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# Virtual fencing of captive Asian elephants fitted with an aversive geofencing device to manage their movement

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ABSTRACT

Aversive Geofencing Devices (AGDs) are designed to emit audible warning signals followed by electric shocks when animals reach virtual fences (VFs) with the intent that animals will learn to turn away at audio warnings and thereby avoid receiving shocks. AGDs are a potentially useful tool for mitigating human-elephant conflict, but a greater understanding of captive elephant responses to AGDs is required before they might be confidently used on wild elephants. We conducted experiments with eight, female captive Asian elephants using a modified dog-training collar to deliver mild electric shocks (4 kV) of varying strength (pulse frequencies) to determine the ideal location on the neck to deliver the stimuli and the optimum strength of the shock required to generate desired aversive responses. Ten shocks (<1 s duration) of different strengths were delivered during a 10 min session (i.e., one shock per minute) at two positions on one side of the elephant's neck. Results indicated that elephants were more likely to display desirable aversive behaviours at the upper position tested on the neck (odds ratio=0.47, 95% CI 0.25–0.87, $P = 0.018$) and at higher stimuli strengths (odds ratio=1.03, 95% CI 1.01–1.04, $P \leq 0.001$). A conditioning experiment was then conducted several months later with five of the same elephants. These were individually trained to walk along a ~100 m path to a food reward on three consecutive days, wearing a dummy collar. On the next three days and on one other day few months later, the elephants were fitted with a similar shock collar (positioned at the upper neck location, and with the highest strength tested earlier) to determine if the AGD could prevent the elephants from accessing the food reward. Three VFs were established at ~30 m, ~50 m and ~60 m points along the path. As the elephant approached the food, a mild audio warning, a more aggressive audio warning, and an electric shock was administered at the first, second and third VFs respectively. Warnings and shocks were not delivered if elephants heeded earlier warnings. A maximum of five such trials were attempted. The VFs successfully kept elephants from reaching the food 77.8% of the time, with elephants responding to the audio warnings and avoiding electric stimulation 47.2% of the trials. These findings suggest that AGDs are a promising method to manage elephant movement, but further research is needed to develop a reliable approach for wild elephants.

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## 1. Introduction

Asian elephants *Elephas maximus* (Linnaeus 1758), listed as Endangered in the IUCN Red List of Threatened Species (Williams et al., 2020), are a principal cause of human-wildlife conflict (HWC) in the 13 Asian elephant range countries (Fernando and Pastorini, 2011). Many of these countries have developing economies and focus their economic activities on large-scale infrastructure projects which inevitably causes loss and fragmentation of the remaining elephant habitats (Fernando et al., 2015; Liu et al., 2017; Othman et al., 2019; Padalia et al., 2019). Elephants require large spaces and travel long distances for their survival (Baskaran et al., 1995; Fernando et al., 2008b) and fragmentation of habitats increases negative interactions between humans and elephants (Alfred et al., 2012; Goswami et al., 2014). Human-elephant conflict (HEC) often results in the death of both elephants and humans and large-scale damage to crops and property (Naha et al., 2019; Neupane et al., 2017; Prakash et al., 2020). A wide range of strategies are used to mitigate HEC. These mainly include exclusionary methods using aversive stimuli, and removal of elephants by elimination or capture and translocation (Fernando et al., 2008a; Nelson et al., 2003). These strategies mostly address the symptoms of HEC and are either successful only in the short term or are unsustainable (Shaffer et al., 2019). Identification of innovative strategies to mitigate HEC remains a key research and management priority.

Aversive conditioning is commonly used for HWC mitigation, where animals learn to associate unpleasant stimuli with a behaviour and subsequently modify it (Greggor et al., 2014; Snijders et al., 2019). Aversive stimuli used to mitigate HEC include (1) visual stimuli such as bonfires and flashlights (Thaufeek et al., 2014), (2) olfactory stimuli such as chilli smoke (Davies et al., 2011), (3) acoustic stimuli such as shouting, fire crackers and shot guns (Nath et al., 2009; Nyhus et al., 2000), (4) taste stimuli such as growing unpalatable plants (Gross et al., 2017), and (5) tactile stimuli such as pricks from thorny plants (Perera, 2009), the sting of honeybees (Water et al., 2020) or shocks from an electric fence (Liefting et al., 2018). Elephants sometimes habituate to these methods or act aggressively in response to them (Davies et al., 2011; Fernando et al., 2011). However, sufficient pain is always aversive (Snijders et al., 2019), so stimuli like electric shocks could be more effective compared to other stimuli.

Electric fences (EFs) are an effective HEC mitigation method when properly designed, built and maintained (Pekor et al., 2019). Permanent EFs built around villages and temporary EFs built around agricultural lands have been proven quite effective (Fernando et al., 2011; Wijesinghe, 2019). Despite this, the high cost of maintenance, lack of flexibility once built, breaking of EFs by elephants, restricted access to resources, inhibited movements of non-target species and disruption of their dispersal (Desai and Riddle, 2015; Gunaryadi et al., 2017; Hayward and Kerley, 2009; Saaban et al., 2020; Smith et al., 2020) each makes EFs disadvantageous in many HEC situations. Early warning systems (EWSs) are gaining interest as an HEC mitigation tool where elephant movement is monitored using sightings (Gupta, 2017), geophones (Sugumar and Jayaparvathy, 2013), infra call detectors (Dabare et al., 2015), Global Positioning System (GPS) collars (Venkataraman et al., 2005), drones and infrared triggered cameras (Chen et al., 2021) to alert people via automatically activated sirens or phone messages. Such EWSs can prevent accidental encounters with elephants. But if these systems are not simultaneously coupled with an aversive stimulus to deter approaching elephants, substantial human input would still be needed to chase the elephants away using a variety of additional and potentially dangerous or harmful means.

Satellite-linked animal-borne Aversive Geofencing Devices (AGDs) have recently emerged as a potential solution to many of these issues. They work by delivering an audible warning signal followed by an electric shock as a collared animal reaches and breaches a virtual boundary established by managers. Such 'shock collar' devices are now commercially used to manage the movement of livestock (Campbell et al., 2020). They have been suggested as a potential HEC mitigation tool as well (Cabral de Mel et al., 2022; Fernando, 2011) even though they have not yet been trialled on elephants. AGDs have been used on domestic dogs for decades (Christiansen et al., 2001; Dale et al., 2013) and have also been tested on various domestic animals such as goats *Capra hircus* (Fay et al., 1989), cattle *Bos taurus* (Bishop-Hurley et al., 2007), and sheep *Ovis aries* (Jouven et al., 2012). They have further been tested on wild animals including coyotes *Canis latrans* (Andelt et al., 1999), grey wolves *Canis lupus* (Rossler et al., 2012), dingoes *Canis familiaris* (Appleby, 2015), island foxes *Urocyon littoralis* (Cooper et al., 2005) and black-tailed deer *Odocoileus hemionus* (Nolte et al., 2003). Modern AGDs used on livestock allow farmers to establish virtually fenced areas on a digital device to programme the AGD to automatically deliver an audio warning when the animal reaches a virtual fence (VF) and, if ignored, then deliver a mild electric stimulus when the virtual boundary is breached, thereby guiding the animal away from the exclusion zone (Boyd et al., 2022; Lomax et al., 2019). Livestock species quickly learn to avoid shocks by associating them with the audio warning after only a few attempts (Lee et al., 2009; Marini et al., 2018), suggesting that such devices may also be used on other intelligent species.

Elephants have superior cognitive abilities compared to many other species (Bates et al., 2008; Hart et al., 2008), which makes them excellent candidates to investigate the potential of AGDs to manage their movement. AGDs combine aversive conditioning with an EWS, where elephants may learn to avoid receiving the shock, while the people (local communities) can be notified automatically when animals breach a boundary. Such a tool would negate the need of a human response, if proven to be effective. AGDs may also be a good alternative in places where erecting EFs in large areas is impractical or cannot be permanently installed (Cooper et al., 2005). But whether or not elephants would respond to AGDs the same way livestock do is unknown.

Elephants have a comparatively thick skin, and the thickness of the skin and distribution of nerves in different parts of the body varies (Isaza and Hunter, 2004; Smith, 1890). Sensitivity and perception of stimuli could therefore differ at different locations on the body, particularly at many known nerve centres or pressure points used by mahouts (elephant handlers) to steer or control elephant movement (Deraniyagala, 1955). Determining the optimum strength of the shock where elephants would not show undesirable behaviours is also very important (Marini et al., 2018). Undertaking experimental trials to optimise the functionality of AGDs on captive elephants under controlled conditions would advance knowledge on the potential use of AGDs more rapidly. In this study, we conducted field trials on captive elephants to determine (1) the ideal location to apply the electric stimuli, and (2) the optimum strength of stimuli to apply. We further sought to determine (3) elephants' ability to recognise VFs using AGDs and respond accordingly. Our overall goal was to advance the development of AGDs as a potential tool to mitigate HEC.

## 2. Materials and methods

### 2.1. Ethical statement

The protocol and conduct of our experiments were approved by the University of Southern Queensland Animal Ethics Committee (19REA007) in Australia and the Institute of Biology in Sri Lanka (ERC IOBSL 193 04 2019 and 252 08 2021). Permission to conduct this research was also granted by the Department of National Zoological Gardens, Sri Lanka (DZG/DEV/02/Research work/2019). Our research was conducted in accordance with these approvals.

### 2.2. Study site and animals

The study was conducted at Pinnawala Elephant Orphanage (PEO), situated in the Kegalle district of Sri Lanka. In consultation with the staff

**Table 1**
Details of elephants selected for the study.

| | Animal ID | Birth year[a] | Age at the time of experiment (year 2021)[a] | Place of birth | Number of years in captivity |
|---|---|---|---|---|---|
| 1 | S1 | 1997 | 24 | Wild | 24 |
| 2 | M1 | 1981 | 40 | Wild | 40 |
| 3 | K1 | 1971 | 50 | Wild | 46 |
| 4 | M2 | 1970 | 51 | Wild | 46 |
| 5 | S2 | 1989 | 32 | Wild | 31 |
| 6 | S3 | 1984 | 37 | PEO | 37 |
| 7 | M3 | 1990 | 31 | Wild | > 16[b] |
| 8 | M4 | 1997 | 24 | Wild | 24 |

[a] Birth year and age of wild born elephants are an approximation based on the assessment made at the time the elephant arrived at PEO.
[b] Number of years in captivity of M3 given here is the number of years she had been a resident at PEO. However, she had been in captivity from a much younger age, but details are not available.

veterinarians and the curators of PEO, eight adult female captive Asian elephants (Table 1) were selected as candidates for the experiments. Each day these elephants are released from their overnight sheds into a ~3 ha open area or large pen called the "Freeland" at 08:30 h and are then taken ~500 m to a water body called "Ma-Oya" twice daily between 10:00 h and 12:00 h and between 14:00 h and 16:00 h. All elephants are herded back to their sheds after returning from Ma-Oya in the evening, before being let free again the following morning. One of our study elephants (M3) is an individually managed working elephant that works for about 1 h each day delivering food to other elephants within PEO. She is taken to Ma-Oya twice a day, between 09:45 h to 11:00 h and again between 14:00 h to 15:00 h and remains in her shed during the rest of the day.

### 2.3. Electronic collars

Off-the-shelf dog-training collars, controlled by a remote-control device to deliver an electric shock of 4 kV, ~51.7 μs, with no resistance at 99 different strength levels (varying pulse frequencies) were physically modified and used for this study. These devices typically expose animals to a fixed current of very low amperage (Andelt et al., 1999; Lines et al., 2013) thereby minimising harm to the animal (Agrisellex, 2012). For ease of understanding electricity flow, their function is commonly compared with water flowing through a pipe, where voltage (measured in Volts (V)) is the pressure that pushes water and current (measured in amperes (A)) is the flow of water (amount of water) through a pipe. A separate customised prototype collar developed to deliver electric stimuli similar to the dog-training collar was also tested on two elephants, but these results are presented in Supplementary material (Table S1).

### 2.4. Experimental protocol

This study was conducted as two field experiments: An initial study to identify the ideal location on the neck and the optimum strength of the electric stimuli that would generate aversive behavioural responses from elephants, and a subsequent aversive conditioning experiment to understand elephants' ability to learn the concept of VFs. A single observer delivered both audio and electric stimuli for all animals tested throughout this study to eliminate any inter-observer differences. All behavioural responses of elephants during experiments were video recorded using a camera (Nikon Coolpix B600). Experiments were conducted under the constant supervision of veterinarians, mahouts and researchers at all times. All experiments were conducted between 08:30 h – 11:00 h each day. Collars were removed each evening, when the elephants returned to the sheds for the night and were re-fitted the following morning. The stress and welfare effects of our experiments were quantified before during and after our experiments and no undesirable reactions, excessive pain or discomfort were observed (data not reported here), and hence no animal had to be removed from the study at any point in time.

#### 2.4.1. Experiment 1

This experiment involved delivering electric stimuli of different strengths at two positions on the neck to determine the ideal position and optimum strength that would generate desirable aversive behavioural responses, i.e., behavioural responses by elephants that showed displeasure. A summary of the steps involved in this experiment is given in Table 2. Elephants (n = 8) were fitted with a dummy collar (~10 cm machine belt and counterweight of 5–7 kg) for three days before the experiment to allow the animal to acclimatise to wearing a collar. We then fitted a physically similar shock collar on Day 4 which included two modified dog-training collar units (electrodes) attached to the belt at positions A and B (Fig. 1). Testing locations on the neck were selected in consultation with mahouts and veterinarians at PEO. Given there are certain pressure points on an elephant's body when goaded could benumb the animal if prodded deeply (Deraniyagala, 1955), such points on the neck were identified and avoided when placing the electrodes around the neck. Each position was tested during a ~10 min testing session, and one shock (each stimulus <1 s duration) per minute was delivered as described in Table 3.

#### 2.4.2. Experiment 2

This experiment was designed based on experimental protocols used previously on cattle (Campbell et al., 2018; Lee et al., 2009) and was conducted with five of the same elephants used in Experiment 1 about 1–12 months after the initial study with each elephant. Though testing might have been undertaken in groups, we tested each animal individually (1) for safety reasons; to avoid potential harm to other elephants and people, (2) because the effect of external factors on elephant responses could be more easily managed and (3) because technical

**Table 2**
Steps involved in Experiment 1.

| Day | Activity | Details | |
|---|---|---|---|
| Day 1<br>Day 2<br>Day 3 | Acclimatisation to wearing a collar | Animals wear dummy collar during the day | |
| Day 4 | Testing and post-test monitoring* | Animals S1, K1 and M1 ($n = 3^{\#}$) wear shock collar during experiment, which is removed soon after. Elephants do not wear a collar during rest of the day | Animals M2, S2, S3, M3 and M4 ($n = 5^{\#}$) wear shock collar during experiment which is replaced with the dummy collar soon after and continue to wear it for the rest of the day. |
| Day 5<br>Day 6 | Post-test monitoring* | Elephants do not wear a collar during the day | Elephants wear dummy collar during the day. |
| Day 7<br>Day 8<br>Day 9 | | Post-test monitoring not coducted[#] | Elephants do not wear a collar during the day |

#Post-test monitoring procedure modified after conducting the experiment with first three elephants. *Post-test monitoring results not presented here.


**Fig. 1.** The two test locations (A and B) on an elephant's neck in Experiment 1.

**Table 3**
Testing protocol on Day 4 of Experiment 1.

| Test session | Time | Strength level of the shock collar |
|---|---|---|
| Position A | Min 1 | 10 |
| | Min 2 | 20 |
| | Min 3 | 30 |
| | Min 4 | 40 |
| | Min 5 | 50 |
| | Min 6 | 60 |
| | Min 7 | 70 |
| | Min 8 | 80 |
| | Min 9 | 90 |
| | Min 10 | 99 |
| | Rest period of at least 5 min | |
| Position B | Min 1 | 10 |
| | Min 2 | 20 |
| | Min 3 | 30 |
| | Min 4 | 40 |
| | Min 5 | 50 |
| | Min 6 | 60 |
| | Min 7 | 70 |
| | Min 8 | 80 |
| | Min 9 | 90 |
| | Min 10 | 99 |

constraints meant that researchers needed to maintain line-of sight and close proximity to elephants, which could not be maintained if elephants were tested in groups. On Days 1–3, elephants were fitted with the dummy collar and were individually trained to walk down a ~100 m path towards a food attractant or reward (Fig. 2) following the steps described in Table 4. Two observers were present during training, to simulate the presence of the two researchers that would later be present during experimental testing days. During the first few trials on Day 1, elephants were accompanied by the mahout along the path towards the food attractant. By Day 3 all elephants were voluntarily walking directly towards the food attractant with only a verbal command given by the mahout or the mahout walking behind or alongside the elephant for a short distance (<10 m) from the starting point of the path to encourage the elephant to begin the trial. After training on each day, the animal returned to its usual routine.

The conditioning experiment was conducted on Days 4, 5 and 6 (Table 4). Each elephant was fitted with the shock collar, with the dog-training collar unit fixed at position A and a small mobile phone attached to the collar to deliver the audible warning signal (a monophonic ringing tone of ~70 dB). The highest stimuli strength (level 99) in the dog-training collar was used as the aversive stimulus. VFs were established at ~30 m, ~50 m and ~60 m from the starting point of the path, using a visual cue for the observer to deliver the first and second audio warnings and electric shock respectively (Fig. 2). The elephant was encouraged to move forward towards the food attractant under observation following the steps described in Table 4. The signal for audio warning (~2 s) was given by the observer by ringing the mobile phone attached to the collar when the elephant crossed the first VF. If the elephant walked further and reached the second VF, a second audio warning of longer duration (~4 s) was delivered to enhance the effect of the warning if the first warning was ignored. Audio warnings were ceased immediately if the elephant stopped moving forward along the path. If the elephant ignored both warnings and continued to walk forward towards the food, a brief electric shock (<1 s) was given soon afterwards at the third VF. The audio warning typically ceased (dialling was stopped) just before the shock was delivered at the third VF (with the audio warning sometimes overlapping with the shock). If the elephant still continued to walk forward despite the shock, the aversive stimulus was enhanced by delivering the shock in repeated pulses of < 1 shock per second allowing time for the elephant to show a response to each shock; each shock < 1 s duration until the elephant stopped or changed the direction of movement. If this failed and the elephant continued to walk forward the electric shock delivery was stopped after a maximum duration of 15 s or as soon as the elephant reached the food attractant. If at any time the elephant stopped or turned, the electrical

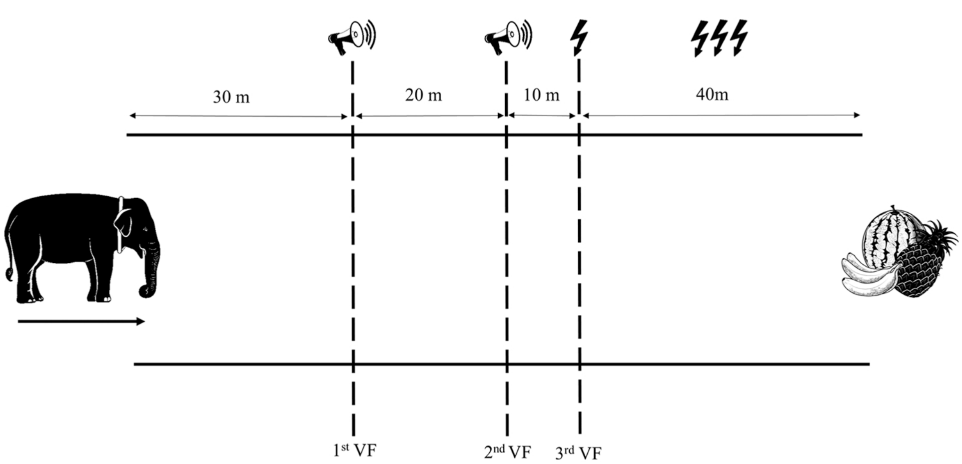


**Fig. 2.** Schematic diagram of virtual fences (VFs) along the testing path in Experiment 2. As the elephant approached the food attractant the first and second audio warnings and the electric shock were given at ~30 m, ~50 m and ~60 m, respectively. If the elephant continued ignoring these stimuli shocks were delivered in repeated pulses after the 3rd VF.

**Table 4**
Steps involved in Experiment 2.

| Day | Activity | Step no. | Details |
|---|---|---|---|
| Day 1 | Training day 1 | Step 1 | Encourage the animal to walk 100 m along a path towards a fruit reward |
| Day 2 | Training day 2 | Step 2 | Allow feeding for up to 30 s |
| | | Step 3 | Herd the animal back to the beginning of the path |
| Day 3 | Training day 3 | Step 4 | Rest for 2–5 min |
| | | Step 5 | Repeat Steps 1–4 four more times |
| Day 4 | Experiment day 1 and post-test monitoring* | Step 1 | Encourage the animal to walk 100 m along a path towards a fruit reward, but activate the audible and electric stimuli as shown in Fig. 2 |
| Day 5 | Experiment day 2 and post-test monitoring* | Step 2 | If the elephant responds to the stimuli and stops or changes the direction of movement herd the elephant back to the beginning |
| | | | If the elephant reaches the fruit, allow feeding for up to 30 s and then herd the elephant back to the beginning of the path |
| | | Step 3 | Rest for 2–5 min |
| Day 6 | Experiment day 3 and post-test monitoring* | Step 4 | Repeat Steps 1–3 up to four more times |
| | | Step 5 | Shock collar replaced by dummy collar and elephants wear dummy collar during the day |
| Day 7 | | | |
| Day 8 | Post-test monitoring* | | Elephants wear dummy collar during the day |
| Day 9 | | | |
| | | | After a gap of 1–4 months |
| | | Step 1 | Carry out steps 1–4 of training days (Day 1 – 3) (3 times) |
| Day 10 | Experiment day 4 and post-test monitoring* | Step2 | Carry out steps 1–4 on experiment days (Day 4 – 6) |
| | | Step 3 | Shock collar removed after experiment and is not replaced by dummy collar |
| Day 11 | | | |
| Day 12 | Post-test monitoring* | | Elephants do not wear a collar during the day |
| Day 13 | | | |

* Post-test monitoring results not presented here.

stimuli were ceased and was continued only if it walked forward again. A complete or successful trial was recorded if the elephant experienced at least one audio warning. A maximum of five trials were attempted each day with each elephant.

One to four months after the initial aversive conditioning experiment, three elephants (S1, M2 and M3) were tested again on a fourth day (Table 4) to determine how they responded to the audio warnings and the electrical stimuli given a period of time since their first experience. Elephants were fitted with the electric shock collar and allowed to acclimatise to it for about 30 min and the steps outlined in Table 4 were repeated. Elephants were first allowed to walk towards the food without receiving any stimuli as on their training days, to prevent the elephant from relating the receipt of the shock with the path or the collar from their previous experience.

During the testing of the first elephant (S1), the mahout always maintained ~5–10 m distance from the elephant for safety reasons in case the elephant showed any unexpected adverse response. However, this was discontinued thereafter as elephants did not show adverse responses (see below). The other four elephants were allowed to walk along the path on their own with the mahout stopping at < 10 m from the starting point. If elephants showed reluctance to walk through repeated trials and stopped walking when the mahout stopped, the mahout gently encouraged the elephant by continuing to walk along with it for another 5–10 m. This encouragement was aimed at getting the animal to experience an audio warning to determine if an association between the audio warnings and electrical stimulus had developed, but not to force the animal to receive the electrical stimulus (Campbell et al., 2018).

### 2.5. Statistical analysis

All analysis were conducted using the statistical software R (R Core Team, 2020). A single observer analysed all video recordings and recorded all elephant responses to experiments. Intra observer error was not measured, but videos were rewatched on a later date by the same observer for 100% agreement of observations.

The behavioural responses observed in Experiment 1 were classified into four categories (Table 5) and frequency of each behaviour category shown at different stimuli strengths and locations were calculated. Fischer's exact test was performed for no response vs. response shown to test two hypotheses: (1) The distribution of behavioural responses was the same between the two locations tested; and (2) The distribution of behavioural responses was the same between the different stimuli strengths tested. To analyse the likelihood of observing each behaviour category in relation to location on the neck and strength of stimulus a binomial logistic regression was employed using a generalised linear model (assuming a binomial distribution and a logit function) with "location A" and "strength 10" as reference categories respectively. The "glm" function in statistical software R was used for this.

The observer evaluated the sequence of stimuli received by elephants, i.e., if either one or both audio warnings received (O) or if audio and electric stimuli (either as a single shock or as pulses) were received (X) during each trial and whether the animals reached and consumed the food attractant during each trial in Experiment 2. A binomial logistic

**Table 5**
Behaviours observed in response to electrical stimuli in Experiment 1.

| Behavioural category | Description of behaviours |
|---|---|
| No change in behaviour | Continue its previous behaviour |
| Involuntary behaviour | Strong or mild body flinch, shut eyes, cessation of previous behaviour |
| Collar/ trunk/ agitation behaviours | Touch collar, pull collar, shake or hit collar, trunk sway, lift trunk towards collar, swaying from side to side or back and forth, slight turning of body from side to side |
| Locomotory behaviours | Stop, turn, turn and move away, move backwards, move forwards, turn and run |

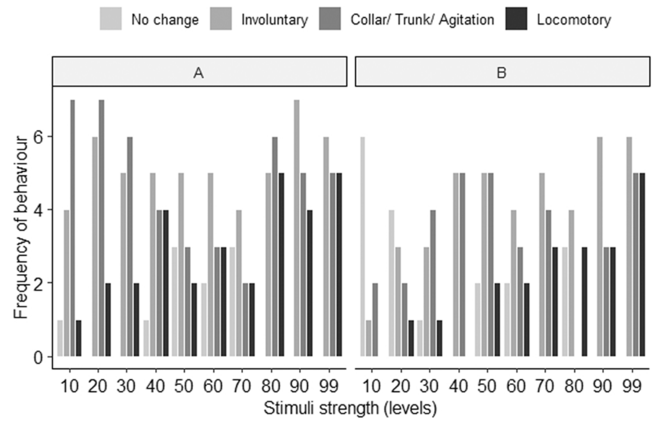


**Fig. 3.** Frequency of responses to different strengths (levels) of electrical stimuli at position A and B, during Experiment 1.

regression was used to determine the likelihood of receiving an electric stimulus across trials. Percentage frequencies of behavioural responses to the audio warnings and electric stimuli in Experiment 2 by each elephant across all trials and on each day by all elephants were calculated. Small sample size, uneven number of trials and not enough instances of individual behaviours limited further statistical analysis.

## 3. Results

### 3.1. Experiment 1

Responses by each elephant to different stimuli strengths at the two positions tested around the neck varied and multiple behaviours were exhibited by elephants in response to a single stimulus on most occasions (e.g. body flinching, shaking collar and moving backwards in response to one stimulus). There were no differences in the frequency of ‘no response vs response shown’ at different stimuli strengths (two-tailed Fisher’s exact test, $P = 0.174$) or between the two positions tested (two-tailed Fisher’s exact test, $P = 0.172$). However, the observed frequency of desirable responses such as collar or trunk or agitation and locomotory behaviours was greater at higher stimuli strengths and at position A compared to position B (Fig. 3). The odds ratios calculated using logistic regression indicated that collar or trunk or agitation behaviours were more likely to be observed at position A compared to position B (see Table 6). The odds ratios also showed that it was less likely to observe no change in behaviour and more likely to observe involuntary and locomotory behaviours with increasing stimuli strength. There was also a statistical tendency to observe no change in behaviour at position B and to observe more locomotory behaviours at position A, though these results were inconclusive (Table 6).

### 3.2. Experiment 2

All five elephants voluntarily walked down the path during the first trial on Day 4 during which all elephants received the electric shock, and only two reached the food attractant (Table 7). Only three elephants could be encouraged to participate in a second trial on Day 4 out of which two responded immediately to the audio warning and did not proceed towards food. We also observed substantial variation and inconsistency in responses to the stimuli. S1, K1 and M3 clearly responded to the audio warnings after their first trial (Table 7) and avoided receiving the electric shock. However, M4 received electrical stimuli during her 4th trial on Day 5 and 2nd trial on Day 6 after avoiding the electric shock in the previous trials on the same day. Out of the 36 trials conducted with all five elephants, VFs were successful in preventing elephants from reaching the food attractant in 77.8% (n = 28) of the occasions with 47.2% (n = 17) of the trials requiring only the audio warnings to prevent elephants from proceeding and receiving the electric shock. The odds ratio of receiving a shock during a trial was 0.86 (95% CI 0.70–1.05, $P = 0.151$) suggesting that elephants were less likely to receive an electric shock with an increasing number of trials, though this could not be confirmed.

Reluctance to repeat the trials, was particularly observed with K1, M2 and M3. Therefore, the number of trials that could be conducted

**Table 6**
Odds ratios of observing each behaviour category in Experiment 1.

| Behaviour category | Location (A and B) | | | Strength (10 – 99) | | |
|---|---|---|---|---|---|---|
| | Odds ratio | 95% CI | P value | Odds ratio | 95% CI | P value |
| No change | 2.11 | 0.90 – 5.19 | 0.092 | 0.98 | 0.96 – 0.99 | 0.007 |
| Involuntary | 0.58 | 0.30 – 1.11 | 0.102 | 1.02 | 1.00 – 1.03 | 0.011 |
| Collar/Trunk/Agitation | 0.47 | 0.25 – 0.87 | 0.018 | 1.00 | 0.98 – 1.01 | 0.408 |
| Locomotory | 0.52 | 0.25 – 1.06 | 0.073 | 1.03 | 1.01 – 1.04 | < 0.001 |

**Table 7**
Sequence of stimuli received (audio warnings only (O) and audio followed with the electrical stimuli (X)), across the testing days for each individual elephant during each trial in Experiment 2.

| Elephant ID | Experiment day | | | |
|---|---|---|---|---|
| | Day 4 | Day 5 | Day 6 | Day 10 |
| S1 | XOOOO | X[a*]X[a*]X[a*] | X[a*]OO | O |
| K1 | X[b] | O | O[#]X | N/A |
| M2 | X[b] | X | X[b] | O |
| M3 | X[a]O | O | – | X |
| M4 | X[a]X[a]X[a]XO | XOOX | OXO | N/A |
| Total trials | 14 | 10 | 9 | 3 |
| % Trials - elephants received electric stimuli | 57.1 | 60.0 | 44.4 | 33.3 |
| % Trials - elephants reached food attractant and consumed it | 28.6 | 30.0 | 11.1 | 0.0 |

[a] - Elephant reached food attractant and consumed it.
[b] - Elephant walked/ran past the fruit attractant without consuming it.
[*] - Elephant’s behaviour was influenced by mahout movement.
[#] - After the elephant stopped at the first audio warning, the mahout’s hand gestures triggered the elephant to begin walking forward again and hence was considered as two separate trials.

**Table 8**
Behavioural responses to audio warning and electrical stimuli shown by individual elephants and on each experiment day in Experiment 2[a].

| | No. of Trials | No. of audio warnings | Responses to audio warning | | | | | No. of electrical stimuli | Responses to electrical stimuli | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Continue walking | Walk reluctantly | Pause and touch/ shake collar | Stop, turn and walk away | Stop and turn | | Continue walking | Body flinch | Pause and touch/ shake collar | Walk fast/ run forward | Stop and move backwards | Stop, turn and walk away | Stop and turn |
| Elephant | | | | | | | | | | | | | | | |
| S1 | 12 | 18 | 33.3 (6) | 22.2 (4) | 33.3 (6) | 27.8 (5) | 11.1 (2) | 10 | 30.0 (3) | – | 70.0 (7) | – | – | 10.0 (1) | 10.0 (1) |
| K1 | 4 | 5 | 60.0 (3) | – | – | – | 40.0 (2) | 3 | – | – | 33.3 (1) | 33.3 (1) | 33.3 (1) | – | – |
| M2 | 4 | 7 | 85.7 (6) | – | – | – | 14.3(1) | 4 | – | – | – | 50.0 (2) | 25.0 (1) | – | 25.0 (1) |
| M3 | 4 | 6 | 66.7 (4) | – | – | 33.3 (2) | – | 3 | – | – | 100 (3) | – | – | 33.3 (1) | 33.3 (1) |
| M4 | 12 | 19 | 68.4 (13) | – | 15.8(3) | 15.8 (3) | 15.8 (3) | 12 | – | 41.7 (5) | 50.0 (6) | – | 25.0 (3) | 8.3 (1) | 16.7 (2) |
| Day | | | | | | | | | | | | | | | |
| Day 4 | 14 | 22 | 68.2 (15) | – | 18.2 (4) | 22.7 (5) | 9.1 (2) | 15 | – | 13.3 (2) | 60.0 (9) | 13.3 (2) | 6.7 (1) | 6.7 (1) | 33.3 (5) |
| Day 5 | 10 | 16 | 56.3 (9) | 18.8 (3) | 18.8 (3) | 12.5 (2) | 12.5 (2) | 11 | 18.2 (2) | 27.3 (3) | 45.5 (5) | – | 18.2 (2) | 9.1 (1) | – |
| Day 6 | 9 | 12 | 50.0 (6) | 8.3 (1) | 8.3 (1) | 25.0 (3) | 16.7(2) | 5 | 20.0 (1) | – | 40.0 (2) | 20.0 (1) | 40.0 (2) | – | – |
| Day 10 | 3 | 5 | 40.0 (2) | – | 20.0 (1) | – | 40.0 (2) | 1 | – | – | 100.0 (1) | – | – | 100.0 (1) | – |
| Total | 36 | 55 | 58.2 (32) | 7.3 (4) | 16.4 (9) | 18.2 (10) | 14.6(8) | 32 | 9.4 (3) | 15.6 (5) | 53.1 (17) | 9.4 (3) | 15.6 (5) | 9.4 (3) | 15.6 (5) |

[a] Numbers listed under each behaviour are percentages of that behaviour with the frequency in parentheses. The 1st and 2nd audio warnings were considered as two separate audio stimuli and the electric shock given at the 3rd VF and the series of electric pulses were counted as two separate electric stimuli during each trial. Hence the maximum number of audio or electric stimuli delivered during a trial was counted as two.

with each elephant varied across the days and was limited to just one trial on many days. M3 could not be encouraged to walk through even one trial on Day 6. Even with the mahout continuing to walk with the elephant few more metres, elephants either stopped or turned and did not experience the first audio warning during many attempts. The response of the first elephant tested (S1) on Days 5 and 6 may have been influenced by the mahout's behaviours, such as his pace and instinct to prevent the elephant from damaging plants alongside the path. During these trials S1 showed some reluctance to proceed after the first audio warning but continued ignoring the second audio warning and the shocks that followed, ultimately reaching the food attractant. Even though mahouts were advised to stop walking after ~10 m from the starting point of the path for the latter four elephants tested, a similar event occurred on Day 6 with K1. During this event, the mahout continued to walk forward making a hand gesture with a stick and causing the elephant to start walking forward again, ~10 s after the elephant had stopped at the first audio warning. In this case, it was clear that the elephant would not have walked forward if not for the mahout's movement. Therefore, stimuli delivered after elephant started to walk again was considered as a separate trial. Such human errors were avoided during later trials.

Elephants' responses to audio and electric stimuli were classified into five and seven behaviours respectively (Table 8). Elephants sometimes showed multiple behaviours in response to a single stimulus; for example, 'pause and shake the collar' and then 'stop turn and walk away'. Elephants showed favourable behaviours 'stop, turn and walk away' and 'stop and turn' to audio warnings at 32.7% ($n = 18$) of occasions and 'stop and move backwards', 'stop, turn and walkaway', and 'stop and turn' to electric stimuli at 40.6% ($n = 13$) of the occasions.

## 4. Discussion

Our experiments provided some evidence that Asian elephants showed desired responses to electrical stimuli delivered from an AGD, which may be useful in managing their movement. The aversive conditioning experiment showed that the electric shock was successful in preventing elephants reaching the food attractant on most occasions, and that some elephants learnt to associate the audio warning with the aversive electrical stimulus and avoided receiving it by responding to the audio warning. The results of this study were similar to previous studies conducted on cattle (Campbell et al., 2018; Lee et al., 2009) thus demonstrating the potential use of AGDs to manage elephant movement.

Experiment 1 revealed that more involuntary and locomotory responses could be observed at higher stimuli strengths and more collar or trunk or agitation behaviours could be observed at position A (Fig. 3, Table 6). Elephants showed involuntary reactions as the shock startled them, touched the point of the electrodes as they perceived pain, showed displeasure by shaking the collar, showed stereotypic behaviour probably due to confusion, and locomotory behaviours to try and move away from the unpleasant situation. The increased chances of observing no change in behaviour at position B, however, may have occurred due to the displacement of electrodes resulting from heavy shaking of the collar by elephants during the first testing session at position A. As done in similar situations with sheep (Marini et al., 2018), when a displacement was suspected, collars were adjusted by a mahout with minimum disturbance to the elephant. Regardless, positioning electrodes towards the top of the neck would make it easier to be connected to the GPS unit of the AGD that would be placed on the dorsal side of the elephant's neck (Pastorini et al., 2015). Furthermore, the electrodes may not directly touch the skin on the lower parts of the neck due to the presence of transverse throat folds (thick skin folds) towards the ventral region of the neck of elephants (Deraniyagala, 1955). Placing electrodes towards the dorsal side may also minimise damage to them that could otherwise occur when elephants rub the collar against various surfaces. For these reasons the highest stimuli strength in the dog-training collar and the upper most position tested was used during Experiment 2.

During Experiment 2, it was evident that some elephants responded to the audio warning and either stopped, turned or moved away from the path. Due to the low number of individual trials and the inconsistency in the receipt of electric shocks over the experiment days, it is unclear if all elephants had thoroughly learnt the association between the electric shock and audio warning. Similar inconsistencies in receipt of electric shocks over the experiment days and variability in learning to recognise VFs between individuals have been reported in studies conducted on livestock (Campbell et al., 2018; Colusso et al., 2021; Lee et al., 2009; Marini et al., 2018; Verdon et al., 2020). Responses shown to electric stimuli by individual elephants varied considerably during both experiments. Such variability between individuals exists in other species as well (Jouven et al., 2012; Lee et al., 2007; Shivik et al., 2003). These variations between individuals may have depended on individual elephant's personality (Found and St. Clair, 2018), temperament (Finkemeier et al., 2018; Réale et al., 2007), sensitivities and the way each animal perceives pain (Lines et al., 2013; Norell et al., 1982; Reinemann et al., 1999). Even though determining a single most appropriate stimulus level for all elephants is not easy, our study provided sufficient evidence to establish clear hypotheses for future research on managing elephant movement using AGDs.

The behaviour of elephants during this study may have been affected by external factors such as presence of food plants on the sides of the experimental path, vehicles bringing in food within PEO, and the movements of other mahouts, elephants and staff members within close proximity. Conducting the experiment in PEO on a path with minimum external disturbances was impossible because elephants were not willing to walk on some selected paths, possibly because of unfamiliarity and the increased distance from other familiar elephants. Captive elephants are known to show reluctance like this when introduced to novel environments (Liehrmann et al., 2021). Avoiding the influence of the handling mahout on the elephant during the aversive conditioning experiment, is also very important for which proper training of mahouts on the experimental procedure is essential. The individual mahouts changed frequently during our study, which was particularly problematic when a new mahout was involved directly on an experiment day without being involved on a previous training day. Individual mahout's personality, behaviour (e.g., speed of walking, gestures and handling) and capacity to comprehend the experimental requirements also varied. Mahouts were advised to keep their intervention to the minimum and maintain distance from the elephant. However, difficulty in avoiding the effect of unconscious or unintentional behaviours by mahouts during experiments has been highlighted in other studies as well (Chu et al., 2022). Further, elephants are known to develop unique relationships with their mahouts and respond differently to other unfamiliar mahouts (Mumby, 2019). Level of familiarity with mahout can also affect the cooperation of the elephant in a novel situation (Liehrmann et al., 2021). Therefore, even though elephants involved in Experiment 2 were accustomed to being handled by multiple mahouts, elephants may have perceived each mahout differently and responded to them and the experiment differently depending on elephant's familiarity with each of them. Working with the same mahout during each experiment would have been ideal to minimise these potentially confounding factors.

Elephants showed reluctance to walk through repeated trials (Table 7), which may have been because elephants associated the receipt of the aversive stimuli with the presence of fruits or walking on the path rather than hearing the audio warning. Similar instances have been recorded with cattle where the presence of the food attractant may have acted as the conditioning stimulus and expedited the learning process (Lee et al., 2009) or negative association being made with the experiment path resulting in cattle not approaching the VFs towards the end of the experiments (Campbell et al., 2018). This could also be considered a positive result given that it shows that elephants perceived the path as a no-go zone. If AGDs could condition a wild elephant to perceive a human habitation as a no-go zone and prevent it from approaching it, then that could be considered a desirable outcome. To confirm if elephants learnt to associate the audio warning with the aversive stimulus, it would be appropriate to repeat the experiment with the same elephant on different paths. Both time and logistical limitations within PEO prevented the experiment from being repeated in this way. We therefore recommend that future studies avoid these potential issues as much as possible.

The chances of elephants more effectively learning to associate the electric shock with the audio warning might be improved by pairing each shock with an audio warning (Campbell et al., 2018), rather than enhancing the aversive stimulus by delivering the shock as pulses. This may be accomplished had we used an automated AGD along a longer path or in a larger space. Pairing the shock with the audible warning might also enhance predictability and controllability of receiving the electric shock (Lee et al., 2018), thereby reducing the stress or anxiety faced by the animal (Kearton et al., 2020) which is important for the welfare of animals during aversive conditioning.

Some behaviours of wild and captive elephants are known to be quite different; e.g. stereotypic behaviour (LaDue et al., 2022). Therefore, there is a possibility that responses from wild elephants to the mild stimuli from the dog-training collar unit will be different to those we observed in captive elephants. Wild male elephants in particular are known to show high tolerance to human disturbances (Fernando, 2011; Nath et al., 2009) and could be indifferent to audio and electrical stimuli as shown by less fearful cattle (Verdon et al., 2020). A much stronger stimuli than that tested in this study may be required for wild elephants, which needs to be further explored. There is also a possibility that wild elephants may panic or act aggressively in response to the shock, as has been shown when loud noises are used as an HEC mitigation tool (Davies et al., 2011). It is also uncertain whether wild elephants would always move in the desired direction in the absence of a visual stimulus. These possibilities may be carefully investigated during preliminary studies. Investigation of alternative audio cues may also be of interest. Elephants' responses to different sounds such as carnivore growls or buzzing sound of honeybees have been tested before with some success (Dampage et al., 2021; Dror et al., 2020; King et al., 2018, 2007; Thuppil and Coss, 2016). However, irrespective of the type of sound, attenuation of its efficacy over time is inevitable if elephants learn that the sound does not cause any harm to them (Goodyear and Schulte, 2015). For this reason, sounds must always be accompanied by a truly aversive stimuli, such as an electric shock if they are to remain effective.

There are also concerns related to the physical design of AGDs that need to be resolved before they can be tested on wild elephants such as durability to withstand changing environmental conditions in the wild or strong movements by elephants, limited battery lives and costs involved in developing and fitting AGDs on elephants (Pastorini et al., 2015). The welfare impact of AGDs on elephants is also a debatable subject. Assessment of physiological and behavioural responses have been used as an indicator to understand the welfare impact of AGDs on livestock (Campbell et al., 2019, 2017; Kearton et al., 2019). Similarly, an analysis of behavioural and physiological responses of elephants should be conducted when testing AGDs on elephants. Positive reinforcement is always preferred over punishment-based training of animals. This may be accomplished alongside AGDs, by increasing attraction to areas outside human habitats through habitat enrichment and improving connectivity of elephant habitats (Bakri et al., 2019; Menon and Tiwari, 2017; Wahed et al., 2016). Compared to elimination, translocation and domestication of elephants (Desai and Riddle, 2015; Fernando et al., 2015; Lahdenperä et al., 2018), AGDs may still be a more ethically acceptable non-lethal HEC mitigation method.

## 5. Conclusions and recommendations

Finding effective and innovative HEC mitigation tools remains a high priority and use of AGDs to manage elephant movement is one tool worthy of further exploration. This study showed that an AGD delivering a mild electric shock closer to the dorsal side of the neck was generally effective in producing favourable responses to manage movement of captive elephants. This study also indicated that captive elephants could learn to associate an audible warning with the electric shock and avoid otherwise attractive locations. These preliminary results are encouraging, but further research is required, with a larger sample size, to develop automated AGDs with the ability to manage wild elephant movement. It would also be beneficial to investigate if social facilitation could occur when collars are put only on a few individual elephants in a group. Studying AGDs with captive elephants may not replicate the real-life situation of HEC with wild elephants, however, it may still be essential to resolve many uncertainties in the technology, efficacy and welfare impacts prior to testing them on wild elephants. Application of this tool to mitigate HEC is still in its infancy and will therefore take a while before it can be fully developed as an ethically acceptable and effective HEC mitigation method for elephants. If elephants can recognise VFs from AGDs and modify their movement successfully, it could become a powerful management tool for reducing HEC in the future.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.applanim.2022.105822.

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