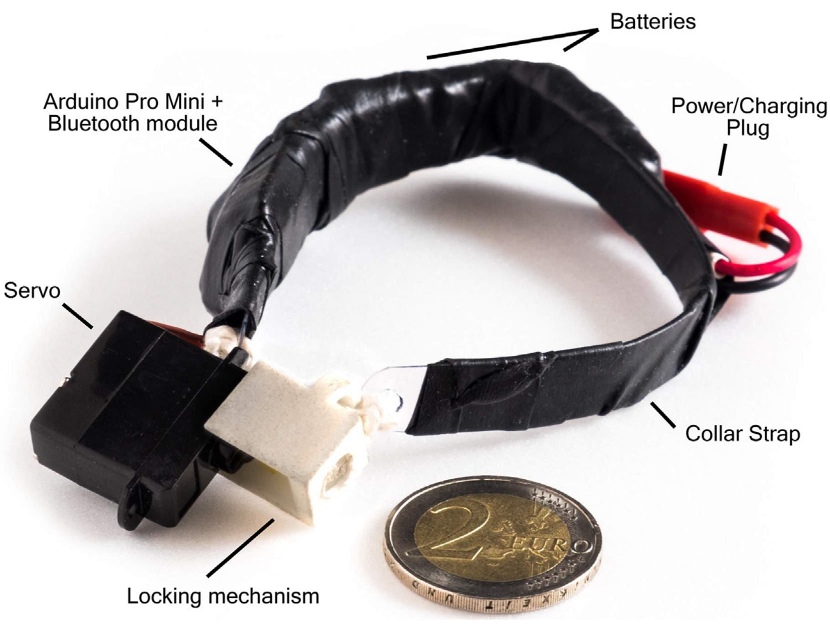

Figure 1. Releasable collar. Collar in its locked state with labelled components. All electronics parts are wrapped in self-fusing silicone rubber tape to provide basic protection against the elements. Only the power/charging plug is left bare to allow charging and powering the device (note that it is recommended to fit an additional layer of insulation tape before equipping the animal).

essential. The designed collar is operated through Bluetooth 4.0, as this transmission protocol is versatile, digital and has sufficient range of 10–20 m. We considered other solutions, such as 433 MHz UHF (ultra high frequency) transmitters that have a longer range than Bluetooth. However, with analogue signals, the signal integrity cannot be assured, since external noise can interfere with the signal reception, in contrast to digital connections like Bluetooth, where the transmitted command is always received as long as the device is connected.

Hardware

The proposed releasable locking mechanism has a weight of 22 g. This weight includes the required electronics and the locking mechanism incorporated in a wrapped collar, leaving sufficient weight to attach a payload, like a data acquisition device. Fortunately, with the current technology, it is possible to fabricate small and lightweight data acquisition devices, e.g. stand-alone microphone or GPS chips are available from ~5 to 20 g. This weight added to the 22 g of the collar itself would still be within the 5% rule. Moreover, all required parts are accessible for a total of less than €50 (Table 1).

The releasable locking mechanism relies on Bluetooth communication and the operation of a servo motor (i.e. a rotary actuator with precise angular control) to open and close the collar. The device, therefore, requires an electronic processing unit. A single-board microcontroller (i.e. circuit board with embedded CPU, memory and controllable input/outputs) suited the needs, as it generally has a low power requirement and a small form factor while providing ample processing power. We choose the 8 MHz Arduino Pro Mini, since it was the smallest form factor, commercially available, single-board microcontroller at the time of development. The 8 MHz version has sufficient computational power and requires only 3.3 V (as opposed to 5 V of the 16 MHz edition), hence a single cell Lithium Polymer (LiPo) battery was sufficient to power it. The integrated I/O ports allow servo and Bluetooth control and an HC-05 module provided Bluetooth 4.0 communication support. We provide an electronic schematic in the Supplementary material Appendix 1. Note that additional hardware modifications of the Arduino Pro Mini are required to achieve a low power draw.

Locking mechanism

The Arduino operates and powers a servo-driven locking mechanism (Fig. 2, Supplementary material Appendix 1), consisting of a servo with a screw mounted on the rotational axis and a 3D-printed polylactic acid (PLA) casing, which can slide around the servo. By powering the servo, it will screw itself tightly into or out of the casing and thus lock or unlock the mechanism, respectively (opening/closing time: ~1 s). By removing the physical endpoint barriers and replacing the potentiometer inside by two 2.2 kΩ resistors, the servo can spin indefinitely in both directions. A servo is chosen as the driving mechanism for the lock since it can exert a high torque that prevents the locking mechanism from jamming when under pressure.

Software

Two pieces of software are required to operate the remotely releasable locking mechanism: an Arduino script and an Android application (provided in the Supplementary material Appendix 1 File A1, A2). The Arduino script initialises the Bluetooth connection and the required ports upon start-up, after which it periodically checks (every 3 ms) whether there is a (serial) data package available from the Android app. This data package contains one out of three commands: open collar, close collar and initiate sleep mode for the specified period. The first two commands activate the servo and initiate spinning for a set period. The sleep command disables power to the servo and the Bluetooth module and puts the Arduino in a low power sleep mode. This mode is crucial for power saving, and without it, the battery is drained in a matter of hours. A custom-made Android graphical user interface (GUI) developed with MIT App Inventor allows interacting with the collar over Bluetooth when the collar is powered and not in sleep mode (Fig. 3). To put the collar into a sleep state, one has to set a date and time at which the device should wake up. Both scripts have the needed fail-safes built in to ensure safe use for the animal as well as to prevent equipment damage.

Table 1. Component list. Releasable collar components with respective quantity, weight and cost estimate (based on current local supplier).

Component	Quantity	Weight (g)	Cost (€)
Arduino Pro Mini	1	2	20,–
Lipo battery, 1S 110 mAh (type: 061225)	2	4 (2 g each)	14,– (~7,– each)
HC-05 Bluetooth module	1	1	3,–
Turnigy TGY-1370 micro servo	1	5	6,50
Resistor 2.2 kΩ	2	~	0,10
Resistor 1 kΩ	1	~	0,10
Resistor 275 Ω	1	~	0,10
Transistor (2N3704)	2	~	0,40 (~0,20 each)
3D printed lock + screw	1	2	0,05–3,00*
Plugs (male + female)	1	1	0,20
Wiring and wrapping	n/a	7	~
Total		22 g	~€47.–

~ indicates negligible weight or cost.
* Dependent on in house versus outsource printing.

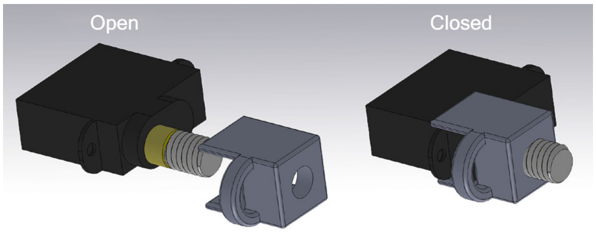

Figure 2. Locking mechanism. By activating the servo clockwise or counter-clockwise, it will screw itself in and out of the 3D-printed casing (in dark grey), respectively. The collar band and the rest of the electronics are attached to the rings at both ends.

Power consumption

Keeping the power draw of the remotely releasable locking mechanism minimal was the biggest challenge to solve. In its active state, the Arduino draws current between 60 and 100 mA (depending on whether the servo is idle or running) and this power consumption would drain two 110 mAh LiPo batteries within one day. Increasing the battery count would strongly increase the weight and bulk, so instead, we resolved the problem by decreasing power consumption.

The first step was to switch off the power supply to the servo and Bluetooth module with a transistor when they are not in use, since they both draw power even when idling. As Table 2 shows, this reduced the power draw to 6–12 mA. The second power optimisation was to put the Arduino in a low power state. A low-power library (RocketScream), was used to install a 'powered-down sleep' (PDS) mode that can disable onboard peripherals to draw power continuously. Disabling the analog to digital converter (ADC) and the brown-out detection (BOD) for a pre-specified time further reduced power consumption by half. Deeper sleep modes could deactivate even more onboard peripherals; however, the Arduino would not wake up until receiving an external trigger, which is undesirable for our application. By putting the device in PDS after locking, the battery life did span a couple of days, but even longer battery life was desired.

To achieve this, we made physical changes to the Arduino board. Removing (unsoldering) the status and power LEDs (of which the latter cannot be switched off in software) conserved another 6 mA of power draw and extended the battery life to several months in PDS. Finally, the last hardware change was to remove the voltage regulator from the Arduino Pro Mini board. With its power draw of 0.27 mA, it seems insignificant compared to the 12 mA when the device is idling, but in PDS mode without any LEDs consuming power, power reduction was a factor of 40. Combining these modifications allowed the realisation of a theoretical PDS runtime of well over several years for a battery capacity of 220 mAh (assuming no self-discharge). Please note that without a voltage regulator, a stable power source is required to prevent damage to the microcontroller. This design incorporates 3.7 V, single-cell LiPo batteries, for which the voltage range stays within the operation range of the Arduino Pro Mini. A micro USB (1S) LiPo charger allows easy recharge,

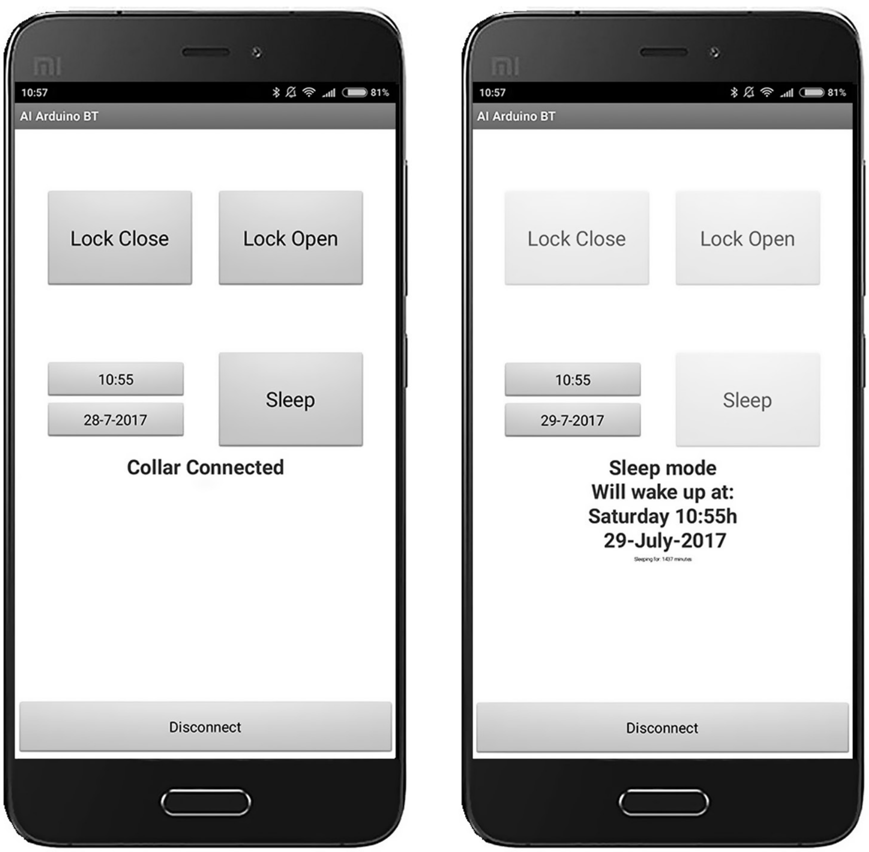

Figure 3. Android GUI. Screenshots of the control GUI that runs on Android. The app connects to the Arduino mounted on the collar and allows it to open and close remotely (left) and to put it in powered down sleep mode for a custom set period (right).

Table 2. Power consumption chart of the ATmega328P Pro Mini 8 MHz.

States	Unmodified		NO LED's		No voltage regulator	
	Current (mA)	Battery life (h)	Current (mA)	Battery life (h)	Current (mA)	Battery life (h)
ACT, BT disconnected, servo idle	62	3.5	57	3.9	57	3.9
ACT, BT connected, servo spinning	95	2.3	95	2.3	95	2.3
ACT, BT disabled, servo disabled	12	18.3	6	36.7	6	36.7
PDS, BT disabled, servo disabled	6	36.7	0.28	32.7	0.007	3.6 years

ACT = active mode; PDS = powered-down sleep; BT = Bluetooth. Time indications are theoretical runtime estimates based on a battery capacity of 220 mAh, assuming no self-discharge and room temperature.

e.g. using a laptop port or a standard phone charger. Table 2 provides an overview of the power consumption in different hardware configurations. While the power draw in this modified sleep mode is minimal, the device consumes a factor of 1000 more energy when activated. This means that once the device wakes up from its low power state and goes into active mode (ACT), it starts draining the battery rapidly and one should not wait too long before opening the collar. In practical terms, a period of several hours in ACT mode was more than sufficient, and a battery capacity of 220 mAh provided a suitable balance between form factor and sufficient run time.

Operational procedure

The locking mechanism operates as follows: 1) power the collar by inserting the power/charging plug and connect to the app via Bluetooth. 2) Attach the collar and close it using the app. 3) Set the date and time when the collar should wake up from the low-power sleep mode. 4) To retrieve the collar, approach the collar within a range of ~10–30 m after the device has woken up, and connect to the app to open the collar.

Operational distance tests in open areas

A Bluetooth 4.0 connection has a theoretical maximum operation range of about 60 m. The practical range, however, is determined by the orientation of the antennas, the influence of noise sources and most importantly, the presence of obstacles between the devices. To determine the maximal distance of successful collar opening empirically, we conducted five repeated measurements at various distances (stepsize: 5 m) in two open areas and determined the longest distance with 100% successful collar opening. In arboreal terrains, the specific density of the foliage will further impact the maximum operating range.

Field tests with animals

To test these collars in a field-like condition, we equipped, in September 2017, one male and one female adult ring-tailed lemurs *Lemur catta* housed in the Wildlife Park Affenwald (Germany) with releasable collars. These releasable collars were equipped with an EDIC-mini Tiny B47 miniature digital voice recorder (19 g) giving them a total weight of 41 g, which represented ~2% of the body weight (average weight of ring-tailed lemurs: 2.2 kg, Baumhofer 2017). In this park, ring-tailed lemurs are habituated to human presence and contact and are used to be briefly restrained by the animal caretakers. Hence, the usual caretaker performed animal handling and could put the collars around their neck without requiring any capture or anaesthesia. After attaching the collars, we put them into low-power sleep-mode for 45 min. During this time, the animals were allowed to roam freely within their 3.5 ha home enclosure. After their release, we followed and observed them to identify any discomfort behaviour associated with wearing the collar, i.e. excessive pulling on the collar or restrained/abnormal movement. After 45 min, we tested the remote release mechanism of the collar. In order to test the maximum release distance, we performed a first releasing attempt at 40 m distance from the individual. If the collar did not open, we performed further attempts at increasingly shorter distances, until success.

Results

After mounting the collar on the animals, we made the following behavioural observations on the male and female lemurs: when the male lemur was released, he ran away and went 2 m up in a tree, during the first two minutes he tried on two occasions to pull his collar over his head and attempted to lick it. A juvenile approached him and also briefly grasped and pulled the collar. Afterwards, the male went down to the ground and joined the group movement. We did not observe any other discomfort behaviour until the release. When the female lemur was released, she stayed in proximity and did not show any discomfort behaviour. Nevertheless, several group members approached her and sniffed at the collar. During the full 45 min of observation, both individuals were observed jumping without obvious restrictions, interacting with other individuals and following the group's movements.

In the arboreal environment of the animals, we performed a first release trial at 40 m for each collar, but the connection failed, as the arboreal environment decreased the maximum operating range. We successfully released the first collar at a distance of 10 m. As the individual was resting and not moving, the collar remained on the individual's shoulder until the animal moved away. We released the second collar successfully at a distance of 15 m while the animal was moving, and it fell immediately on the ground. Both individuals appeared to be unfazed by the collar opening.

With the HC-05 Bluetooth module in an open range (without the animal), the largest distance with 100% successful collar opening trials was 50 m, which aligned well with the theoretical maximum Bluetooth range of ~60 m.

Discussion

Data acquisition devices for mammals currently either require capturing the animal to retrieve the collar or using large and disposable explosive-charged locking mechanisms. Here we describe the design of a new type of release mechanism that may be integrated to device-mounted collars for studying medium-size mammals that can be approached safely within Bluetooth 4.0 range. The design mechanism offered here has several essential assets: it is lightweight and relatively compact, cheap to manufacture and reusable, easy-to-use and versatile. In the following sections, we discuss some drawbacks of this design and offer potential design improvements and their consequences. Nevertheless, we argue that this locking mechanism in its present form can be readily employed for many species and field sites, and hence may substantially reduce the number of required captures already in its present development stage.

Operating range

We designed this releasable collar mechanism with a Bluetooth 4.0 communication interface. Therefore, this collar is particularly relevant for individuals that are reliably approachable at a distance of 20–30 m in an open area and of 10–15 m in a closed area. We believe that this operating range is applicable for several species/field sites as it is similar to the ones required for some capture methods (e.g. darting, net-capturing, etc.). For instance, from our experience, it seems to be particularly applicable to the study of lemur species (both nocturnal and diurnal) as they are known to be easily habituated to the presence of human observers (Williamson and Feistner 2003). Indeed, several lemur populations have been equipped with bio-logging devices like GPS, temperature captors or accelerometer tags (red-fronted lemurs *Eulemur rufifrons*: Pyritz et al. 2011, Verreaux's sifaka *Propithecus verreauxi*: Koch et al. 2016, rusty-grey lesser bamboo lemur *Hapalemur meridionalis*: Eppley et al. 2017, southern wooly lemur *Avahi meridionalis* and Fleurete's sportive lemur *Lepilemur fleuretae*: Campera et al. 2019). However, our releasable collar mechanism could be of use also in a much broader range of medium size species. Several recent studies have reported multiple captures procedures to equip medium-size mammals with bio-logging devices attached on a collar (among others: feral cats *Felis catus*: McGregor et al. 2016; lowland paca *Cuniculus paca*: Bizri et al. 2016; alpine ibex *Capra ibex*: Brivio et al. 2015). Mentioned ranges of distances associated with these captures are often comprised in the operation range of the release mechanism presented here (in the examples above: 8–27 m). If such a close approach is not possible, a practicable compromised solution may be to first lure and trap the animal, which allows an easy and safe approach within the operating distance, before to detach the collar without the need for anaesthesia. In other cases, increasing the operating range should be possible by using a different communication interface, e.g. the UHF communication at 433 MHz. However, the latter would be at the cost of a larger antenna and of losing the versatility of operating the collar with a standard smartphone. More importantly, when increasing the operating range, especially in areas of dense vegetation, one should also consider to add a captor to help localise the collar on the ground after release.

Robustness

The locking mechanism was designed to be re-usable directly after recharge. Its parts have an operational temperature range of ~0–50°C, which covers a wide range of outside temperatures. However, caution is required when using the device in substantial freezing temperatures, as the risk of the servo blocking increases and the LiPo batteries have reduced battery life in cold temperatures. The collar itself can withstand a pulling force of over 10 N, which makes it strong enough to withstand most of the potential animal interactions. However, the mechanism may not be strong enough for species with more dexterous and stronger hand-grasping abilities like some Old World primates. For these species, replacing the plastic parts with metal ones could increase the strength that the mechanism can withstand. Lightweight alloys such as aluminium or titanium can help limit the weight increase while significantly increasing the durability and sturdiness of the collar.

Fixed time sleep mode

We designed the collar such that the control board can be put in a low-power standby mode for a pre-set amount of time to increase battery life dramatically. This time window may be problematic for species and situations for which it is hard to predict when a particular animal can be found at a specific time and location. However, many currently available devices do not provide this flexibility but are rather programmed to be released at a given time (Matthews et al. 2013, Rafiq et al. 2019). In its current form, the locking mechanism can run in Active mode for almost four hours (i.e. fully charged; subtract ~1 h for every year the device was kept in PDS mode). Depending on weight and volume constraints, a simple solution to increase the possible time in active mode is to attach additional batteries. Each 110 mAh LiPo battery (weight: 2 g) would increase the time in active mode by about two hours.

Despite the small sample size of only two animals, the field-like condition testing showed that the collar opens reliably even on a moving animal and animals are not bothered by the collar release. We are confident that the collar with its current operation range and battery life is adequate for medium-sized mammals (weight above 1 kg) even in a forest environment.

Depending on the species ecology, additional constraints might have to be considered when integrating the design features of the collar. For example, waterproofing could be provided by heat shrink wrapping the electrical components or embedding them in epoxy, in case the animal comes in substantial contact with water, or component weight balancing when a relative heavy monitoring device is mounted.

The additional costs of implementing a remotely releasable locking mechanism to a data acquisition collar approximate a single investment of about €50 in equipment and two–three labour hours for assembly. This investment, however, is easily compensated by the fact that the collar release mechanism is re-usable and the avoidance of the otherwise necessary second capture of the animal.

In conclusion, we emphasise the importance of putting more effort into the technical improvement of tools that are used to study wild animals to address our ethical responsibilities for animal welfare. We believe that the present device, a collar with a remote release mechanism, can significantly reduce the number of captures in numerous bio-logging studies of medium-sized mammal species. With this paper we also aim to encourage researchers to think about the relevance of such technology and by providing a precise description of this new device, to give a starting-block for potential adaptations for other species and studies.

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Author contributions – JMMB and LRP contributed equally to this paper.
Permits – We conducted animal care and experimental procedures in accordance with German and European law, and with the Guidelines for the Care and Use of Mammals in Neuroscience and Behavioural Research (Council National Research 2003). Experimental procedures were ethically approved by the Animal Welfare Body of the German Primate Center Gottingen (E11-17).

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Supplementary material (available online as Appendix wlb-00581 at <www.wildlifebiology.org/appendix/wlb-00581>). Appendix 1.