RESEARCH ARTICLE

The significance of respiration timing in the energetics estimates of free-ranging killer whales (*Orcinus orca*)

Marjoleine M. H. Roos[1]*, Gi-Mick Wu[1] and Patrick J. O. Miller[1]

[1]**Sea Mammal Research Unit,** Scottish Oceans Institute, University of St Andrews, St Andrews, Fife, KY16 8LB, UK

* Author for correspondence (marjoleineroos@gmail.com)

ABSTRACT

Respiration rate has been used as an indicator of metabolic rates and associated cost-of-transport (COT) of free-ranging cetaceans, discounting potential respiration-by-respiration variation in O_2 uptake. To investigate the influence of respiration timing on O_2 uptake we developed a dynamic model of O_2 exchange and storage. Individual respiration events were revealed from kinematic data from ten adult Norwegian herring-feeding killer whales (*Orcinus orca*) recorded with high-resolution tags (DTAGs). We compared fixed-O_2-uptake-per-respiration models to O_2 uptake per respiration estimated through a simple 'broken-stick' O_2-uptake function, in which O_2 uptake was assumed to be the maximum-possible O_2 uptake when stores are depleted or maximum total body O_2 store minus existing O_2 store when stores are close to saturated. Conversely to assuming fixed O_2 uptake per respiration, uptake from the broken-stick model yielded a high correlation ($r^2 > 0.9$) between O_2 uptake and activity level. Moreover, we found that respiration intervals increased and became less variable at higher swimming speeds, possibly to increase O_2 uptake efficiency per breath. As found in previous studies, COT decreased monotonically versus speed using the fixed-O_2-uptake-per-respiration models. However, the broken-stick uptake model yielded a curvilinear COT-curve with a clear minimum at typical swimming speeds of 1.7-2.4 m s^{-1}. Our results showed that respiration-by-respiration variation in O_2 uptake is expected to be significant. And though O_2 consumption measurements of COT for free-ranging cetaceans remain impractical, accounting for the influence of respiration timing on O_2 uptake will lead to more consistent predictions of field metabolic rates than using respiration rate alone.

KEY WORDS: Metabolic rate, Oxygen uptake, Respiration timing, cetaceans, Respiration rate, *In-situ*