Respiration timing and underwater activity in killer whales (*Orcinus orca*)

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Abstract

Accurate estimates of energetic requirements of top predators *in-situ* are essential to improve sustainable marine ecosystems' management. Yet, obtaining direct energetic measurements of free-ranging cetaceans is unfeasible. Breathing rate has been used as indicator of cetacean metabolic rates, though rate alone does not account for breath-by-breath variation in gas exchange. This study's aim was to investigate 1) the strength of correlations between respiration rates and underwater activity levels; and 2) the potential influence of including respiratory timing (besides rate) and oxygen uptake dynamics on *in-situ* cetacean energetic studies. Kinematic data from 12 adult wild Norwegian herring-feeding killer whales (*Orcinus orca*) were recorded with high-resolution tags (DTAGs) to reveal individual breathing events. Three-axis accelerometer and flow noise data were used to derive stroking rate and speed as underwater activity level metrics. An oxygen exchange model, including an oxygen uptake curve as key feature, and oxygen consumption from swimming speed or stroke number, was established to estimate oxygen extraction dynamically per individual breath, based upon modeled oxygen store at the time of each breath. Correlations between predicted oxygen uptake and activity level over 15 min periods were relatively weak when using constant uptake per breath (for both speed and stroking $r^2 < 0.1$). Including fluctuating oxygen uptake per breath significantly improved the correlation between modeled oxygen uptake and activity (for both speed and stroking $r^2 > 0.9$). Model outcomes found that cost of transport kept decreasing when assuming fixed oxygen uptake, whereas applying fluctuating uptake revealed a clear minimum cost of transport speed of 2.0-2.5 $m \cdot s^{-1}$. With on-going development and effort concerning bio-logging, together with gain of accurate information on energetic costs relating to kinematics, the proposed model could become a useful tool to improve our knowledge of free-ranging cetaceans' energetic requirements in relation to more advanced sustainable marine ecosystem management.