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Photo identification for sea turtles: Flipper scales more accurate than head scales using APHIS

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ABSTRACT

Photo identification involves classifying unique features of a specific individual. The distinguishing feature used in most sea turtle photo ID studies are the scale patterns on the head. Yet the scale patterns on the turtles' flippers are arguably more complex and could provide an alternative and more robust area for photo ID. Here, we compared the accuracy of the Automatic Photo Identification Suite (APHIS) software to identify individual juvenile and subadult green turtles (*Chelonia mydas*) based on scale patterns on either the head or the flippers. Photographs were taken using standardized guidelines and then analyzed via APHIS after manually placing marks at intersection points between all scales around a predefined area. We tested whether using 6, 10, or 14 scales influenced accuracy of identifications, and determined that incorporating 14 scales provided the most correct identifications (1st rank) for both head and flipper photo ID. After determining the most accurate location for identification for the head and flippers (dorsal view of the head and digits of the fore-flipper), we conclude that photo ID using flipper scales in APHIS can identify individuals with higher accuracy (100%) than head scales (86%). Nevertheless, as turtles may contort the shape of their flippers during natural movements while the surface of the head remains rigid, photo ID for flippers may currently only be suitable when the flipper can be maintained in a flat position.

1. Introduction

Mark-recapture is arguably the most common method for assessing the status, health, and behaviour of wild animals (Buckland et al., 2000). In sea turtles, mark-recapture is typically achieved using external flipper tags and/or Passive Integrated Transponder (PIT) tags (Balazs, 1999; Gibbons and Andrews, 2004). The physical tagging of sea turtles can, in some cases, physically impact the animal long term (Hamelin and James, 2018), and be subject to tag loss (Wyneken et al., 2010; Pfaller et al., 2019). In the past three decades, however, there has been a steady growth in the use of photo identification (photo ID) (Schofield et al., 2008; Dunbar et al., 2021). This method uses host specific patterns to distinguish between individuals (de Urioste et al., 2016). Such tools can utilize photographs taken without contact, in-water or on beaches. Photo ID leaves no physical trace on the sea turtle and can be used over a number of years (Carpentier et al., 2016). Typically, photo ID studies in sea turtles use head scale patterns (e.g. Calmanovici et al., 2018) although recent studies have also used scale patterns on the fore-flipper (Gatto et al., 2018; Pursley, 2020), hereafter referred to as flipper. While both techniques are promising, no studies have conducted a standardized comparison of the accuracy of head or flipper photographs.

An inherent advantage of using head scales for photo ID in sea turtles is that it provides a rigid surface that does not contort with movement. However, photographs taken of the head can be challenging in water while on nesting beaches may require the use of bright light or flashes with the potential to elicit a stress response from nesting animals (Waayers et al., 2006). In contrast, turtle flippers are contorting, semi-rigid appendages. This contortion may reduce accuracy when assessing scale patterns from a 2D perspective. Nevertheless, flipper scale patterns are more complex which may mean they possess more variable

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scale patterns. Flippers may therefore provide a more accurate reference location for photo ID as they could produce more unique scale patterns. Some photo ID tools, such as APHIS, use the Interactive Individual Identification System (I^3S) that utilizes scale patterns distinguished by a human (Van Tienhoven et al., 2007). There are drawbacks to requiring human input using I^3S algorithms, such as increased time taken to process images manually.

There are some elements to consider when taking photographs for use in semi-automated photo ID. Studies using photo ID for other species have found that the angle of the appendage being photographed can affect identification accuracy, as an increase in the angle of the camera from the appendage decreases the likelihood of a correct match (Speed et al., 2007). The points used to outline the area to be used for identification reportedly do not affect matching success rate as they are used for orientation rather than pattern matching (Steinmetz et al., 2018). Finally, the number of scales used for identification may have an impact on the percentage of correct identifications.

In this study, we compare the accuracy of head or flipper scale patterns for photo ID of juvenile and subadult green turtles using the Automatic Photo Identification Suite (APHIS) (Moya et al., 2015). APHIS is a free software that has been successfully used in the identification of other reptiles from their scale patterns such as lizards (Rotger et al., 2016), snakes (Rotger et al., 2019), or sea turtles (Gatto et al., 2018). We used APHIS to test whether head or flipper scales provide more accurate identifications in a standardized manner. These results can be employed within other tools that require less manipulation and can utilize photographs of varying qualities (e.g. Dunbar et al., 2021). We had four main objectives: (1) to assess whether photo quality influences identification accuracy, (2) to assess whether increasing the number of scales used within the defined area influences identification accuracy, and (3) to determine how different areas within the head or flipper influence identification accuracy. Finally, when we had completed objectives 1 to 3 and identified the optimal areas for photo ID on the head and flippers, we (4) compared the accuracy between using head or flipper scales.

2. Methods

From August 2018 to March 2020, we hand-captured green turtles from five tidal creeks in Eleuthera, The Bahamas (Fig. 1) using "rodeo" or seine netting methods (for details see Ogren and Ehrhart, 1999). Once removed from the water, we conducted routine measurements (e.g. straight carapace length/width, curved carapace length/width) and we checked turtles for tags. If no previous tags were present, we tagged them with metal flipper tags. Finally, we collected photographs of the head and flipper from each turtle for photo ID (details below). After data collection was complete, we returned turtles to the water within at most 50 m of their original capture location.

2.1. Photo quality guidelines

We photographed from the dorsal and lateral (right) side of the head. As turtles can partially retract their head into their shell causing the skin of the neck to partially cover the parietal scales on the face, we gently extended the head by hand to ensure that all proximal or parietal scales for the lateral and dorsal views were visible (Fig. 2 A, B). We also photographed the right flipper and minimized any distortion caused by flexing of the flipper by placing it upon a flat surface (e.g., a clipboard) before the photograph was taken. We took photographs using phone cameras with no filter or image distortion (72–96 dpi) as these were readily available in the field. Previous studies have shown that identification accuracy obtained using phone cameras is comparable to higher resolution DSLR cameras when using APHIS to identify other reptiles

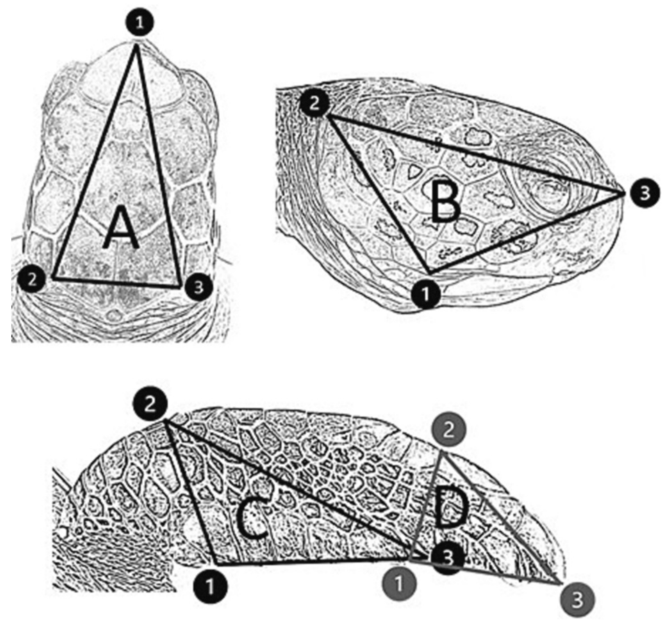

Fig. 2. Example of photos taken of the dorsal view of the head (A), lateral view of the head (B) the wrist of the right fore flipper (C) and the digits of the right fore flipper (D) of green turtles, along with the placement of reference points (1) bottom reference, (2) left reference, (3) right reference, in Eleuthera, The Bahamas, 2018–2020.

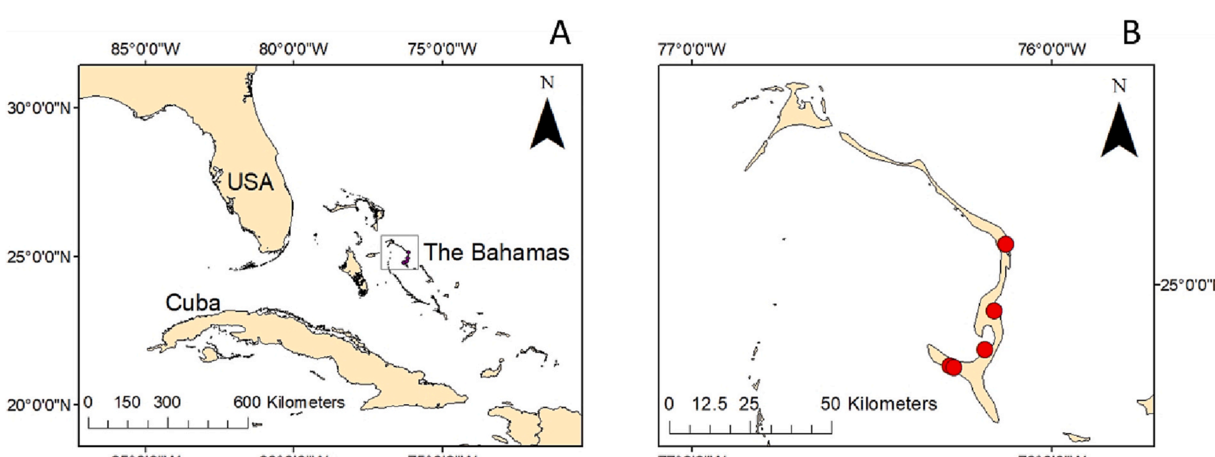

Fig. 1. Outline map of The Bahamas (A) and the island of Eleuthera (B) with sampled creeks denoted by circles.

(Hoefer et al., 2021).

We devised the following guidelines for taking photos. Photographs should (1) be taken directly perpendicular to the head or flipper, (2) include the entire appendage in the photograph, (3) not be blurry or out of focus. We used 6 scales within each reference area to test whether following this guideline affected identification accuracy.

2.2. Processing images

APHIS uses a Spots Pattern Matching (SPM) routine based on the Interactive Individual Identification System (I^3S) (Van Tienhoven et al., 2007). SPM requires the placement of 3 reference points to approximately outline the area to be used for pattern recognition, hereafter referred to as the "reference area". All marks were included in the analysis, even if they fell outside of the reference area. Within and around the reference area, we placed marks (spots) at intersections between the scales. APHIS spatially aligned the reference points before comparing all scale patterns in the database and assigned a rank to matched photographs. APHIS calculated the rank by summing the metric distances between pairs of every mark from the comparison and database photographs, then dividing by the square of the total number of paired marks. The rank denoted how likely it was a correct match with the inputted photograph, from the best match (1st rank) to worst match. We recorded a correct match when the correct individual was the top ranked match (1st). A partial match was recorded when the correct individual was within ranks 2–10. Finally, no match was recorded when the correct individual was outside of the top 10 ranked matches. All matches were visually confirmed by the researcher using flipper tag information.

While our photo database included multiple photos of many individuals, we did not want the number of photos of a specific individual in the database to influence the probabilities of being identified correctly. Thus, we only included two sets of photos (including head and flipper photos) for each individual. We did not include any individuals with missing or severed flippers.

2.3. Number of scales

To test whether the number of scales used for identification influenced the accuracy of photograph matching, we analyzed the database using 6, 10, and 14 scales. We chose the number of scales to include the minimum number of marks (15 marks minimum = ~6 scales), and then increased by 4 scales each time until the smallest area was saturated (dorsal view of the head, Fig. 2 A) at 14 scales.

2.4. Determining the reference areas

We placed three reference points to define references areas from two locations from both head and flipper photographs. These were:

Head: Dorsal view – (1) between the prefrontal scales, closest to the nares (bottom reference), (2) in the back left corner of the left parietal scale closest to the neck (left reference), and (3) in the back right corner of the right parietal scale closest to the neck (right reference) (Fig. 2 A).

Head: Lateral view - (1) in the corner of the mouth (bottom reference), (2) in the top proximal scale determined by the scale that extends farthest to the left than any other towards the top of the face (left reference), and (3) at the tip of the nose (right reference) (Fig. 2 B).

Flipper: Wrist – (1) on the posterior edge of the flipper at the join between the two proximal thickened scales (bottom reference), (2) between the two scales directly anterior to the bottom reference (left reference), (3) the posterior edge of the flipper distal from the axilla between the last thickened scale and the first non-thickened scale (right reference) (Fig. 2 C). This matched with reference points used by Gatto et al. (2018).

Flipper: Digits - (1) in the left corner of the first non-thickened scales, distal from the axilla (bottom reference), (2) in the left top corner of the longest scale along the anterior edge of the flipper (left reference), (3) at the tip of the furthest right scale (right reference) (Fig. 2 D).

2.5. Statistical analyses

Significance between the investigated elements in Sections 2.1, 2.3, and 2.4 were tested using Fishers Exact test (Kim, 2017). After determining which area of the head (dorsal or lateral) and flipper (wrist or digits) provided the most correct identifications (see Sections 2.3 and 2.4), we also compared the accuracy of using the flipper or head for identification using Fishers Exact test (Kim, 2017).

3. Results

Our photo ID database included 51 individuals, each with two complete sets of photos. All turtles were juveniles or sub-adults with straight carapace lengths (notch to notch) ranging from 23 to 61 cm (41 ± 1.2 cm; mean ± sd).

3.1. Photo quality comparison

Of the 51 paired photographs of the dorsal view of the head (first capture and one recapture), 35 followed the photo quality guidelines. These photographs resulted in 51% correct identifications and 63% partial identifications (13.8 ± 17; mean rank ± sd). From this point forward, partial identification will be repeated in parentheses following the correct identification. Those that did not follow the photo quality guidelines ($n = 16$) were correctly identified 44% (50%) of the time (19.7 ± 20.4). Of the 51 paired photographs of the lateral view of the head, 29 followed the photo quality guidelines. These photographs resulted in 41% (48%) correct identifications (18.3 ± 18.6). Those that did not follow the photo quality guidelines ($n = 22$) were correctly identified 45% (68%) of the time (15.9 ± 21.2).

Of the 51 paired photographs of the digits of the flipper (first capture and one recapture), 36 followed the photo quality guidelines. These photographs resulted in 86% (97%) correct identifications (2 ± 4.4). Those that did not follow the photo quality guidelines ($n = 15$) were correctly identified 53% (67%) of the time (10.3 ± 14.3) and were significantly different to those that followed the guidelines ($p \leq 0.01$). Of the 51 paired photographs of the wrist of the flipper, 30 followed the photo quality guidelines. These photographs resulted in 40% (57%) correct identifications (14.3 ± 16.2). Those that did not follow the photo quality guidelines ($n = 21$) were correctly identified 19% (67%) of the time (20.2 ± 15.3).

We then removed photographs that did not follow the photo quality protocol for the rest of the analyses. This resulted in a total of 35 individuals with dorsal head photographs, 29 individuals with lateral head photographs, 36 individuals with photographs of the digits of the flipper, and 30 individuals with photographs of the wrist of the flipper.

3.2. Number of scales

When using 6 scales on the dorsal view of the head, individuals were correctly identified 51% (63%) of the time (10.1 ± 12.1; mean rank ± sd), 83% (94%) when using 10 scales (2.8 ± 6.7), and 86% (97%) when using 14 scales (1.7 ± 3.1), and was significantly different ($p \leq 0.01$, Fig. 3 A). When using 6 scales on the lateral view of the face, individuals were correctly identified 48% (72%) of the time (7 ± 9.1), 55% (72%) when using 10 scales (6.3 ± 7.7), and 66% (83%) when using 14 scales (5.3 ± 7.7) (Fig. 3 B).

When using 6 scales on the digits of the flipper, individuals were correctly identified 83% (94%) of the time (2.3 ± 4.3), 89% (97%) when using 10 scales (1.7 ± 3.7), and 100% when using 14 scales (1 ± 0), and was significantly different ($p \leq 0.01$, Fig. 3C). When using 6 scales on the wrist of the flipper, individuals were correctly identified 43% (67%) of the time (8.2 ± 9.8), 47% (77%) when using 10 scales (7.2 ± 9.6), and

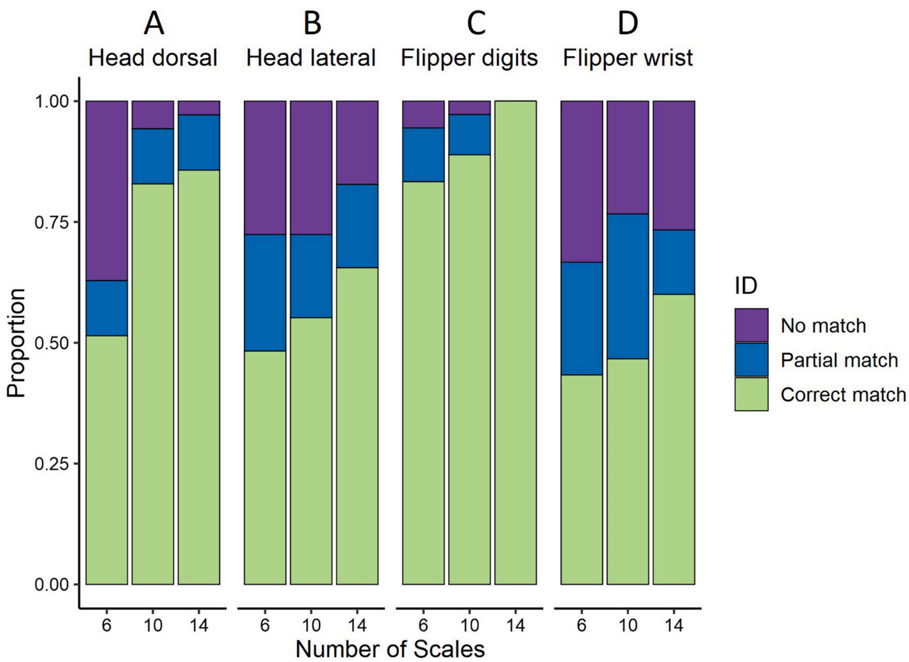

Fig. 3. A: Proportion of individual green turtles from The Bahamas (2018–2020) correctly, partially or not identified using the dorsal view of the head (n = 35) in increments of scales (6, 10, 14). B: Proportion of individuals correctly, partially or not identified using the lateral view of the head (n = 29) in increments of scales (6, 10, 14). C: Proportion of individuals correctly, partially or not identified using the digits of the flipper (n = 36) in increments of scales (6, 10, 14). D: Proportion of individuals correctly, partially or not identified using the wrist of the flipper (n = 30) in increments of scales (6, 10, 14).

60% (73%) when using 14 scales (6.2 ± 9) (Fig. 3 D).

3.3. Determining the reference areas

Of the two head reference areas using the optimized number of scales (14 for each area), the dorsal view provided 86% (97%) correct identifications compared to 66% (83%) achieved using the lateral view. Of the two flipper reference areas using the optimized number of scales (14 for each area), the digits provided 100% correct identifications compared to 60% (73%) achieved using the wrist ($p \leq 0.01$).

3.4. Flipper vs head scales

A final comparison between the optimized head scales (dorsal view, quality photographs, 14 scales) and the optimized flipper scales (digits, quality photographs, 14 scales) resulted in the flipper providing 100% correct identifications (1st rank) whereas the head provided 86% correct identifications ($p = 0.02$).

4. Discussion

Using the APHIS algorithm, we sought to provide guidelines on how to increase the accuracy of identifications of green turtles using head or flipper scales. To achieve this, we assessed the quality (angle, focus, coverage) of the photographs, whether the number of scales used influenced identification accuracy, and which section of the head or flipper was the most accurate. We then determined whether flipper photographs could provide comparable or more accurate identifications than head photographs within APHIS.

Not following the photograph guidelines reduced the likelihood of correct identifications using the dorsal view of the head, the digits of the flipper, and the wrist of the flipper. Steinmetz et al. (2018) found that when scales were obscured by sand (>21% sand coverage), the individuals were less frequently correctly identified (1st rank) than those that were less obscured (<20% sand coverage). Speed et al. (2007) found that an increased angle of the photograph (images skewed at 20° increments) negatively affected the likelihood of correct identification; a factor we included in our photo quality guidelines. This indicates that photo quality is an important factor to consider when using APHIS and other photo ID tools. We did, however, find that likelihood of identification increased when photographs of the lateral view of the head did not follow the photo quality protocol. This could be explained by using only 6 scales for this analysis, which we later found to produce the lowest percentage of correct identifications compared to more scales. Alternatively, this could be due to both photographs used in the comparison having similar deviations from the photo quality guidelines, for example if both photographs were at a similar angle. This would indicate that the consistency of the angle of the photograph may increase the likelihood of identification.

As other studies used different areas of the head to conduct analyses, we tested different reference areas of both the head and the flipper to determine the location that could most often individually identify green turtles. Within these areas, we tested how the use of different numbers of scales affected identification likelihood. All the areas achieved an increased percentage of correct matches as the number of scales increased, with all producing more correct identifications when using 14 scales. Manually placing more marks meant that we increased the amount of pre-processing time per image. It could, therefore, be argued that this time inefficiency outweighs the benefit of an increased accuracy. Other studies placed marks in the corners of scales up to a limit e.g. 35 marks (Dunbar et al., 2014; Calmanovici et al., 2018) and 80 to 100 marks (Gatto et al., 2018). We believe this is the first evaluation of whether using differing numbers of scales affects identification accuracy. Our findings could be utilized in other photo ID tools that require less manipulation, such as Hotspotter (Tabuki et al., 2021).

When investigating head scales, the dorsal scales provided more correct identifications than the lateral scales, indicating this may be a more accurate location for photo ID than the more commonly used lateral view. When looking at flipper scales, the digits of the flipper (Fig. 2 D) generated more correct matches than the wrist. Gatto et al. (2018) correctly matched (1st rank) individuals 89% of the time for adult green turtles and 93% for hatchlings using the wrist of the flipper (Fig. 2 C). Our findings showed that this area of interest was not the optimal area for the flipper; however, Gatto et al. (2018) utilized a smaller adult database (n = 14) that may have affected their results. They also conducted their research with turtles at different life stages, which may produce differing results to our study that used only juveniles and sub-adults.

We found that head photographs provide fewer correct identifications compared to the flipper photographs (head = 86%, flipper =

100%). Other studies have reported accuracies of 80–97% using head scales (Calmanovici et al., 2018; Dunbar et al., 2021), and 82–93% when using flipper scales (Gatto et al., 2018). Our findings suggest that the flipper provides a more accurate area for identification of green turtles. There are, however, differences between the photo ID tools used throughout these studies, and a comparison between such tools, including their time commitment vs accuracy outcomes, could be an important future study objective.

While photo ID using the flipper is beneficial, it also has limitations such as when flippers are missing, which led to the exclusion of one individual in our database. However, in most instances, the percentage of wild sea turtle populations with missing flippers is likely minimal. Photographs of the face can also be taken in-water whilst a turtle is swimming with relatively little distortion. This removes the need for physical interaction with the subject as shown by Dunbar et al. (2021) who achieved correct identifications (1st rank) of free-swimming turtles 84% of the time. As the flipper is moving and changing shape from flat to curved whilst moving in-water, it is unlikely to provide an option for identifying an individual without any physical contact, unless the individual is resting on the sea floor. The flipper could, however, be a viable option for those studies conducted on nesting beaches where the flipper can be photographed flat, as the results from our study show that when photographs are taken of the flipper from a static turtle, they can be correctly identified (1st rank) 100% of the time. A high number of sea turtle monitoring projects take place on nesting beaches, whereby researchers collect measurements from nesting females (Mazaris et al., 2017; Phillips et al., 2021). This provides an opportunity to take photographs of the flipper, which may decrease the disturbance turtles experience whilst taking photographs of the head (Waayers et al., 2006; Tabuki et al., 2021).

5. Conclusions

We conclude that flipper scales can identify individuals more accurately than head scales when using APHIS in a stationary setting. When photographing the flipper, the photo quality guidelines should be followed. Within the flipper, the area to place reference points is at the digits of the fore flipper, using 14 scales to create the scale pattern. Using these techniques simultaneously produces correct matches (1st rank) for 100% of individuals, which suggests this is a promising setup for future photo ID studies when sea turtles are already being captured or encountered out of water. This could help minimize intrusion and disruption during nesting beach research and negate the need to further handle turtles by extending the head in static capture situations. The flipper does, however, have limitations, such as only being suitable when the flipper is laid flat and thus potentially unsuitable for in-water photo ID. As such, the flipper provides a favorable, albeit situational, alternative to head scales for photo ID. We also suggest further research avenues to determine if flipper scale patterns remain suitable for photo ID over an animals' entire life cycle and whether this technique is suitable for other sea turtle species.

CRediT authorship contribution statement

Sophie K. Mills: Investigation, Writing – original draft, Visualization, Project administration. **Andreu Rotger:** Software, Resources, Writing – review & editing. **Annabelle M.L. Brooks:** Investigation, Writing – review & editing, Supervision. **Frank V. Paladino:** Writing – review & editing, Supervision. **Nathan J. Robinson:** Conceptualization, Methodology, Investigation, Writing – review & editing, Supervision, Project administration.

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.

Data availability

Data will be made available on request.

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