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Spying the dog: Wearable action camera as a tool to understand dog's behaviour during homing (Carnivora: Canidae)

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Abstract. Automated data collection methods, such as using GPS collars and animal-borne cameras, represent an efficient way of data collection and may be instrumental in the research of animal orientation, including magnetoreception. In this study, we designed a wearable dog action camera (DAC) system for hunting dogs consisting of a Garmin Virb Elite camera housed in the stainless mount attached to the dog harness. We evaluated the DAC's reliability and potential to capture various behaviour, and we tested the effect of the DAC on the dog's activity and well-being. We found no significant impact of the DAC on the dogs' average speed. The tested system was reliable, efficient and safe for dogs. We recorded various behaviours connected to orientation, such as olfactory behaviour and head scanning, the latter described for the first time in domestic dogs. Furthermore, we observed other important behaviours such as hunting, exploration and comfort behaviour. Using wearable action cameras for studying domestic and free-roaming tame animals can bring new opportunities for future behavioural and sensory ecology research.

Key words. Hunting dog, scent hound, navigation, orientation, bio-logging, animal-borne video, video-tracking, behavioural observation.

INTRODUCTION

Studying animal behaviour has a long research tradition (Tinbergen 1974) and is an essential tool in many scientific disciplines, such as cognitive research (Berghänel et al. 2022), pharmacology (Cilia & Piper 1997) or conservation (Grimm-Seyfarth et al. 2021). Direct observation has been one of the most frequently used methods in which an observer follows a study subject and records its behaviour (Bateson & Martin 2021). Despite its merit in the detailed record of individual behaviour, this method is limited. Direct observation requires trained and experienced observers, is time-consuming and can be physically demanding in rugged terrain (Bateson & Martin 2021, Masilkova et al. 2018). Moreover, the presence of a human observer can affect the behaviour of the study subject (Samhita & Gross 2013). In certain contexts, such as underwater (e.g. marine mammals; King & Jensen 2022) or high in

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the dense canopy (e.g. volant or arboreal species; Moore et al. 2021), it is virtually impossible to conduct direct observation.

To overcome these limitations, a wide array of technological tools, such as camera traps, drones, and telemetry, including GPS technology and bio-logging, can be employed (Erdtmann & Keuling 2020, Painter et al. 2016, Schad & Fischer 2022, Walton et al. 2018). Using modern technology to record behaviour is more accurate and objective (Kays et al. 2015, Nathan et al. 2022) and allows studying species that are elusive, nocturnal or difficult to habituate to the presence of a human observer (Erdtmann & Keuling 2020). Each method has advantages and disadvantages, and the selection of the appropriate recording technology depends on the study questions. For studying animal movement and mechanisms of orientation, such as piloting, tracking or using magnetic sense, collars or tags with GPS technologies are employed (Benediktová et al. 2020, Græsli et al. 2020, Walton et al. 2018). GPS tracking allows the collection of data on the animal's position, direction or speed (Bombara et al. 2017, Stabach et al. 2020). Yet, GPS tracking does not provide any information about an individual's behaviour during movement or environmental factors, which hinders the understanding of cognitive mechanisms underlying the orientation.

One relatively rarely used method in animal behaviour research is video-recording of behaviour by an action camera borne by animals (Moll et al. 2007). Employing action cameras revealed contact rates and helped to understand the disease transmission in free-roaming domestic dogs (Bombara et al. 2017). Furthermore, the cameras showed the underestimated risk of predation by domestic cats on wildlife (Loyd et al. 2013, Seymour et al. 2020) and the food preferences of free-ranging cattle (Rosa 2019). Hence, animal-borne cameras can be informative not only in the field of movement ecology but also in the field of disease ecology, conservation or feeding behaviour. Nonetheless, animal-borne cameras should meet several criteria to collect data efficiently and promote animal well-being. The former refers to the battery life span, data storage capacity and field of view range. The latter relates to the weight and placement of the camera on the animal's body, which should not restrict the animal's movement or otherwise inhibit naturally occurring behaviours. The weight of tags and equipment borne by animals is a frequently discussed topic (Moll et al. 2007, Wilson et al. 2021).

In this study, we propose and test the design of a commercially available action camera for hunting dogs, the model species currently used in sensory ecology, including magnetoreception research. In the previous research, prof. Burda's team (Adámková et al. 2017, 2021, Hart et al. 2013, Martini et al. 2018) confirmed that dogs use the magnetic field to orient themselves in space. Using GPS collars revealed that dogs use two strategies during homing – tracking (return using the same outbound track) and scouting (return using a novel route). In the case of scouting, the dogs begin their return by so-called compass run (short run according to the north-south axis; Benediktová et al. 2020). Yet, many aspects of dog orientation behaviour are unknown. For instance, it is unclear whether the tracking is based on olfaction or memory. Furthermore, the decision-making process during critical moments of return (e.g. behaviour at the turning point, during a change of direction or unexpected deceleration) is unknown. Employing action cameras as an additional data collection method could help to understand these processes.

Therefore, the main aim of this study was to find a suitable commercially available action camera for hunting dogs that would be efficient and reliable (the sufficient battery life and memory card capacity and resistance to external conditions – water, weather, collisions and vibration) and to design a system for attaching the camera to a dog's body, which would be comfortable for the dog and applicable for different dog breeds and sizes. We tested whether the presence of the dog-borne cameras affects the locomotion (measured as the dog's average speed) in ten dogs. Finally, the last aim was to assess the action camera's potential to capture dogs' behaviour during homing.

MATERIAL AND METHODS

Study subjects

The study subjects were hunting dogs from our previous study (see Benediktová et al. 2020). These scent hounds, including dachshunds, fox terriers and beagles, are suitable breeds for studying orientation in space because they frequently move on relatively long distances and are independent of their masters when executing their tasks (Van Poucke et al. 2022).

Wearable dog action camera (DAC)

The dogs were equipped with a commercially available action camera (Garmin Virb Elite, Garmin Ltd., USA). The camera (32×53×111 mm, 177 g) is waterproof (IPX7), resistant to damage, and has an internal and external microphone, internal GPS, accelerometer, altimeter, image stabilisation and lens distortion correction. Operating temperature range is from –15 °C to 60 °C. The camera records video on a microSD memory card up to 64 GB (max. 7 hours of recording, video file type mp4). The removable and rechargeable Lithium-ion battery (2000 mAh) allows recording up to 3 hours.

In this study, we used two video modes: 960p HD video (1280×960; 48 fps; Figs. 1a and 1d) and 720p HD video (1280×720; 60 fps; Figs. 1b and 1e) according to the position of the device on the dog's body. Besides video and audio, the camera also collects position data delivered from the high-sensitivity GPS (1 Hz; the separate track log for each video recording as gpx files; Fig. 1f).

To protect the camera from being damaged (e.g. through collision with an obstacle in the forest), we housed it inside a stainless-steel mount (120 g; Fig. 1c). We attached the mount with the camera on a custom-fitted harness (Bracco, Czech Republic) using a bind (Fig. 1c). We placed the mount on the side of the dog's thorax. The position on the dog's side allows capturing the dog's surrounding from an animal's perspective, including the vegetation (Fig. 1d) and wild game (Fig. 1e). Notably, a portion of the dog's head in each frame is also captured, providing thus information about the dog's behaviour and movement dynamics (e.g. activity, head movements, head orientation). We mounted the camera in the position "portrait" for small-sized breeds (dachshunds; Fig. 1a) and in the position "landscape" for middle-sized dogs (Fig. 1b).

The harness was made in several sizes for each size category and is individually adjustable using strong Velcro fasteners. The harness was designed to minimise discomfort; it is anatomically shaped, allowing free movement of the shoulder joint and full mobility for each dog (Fig. 1c). The DAC system (the action camera, mount, and harness, including the batteries) weighed 437 g.

The effect of the DAC on dogs

The DAC's efficiency, reliability, safety and the effect of DAC on the dog's locomotion were assessed during diurnal walks with dogs on forested hunting grounds in the Czech Republic from January 2016 to January 2018. Dogs were walked individually and were allowed to roam freely (off the leash) (mean length of walk±SD: owner: 2.4±0.98 km, dog: 6.8±2.69 km). We defined the walk as the entire continuous journey (duration: 30–90 min) of the owner with the freely roaming dog (including the spontaneous independent excursions out of the owner's view) from the starting point to the goal point (usually the same place as the starting point). During the walks, dogs explored the forested area and searched for game scent tracks, an innate behaviour in breeds used in the study. Dogs were equipped with GPS collars Garmin T5 mini (Garmin Ltd., USA; weight: 199 g), recording positions at 2.5-second intervals and transmitting them to handheld Garmin Alpha 100 or Astro 320 via an integrated VHF antenna (for details see Benediktová et al. 2020). During each walk, the GPS collar and the handheld recorded the following parameters: the dog's average speed (km/h), the length of the dog's walk (dog's travel distance, km) and the length of the owner's walk (owner's travel distance, km).

To test the effect of the DAC's presence on dog's locomotion (i.e. dog's speed, see Statistical analysis), ten dachshunds (3 males and 7 females, mean weight±SD: 5.85±0.45 kg) were walked under two conditi-

Fig. 1. Dog action camera system: (a) vertical placement of the camera, (b) horizontal placement, (c) custom-fitted harness, Garmin Virb Elite camera, stainless steel camera mount, (d) recording in 960p mode with the visible position of the dog's head, (e) recording in 720p mode, when the dog is marking the game by barking, (f) camera recording with displayed data.

ons – control (first phase, with GPS collar but without DAC) and test (second phase, with GPS collar and DAC) condition. Each dog experienced the same number of walks (2–5 walks) in the control (mean±SD: dog's travel distance: 7.1±2.58 km, owner's travel distance: 2.51±0.97 km, dog's speed: 6.02±1.05 km/h) and test (mean±SD: dog's travel distance: 6.53±2.78 km, owner's travel distance: 2.24±0.98 km, dog's speed: 5.71±1.05 km/h) condition (altogether 88 individual walks).

After this pilot study, we have deployed the DAC system on another 36 hunting dogs of small and also middle-sized breeds participating in our homing experiments to assess DAC's efficiency, reliability (i.e. number of recorded hours, number of failures), safety (i.e. presence of skin abrasions or injuries) and DAC's potential to record dog's behaviour.

Video recording processing

For the processing of video records, we used software Garmin Virb Edit (v. 4.2.3.), combining the video footage with GPS data and other data from the VIRB action camera (G-Metrix™ data, e.g. speed, distance, elevation, azimuth, position etc.; Fig. 1f). This software contains tools for cutting, trimming, and merging records.

Using these tools, we cut out independent excursions (starting when the dog leaves the owner and ending when the dog returns to the owner) from each walk (for details, see Benediktová et al. 2020) and added G-Metrix™ data overlays using pre-prepared templates. Finally, we exported records to the format *.mp4, creating two files – the standard video file mentioned above and *.gpx file for storing coordinate data.

To assess the potential of DAC to record dogs' behaviour and surrounding, we focused on orientation-related behaviour during independent excursions. Specifically, we focused on the behaviour during inbound trajectory: behaviour at the turning point (the spot where the dog decided to return to the owner), the reasons for deceleration, stops, unexpected changes of direction, long-lasting stops and when the dog became lost. Furthermore, we noted the presence of game species and dog's hunting behaviour (barking at and pursuing the game). We also noted the other observable behaviours (e.g. comfort behaviour). We assessed the diversity of behavioural displays, not their frequency.

Statistical analysis

The data were analysed using the SAS System (SAS, version 9.4). A multivariate General Linear Model (GLM, PROC MIXED) was run to test the effect of DAC's presence on the dog's average speed. The model was applied as a fixed-effect model designed for the repeated measures, i.e., in SAS, with REPEATED=Order of testing and the SUBJECT=ID of the dog, with compound symmetric covariance structures for repeated measures (TYPE=cs). Because the dog's average speed is a function of travel distance, we added dog's travel distance (Pearson correlation between dog' and owner's travel distance: $r=0.75$, $P<0.01$) as the additional fixed factor in the model.

RESULTS

The effect of the DAC on dogs

Of 46 dogs involved gradually in our homing experiments, two were unwilling to walk with DAC (6 years old female dachshund; 1 year old male border terrier). Altogether, we completed 1052 walks with DAC and obtained 1114 hours of video records.

None of the dogs was injured or permanently harmed while wearing DAC. During the first walks, we registered minor skin abrasion (located directly behind the left elbow where the camera was attached) in two dachshunds wearing the DAC. The abrasion was caused by a small space between the elbow and the edge of the harness. The walk was immediately interrupted, and the harness was re-designed. After that, no skin abrasions appeared again.

Several minor accidents occurred during the first walks with the DAC. The dogs hit trees by the mount or collided with their owner scratching them with the mount. The dogs also faced difficulties in the dense vegetation, especially when the sprout of blackberries captured the camera's mount until they learnt how to deal with it. After the first walks, the dogs learned to move with the camera and successfully avoided obstacles.

The DAC, together with the GPS collar, weighed 636 g representing 10.9±0.86% (mean±SD) of the body mass of dachshunds (small breed) and 3.9±0.99% (mean±SD) of the body mass of the middle-sized breeds. Neither the DAC ($F_{(1, 78.5)}$, F=2.72, P=0.10, slope=0.31, Intercept=5.78) nor the dog's travel distance ($F_{(1, 84.9)}$, F=0.03, P=0.86, slope=-6.75×10^{-6}) affected the average speed of dachshunds.

DAC reliability

The dogs never destroyed or lost any of the cameras, stainless mount, harness, or GPS collar during the walks except in four cases when the camera fell out from the mount due to a human mistake (unfastened strap).

The camera failed in 37 cases (3.5%) from all walks with DAC. Of these, 28 events were caused by the GPS failure of the camera. The camera did not save the track log, and we had to do a manual synchronisation by using the track log from the GPS collar. Approximately half of these cases were caused by a human mistake (the owner released the dog before the satellite

Fig. 2. The examples of inferior quality records caused by: (a) attached leaves, (b) drops of water, (c) mud, (d) snow.

signal was established), and undefined errors in the device caused the rest. In the remaining 9 cases, the camera failed (i.e., the camera saved neither video records nor track logs) due to faulty batteries.

Occasionally we observed inferior quality records (mostly poor visibility) because of external factors (the presence of leaves, water drops, mud or snow on the camera's objective; Fig. 2).

Dogs' behaviour revealed by DAC

The video-tracking by DAC documented various behaviours during the dogs' excursions. Besides the expected hunting behaviour (barking at the game track, visual contact with the game, the pursuit of game) and the exploration connected with the hunt (searching in the dense vegetation, sniffing, looking around, exploring animal burrows), we also observed other behaviours unrelated to hunting.

Thanks to the camera, we could reveal the reasons for the deceleration, stops, long-lasting stops and unexpected changes of direction of returning dogs during the inbound trajectory. These included: avoiding obstacles, crossing rugged terrain, rolling, bathing, swimming, drinking from puddles or streams, consuming trash, sniffing at cadavers, encounters with unfamiliar people and dogs, and humans attempting to "save the poor lost dog" (Fig. 3). We also recorded the behaviour of dogs unable to return to the owner (howling, shaking, lying, sleeping or waiting on the spot, confused running within a small area, frequent looking around).

Most importantly, the DAC revealed behaviours potentially important for orientation during excursions. Firstly, we were able to observe the sniffing at track or air. Secondly, we noticed very short stops (1–3 sec) when dogs were standing with the raised head, quickly looked around and continued in the same or changed direction. This head scanning behaviour (Kral 2003, Dupret & Csicsvari 2014) often occurred also at the turning point.

DISCUSSION

The navigation abilities of domestic dogs have been rarely studied (cf. Benediktová et al. 2020) and are known mostly from anecdotal accounts (reviewed by Nahm 2015). In this study, we describe using wearable dog action cameras (DAC) as a tool for evaluating orientation-related behaviour of dogs during independent excursions for the first time in hunting dogs. We confirmed that the DAC has no impact on dogs' locomotion and well-being. The tested system was reliable, efficient and revealed various behaviours crucial to understanding the dogs' orientation.

The total weight of the DAC system (including camera, mount and harness) and GPS collar represented 10.9% of the body mass of small-sized dog breeds. The weight of the system for the small-sized breeds is thus well above the recommended 3–5% mass limit for terrestrial animals (Moll et al. 2007, Coughlin & van Heezik 2014). However, we did not recognize any indication that the mounted camera would restrict the dogs' speed, similar to the study of Wilson et al. (2021). Nevertheless, other factors than the tag mass must be considered, such as weather conditions, terrain slope, and the total length of camera deployment. Due to technical reasons, we were not able to analyse these variables ex-post. Dogs in our study wore the DAC only for a short time (30–90 min a day) in contrast with studies on wild animals with tags attached for a long time, often more than several months (Brooks et al. 2008). It is thus possible that if the dogs were moving in rugged steep terrain or for longer time periods, the DAC would negatively affect their speed and locomotion. When using tags to study animal behaviour, Wilson et al. (2021) suggested also considering the tag placement (i.e. body part) in relation to the species

Fig. 3. The examples of various behaviours and situations documented by DAC during excursions: (a) an encounter with unfamiliar people and their two german shepherds, (b) eating leftover food, (c) drinking water from the puddle, (d) cooling in the puddle, the camera was under the water, (e) sniffing at shed antler of the red deer, (f) following the group of wild boar and indicating their presence by barking, (g) the animal burrow exploration, (h) sniffing at cadaver.

lifestyle or athleticism (e.g. the length of time of animal activity, speed and acceleration during movement). For instance, placing the tag on the animal's neck increases the gravitational forces exerted on the speedy predator's body. In our study, we placed the camera on the dog's thorax, and due to the width of the harness, we spread the weight of the tag over the larger space. Also, the robust and motionless attachment of the camera to the harness restricted the camera's movement with respect to the dog's body.

Furthermore, we did not notice any change in the dog's behaviour when wearing the DAC (e.g. increased shaking, scratching, attempts to remove DAC). Similarly, studies on domestic animals do not mention any effect on their behaviour either (Loyd et al. 2013, Bombara et al. 2017, Huck & Watson 2019, Rosa 2019) or the effect is only short-term (Stabach et al. 2020). Taken together, our study showed no adverse effects on dogs' behaviour and physical condition. For the dog's well-being, we however do not recommend applying the DAC on dogs smaller than dachshunds or for long periods of time. The DAC with GPS collar represented 3.9% of the body mass in the middle-sized breeds. Although we did not statistically test the effect of DAC on the activity of middle-sized breeds, we expect to find no effect.

The harness design came from a commercially produced reflex vest for hunting dogs in the Czech Republic. This design enables dogs to move without restrictions. However, to allow maximum mobility of dogs, especially to ensure unrestricted mobility of joints (Knights & Williams 2021), and prevent skin abrasions and injuries, it was necessary to re-design the harness and increase the space above the elbow joint, behind and under the neck. Also, adjustable Velcro fasteners minimised possible discomfort, for example, when the dog's weight increased or decreased (the change of the body dimension). We prolonged the harness length for dachshunds (because of their long body). We recorded only superficial and minor skin abrasions in two cases compared to Hopkins & Milton (2016), where 38% of mantled howlers showed damage to a dermal layer or even subcutaneous structures caused by wearing ball-chain radio-collars. The use of wider collars and more extensive contact areas is recommended to reduce pressure at the tag-animal interface (Wilson et al. 2021). Our harness is designed with a vast contact area around the mount, and no physical contact occurs between the mount and the dog's skin. Furthermore, using smooth fabric prevents the dog from decelerating by being caught in dense vegetation. Thus, the harness in our study is designed to minimise physical injuries while maximising the dog's movement and comfort.

We noticed minor accidents during the first walks with DAC, such as collisions with the owner's leg caused by the placement of the mount on the left side of the dog's thorax (Figs. 1a and 1b). Dogs, however, become accustomed to a "new width" of the thorax relatively quickly (within the first three walks), and collisions have stopped. The camera placement depends on the study question and species (Bombara et al. 2017, Yoda 2019, Andersen et al. 2020). In studies focused on cat predation, the camera was attached to the neck (Loyd et al. 2013, Huck & Watson 2019, Seymour et al. 2020). In the study on calf feeding behaviour, the camera was mounted on the head (Saitoh & Kato 2021). The camera's position on the dog's head or neck could supply the same view as the lateral position. But the weight of the head and neck of the dog represents about 14% of body mass (Taylor & Heglund 1982), and the placement of the camera on the neck or head would severely influence of dog's well-being (Coughlin & van Heezik 2014). Therefore, the lateral placement captured a similar viewpoint as the dog and the portion of the dog's head, providing information not only about the dog's activity, head movements, and head orientation but also about the dog's surroundings (Figs. 1d–f). Dogs are well known for their excellent orientation skills (Richardson 1920, Nahm 2015), yet, their cognitive and sensory underpinnings remain unclear. For example, it is unknown whether dogs rely more on their olfaction or sight and memory during returns by tracking. Employing cameras in orientation studies can help to answer these questions, as the cameras provide detailed data on sniffing behaviour and visual assessment of the environment. Especially the possible involvement of a dog's excellent olfaction is frequently criticised as a weak point of studies of magnetoreception. However, the importance of a dog's olfaction may be overestimated because dogs often prioritise other senses for solving tasks (Polgár et al. 2015).

Specifically, we noticed that dogs were making very short stops (approximately 1–3 sec) while standing with the raised head, quickly looked around and continued in the same or changed direction. This behaviour is similar to the head scanning behaviour described in birds, rodents and other mammals (reviewed in Kral 2003) but not yet described in domestic dogs. Head scanning in dogs might have several functions. It may be connected with visual perception (Miller & Murphy 1995), magnetoreception (Mouritsen et al. 2004, Hart et al. 2013, Benediktová et al. 2020) or deliberating over the choice, also known as "vicarious trial and error" (Tolman 1948, Redish 2016, Santos-Pata & Verschure 2018). We observed head scanning throughout the excursion, i.e. in outbound and inbound trajectory, at the turning point, before the change of direction, and in dogs using both scouting and tracking strategies (Benediktová et al. 2020). The functional significance of head scanning in dogs during particular parts of the excursion remains to be resolved. For example, head scanning in rats facilitated remembering places (Dupret & Csicsvari 2014), while head scanning in birds helped to establish the migratory direction (Mouritsen et al. 2004). From a future perspective, subsequent research will be necessary to clarify the involvement of complex sensory perception in dogs' homing abilities.

Our previous study found that 2.4% of returning dogs could not find their way back to their owner (Benediktová et al. 2020). We could only speculate about the reason, but thanks to cameras, we can reveal the cause, such as attempts to save a lost dog by unfamiliar people. Such potentially stressful situations could have distracted the dogs and, thus, caused the loss of heading to the goal (Dreschel & Granger 2005, Græsli et al. 2020). Furthermore, we unveiled the reasons behind stops, slowdowns, or unexpected direction changes caused by external factors (i.e. avoiding obstacles, crossing rugged terrain, consuming trash, sniffing at cadavers).

Apart from orientation-related behaviour, the cameras provided excellent records of the dog's hunting behaviour (the species and number of game that the dog followed, audio records of barking at the animal's tracks), opening new opportunity to study the communication of hunting dogs with their owners (Policht et al. 2021). We also observed comfort and other behaviour (rolling, bathing, swimming, drinking from puddles or streams).

To conclude, the DAC enabled us to obtain more detailed information about the dogs' behaviour during homing activity and detected previously undescribed head scanning in dogs during navigation. Action cameras can be instrumental in studying the underpinnings of animal orientation, in behavioural ecology, cognitive research or conservation (Moll et al. 2009, Bombara et al. 2017, Huck & Watson 2019, Rosa 2019, Saitoh & Kato 2021). Given the current trend of the device's miniaturisation (Moll et al. 2007), supplementing tracking devices with animal-borne cameras might become a common practice (Bombara et al. 2017, Rosa 2019) for studying free-roaming tame and domestic animals. The cameras provide reliable and accurate animal behaviour data in its natural environment without the effect of a human observer. Several factors (such as the tag mass and attachment, species lifestyle, study question and duration of the study) have to be considered to minimise the tag's effect on an individual's behaviour and maximise the animal's well-being (Moll et al. 2007, Kays et al. 2015, Wilson et al. 2021).

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