Assessment of a generalizable correction method and R package *gRumble* for orienting unfixed biologging devices in the stomach of white sharks

Connor F. White[1], **Jerry H. Moxley[1]**, Adrian C. Gleiss[2], Taylor K. Chapple[3], Paul E. Kanive[4], Scot D. Anderson[5], Salvador J. Jorgensen[1]

[1] Monterey Bay Aquarium; [2] Murdoch University; [3] Stanford University;
[4] Montana State University; [5] Point Blue

Background

Challenges:

1. Instrumenting animals with biologging sensors has transformed behavioral and physiological observation and unleashed significant scientific discoveries in respective fields.
2. Deployment of biologging devices remains a significant challenge for certain animals, resulting in operational barriers to technological-enable scientific advancement.
3. Quantification and growing appreciation for the significance of tagging effects related to capture/handling stress and invasive tag attachments (Jepsen et al. 2015) further highlight needs for new approaches.

Alternatives:

4. Biologging sensors deployed in stomachs via natural feeding behavior can be deployed without animal capture or handling, do not affect external appearance or hydro/aerodynamics, and have no long-lasting bodily damage from tag attachment.
5. Data recovered from non-invasive stomach deployments, however, requires post-processing to account for tag repositioning throughout deployment.
6. Correction angles must be estimated dynamically and applied continuously to ensure acceleration traces match dominant axes of the tagged animal (i.e., heave, surge, and sway; Gleiss et al. 2011).

Novel methods:

7. *gRumble* is an R package that encapsulates post-processing correction methods for rotating and re-aligning tri-axial sensor data from unaffixed sensors.
8. To test the method's accuracy, we simulated tag rotations expected from unaffixed sensor data like stomach deployments, introduced these rotations into a traditional biologging dataset from affixed sensors, and analyzed the post-processing for recovery of known information in the source fin-mounted data.

gRumble's Correction Method

Processing steps:

- Unfixed biologging devices are deployed non-invasively in a shark's stomach via natural ingestion.
- Jorgensen et al. (2015) developed post-processing methodology to realign a stomach-deployed logger with the animal's alignment.

- Tri-axial correction angles are estimated continuously & applied dynamically through 3 steps:
  1. **Find 'up'**: isolate gravitational acceleration in Z dimension by averaging over period when tag is "prone" (*see below*)
  2. **Find 'sway'**: identify tail beat locomotion through power maximum in a FFT
  3. **Find 'forward'**: correlate pitch with ascent rate

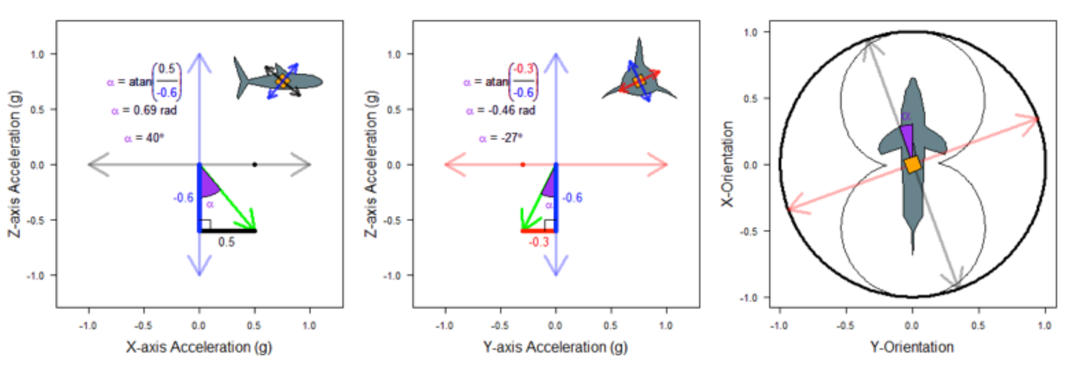
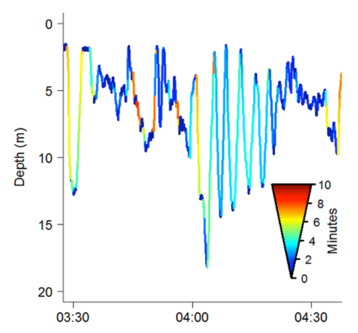


Fig 1: To align an unfixed tag with the animal, correction angles are estimated and applied with rotation matrices once tag orientation is determined via post-processing steps above.

Windowing:

- Rotation angles are estimated and applied at standard time steps, but draw information from behavioral windows dynamically sized to minimize error introduction.



- Correction windows expand to encapsulate periods of equal proportion ascending/descending behavior during which gravitational acceleration can be reliably isolated (i.e., step 1).
- Dynamic adjustments to window size minimize Type I/II error introduction.

Fig 2: This depth trace shows dynamic adjustments to window size, refining correction estimates during prone behaviors while broadening during more active behavior

Simulation Results

- Stomach-deployed biologging data was simulated by introducing rotations into traditional fin-mounted data that is anchored and affixed in a permanent orientation relative to the animal's orientation. To investigate sensitivity to the rate of rotation, a random walk of rotations was sampled from 15 individual normal distributions centered on 0 with increasing standard deviations

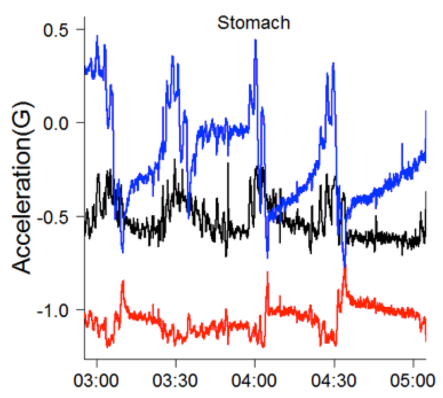


Fig 3 (above): Acceleration traces are corrected with estimated rotation angles that align the tag and animal's orientations. In unfixed stomach deployments, estimation and correction is a continuous process.

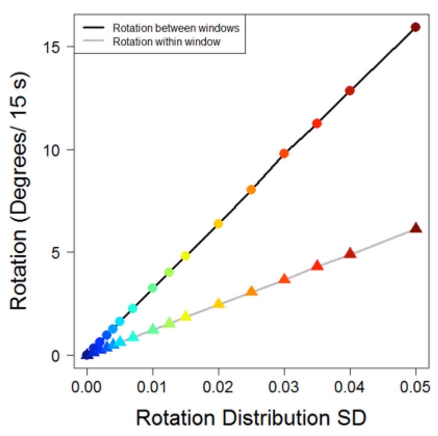


Fig 4 (left): Increasing variability and subsequent rotation rates in the simulation investigate the method's sensitivity.

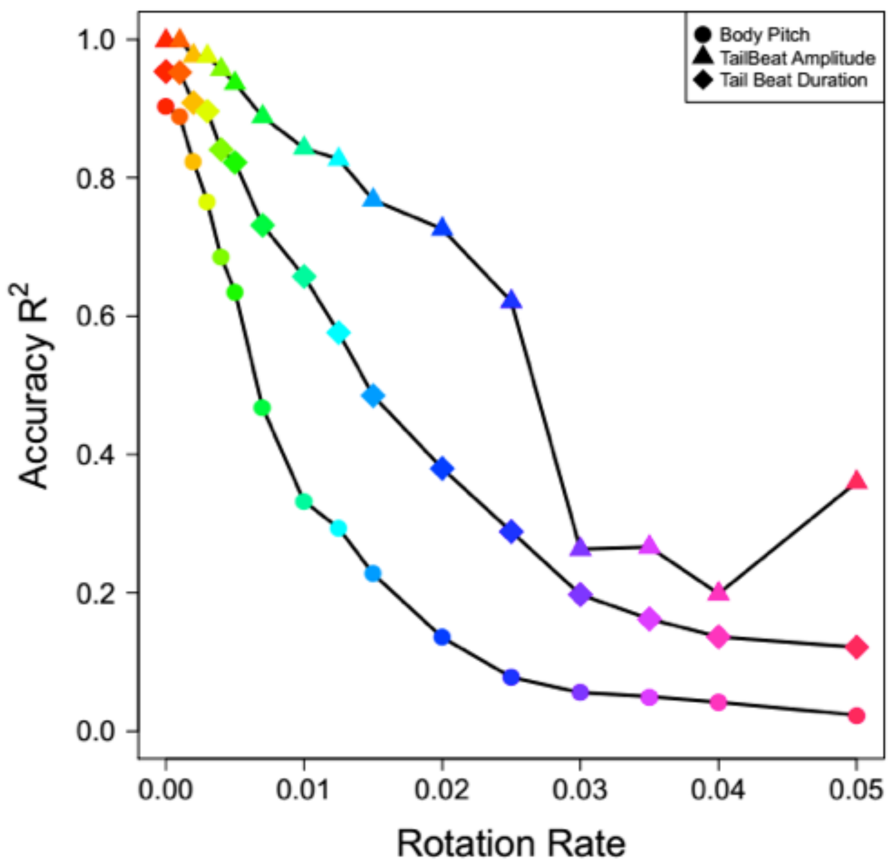


Fig 5: Accuracy of the correction method at recovering swimming metrics identified in the fin-mounted source data. Increasing rotation rates simulate increasing effects of stomach movements on tag repositioning that require continual realignment. Kinematic metrics like tail beat amplitude and duration are comparatively more robust to post-processing errors associated with estimating and applying correction angles.

- There is ample variability in the robustness of the three biological metrics investigated for their sensitivity to the effects of stomach movements, as modeled by increasing rotational rates (warmer colors, Figs 4-6) introduced into the fin-mounted source data.
- Locomotory metrics appear relatively robust to the process error introduced into the data by increasing rotational rates. Estimates of tail beat amplitude and, to a lesser degree, duration appear reliably determined and relatively insensitive to differences in the size of correction windows.
- Instantaneous measures of body pitch are less robust to errors associated with tag rotations. Furthermore, body pitch estimates are quite sensitive the size of window needed for estimation.

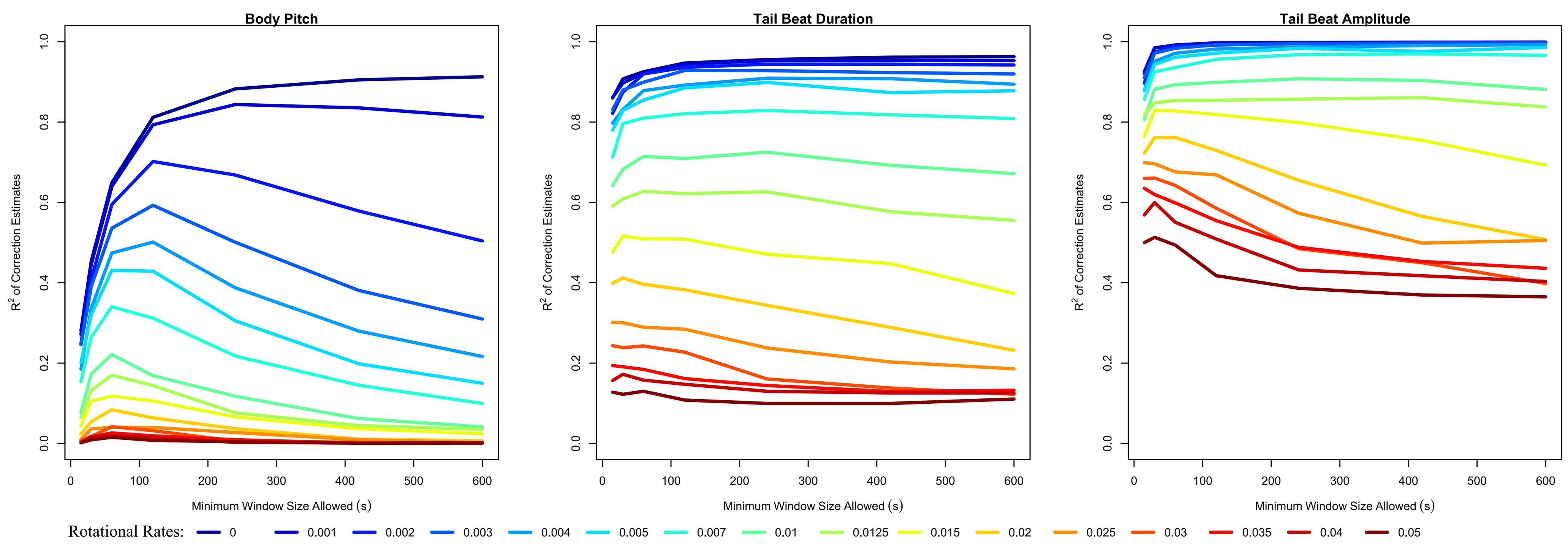


Fig 6: The sensitivity of three behavioral and kinematic metrics to increasing rotation rate demonstrate the method's robustness of correction estimates for Tail Beat amplitude and duration, to a lesser degree. Instantaneous estimates of body pitch show high susceptibility to effects of increasing rotation rates

Conclusions

- New methods and novel approaches are needed to transition biologging instrumentation of animals from invasive techniques that often rely on animal capture/handling and harmful attachment techniques to less impactful, non-invasive approaches.

- Growing appreciation for the potential of tagging effects biasing behavioral observation further underlines these needs, especially for biologging datasets that tend to be short-term, high-resolution behavioral records.

- The *gRumble* method is capable of generating accurate correction angles that realign an unaffixed and rotating biologging sensor with the primary axes of the animal (Fig 3). Simulations validated the method's accuracy in correction estimates, even at moderate to high rotation rates, due to dynamically adjusting correction windows that adjust accordingly based on animal's activity (Fig 2, 5).

- Behaviorally, the method is more capable at recovering locomotory metrics from noisy tag rotations and repositioning than instantaneous estimates of body position, suggesting it is more applicable to movement and energy studies than questions involving explicit understanding of body positions and postures.

- New applications of the *gRumble* methodology to other tagging contexts can aid the use and analysis of other sensor setups that may shift orientation over time, like suction cup mounts, collared tags, or even bolted attachments that may tear skin. Future work must explore generalizing the method to other biologging studies with similar simulation and sensitivity analyses.

References

N Jepsen et al. 2015. The use of external electronic tags on fish: evaluation of tag retention and tagging effects. Animal Biotelemetry (3):49.

SJ Jorgensen et al. 2015. In the belly of the beast: resolving stomach tag data to link temperature, acceleration, and feeding in white sharks (*Carchorodon carcharias*). Animal Biotelemetry (3):1.

AC Gleiss et al. 2011. Making overall dynamic body acceleration work: on the theory of acceleration as a proxy of energy expenditure. Methods in Ecology and Evolution (2):1.

Find *gRumble*: https://github.com/MBayOtolith/gRumble

Special thanks to my co-authors, particularly Connor White who developed the *gRumble* package independently and Dr. Sal Jorgensen who supported my research role. Further acknowledgements to our extended research team, Conservation Research at the Monterey Bay Aquarium, and special thanks to the David and Lucile Packard Foundation and other funding resources.