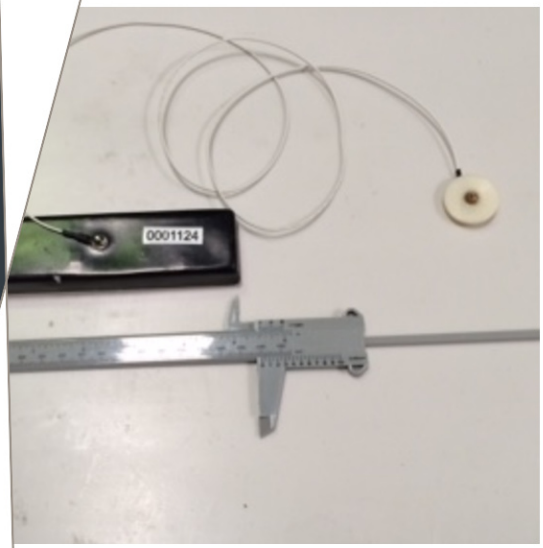
RPELA v2

Testing effectiveness against white sharks

59918196



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Executive Summary

Globally, the occurrence of unprovoked shark bite has been increasing due to various natural and anthropogenic factors and many of the bites, including some that were fatal, have been to surfers. White sharks (*Carcharodon carcharias*), tiger sharks (*Galeocerdo cuvier*) and bull sharks (*Carcharhinus leucas*) have accounted for most of the bites.

Various personal shark deterrents are commercially available to surfers. The Rpela is a battery-powered, water-activated electric personal deterrent fitted to a surfboard that produces an electric field around the surfer. It is designed specifically to deter sharks from approaching or biting surfers by disrupting a sharks' sensitive electro-reception organs. It has been recently reconfigured from previous models to increase the strength of its electric field with a view to increasing its effectiveness.

The reconfigured Rpela (version 2) was tested on white sharks at Salisbury Island, Western Australia, in March and April 2018 using a custom-built floating board with fish bait attached (to tempt a bite). Testing involved attracting white sharks to the stern of an anchored vessel by hanging bait (tuna) in the water and tapping the hull of the vessel with a metal pole then removing and replacing it with the test board mounted with the Rpela v2. The test board also had fish bait hanging 45 cm below it in a canister. In total, 46 trials were done with the Rpela v2 either active or inactive (a control) to determine the device's effect on (1) the probability of a shark biting or touching (interacting) with the bait, (2) the number of passes a shark took prior to biting or interacting with the bait and when it did not, (3) the mean distance between a shark and the bait. The presence of any habituation in shark behaviour was also explored by examining the number of passes and mean distance for sharks through time. Each trial was recorded by independent scientific observers and statistical analyses were done to determine the significance of differences in shark response when Rpela v2 was active and inactive.

Key findings include the following:

- When active, Rpela v2 significantly reduced the probability of a bite and interaction (i.e. bite or touch) occurring compared with when it was inactive. The probability of a bite reduced from 0.75 to 0.25 (a 66% reduction) and an interaction from 0.80 down to 0.50 (a 38% reduction);
- The number of passes taken by a shark regardless of whether a bite or interaction took place and when a bite or an interaction did take place also reduced when Rpela v2 was active; and
- The mean distance between the shark and the bait increased when Repla v2 was active.

When active, Rpela v2 did not completely remove the risk of shark bite, but there was strong evidence that it did deter sharks from doing so. The magnitude of the reduction in risk is of a level that consumers are likely to consider meaningful. It is noted that the nature of the trials, using fish bait to attract sharks, does not make it directly comparable with the type of encounter for which the device is designed (i.e. whilst surfing). However, it is reasonable to assume that if the device is effective at deterring sharks from biting fish baited surfboards, it would also be so during chance encounters with surfers where fish bait was absent.

Based on these results, it could be expected Rpela v2 would benefit surfers by significantly reducing the risk of shark bite and providing more time to leave the water (i.e. as inferred from the number of passes) when a potentially dangerous shark is present. It is noted that the small sample size (seven sharks), limited size range of sharks in the trials (i.e. 2.4 – 3.6 m) and single location of the study limits generalisations regarding Rpela v2's effectiveness. These limitations could be overcome with further trialling at other locations, in other seasons at the same locations, with larger sharks and on other potentially dangerous species, particularly bull sharks or tiger sharks. It is also recommended that further studies are done if any further substantial modifications to the Rpela v2 are made that may influence its effectiveness. Finally, although the results of the Salisbury Island trials infer that the configuration of Rpela v2 has improved its effectiveness from a previous version, this can only be proven unequivocally if Rpela v2 is tested against the previous version in a further trial.

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1 Introduction

1.1 Background

Globally, the occurrence of unprovoked shark bite is increasing due to various natural and anthropogenic factors (Amin et al. 2012; McPhee 2014). Over the last 30 years unprovoked shark bite has been recorded from 56 countries and territories, with most (84%) having occurred in the United States, South Africa, Australia, Brazil, the Bahamas and Reunion Island (McPhee 2014). Unprovoked shark bites occurring at one location or region over a short period of time present a significant public safety concern which inevitably requires intervention (or additional intervention) to enhance public safety. Recent examples of these situations have included at Reunion and in Australia (Western Australia and New South Wales), where a number of fatalities occurred over a relatively short time frame.

Many of the bites and associated fatalities have involved surfers (McPhee 2014, Chapman and McPhee 2016) and white sharks (*Carcharodon carcharias*), tiger sharks (*Galeocerdo cuvier*) and bull sharks (*Carcharhinus leucas*) account for 55.6% of all bites (including many fatalities) over a thirty year period(McPhee 2014). In Australian waters, tiger, bull and white sharks occur over a broad geographic area. In Western Australia (WA) in 2011/12 and 2016, and on beaches of the New South Wales (NSW) north coast in 2015, the most recent unprovoked bites have been attributed to white sharks.

Traditional beach-scale shark barriers and the majority of emerging beach-scale deterrents would likely provide limited protection to surfers (McPhee et al. submitted). In contrast to bathers who generally tend to swim closer to the shore and are amenable to be directed to the safest place to swim (i.e. within an enclosure), surfers tend to go where the breaking waves are most appealing and this can vary on a daily basis along the length of any beach. The most attractive surfing spots are often found at the edges of beaches where the beaches abut a rocky shore or headland or where breaks occur on reefs offshore from beaches. Surfers may also oppose the use of barriers or nets if they impede or are perceived to impede their access to and use of surf breaks.

There has been substantial investment recently to develop new tools to reduce the risk of shark bite to surfers. The range of products all claim to reduce risk by deterring sharks through disruptions to vision or smell or by or by creating magnetic or electric fields (see Cardno 2015, Hart and Collin 2015). The scientific evidence verifying the effectiveness of most devices, however, is limited and we could not find any studies of controlled testing of deterrents specifically designed for surfers, apart from Huveneers et al. (2018) (see below).

It is well recognised that sharks can detect electrical fields in the water through their ampullae of Lorenzini - which are specific structures concentrated around the head of elasmobranchs (Murray 1962). These sensory organs are very sensitive (Murray 1962; Kempster et al. 2016) and “overwhelming” these organs with an unnaturally large electrical stimulus has long been recognised as a potential approach from deterring sharks from biting people (Smit and Peddemors 2003; Huveneers et al. 2013). Such a stimulus does not harm a shark but may encourage a shark to rapidly move away from an area or change its behaviour. A simple human analogy is of a very loud music that becomes unpleasant and encourages you to move away with no long-term negative impacts.

1.2 The ‘Rpela’ Shark Deterrent

The Rpela is a battery-powered, water-activated device fitted to a socket on the rear underside of a surfboard with a cable imbedded in the core leading forward by one metre to a positive output electrode. The device produces an electric field around the surfer, designed specifically to deter sharks from approaching or biting the surfer.

Figure 1-1 The Rpela device

1.3 Previous Testing

Huveneers et al. (2018) tested an earlier version of the Rpela (Rpela v1) and four other shark deterrents (50 trials per deterrent) developed for surfers by examining a number of parameters including the percentage of baits taken by white sharks, time to take the bait, number of passes, distance to the bait, and whether a shark reaction (to deterrents) could be observed. The trials were done at the Neptune Islands Group Marine Park (35°149 S, 136°049 E), off the southern coast of South Australia. In Huveneers et al. (2018), sharks were attracted to the stern of an anchored vessel using an odour corridor, which was established by disbursing into the water a mix of unrefined fish oil and minced southern bluefin tuna, *Thunnus maccoyii* (i.e. chumming). There was a small but non-significant, difference in the probabilities of sharks that reacted to the Rpela compared to the control board (0.09 vs. 0.02 of the passes), whereas another electric device (the Surf+) also designed for surfers, showed a statistically significant effect.

There is evidence in the previous testing of personal shark deterrents (for divers) that use electric fields that they can be effective deterrents but the waveform, size of the electric field and position of the electrodes in relation to the bait (in test studies) are very important (Huveneers et al. 2013b, Kempster et al. 2016, Smit and Peddemors 2003). Given the size of the effective electric fields can be small (less than a few metres at most), the electrode needs to be close to the bait for it to be contained within the field. The same goes for the position of the electrode relative to a diver or surfer when the device is worn. The electrodes for the Rpela and Surf+ for surfers are located ~ 1.2 m apart underneath the surfboard, allowing surfers to sit in the middle of the generated electric field when they are waiting for waves. The configuration of the version of the Rpela (v1) trialled by Huveneers et al. (2018) trial indicated, however, that the electric field did not reach as far as the Surf+'s even despite producing an electric field at a higher voltage gradient than the Surf+ (200 V vs. 115 V). The Surf+ which discharges alternating current at a frequency of ~ 1.6 Hz had a higher maximum effective distance at 3 V m-1 than the Rpela v1 (0.7 vs. < 0.5 m) which discharged direct current at a frequency of ~ 14.5 Hz (Hart and Ryan 2018). As a result, the duration of the pulse was also much shorter in the Rpela v1 (~ 0.2 ms) than the Surf+ (~1.5 ms).

Huveneers et al. (2018) speculated that, in their trials, the greater effectiveness of the Surf+ relative to the Rpela could have been due to the short pulse duration of the Rpela or the longer frequency of the Surf+, which might be more likely to disturb an approaching shark because the animal is able to come closer to the deterrent between pulses, thus feeling the electric pulse more strongly. Alternatively, the effect of the Rpela may have been a consequence of the circumstances of the testing environment. In a previous study, Huveneers et al. (2013b) discussed how the behavioural response of sharks may depend on context. The context of the Neptune Island[1] testing in which sharks were attracted, and potentially excited, by the stimulus of blood in the water is quite different to situations when most swimmers or surfers would encounter a shark. Although most sharks use alternate sensory modalities to locate and capture prey (olfaction, vision and electroreception) (Gardiner et al. 2014), there is experimental evidence that some carcharinid sharks deprived of olfactory cues are less motivated to take prey when odour cues are not available (Gardiner 2012). Hence, it is possible that the previous configuration of the Rpela used in the Neptune Island trials could have been more effective in a less than extreme situation. However, even if the previous version of the Rpela was more effective in a situation that was less extreme than for the Neptune Islands trials, practically and ethically it is not possible to undertake an experiment to test for this (see **Section 4** for further discussion).

1.4 Versions of the 'Rpela'

Rpela version 2 (v2) was used for the trials presented in this report. Rpela v2 had beenmodified from the device used in Huveneers et al. (2018) trials (Rpela v1) in terms of its electrode size, field propagation, pulse type, duration and frequency. The details of modifications are given in **Table 1-1**.

Table 1-1 Modifications to the Rpela

Component	Rpela v1 Neptune Islands trials (Huveneers et al. 2018)	Rpela v2 Salisbury Island trials (this report)
Electrode sizes	50 cm[a]	10 cm
Space between electrodes	100 cm	100 cm
Voltage gradient	200 V	200 V
Magnitude of electric field @ 1.0 m	0.88 V	1.75 V
Frequency of discharge	14.5 Hz	9.5 Hz
Pulse duration of discharge	0.2 ms	0.2 ms

[a] Some changes to electrode size occurred in Huveneers et al. (2018) trials, but this did not appear to affect shark responses

With an electrode size of 50 cm and a frequency of discharge frequency of 14.5Hz, the ability of the Rpela v1 to recharge between pulses was limited and potentially affected the strength of the electric field. By reducing the size of the electrodes and reducing the frequency of discharge in Rpela v2, the strength of the electric field has effectively doubled, as determined by the voltage measured at 1 m from the device (**Table 1-1**).

1.5 Aims

Cardno was commissioned by Surfsafe Pty Ltd to analyse, interpret and report on data collected during controlled field-testing of the Rpela v2. Data were collected independently by two marine scientists. Cardno's aims were to test the data with respect to the potential effectiveness of the Rpela v2 as a shark deterrent and to quantify the behavioural response of white sharks in its presence. Specifically, we assessed these data with respect to the effects of the Rpela on (1) the probability of a shark biting or interacting with the bait, (2) the number of passes a shark took prior to biting or touching (interacting) with the bait and when it did not, (3) the mean distance between a shark and the bait and (4) the amount of time sharks took to interact with the bait..

[1] An experimental difficulty with testing shark deterrents is the need to ensure that sufficient interactions with sharks can occur so that statistical power can be sufficient. Thus, places such as Neptune Islands which have reliable populations of white sharks, are often the focus of testing. A limitation of this experimental necessity may be that animals may be habituated to human activities (e.g. research and tourism activities) and as such, their behaviours may not be completely representative of key shark species as a whole.

2 Study Methods

2.1 Field Methods

2.1.1 Study Sites and Trial Dates

Trials were done on the western and eastern sides of Salisbury Island (Error! Reference source not found.), which is located in the Recherche Archipelago off the south coast of Western Australia (34°21′39″S, 123°33′01″E). Twenty-five trials were done on each of two trips between 29-30 March 2018 and 24-25 April 2018. The weather during the trials was good and the seas were calm (i.e. < 1 m). On each day of the trials, testing occurred between the 0700and 1700.

The number of trials done on each day for each of the two trips is given in **Table 2-1**.

Table 2-1 No. of trials done on each day

	No. Trials	
Date	Active	Control
29.3.18	6	8
30.3.18	4	6
24.4.18	4	6
25.4.18	7	7
Total	21	27

2.1.2 Collection of Data

The Rpela v2 was tested using a custom-built floating test board, with the same dimensions and made with the same material as Huveneers et al. (2018) (**Figure 2-1**). The test board was 120 × 30 cm and made of polystyrene foam covered with layers of fibreglass cloth and epoxy resin and strengthened with wood on the sides where the bait was attached.

Apart from the method used to attract sharks, the trial methods closely followed Huveneers et al. (2018) methodology. White sharks were first attracted to the stern of an anchored vessel by hanging pieces of raw tuna in the water and by tapping a metal pole against the hull. The bait was allowed to drift from the stern of the vessel to attract white sharks. When a white shark was sighted near the vessel at least twice within five minutes or when a shark showed consistent interest in the tethered bait, the bait was removed and replaced with the test board, which was only deployed when the shark had left the proximity of the vessel and was not immediately visible.

In each trial, a piece of tuna (~ 2 kg), referred to as the 'fish bait', was placed in a 40 x 120 cm long canister hung on a tether ~ 45 cms beneath the test board. This replicated the typical distance between a surfer's foot and the board when sitting on the board. The board was attached to the stern of the anchored vessel, and left to drift with the wind and tide. The distance of the surfboard from the vessel varied between 5 and 15 m depending on the wind, swell and tide, and was sufficient for observers on the vessel to identify sharks and record their behaviour accurately. Trials ran for 15 minutes or until a shark touched the bait or board with an intent to consume the bait. Trials were excluded if a shark did not approach the surfboard with an intent to take the bait to ensure the results were not biased by trials during which sharks did not attempt to consume the bait.

Trials where the Rpela v2 was switched off were considered to be 'controls'. A total of 21 active and 27 control trials were run in a randomised sequence across the two trips (see above). Equipment failure meant that video was not available for four of the trials, hence only the video from 46 trials was analysed.

During each trial, a video unit was deployed from the stern of the boat ~ 50 cm below the surface (**Figure 2-2**) and overhead to film and record each trial (**Figure 2-3**). The video units consisted of two GoPro Hero4 Silver edition cameras.

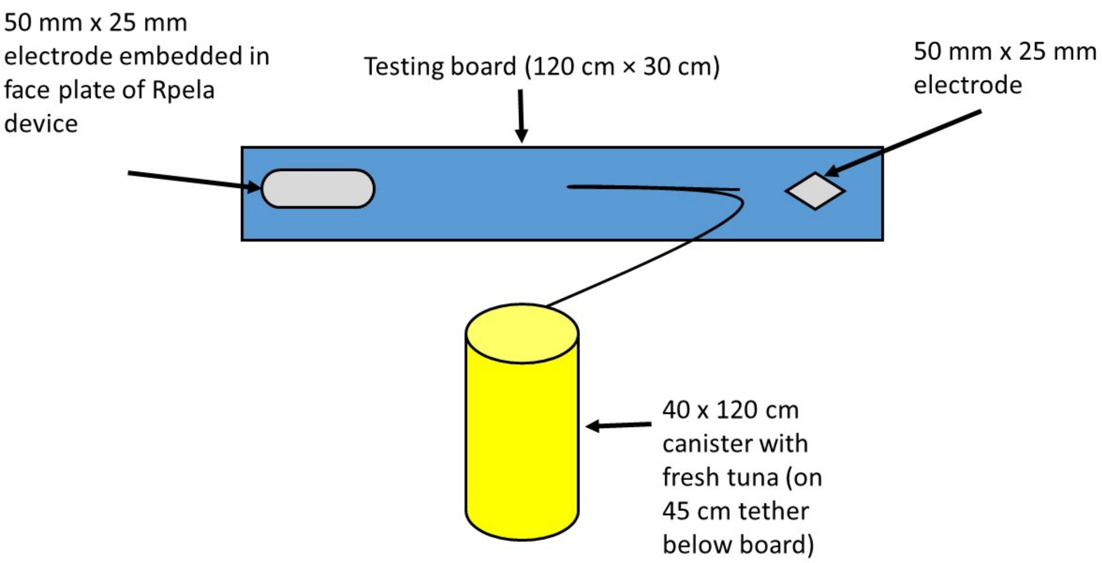

Figure 2-1 Illustration of the test board set-up (not to scale)

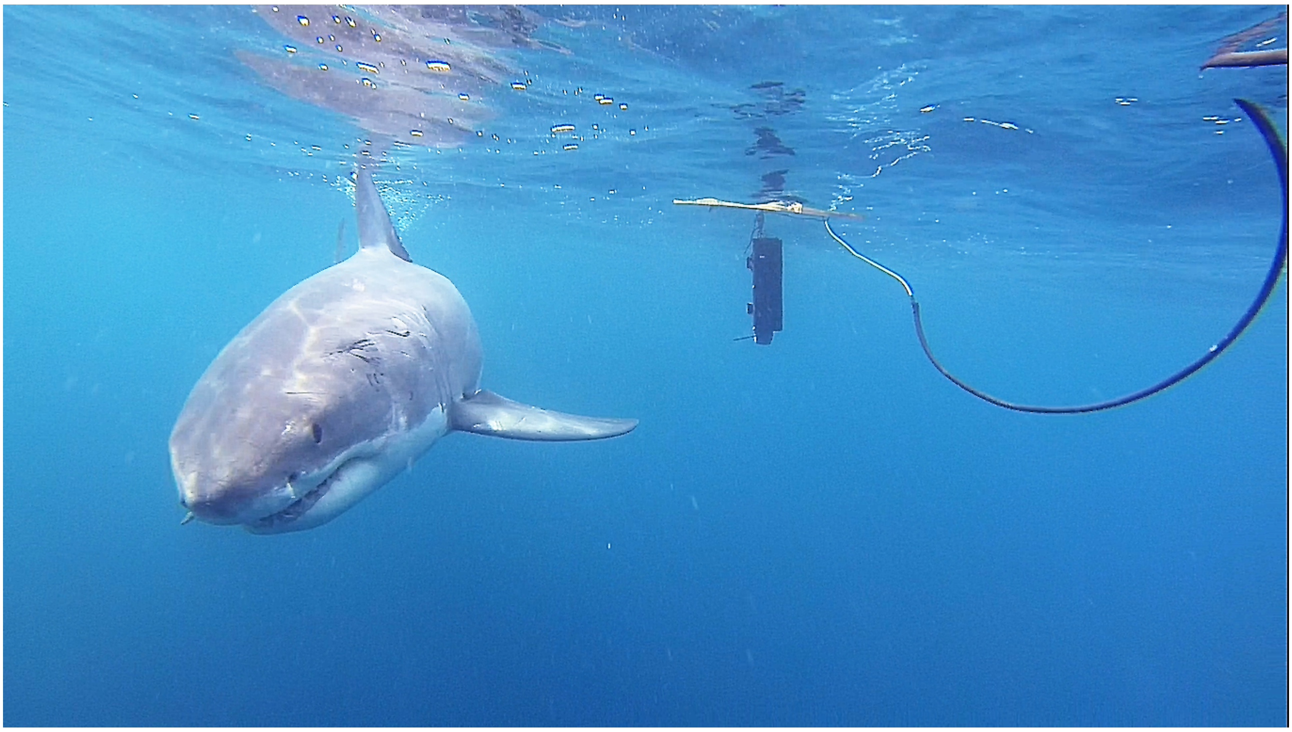

Figure 2-2 Underwater shot of a shark passing the test board

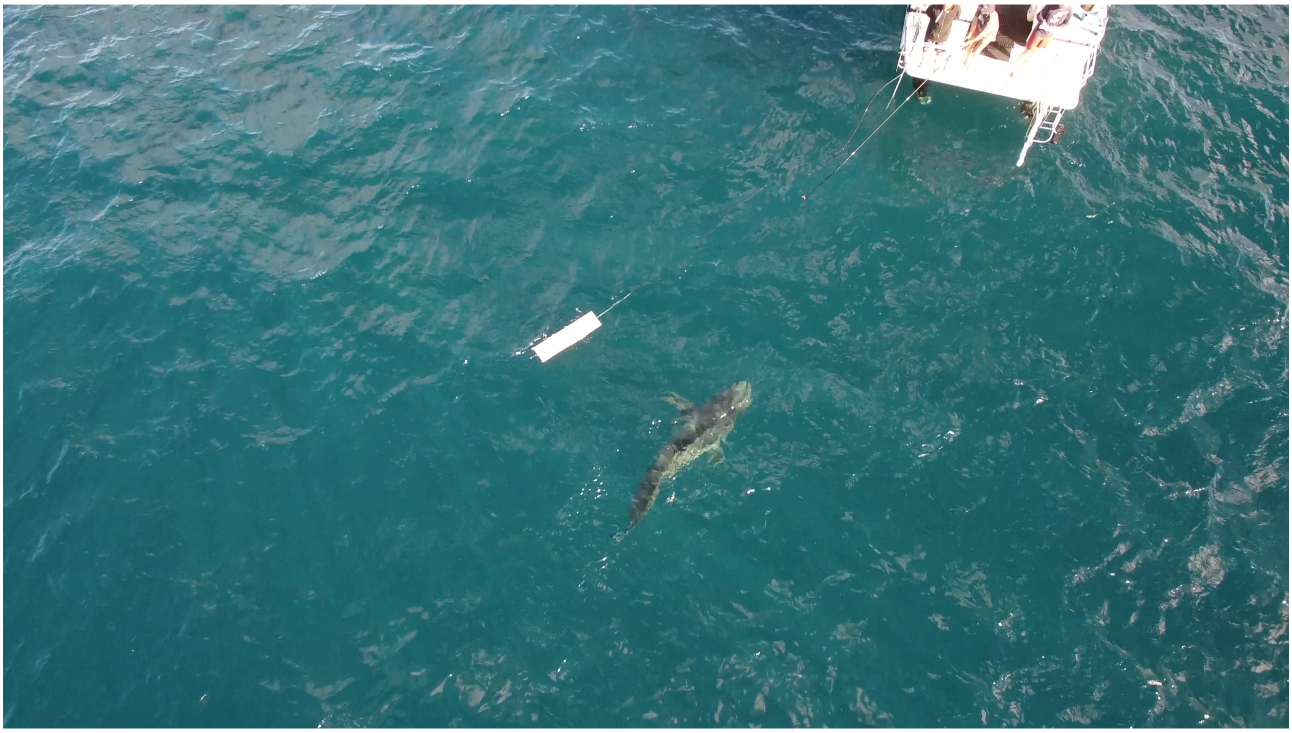

Figure 2-3 Aerial shot of a shark passing the test board

2.2 Laboratory Methods

2.2.1 Video Processing

The following terminology to describe and code shark behaviour, following Huveneers et al. (2013b):

> Pass: a directed swim towards the experimental set-up (each time a shark veered away from the board and swam back we classified it as a new pass);

> Shark identity: Scientists identified individual white sharks based on markings on five morphological areas: caudal fin, pelvic fins, first dorsal fin (hereafter dorsal fin), gills, and pectoral fins using established white shark identification methods (Nasby-Lucas and Domeier 2012, Nazimi et al. 2018).

> Distance to bait: distance from the sharks' nose, where the shark's sensory organs that are susceptible to the deterrent (ampullae of Lorenzini, nostrils) are located, to the top of the bait; scientists estimated this from both visual observation and an overhead Gopro camera with reference to the size of the board.

Prior to analysis, passes were removed that had low intent or that were deep and not directed at the board to avoid including behaviours where sharks were not attempting to consume the bait.

2.3 Data Analysis

2.3.1 Statistical Analysis

2.3.1.1 Analytical Design and Interpretation

Statistical analyses were used to test differences in the probability of sharks biting the bait or interacting (i.e. biting or touching) with the bait when the Rpela v2 was active (treatment) versus when it was inactive (control). Also, when sharks bit or interacted with the bait, whether there was a significant difference in the number of passes that sharks took prior to doing so. Further, whether there was a significant difference in the number of passes or mean distance between the shark and bait (averaged across all passes) regardless of whether a bite or interaction occurred.

Differences in probabilities and numbers of passes were examined using generalised linear mixed modelling (GLMM) using the Ime4 package in R programming environment. A binomial error distribution was used for probability of bites and interactions and a Poisson error distribution used for numbers of passes. A Gaussian error distribution was used for mean distance. The fixed effect of primary interest was Rpela v2 status (Active or Not Active). Trial No. was also included as a fixed integer covariate to investigate the presence of potential habituation to the experimental set-up (e.g. whether sharks became more or less responsive to the deterrent or if there was positive reinforcement associated with the bait through time). The interaction of Rpela status and Trial No. was also included to examine whether there was an effect of Rpela status on any habituation. The presence of potential habituation was also explored graphically by plotting the number of passes undertaken by each shark and the mean distance between the shark and bait for each trial where there were more than two interactions (sharks M1, M2, M3 and M4). Individual shark was included as a random effect to account for potential lack of independence in shark behaviour among individuals.

The presence of a significant interaction of Rpela status and Trial No. was determined using the likelihood ratio test (LRT), which is equivalent to an F-test. The LRT requires fitting two models, a full model (i.e. with the interaction) and a nested model (i.e. without the main effect). The likelihood ratio test statistic is twice the log of the likelihoods ratio, or twice the difference in the log-likelihoods. Statistical significance was determined at $P \leq 0.05$. The presence of significant main effects was examined using the drop1 function. This removes each covariate from the model in turn and re-fits, undertaking a LRT test of the full (all covariates) and reduced (full model minus one covariate) models and returning Akaike information criterion (AIC) values for each model. When a main effect of Rpela Status was detected, tests of the pairwise difference between Active and Non Active was examined and graphed using the estimated marginal means package for R. Parameter estimates were examined to determine the influence of Trial No. on probabilities and numbers of passes.

Due to the nature of the study (i.e. repeat observations on the same sharks through time) data may also not be statistically independent. The consequences of potential non-independence could be an increase in the Type 1 error (false positive) or Type 2 error (false negative) rate. Potential sources of non-independence include inherent differences in the behaviour of individual sharks (e.g. some may be more aggressive than others) and potential habituation to the experimental set up through time. Sharks might become habituated to the deterrent, or sharks that consumed the bait might become less likely to respond to the deterrent due to the positive reinforcement provided by the bait. We used the same approach as Huveneer's et al. (2018) to investigate these potential biases. We minimised potential pseudo-replication by testing the effects of deterrents on all response variables using a generalised linear mixed-effects model (GLMM) with individual shark coded as a random effect, and the deterrent used as the fixed effect. Including individual shark as a random effect accounted for the potential lack of independence in behaviour within each identified shark. To investigate habituation we included 'trial' as a fixed integer covariate in the models (i.e., ignoring the real elapsed time between successive exposures but including the information indicating relative serial time; e.g., 2 followed 1), the interaction between trial and deterrent to account for potential temporal effects and by plotting the mean distance between the shark and the board, and the number of passes across trials for sharks that interacted more than once with the board.

3 Results

Of the 46 trials, we recorded 388 passes from a total of seven individual sharks. Most passes occurred at the surface. All sharks were males and ranged in size from 2.4 m to 3.6 m.

> Probability of bite: Significant effect of Treatment indicating that when active the Rpela reduced the probability of a bite occurring from approximately 0.75 to 0.25. Also a significant effect of Trial No. that indicated a reduction in the probability of a bite with time when the Rpela was active and not active (**Table 3-2, Table 3-3, Figure 3.1a**).

> Probability of interaction: Significant effect of Treatment indicating that when active the Rpela reduced the probability of an interaction occurring from approximately 0.8 to 0.5. A significant effect of Trial No. was not detected (**Table 3-2, Table 3-3, Figure 3.1b**). For those sharks where there was more than one interaction, there did not appear to be an increase in interactions throughout the study that would indicate habituation (**Figure 3.3**).

> Number of passes before bite: Near significant effect of Treatment indicated by LRT. The significant parameter estimates indicated that when active the Rpela resulted in an increase in the number of passes prior to a bite from approximately 5 to 6.5. Also a significant effect of Trial No. indicating that there was an increase in the number of passes with time when the Rpela was active and not active (**Table 3-2, Table 3-3, Figure 3.1c**).

> Number of passes before interaction: Significant effect of Treatment indicting that when active the Rpela resulted in an increase in the number of passes prior to an interaction from approximately 3 to 5.5 (**Table**

3-2, Figure 3.1d). Also a significant interactive effect of Treatment and Trial No. indicating that that there was an increase in the number of passes with time when the Rpela was not active but not when it was active (**Table 3-1**).

> Number of passes (no interaction). Significant effect of Treatment indicating that when active Rpela resulted in an increase in the number of passes that a shark took from approximately 6 to 10 (**Table 2-2, Figure 3.1e, Figure 2**). Also a significant interactive effect of Treatment and Trial No. indicating that that there was an increase in the number of passes with time when Rpela was not active but not when it was active (**Table 3-1**).

> Mean distance: Significant effect of Treatment indicating that when active Rpela resulted in an increase in the distance between the shark and bait from an average of approximately 0.8 m to 1.3 m. Also a significant effect of Trial No. indicating an increase in distance through time when it was active and not active (**Table 3-2, Table 3-3, Figure 3.1f**). For those sharks where there was more than one interaction, there did not appear to be a decrease in the distance between the shark and bait throughout the study that would indicate habituation (**Figure 3.3**).

Table 3-1 Test of interaction of Treatment and Trial No. LRT = Likelihood ratio test statistic. AIC = Akaike Information Criterion. Bold text indicates significant interaction at P ≤ 0.05.

Model	df	AIC	Log Likelihood	LRT	P
Probability of Bite					
Bite ~ (Treatment + Trial No.)	4	56.260	-24.130		
Bite ~ (Treatment * Trial No.)	5	57.511	-23.755	0.749	0.387
Probability of Interaction					
Inter ~ (Treatment + Trial No.)	4	57.014	-24.507		
Inter ~ (Treatment * Trial No.)	5	58.958	-24.479	0.056	0.812
Number of Passes Before Bite					
Bite_Pa ~ (Treatment + Trial No.)	4	116.40	-54.198		
Bite_Pa ~ (Treatment * Trial No.)	5	116.71	-53.354	1.687	0.194
Number of Passes Before Interaction					
Inter_Pa ~ (Treatment + Trial No.)	4	146.58	-69.291		
Inter_Pa ~ (Treatment * Trial No.)	**5**	**135.44**	**-62.720**	**13.142**	**<0.001**
Number of Passes					
Dist ~ (Treatment + Trial No.)	4	319.64	-155.82		
Dist ~ (Treatment * Trial No.)	**5**	**305.94**	**-147.97**	**15.693**	**<0.001**
Distance					
Dist ~ (Treatment + Trial No.)	4	67.734	-28.867		
Dist ~ (Treatment * Trial No.)	5	65.968	-26.984	3.766	0.052

Table 3-2 Test of main effects of Treatment and Trial No using drop 1 function. Test of main effects not undertaken for Number of Passes Before Interaction due to significant interactive effect. LRT = Likelihood ratio test statistic. AIC = Akaike Information Criterion. Bold text indicates significant interaction at P ≤ 0.05.

Model	AIC	LRT	P(Chi)
Probability of Bite			
Full Model (Treatment + Trial No.)	56.260		
Treatment	**62.843**	**8.583**	**0.003**
Trial No.	**62.514**	**8.254**	**0.004**
Probability of Interaction			
Full Model (Treatment + Trial No.)	57.014		
Treatment	**61.476**	**6.462**	**0.011**
Trial No.	58.162	3.148	0.076
Number of Passes Before Bite			
Full Model (Treatment + Trial No.)	116.40		
Treatment	118.20	3.802	0.051
Trial No.	**122.58**	**8.184**	**0.004**
Number of Passes Before Interaction			
NA – Significant interaction detected			
Number of Passes			
NA – Significant interaction detected			
Distance			
Full Model (Treatment + Trial No.)	67.734		

Treatment	**76.826**	**11.091**	**<0.001**
Trial No.	**81.756**	**16.022**	**<0.001**

Table 3-3 Parameter estimates and their significance. Bold type indicates statistical interaction at P ≤ 0.05. Z-Value = Wald test statistic.

Fixed Effect	Estimate	SE	Z-Value	P
Probability of Bite				
Treatment (Active vs. Not Active)	**2.075**	**0.779**	**2.664**	**0.008**
Trial No.	**-0.077**	**0.030**	**-2.570**	**0.010**
Probability of Interaction				
Treatment (Active vs. Not Active)	**1.734**	**0.718**	**2.415**	**0.016**
Trial No.	-0.047	0.028	-1.696	0.089
Number of Passes Before Bite				
Treatment (Active vs. Not Active)	**-0.376**	**0.188**	**-2.003**	**0.045**
Trial No.	**0.034**	**0.012**	**2.847**	**0.005**
Number of Passes Before Interaction				
Treatment (Active vs. Not Active)	**-1.740**	**0.408**	**-4.267**	**<0.001**
Trial No. (Active)	-0.002	0.014	-0.125	0.901
Trial No. (Not Active)	**0.072**	**0.020**	**3.528**	**<0.001**
Number of Passes				
Treatment (Active vs. Not Active)	-1.285	0.366	-3.509	<0.001
Trial No. (Active)	0.009	0.009	0.949	0.343
Trial No. (Not Active)	**0.032**	**0.013**	**2.440**	**<0.015**
Distance			*T-Value*	
Treatment (Active vs. Not Active)	**-0.490**	**0.139**	**-3.516**	**<0.001**
Trial No.	**0.024**	**0.005**	**4.403**	**<0.001**

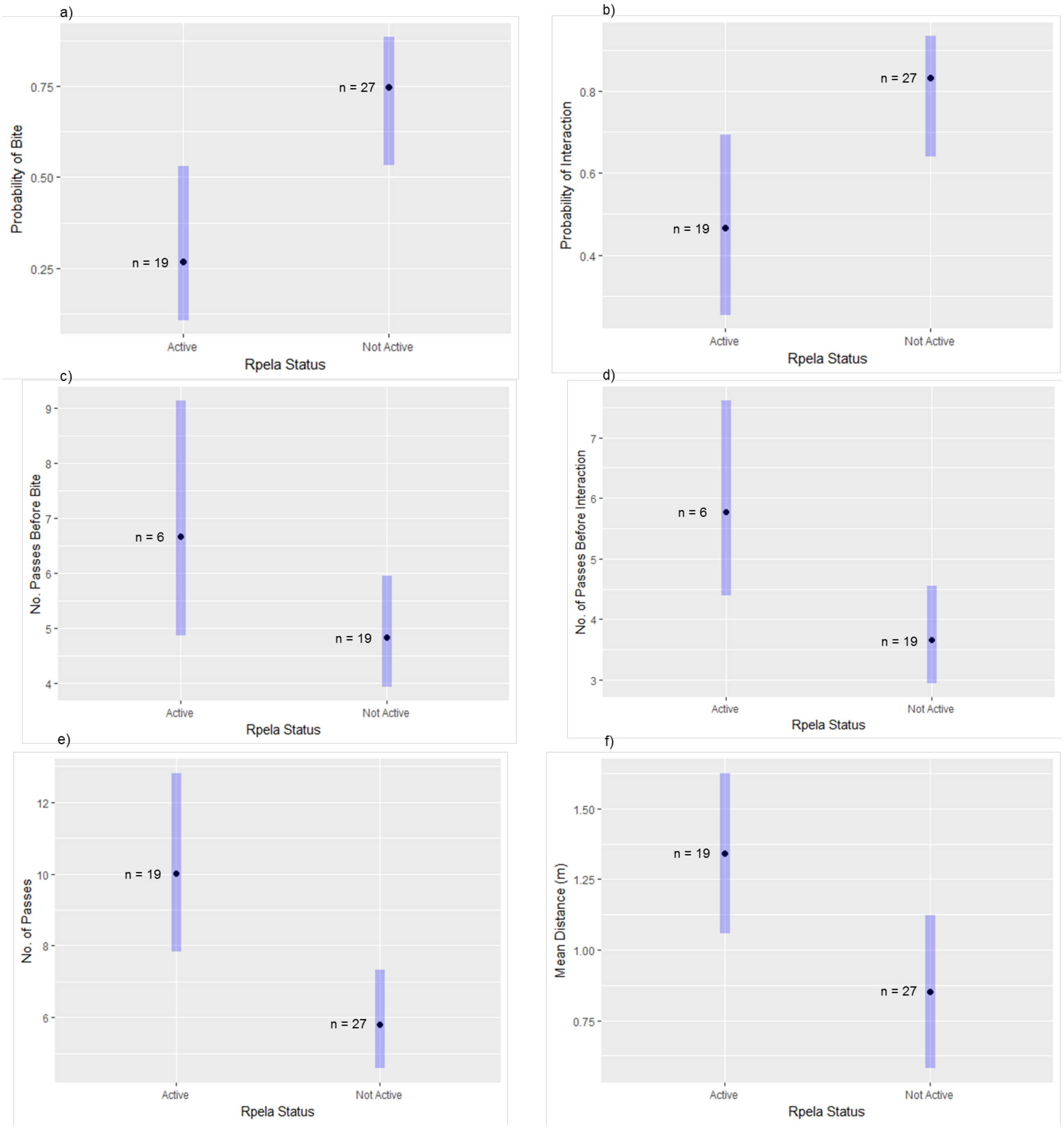

Figure 3-1 a) mean probability of bite and b) interaction occurring and the number of passes c) prior a bite and d) interaction occurring when the Rpela was active and not active. e) number of passes made by sharks and f) mean distance between sharks and bait when Rpela was active and not active. Blue bars indicate 95 % confidence intervals. n = number of trials.

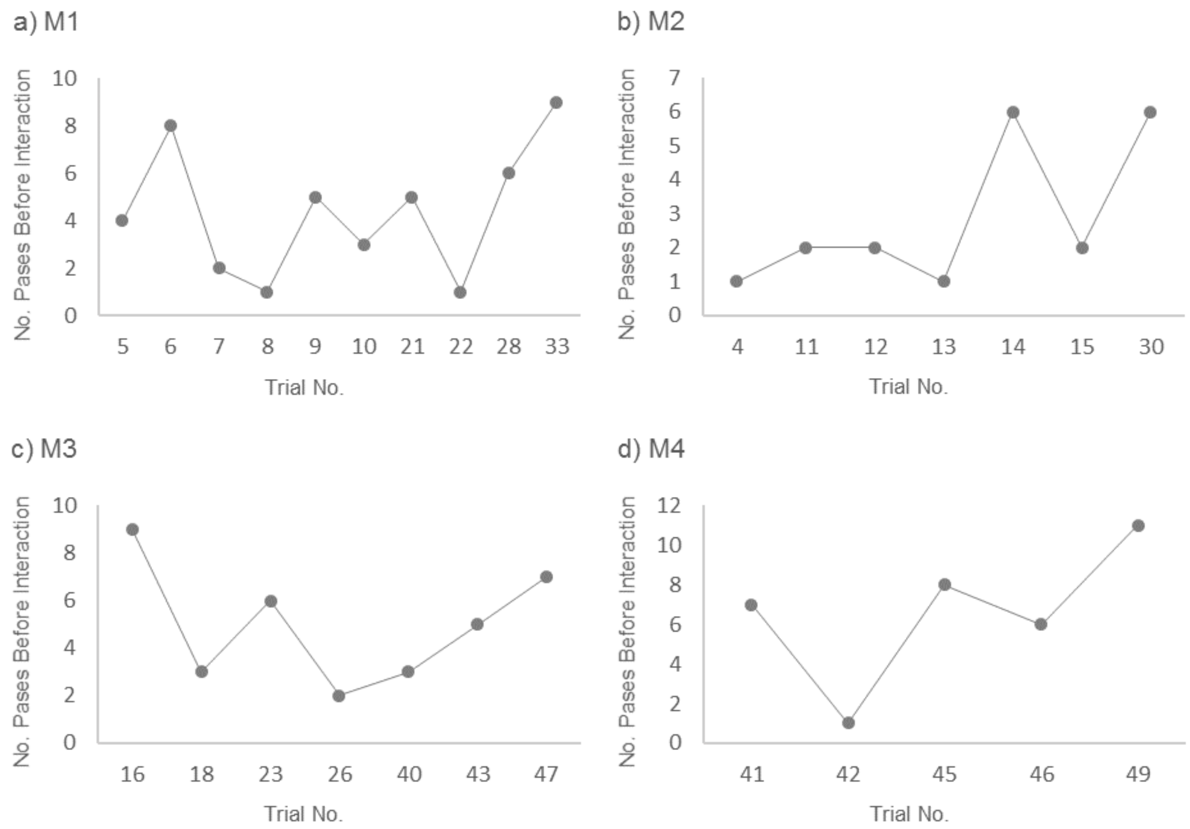

Figure 3-2 Number of passes before interaction for trials where sharks M1 to M4 (those with more than 1 interaction) interacted with the bait.ncludes data from trials Rpela was active and inactive.

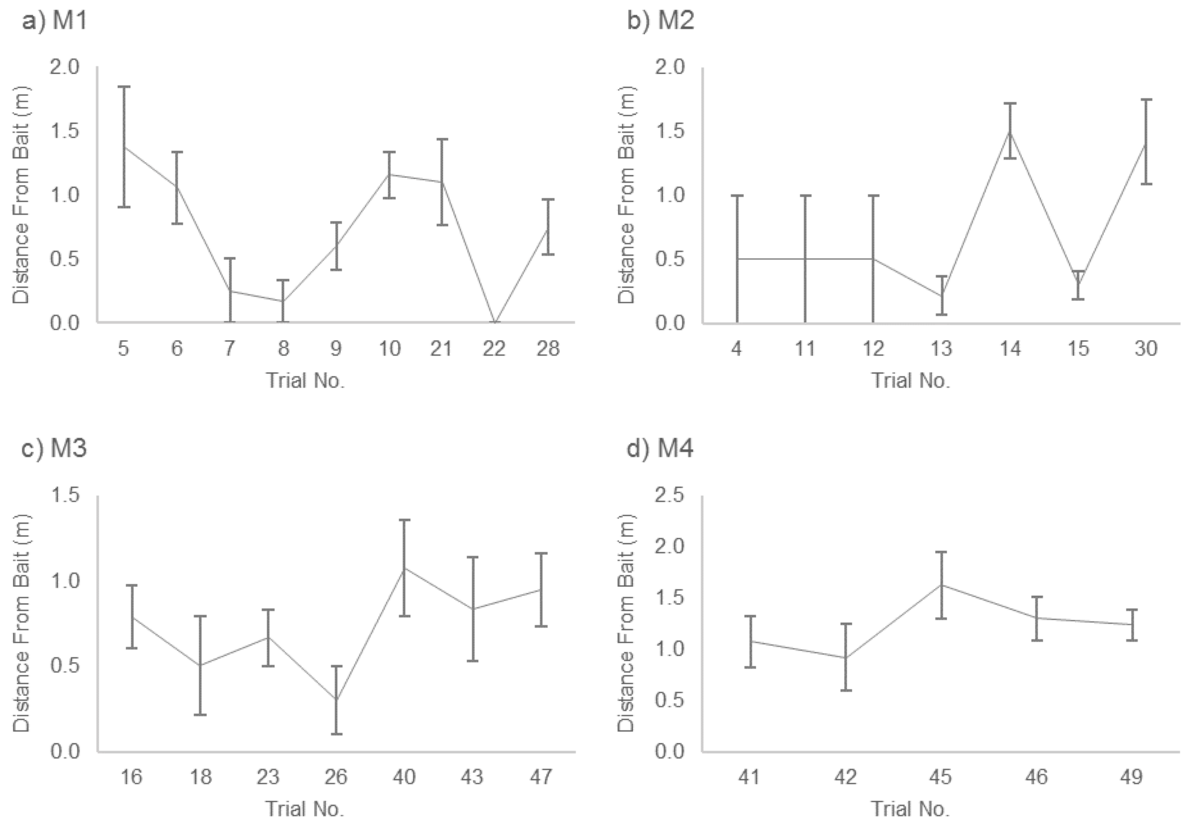

Figure 3-3 Mean distance (± standard error) between shark and bait for sharks M1 to M4 (those with more than 1 interaction). Includes data from trials Rpela was active and inactive.

4 Discussion

Realistically, unprovoked shark bite in areas where dangerous shark species occur, cannot be reduced to zero in all circumstances by a personal shark deterrent. An effective personal shark deterrent, however, will reduce the probability of an unprovoked shark bite by a meaningful magnitude. A reduction in the probability of an unprovoked shark bite should be demonstrated through independent field trials that are ethical from the perspectives of animal ethics and human ethics.

The Rpela v1 shark deterrent was tested along with a number of other personal shark deterrents by Huveneers et al. (2018). Taking into consideration those trials, the Rpela v2 device was modified to improve its effectiveness. Rpela v2 has smaller electrodes and less frequent pulses, which have doubled the strength of its field at 1 m from the device compared to Rpela1 .

These modifications appear to have also improved its effectiveness although this cannot be confirmed unless the two versions are tested side by side. Nevertheless, in the Salisbury Island trials, the Rpela v2 significantly reduced the probability of a bite from white sharks from 0.75 down to 0.25 (a reduction of 66%) and an interaction (touch or bite) from 0.80 to 0.50 (a reduction of 38%). These reductions to probabilities are much greater than what Huveneers et al. (2018) considered would be expected by consumers (i.e. >15%). They are also similar to what Huveneers et al. (2018) measured for the Surf+ for surfers (also an electric device) at the Neptune Islands for the proportion of baits taken (0.96 down to 0.40, a reduction of 58%) and comparable with the most effective electric deterrents made for divers where reductions are in the order of 80-90% (e.g. Smit and Peddemors 1990, Huveneers et al. 2013b).

The number of passes, distance between the sharks and the board potentially affect the time taken prior to a bite or interaction and are also indicative of the effectiveness of the deterrent. In the trials reported here the active Rpela v2 increased the number of passes significantly from 6 to 10 (all trials included) and from 5 to 6.5 (in trials where sharks eventually made a bite) or 3 to 5.5 when sharks eventually touched or bit the board. This compares well with Huveneer's et al. (2018) results for the Surf+ at Neptune Islands where the number of passes was (4.7 ± 0.5) when active, and (2.6 ± 0.3) for the control board (all trials included). the Rpela v2 also increased the distance between the shark and bait from an average of approximately 0.8 m to 1.3 m, less than what Huveneer's et al. (2018) found for the Surf+ at Neptune Islands (2.6 m ± 0.3 when active vs 1.6 ± 0.3 in controls). Such changes to behaviour give the surfer more opportunity to leave the water prior to an interaction if he or she are in the presence of a dangerous shark.

Huveneers' et al. (2018) discussed two potential analytical biases in the data collected in these types of trials associated with potential pseudo-replication from the same shark participating in more than one trial and/or habituation. Unlike Huveneers et al. (2018) we found a generally small effect due to individual sharks, suggesting that the general behaviour of sharks in the current study was similar when responding to the active Rpela or the control board. Only seven sharks were involved in the current study and although they all showed generally similar behavioural responses to Rpela, the possibility remains that our sample of seven is not representative of all areas and populations. In Huveneers et al. (2018) study, variable behaviour in response to deterrents was noted among some of the 44 sharks seen in the trials and given variability in the behaviour of white sharks to deterrents has been noted previously (Huveneers et al. 2013a, b, Towner et al. 2016) these researchers emphasised the need to ensure that testing is done on a sufficient number of individuals to identify and account for such individual variability. Although we suggest that the findings of this study would be expected to be largely representative of those that may occur for other sharks, studies at different locations or seasons would reinforce confidence around the effectiveness of Rpela over the range of locations or seasons within which it could potentially be used. Although such additional studies would ideally be done in coastal areas where surfers are active and in a less extreme situation (i.e. without fish bait), there are practical and ethical limitations to this. Given the need for sufficient replicates to allow robust statistical analyses, trialling requires the use of berley to attract sufficient numbers of sharks. Ethically, shark attraction trials that use fish baits should not be undertaken in coastal areas where there are other water users nor with real surfboards given there would be a risk of not only attracting potentially dangerous sharks to popular areas but also that sharks may associate a food reward with surfboards.

A significant effect of Trial No. was detected for each response except for an interaction. The evidence of a reduction in the probability of a bite through time, regardless of the Rpela status, could suggest sharks became more wary of the experimental set up through time, possibly due an effect of the Rpela device that made sharks less likely to attack the bait when active and not active. There was also evidence of an increase in the number of passes and mean distance through time (before a bite, interaction or neither), and again, this could suggest that sharks became more wary of the experimental set up through time. Interestingly, for number of passes before an interaction and number of passes regardless of whether there was a bite/interaction or not, this was apparent only when Rpela was not active.

5 Conclusion

Only very recently have electric personal deterrents for surfers appeared on the market. Testing in controlled conditions in the field is critical to understanding their effectiveness. Due to practical and ethical reasons testing in the field is restricted to scenarios where sharks are actively attracted to the test area using odour trails and then tempted to bite using fish bait. Although such scenarios don't represent typical encounters between sharks and surfers they probably represent worse-case scenario where if the deterrents are proven to work effectively, it could also be assumed that they would work at least as effectively, if not better, during chance encounters between surfers and sharks.

The Rpela v2 is an electric device for surfers that has undergone modifications to strengthen its electric field with a view to improving its effectiveness. This study at Salisbury Island demonstrated that its current configuration significantly reduced the probability of a bite or interaction, and, when it did occur, the time to bite (i.e. as inferred from the number of passes). Sharks also kept a greater distance from the bait when Rpela v2 was active. Thus, the risk of a bite occurring is expected to be less when the device is used. Importantly, Rpela v2 did not completely remove the risk of shark bite but is expected to benefit surfers by reducing the probability of a shark bite by a meaningful level and potentially giving surfers more time to leave the water when in the presence of a dangerous shark.

A potential limitation of the current study was that the findings may not be representative of different locations and populations of white sharks (e.g. those that frequent populated inshore areas, where surfers are, may behave differently to those that do not). The trials were also limited to male sharks of a length of between 2.4 – 3.6 m. Hence, it is recommended that further trialling is done at another location, and/or at a time in the future at Salisbury Island, where different sharks may be present to get a more general understanding of the Rpela's effectiveness. It is also recommended the further trialling is done on other species of potentially dangerous shark such as the bull sharks or tiger sharks and if any major modifications are done to the Rpela v2. Finally, although the results of the Salisbury Island trials infer that the configuration of Rpela v2 has improved its effectiveness (from Rpela v1), this can only be proven unequivocally by testing the devices against one another in a further trial.

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