**Title**

On the utility of predicting stroke rates from accelerometers in swimming captive marine mammals

**Running title**

Predicting stroke rates from accelerometers

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**Key words**

Otariid, fur seal, sea lion, swim mechanics, energetics,

**Abstract**

**Introduction**

Measuring the energy expenditure of free living animals is an important but difficult task. For free swimming seals, numerous approaches, including heart rate (Boyd *et al.* 1999), doubly labelled water (DLW) (Jeanniard-du-Dot *et al.* 2016a) and overall dynamic body acceleration (ODBA) (Fahlman *et al.* 2013) have been tried and tested with mixed results. Among other things the predictive equations for each of these are liable to change with species, size of the animal, activity type, temperature, or digestive state (Fish 2000, Ladds *et al.* 2016, Rosen *et al.* 2016). Therefore, there is unlikely to ever be a universal method, or universal equation, that can accurately estimate energy expenditure for pinnipeds as a group. However, proxies can still provide important comparative information and may have important practical application. Stroke rate is a relatively non-invasive method that has been suggested as having high potential for measurement of energy expenditure in both otariid seals e.g. Northern fur seals (Jeanniard-du-Dot *et al.* 2016b) and in phocid seals e.g. Weddell seals (Williams *et al.* 2004). That stroke rate is a good predictor for these two species, which are evolutionarily divergent with completely different mechanics for underwater propulsion (otariids propel themselves using a sculling motion of their large fore-flippers (Feldkamp 1987), while phocids rely on lateral movement of their hind flippers (Gallon *et al.* 2007) suggests stroke rate might have wide application as a proxy for energy expenditure (Williams *et al.* 2004)

Pinnipeds perform long and deep dives traversing far-flung areas of the ocean while hunting and so are near impossible to observe *in situ* let alone count stroke rate. Animal borne cameras have been used to identify strokes for some phocids seals, dolphins and whales (Williams *et al.* 2000), but these are expensive, large and often fragile with severe memory and battery limitations.. While their use is insightful it is not universally applicable and simpler biotelemetry devices are much more widely deployed to provide insights on the location, physiology, and behaviour of seals at sea. By contrast accelerometers are small, lightweight, relatively cheap and can measure the acceleration of the body on up to three axes, making them ideal for measuring stroke rate – among other things. Indeed, accelerometers have been successfully used to estimate stroke rates from a number of marine animals including penguins (Sato *et al.* 2011), seabirds (Lovvorn *et al.* 2004), fish (Broell *et al.* 2013) and sharks (Gleiss *et al.* 2009). They have also been used to estimate stroke rate for Northern fur seals (Jeanniard-du-Dot *et al.* 2016b), though the predictions were not validated.

Estimating stroke frequency from accelerometers assumes that the peaks in the outputs correspond to a stroke. Phocids stroke with their rear flippers with a lateral sway, therefore it is assumed that peaks in the sway axis (y axis) correspond to a stroke (Williams *et al.* 2004). Otariids use large fore-flippers to propel forward, therefore peaks in the surge (x axis), heave (z axis) or both (Jeanniard-du-Dot *et al.* 2016b) axes are used to estimate strokes. Peak in lateral sway has been confirmed for Weddell seals using animal-borne cameras (Williams *et al.* 2004), but there is yet to be a validation study for otariids. When using accelerometers to measure proxies, the choice of running mean influences the overall estimate (Shepard *et al.* 2008a). Estimating strokes from accelerometers requires appropriate smoothing of data and the choice of a minimum gradient to determine a peak in the data. The choice of these two parameters will influence the overall estimate and so should be tested across a range of values. Here, we evaluated the best parameters for calculating stroke rate for otariids swimming underwater using animals observed and filmed in captivity while swimming wearing accelerometers.

**Materials and Methods**

*Animals*

We conducted experiments between October and December 2014 at two research facilities: Underwater World (RF2: Mooloolaba, QLD, Australia) and Taronga Zoo (RF3: Sydney, NSW, Australia) with three New Zealand fur seals, two Australian fur seals and four Australian sea lions that were on permanent display at their respective marine facilities. We conducted experiments in November and December 2015 at the Open Water Research Station (RF4: Port Moody, BC, Canada) with four Steller sea lions housed for research purposes (see Table 1 for details of the animals). All animals were non-reproductive during the study period and were cared for under the husbandry guidelines of the individual facility. All the Australian sea lions were born as a part of a captive breeding program ongoing in Australian aquaria, while all the fur seals came into captivity as juveniles having been found in poor health or injured and were considered unsuitable for release back into the wild after prolonged rehabilitation. All animals were in good health and condition as assessed by the in-house veterinary surgeon at the time of the experiments. All Steller sea lions were collected from breeding rookeries as pups and raised in captivity at the Vancouver Aquarium (British Columbia, Canada). Macquarie University ethics committee (ARA-2012\_064) and Taronga ethics committee (4c/10/13) approved experiments conducted in Australia. All animal handling and experimental procedures in Canada were conducted in accordance with regulations of the Canadian Council on Animal Care (University of British Columbia animal use permit #A11-0397), Department of Fisheries and Oceans Canada (MML 2007-001) and the Vancouver Aquarium.

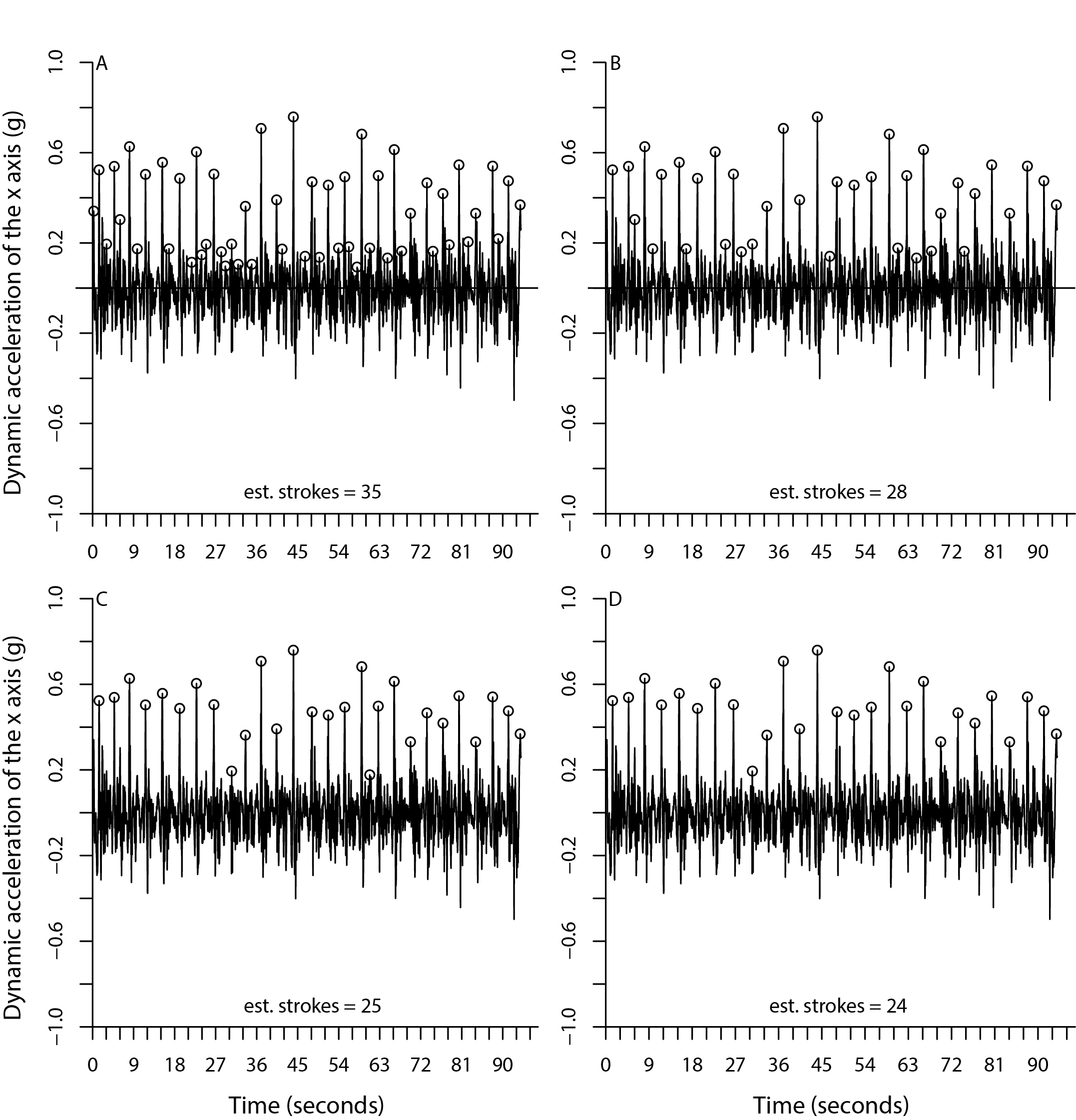
*Trial protocol*

During all experiments otariids were equipped with a 3-axis accelerometer (RF1-3: CEFAS G6a+, ±8g, 40 × 28 × 16.3 mm and mass 18 g in air and 4.3 g in seawater, CEFAS technology Ltd, Lowestoft, UK; or a RF4: Daily Diary, 95 × 45 × 26 mm, 90 g, Wildlife Computers; Table 1.) They were also recorded with an array of static underwater cameras (GoPro Hero 3 Black edition, 1080p / Wide / 60fps). All sea lions (except ASM2) wore a tight-fitting harness which held the accelerometer between on the centre of the dorsal surface while for all fur seals (and ASM2) the accelerometer was attached between the shoulder blades with Tesa tape. Sea lions at RF4 had been trained to swim underwater between two submerged feeding stations (Rosen *et al.* 2016) while otariids at RF1-3 were trained to swim laps of a pool between two stationary targets. All animals were familiar with the experimental equipment and performed all trials voluntarily under trainer control.

*Stroke rate estimation*

Accelerometers (described above) recorded time, depth, and acceleration on 3 axes: anterior-posterior (surge), lateral (sway) and dorso-ventral (heave), from which separate diving and resting ODBA and VeDBA values, plus the stroke rate from trials, were extracted. Video footage from RF2, RF3 and RF4 was pseudo-randomly collected with 10 animals participating in other experiments (Ladds *et al.* 2016) from which we could directly count stroke rate. Underwater swimming at RF2-3 was recorded with GoPro HERO3 (GoPro, USA) mounted inside PVC pipes each with a viewing window cut-out that were placed in the pool during trials (see Hocking *et al.* 2015 for a figure of the set up). Sea lions at RF4 had the GoPro mounted to their harness and oriented towards the pectoral flipper. Videos were downloaded and edited together in Adobe Premiere Pro (Adobe Systems Incorporated, California), before being exported at the same frame rate as the accelerometer recorded (i.e., G6a+ 25 FPS and 25Hz at RF1-3; Daily Diary 32 FPS and 32 Hz at RF4). Accelerometer data was matched with the corresponding frame rate on the video which allowed us to extract data for dives and resting periods.

The dynamic acceleration was then used to predict stroke rate, where strokes were identified as peaks in the x axis (see Fig. 1, and description below). Actual total stroke number for a trial was counted from videos of individual trials. Strokes that used a single flipper or that were only below the body were not included as they were often masked on the accelerometry by other movement. The running mean used and the gradient of the peak affected the overall ability of the peaks to predict total stroke rate, therefore a combination of these variables was created and tested for their ability to predict total strokes for a dive.



**Figure 1. Dynamic acceleration of the x axis from a running mean of 1 second with different gradients applied to find peaks.** A – gradient = 10; B - gradient = 20; C - gradient = 30; D - gradient = 40. Actual number of strokes for this sample (as determined by video footage) was 26.

*Statistical analysis*

Stroke rate was estimated from peaks in the dynamic acceleration of the x, z and x + z axes. Peaks were extracted from the accelerometry data based on a minimum gradient before a peak. Since both the running mean and the minimum gradient of the peaks influenced the overall stroke rate estimate, combinations of these were created. The running means tested were 0.4, 1, 2, 3 and 4 seconds and the gradients tested were 10, 20, 30, 40 and 50 (Fig. 2) for otariids with the accelerometer taped on and 60, 70, 80, 90 and 100 for otariids with the accelerometer in a harness. The gradients differed for the two groups as the accelerometers were recording at different Hz; higher Hz resulted in more noise in the data which required a higher gradient. The best stroke rate prediction was defined as the running mean and gradient that resulted in the fewest errors when compared to observed stroke rates (Fig. 3). This was determined by testing if the differences were significantly different from 0 using a one-sample Z-test.

To assess the impact of the different stroke estimates we chose to investigate how they would affect overall energy expenditure estimation. The expected energy expended from each dive was calculated for both groups by multiplying the total number of actual strokes and estimated stroke rates (using a mean of three seconds and a gradient of 20-50 for the tape group and 60-90 for the harness group) for that dive by 3.8 J/kg. This value was chosen as it was the estimated cost of a stroke for Northern fur seals and Antarctic fur seals combined (Jeanniard-du-Dot *et al.* 2016b). The excess energy expenditure was then plotted on histograms for comparison.

All analysis was completed in R (Version 3.1.3; R Core Development Team 2015) and values are reported as mean ± SD.

**Table 1. Seal characteristics and summary metabolic rates from all trials.** Species, ID, mass (kg), age (years) and marine facility where housed, type of accelerometer used, recording rate and method of attachment for five fur seals and eight sea lions. Marine facility: RF2 – Underwater World; RF3 – Taronga Zoo; RF4 – Open Water Research Station.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Species | ID | Mass | Age | Marine | Device | Recording | Attachment |
|  |  |  |  | **facility** |  | **rate** | **method** |
| Australian fur seal | AFF1 | 69-78 | 17 | RF2 | G6a+ | 25Hz | Tape |
| AFM1 | 179-182 | 14 | RF2 | G6a+ | 25Hz | Tape |
| Australian sea lion | ASM1 | 153-160 | 12 | RF3 | G6a+ | 25Hz | Tape |
| New Zealand fur seal | NFM1\* | 54-55 | 8 | RF3 | G6a+ | 25Hz | Tape |
| NFM2 | 149-161 | 11 | RF2 | G6a+ | 25Hz | Tape |
| NFM3 | 154 | 13 | RF3 | G6a+ | 25Hz | Tape |
| Steller sea lion | F00BO | 155-160 | 15 | RF4 | Daily Diary | 32Hz | Harness |
| F97HA | 172-175 | 18 | RF4 | Daily Diary | 32Hz | Harness |
| F97SI | 230-233 | 18 | RF4 | Daily Diary | 32Hz | Harness |
| F00YA | 214-218 | 15 | RF4 | Daily Diary | 32Hz | Harness |

\*Indicates otariids identified as subadults during trials.

**Results**

*Predicting stroke rates*

We tested 25 different combinations of minimum gradient before peak (tape: 10-50; harness: 60-100) and running means (0.1-4 sec) to smooth data and evaluated the difference between predicted stroke rate and actual stroke rate. Stroke rate could be accurately predicted from finding peaks in the dynamic acceleration of all the axes tested (X, Z and X + Z axes), where no one axis was better at predicting stroke rate than another (Table 2). The accuracy of predictions depended predominantly on the gradient and running mean used. Individuals required different combinations of running mean and gradient to achieve the lowest error rates for stroke prediction (Table 2). The absolute average difference in the number of strokes predicted and the number of actual strokes for all groups was between 0 and 3.1, which represented a percentage difference of between -7.1 and 8.6% (Table 2). This demonstrates that stroke rate predictions were both over- and under-estimated depending on the animal and the running mean and gradient used.

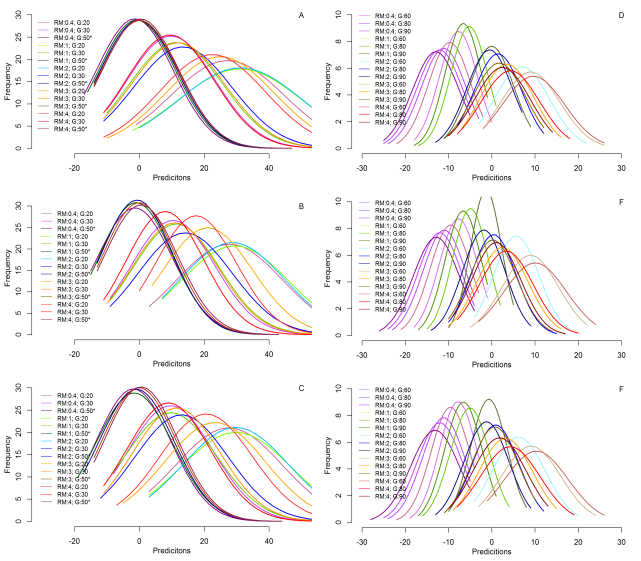
**Table 2. Summary of the combination of running mean and gradient that best predicts stroke rate** **for five fur seals and five sea lions**. With the average of the difference and the percentage difference between the predicted and actual number of strokes for that combination and number of trials.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ID | Method | N | Best running | | | Best | | | | Average | | | | Difference | | | |
|  |  |  | **mean (secs)** | | | **gradient** | | | | **difference** | | | | **%** | | | |
|  |  |  | X | Z | XZ | | X | Z | XZ | | X | Z | XZ | X | Z | XZ |
| Australian fur seal | | | | | | | | |
| AFF1 | Tape | 12 | 4 | 0.4 | 0.4 | | 40 | 40 | 40 | | 0.2 | 0.1 | 0.6 | -3.7 | 0.5 | 1.9 |
| AFM1 | Tape | 19 | 0.4 | 0.4 | 0.4 | | 50 | 50 | 50 | | 3.1 | 2.3 | 2.6 | -7.1 | -5.7 | -6.7 |
| New Zealand fur seal | | | | | | | | |
| NFM1 | Tape | 12 | 0.4 | 4 | 4 | | 40 | 50 | 50 | | 0.5 | 0.2 | 0.1 | -2.1 | -1.3 | -1.5 |
| NFM2 | Tape | 19 | 0.4 | 1 | 1 | | 50 | 50 | 50 | | 2.7 | 0.4 | 1.5 | -2.2 | -1.0 | -2.6 |
| NFM3\* | Tape | 7 | 1 | 1 | 0.4 | | 40 | 40 | 40 | | 0.0 | 0.4 | 0.0 | -0.3 | -5.8 | -2.6 |
| Australian sea lion | | | | | | | | |
| ASM1 | Tape | 17 | 4 | 4 | 3 | | 30 | 40 | 40 | | 2.2 | 0.4 | 1.0 | -5.0 | -2.8 | -1.6 |
| Steller sea lion | | | | | | | | | | | | | | | | |
| F00BO | Harness | 14 | 3 | 4 | 2 | | 90 | 90 | 80 | | 0.1 | 0.1 | 0.2 | -1.0 | -0.8 | -1.6 |
| F97HA | Harness | 7 | 2 | 4 | 4 | | 60 | 70 | 70 | | 1.0 | 0.9 | 0.1 | -3.2 | 8.6 | 2.5 |
| F97SI | Harness | 9 | 2 | 2 | 2 | | 100 | 90 | 90 | | 0.6 | 0.6 | 0.6 | 2.7 | 1.0 | 8.3 |
| F00YA | Harness | 19 | 2 | 1 | 1 | | 100 | 60 | 60 | | 0.2 | 0.1 | 0.5 | 4.4 | 2.0 | 5.0 |

\*Indicates otariids identified as subadults during trials.

The output for the tape group revealed that the choice of axis and running mean were not important in predicting stroke rate correctly, but that a gradient of 40 or 50 was needed (Appendix B). Z-tests revealed that seven of the 25 running mean and gradient combinations were not significantly different from 0. When looking at the output for the harness group, there was no consistent results for the choice of axis, running mean or gradient. Generally, a higher gradient (>70) and a higher running mean (>2 seconds) resulted in lower errors (Appendix C). Z-tests revealed that eight of the 25 running mean and gradient combinations were not significantly different from 0.

Figure 3 displays the distribution of errors for some selected combinations of gradients and running means. Distributions centred on 0 with small variances represent the best combinations which differed for each attachment group. The best combination was chosen from the distribution that was not significantly different from 0. For otariids with the harness, the best combination was a running mean of 1 second and a gradient of 100 (Fig. 3C). For otariids with the accelerometer taped the best combination was a running mean of 4 seconds and a gradient of 30 (Fig. 3F).



**Figure 3. Distributions of differences between predicted stroke rate and actual stroke rate over different running means and gradients.** A-C) otariids with the accelerometer taped on (N = 49 trials); D-F) otariids wearing a harness with the accelerometer (N = 71 trials). A and D – X axis; B and E – Z axis; C and F – X + Z axes.

*Energy expenditure from stroke rates*

Figures 4 and 5 demonstrate the expected loss or gain in estimated energy expenditure from calculating stroke frequency using different gradients using a running mean of three seconds. In Figures 4D and 5D the error is centred around 0, meaning that although on some dives the total number of strokes may be over- or under- estimated, over a long foraging trip these errors will be incorporated into the overall energy estimation. However, if a different gradient is chosen, then the total number of strokes for a dive, and hence the energy expenditure for that dive, is generally underestimated, up to 80J/kg for the harness group and up to 350J/kg for the tape group. Using a conservative value of 40J/kg underestimated on each dive on a typical foraging trip of an Australian fur seal of 500-1500 dives could result in a 20-60kJ/kg difference for that trip.

Excess energy expenditure = ± 40J/kg × 1000 dives = ± 40,000 J/kg ~ ± 40 kJ/kg



**Figure 4. Potential energy expenditure estimation from over- or under- estimation of total stroke rate for the tape group.**

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**Figure 5. Potential energy expenditure estimation from over- or under- estimation of total stroke rate for the harness group.**

**Discussion**

Choosing the correct combination of running mean and gradient to predict stroke rate is important because total number of strokes could be under- or over- predicted by 20%. However, if the goal of the research is to predict energy expenditure from strokes then this error will have little effect on the overall estimate. On a typical foraging trip of an Australian fur seal the lost energy would typically be between 20-60kJ/kg. For a 70kg female this is a loss of 140-320kJ over an entire foraging trip. Therefore while accuracy may be lost from estimating the total number of strokes on a foraging trip, using that estimation to predict energy expenditure over a foraging trip will result in low errors.

These results show that for accurate prediction of stroke rate for otariids the gradient used to detect a peak in the accelerometery is the most important parameter. Accelerometers measure the movement of an animal in three directions – surge, heave and sway – and the amplitude of these measurements are dependent on the activity of the animal. The stroke pattern of otariids causes a surge of acceleration forward (x-axis) and upward (z-axis), which results in steep peaks in these two axes (Jeanniard-du-Dot *et al.* 2016b; Appendix C). Here we have shown that using a simple gradient detection change that we can identify these steep peaks, and using video analysis we can confirmed that these match the strokes of the individual. For otariids that have the accelerometer attached with tape a relatively shallow gradient can be used to detect strokes (40-50; Figure 1). For otariids with the accelerometer placed in a harness a steeper gradient was required to account for the noise in the data (90-100; Appendix C). A larger gradient was required for the otariids wearing harnesses because of the noise generated from the higher sampling rate of the accelerometer (32 Hz vs 25 Hz) and movement from the harness. This is apparent in the video (S1 Video), where nearly double the actual number of stroke rates were recorded for F97SI in one of her trials, as a peak was recorded from a stroke and then another peak was recorded from her sudden stop at the feeding tube. These anomalies resulted in large discrepancies between the predicted and actual number of strokes.

The running mean chosen did not have a large influence on the overall prediction of stroke rate. Dynamic body acceleration (DBA) is derived from applying a running mean over the axes of acceleration to calculate static acceleration (gravity) and removing this from the raw acceleration (Shepard *et al.* 2008b). The value used to calculate the running mean changes the value of the DBA, and thus affects the ability of DBA to predict energy expenditure and to calculate an accurate estimate of stroke rate (Shepard *et al.* 2008a).

Accelerometer attachment (tape or harness), running mean and the axis (or combination of axes) used each had some effect on the results, but overall were not important in accurately predicting stroke rate. For animals wearing a harness there was additional noise in the data, but this could be compensated for by using a steep gradient. However, sharp jolts by the animal (such as stopping suddenly) did cause a spike in the accelerometry data that was interpreted as a stroke. This did not appear to occur with the animals that had the accelerometer attached with tape. Investigations of wild pinnipeds generally involve the device being glued to the animal which is analogous to the tape method, suggesting wild studies will not be adversely affected. However, future studies investigating stroke rate in captivity can still use harnesses to attach devices, provided the noise in the data is accounted for by changing the gradient. This is important for animals such as sea lions where attachment of devices with tape in captivity is difficult because the hair is too short (M. Ladds pers. comm.) or when multiple devices must be placed on the animal to measure activity in the open water (Rosen *et al.* 2016).

While the miniaturisation of data-loggers is making it easier to collect data from free-living animals, data storage can still be an issue, particularly if the goal is to monitor the animal over a long period. We found little variation between the ability of a single axis compared to a combination of axis to predict stroke rate. This suggest that if memory or power of a logger that is to be deployed for long durations is limited, it is still possible to obtain good stroke rate measures using only a single axis – x (Halsey *et al.* 2009). i.e. measuring only this axis allows for robust prediction of stroke rate in otariids. Sample rates of the accelerometers may also affect the ability to predict stroke rate from accelerometers, with lower rates of sampling being more variable, and predictions more robust at rates greater than 0.2Hz (Halsey *et al.* 2009). As we were measuring well above this frequency (25 and 32Hz) sampling frequency was not a confounding factor when estimating stroke rate in our study. Potentially this means that in wild studies a much lower sampling frequency could be used, saving battery and memory of devices, allowing them to be deployed for much longer durations (Halsey *et al.* 2009).

To stop at the feeding tubes, the large females would angle their flippers in such a way as to create as much drag as possible and stop suddenly. This caused an additional spike in the accelerometry, and while it was not related to stroke rate, would have had an energetic cost associated with it, which was incorporated by the DBA estimations.

Conclusion

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**Appendix A. Results for the tape group.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Running mean** | **Gradient** | **Mean x** | **Mean z** | **Mean xz** | **Median x** | **Median z** | **Median xz** | **Range x** | **Range z** | **Range xz** | **SD x** | **SD z** | **SD xz** | **Z-test x** | **Z-test z** | **Z-test xz** | **Sig.** |
| 0.4 | 10 | 83.4 | 82.6 | 82.5 | 77 | 78 | 76 | 171 | 175 | 157 | 33.5 | 33.7 | 32.2 | 201 | 199 | 198.6 |  |
| 20 | 27.2 | 27.8 | 27.7 | 24 | 27 | 27 | 99 | 94 | 94 | 17.3 | 16.2 | 16.2 | 65.6 | 67 | 66.7 |  |
| 30 | 9.8 | 10.3 | 9.6 | 7 | 8 | 7 | 76 | 70 | 72 | 13.5 | 12.8 | 13.1 | 23.5 | 24.7 | 23.2 |  |
| 40 | 1.7 | 2.3 | 1.7 | -1 | -1 | -1 | 64 | 58 | 62 | 12.2 | 11.8 | 11.9 | 4.2 | 5.6 | 4.1 | \*\* |
| 50 | -1.5 | -1.5 | -1.9 | -3 | -4 | -4 | 60 | 56 | 57 | 11.7 | 11.6 | 11.5 | -3.6 | -3.6 | -4.6 | \*\* |
| 1 | 10 | 79.6 | 79.5 | 79.7 | 74 | 73 | 72 | 156 | 171 | 160 | 32.1 | 33.1 | 31.4 | 191.8 | 191.5 | 191.9 |  |
| 20 | 31.1 | 29.6 | 29.9 | 28 | 28 | 27 | 111 | 97 | 102 | 19.1 | 16.5 | 17.1 | 74.9 | 71.2 | 71.9 |  |
| 30 | 11.4 | 11.4 | 9.8 | 9 | 11 | 7 | 82 | 74 | 77 | 14.3 | 13.2 | 14 | 27.4 | 27.4 | 23.5 |  |
| 40 | 2.6 | 2.9 | 1.6 | 0 | 1 | -1 | 66 | 61 | 67 | 12.5 | 11.2 | 12.7 | 6.4 | 6.9 | 3.8 | \* |
| 50 | -0.8 | -1.1 | -1.6 | -3 | -3 | -3 | 58 | 55 | 60 | 11.8 | 11.1 | 11.8 | -1.9 | -2.7 | -4 | \*\* |
| 2 | 10 | 59.9 | 59.6 | 59.8 | 54 | 55 | 54 | 132 | 126 | 116 | 24.9 | 24.8 | 23.2 | 144.3 | 143.4 | 144 |  |
| 20 | 31.2 | 28.9 | 29.9 | 28 | 26 | 29 | 103 | 90 | 93 | 18.8 | 16 | 16.2 | 75.2 | 69.5 | 71.9 |  |
| 30 | 13.4 | 14.2 | 13.1 | 14 | 14 | 13 | 85 | 76 | 83 | 15 | 14.4 | 14.3 | 32.4 | 34.2 | 31.6 |  |
| 40 | 3.4 | 4.3 | 3.7 | 0 | 2 | 1 | 69 | 63 | 63 | 12.8 | 11.3 | 12.1 | 8.3 | 10.4 | 8.9 |  |
| 50 | -0.1 | -0.8 | -0.9 | -3 | -4 | -3 | 56 | 52 | 58 | 11.9 | 10.9 | 11.5 | -0.4 | -1.9 | -2.2 | \*\*\* |
| 3 | 10 | 56.7 | 54.5 | 56.3 | 52 | 50 | 52 | 128 | 105 | 106 | 23.7 | 20.6 | 22.1 | 136.7 | 131.2 | 135.5 |  |
| 20 | 24.9 | 21.2 | 23.4 | 24 | 19 | 23 | 102 | 74 | 89 | 16.5 | 13.8 | 15.4 | 59.9 | 51.2 | 56.4 |  |
| 30 | 12 | 11.1 | 11.5 | 10 | 9 | 10 | 87 | 74 | 77 | 14.4 | 13.1 | 13.4 | 28.9 | 26.7 | 27.8 |  |
| 40 | 4.1 | 5 | 4.8 | 0 | 3 | 2 | 68 | 64 | 63 | 12.7 | 11.4 | 11.6 | 10 | 12 | 11.5 |  |
| 50 | 0.2 | -0.1 | -0.1 | -2 | -3 | -3 | 59 | 53 | 56 | 11.9 | 11.1 | 11.4 | 0.5 | -0.3 | -0.2 | \*\*\* |
| 4 | 10 | 54.7 | 51.4 | 53.6 | 49 | 49 | 50 | 133 | 97 | 110 | 23.1 | 18.9 | 21.1 | 131.8 | 123.7 | 129.1 |  |
| 20 | 22.5 | 17.6 | 20.7 | 22 | 15 | 19 | 104 | 68 | 82 | 16.2 | 12.4 | 14.1 | 54.2 | 42.4 | 49.8 |  |
| 30 | 9.5 | 8.1 | 9.1 | 8 | 6 | 6 | 75 | 68 | 71 | 13.4 | 11.9 | 12.8 | 22.9 | 19.4 | 21.9 |  |
| 40 | 3.4 | 3.9 | 4 | 0 | 1 | 0 | 66 | 60 | 62 | 12.4 | 11.1 | 11.8 | 8.2 | 9.4 | 9.5 |  |
| 50 | 0.4 | 0.5 | 0.6 | -2 | -3 | -2 | 61 | 56 | 58 | 11.7 | 11.3 | 11.3 | 1 | 1.3 | 1.4 | \*\*\* |

**Appendix B. Results for the harness group.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Running mean** | **Gradient** | **Mean x** | | **Mean z** | | **Mean xz** | | **Median x** | | **Median z** | | **Median xz** | | **Range x** | | **Range z** | | **Range xz** | | **SD x** | | **SD z** | | **SD xz** | | **Z-test x** | | **Z-test z** | | **Z-test xz** | | **Sig.** | |
| 0.4 | 10 | 83.4 | 82.6 | | 82.5 | | 77 | | 78 | | 76 | | 171 | | 175 | | 157 | | 33.5 | | 33.7 | | 32.2 | | 201.0 | | 199.0 | | 198.6 | |  | |
| 20 | 27.2 | 27.8 | | 27.7 | | 24 | | 27 | | 27 | | 99 | | 94 | | 94 | | 17.3 | | 16.2 | | 16.2 | | 65.6 | | 67.0 | | 66.7 | |  | |
| 30 | 9.8 | 10.3 | | 9.6 | | 7 | | 8 | | 7 | | 76 | | 70 | | 72 | | 13.5 | | 12.8 | | 13.1 | | 23.5 | | 24.7 | | 23.2 | |  | |
| 40 | 1.7 | 2.3 | | 1.7 | | -1 | | -1 | | -1 | | 64 | | 58 | | 62 | | 12.2 | | 11.8 | | 11.9 | | 4.2 | | 5.6 | | 4.1 | |  | |
| 50 | -1.5 | -1.5 | | -1.9 | | -3 | | -4 | | -4 | | 60 | | 56 | | 57 | | 11.7 | | 11.6 | | 11.5 | | -3.6 | | -3.6 | | -4.6 | | \* | |
| 1 | 10 | 79.6 | 79.5 | | 79.7 | | 74 | | 73 | | 72 | | 156 | | 171 | | 160 | | 32.1 | | 33.1 | | 31.4 | | 191.8 | | 191.5 | | 191.9 | |  | |
| 20 | 31.1 | 29.6 | | 29.9 | | 28 | | 28 | | 27 | | 111 | | 97 | | 102 | | 19.1 | | 16.5 | | 17.1 | | 74.9 | | 71.2 | | 71.9 | |  | |
| 30 | 11.4 | 11.4 | | 9.8 | | 9 | | 11 | | 7 | | 82 | | 74 | | 77 | | 14.3 | | 13.2 | | 14.0 | | 27.4 | | 27.4 | | 23.5 | |  | |
| 40 | 2.6 | 2.9 | | 1.6 | | 0 | | 1 | | -1 | | 66 | | 61 | | 67 | | 12.5 | | 11.2 | | 12.7 | | 6.4 | | 6.9 | | 3.8 | |  | |
| 50 | -0.8 | -1.1 | | -1.6 | | -3 | | -3 | | -3 | | 58 | | 55 | | 60 | | 11.8 | | 11.1 | | 11.8 | | -1.9 | | -2.7 | | -4.0 | | \*\* | |
| 2 | 10 | 59.9 | 59.6 | | 59.8 | | 54 | | 55 | | 54 | | 132 | | 126 | | 116 | | 24.9 | | 24.8 | | 23.2 | | 144.3 | | 143.4 | | 144.0 | |  | |
| 20 | 31.2 | 28.9 | | 29.9 | | 28 | | 26 | | 29 | | 103 | | 90 | | 93 | | 18.8 | | 16.0 | | 16.2 | | 75.2 | | 69.5 | | 71.9 | |  | |
| 30 | 13.4 | 14.2 | | 13.1 | | 14 | | 14 | | 13 | | 85 | | 76 | | 83 | | 15.0 | | 14.4 | | 14.3 | | 32.4 | | 34.2 | | 31.6 | |  | |
| 40 | 3.4 | 4.3 | | 3.7 | | 0 | | 2 | | 1 | | 69 | | 63 | | 63 | | 12.8 | | 11.3 | | 12.1 | | 8.3 | | 10.4 | | 8.9 | |  | |
| 50 | -0.1 | -0.8 | | -0.9 | | -3 | | -4 | | -3 | | 56 | | 52 | | 58 | | 11.9 | | 10.9 | | 11.5 | | -0.4 | | -1.9 | | -2.2 | | \*\* | |
| 3 | 10 | 56.7 | 54.5 | | 56.3 | | 52 | | 50 | | 52 | | 128 | | 105 | | 106 | | 23.7 | | 20.6 | | 22.1 | | 136.7 | | 131.2 | | 135.5 | |  | |
| 20 | 24.9 | 21.2 | | 23.4 | | 24 | | 19 | | 23 | | 102 | | 74 | | 89 | | 16.5 | | 13.8 | | 15.4 | | 59.9 | | 51.2 | | 56.4 | |  | |
| 30 | 12.0 | 11.1 | | 11.5 | | 10 | | 9 | | 10 | | 87 | | 74 | | 77 | | 14.4 | | 13.1 | | 13.4 | | 28.9 | | 26.7 | | 27.8 | |  | |
| 40 | 4.1 | 5.0 | | 4.8 | | 0 | | 3 | | 2 | | 68 | | 64 | | 63 | | 12.7 | | 11.4 | | 11.6 | | 10.0 | | 12.0 | | 11.5 | |  | |
| 50 | 0.2 | -0.1 | | -0.1 | | -2 | | -3 | | -3 | | 59 | | 53 | | 56 | | 11.9 | | 11.1 | | 11.4 | | 0.5 | | -0.3 | | -0.2 | | \*\*\* | |
| 4 | 10 | 54.7 | 51.4 | | 53.6 | | 49 | | 49 | | 50 | | 133 | | 97 | | 110 | | 23.1 | | 18.9 | | 21.1 | | 131.8 | | 123.7 | | 129.1 | |  | |
| 20 | 22.5 | 17.6 | | 20.7 | | 22 | | 15 | | 19 | | 104 | | 68 | | 82 | | 16.2 | | 12.4 | | 14.1 | | 54.2 | | 42.4 | | 49.8 | |  | |
| 30 | 9.5 | 8.1 | | 9.1 | | 8 | | 6 | | 6 | | 75 | | 68 | | 71 | | 13.4 | | 11.9 | | 12.8 | | 22.9 | | 19.4 | | 21.9 | |  | |
| 40 | 3.4 | 3.9 | | 4.0 | | 0 | | 1 | | 0 | | 66 | | 60 | | 62 | | 12.4 | | 11.1 | | 11.8 | | 8.2 | | 9.4 | | 9.5 | |  | |
| 50 | 0.4 | 0.5 | | 0.6 | | -2 | | -3 | | -2 | | 61 | | 56 | | 58 | | 11.7 | | 11.3 | | 11.3 | | 1.0 | | 1.3 | | 1.4 | | \*\* | |

**Appendix C. Identification of peaks in accelerometery data from the harness group.**

