Respiratory Physiology & Neurobiology 259 (2019) 173–175

Contents lists available at ScienceDirect

Respiratory Physiology & Neurobiology

journal homepage: www.elsevier.com/locate/resphysiol

Reply to: Assessment of 'neural respiratory drive' from the parasternal intercostal muscles

Dear Editor:

We thank Drs. Hudson and Butler for taking an interest in our study (Ramsook et al., 2017) and for their valuable insight and suggestions (Hudson and Butler, 2018). As correctly pointed out by our colleagues, electromyographic (EMG) assessments of the respiratory muscles are influenced by a number of factors including, but not limited to, cross-contamination of adjacent skeletal muscles (Hodges and Gandevia, 2000) and the multi-functional nature of the respiratory muscles such as trunk flexion and rotation (Hudson et al., 2010). These are the very reasons why we must be cautious when using parasternal intercostal EMG (EMGpara) as a surrogate for neural respiratory drive (NRD), particularly during dynamic whole-body exercise where the above factors are likely changing with increasing exercise intensity. Both non-respiratory activity of the parasternal intercostal muscles and cross-talk from other muscles make it difficult to differentiate between inspiratory and non-inspiratory EMG activity during progressive exercise testing. To improve our analysis and interpretation, Drs. Hudson and Butler suggest that inspiratory EMG activity should be measured as the change or increase in activity during inspiration above any ongoing or tonic level of activity during expiration. The authors also sought clarification on how potential contamination from the pectoral muscles was taken into consideration when measuring maximal EMG for the purposes of normalization.

Before addressing these points, it is important to emphasize that a previous study recommended using EMGpara as a surrogate for NRD during symptom limited incremental cycle exercise testing (Reilly et al., 2011). This study piqued our interest and served as the impetus for our investigation (Ramsook et al., 2017). Consequently, we felt it was important to replicate the methods used by Reilly et al. (2011) and other studies employing similar assessments of EMGpara (MacBean et al., 2016; Reilly et al., 2013), both for electrode placement and EMG analysis. We also thought it was important to use the same methods of analysis as used for diaphragmatic EMG in order to facilitate a direct comparison with the currently accepted gold standard method for assessing NRD during exercise. Performing additional analyses was beyond the scope of our short communication manuscript. Nevertheless, we fully acknowledge that additional methods of analysis, as suggested by our colleagues, could improve the assessment of EMGpara and we appreciate the opportunity to address their excellent suggestions in this response.

Expressing EMGpara as the change or increase above any ongoing or tonic level of activity during expiration is a valuable suggestion and makes sense under most experimental conditions. This approach involves a breath-by-breath analysis where EMGpara during inspiration is expressed as the change in activity relative to the preceding (or subsequent) expiration. The key assumption with this approach is that non-respiratory EMGpara occurs equally during expiration and inspiration between adjacent breaths. Unfortunately, we do not believe this is a valid assumption, at least during intense upright cycling. For example, Fig. 1 depicts raw traces of EMGpara during exercise in one participant exercising at 300 W in the hands-on and hands-off position. In the hands-off position, increases in EMGpara occur only during the inspiratory phase. In contrast, the hands-on position shows marked bursts of EMGpara activity during both inspiration and expiration. Interestingly, the contraction frequency in the hands-on position appears to align more closely with pedalling rate than breathing frequency. Thus, a pectoral muscle contraction, for example, may occur during various phases of inspiration and expiration, making it very difficult to reliably perform the suggested analysis.

The mean expired EMGpara activity is shown in Fig. 2. As expected, EMGpara activity during expiration is highly variable and is greater in the hands-on compared to the hands-off position ($p < 0.05$). In some cases, EMGpara during expiration exceeded EMGpara during inspiration, which would result in negative inspiratory EMGpara data for some breaths using the suggested analysis. If a burst of non-respiratory activity occurred during inspiration, the proposed analysis would be unable to differentiate between the respiratory and non-respiratory activity. Thus, we think it is unlikely that the suggested analysis provides a valid way of isolating inspiratory activity from the activity of non-respiratory muscles (e.g. pectoralis major) or parasternal activation due to non-respiratory functions (e.g. trunk rotation), at least during vigorous upright cycling.

Regarding the normalization of our data, Drs. Hudson and Butler sought clarification on how we accounted for the activation of the pectoral muscles during the maximal inspiratory capacity manoeuvres. As we did not account for pectoral muscle activity in our EMG analysis (by design) at rest or during the hyperpnoea of exercise, we did not feel it was appropriate to account for this in our inspiratory capacity manoeuvres, which has been the approach used by others (MacBean et al., 2016; Suh et al., 2015). It is important to recognize that changing the normalization methods should not impact our findings as we used the same maximal EMG activity for both the hands-on and hands-off condition within a subject. In fact, it would have been equally appropriate for us to simply report non-normalized data given that we were making comparisons within subjects and on the same testing day, which has been an approach advocated previously (Singh et al., 2005).

In conclusion, Drs. Hudson and Butler are correct in pointing out that non-respiratory activity of the parasternal intercostal muscles can influence EMG recordings during cycle exercise. In cases where the upper body is not likely to experience phasic EMG activity (Hudson et al., 2016), the quality of the inspiratory EMG signal will very likely be improved by subtracting tonic EMG activity during the expiratory phase of respiration as suggested by our colleagues. However, we do not believe the proposed analysis is suitable during exercise as the EMG activity during expiration is not always tonic. Our data suggest that non-respiratory activity can occur during both inspiration and expiration, thus contaminating the EMGpara signal. We speculate that other

https://doi.org/10.1016/j.resp.2018.08.003
Received 3 August 2018
Available online 07 August 2018
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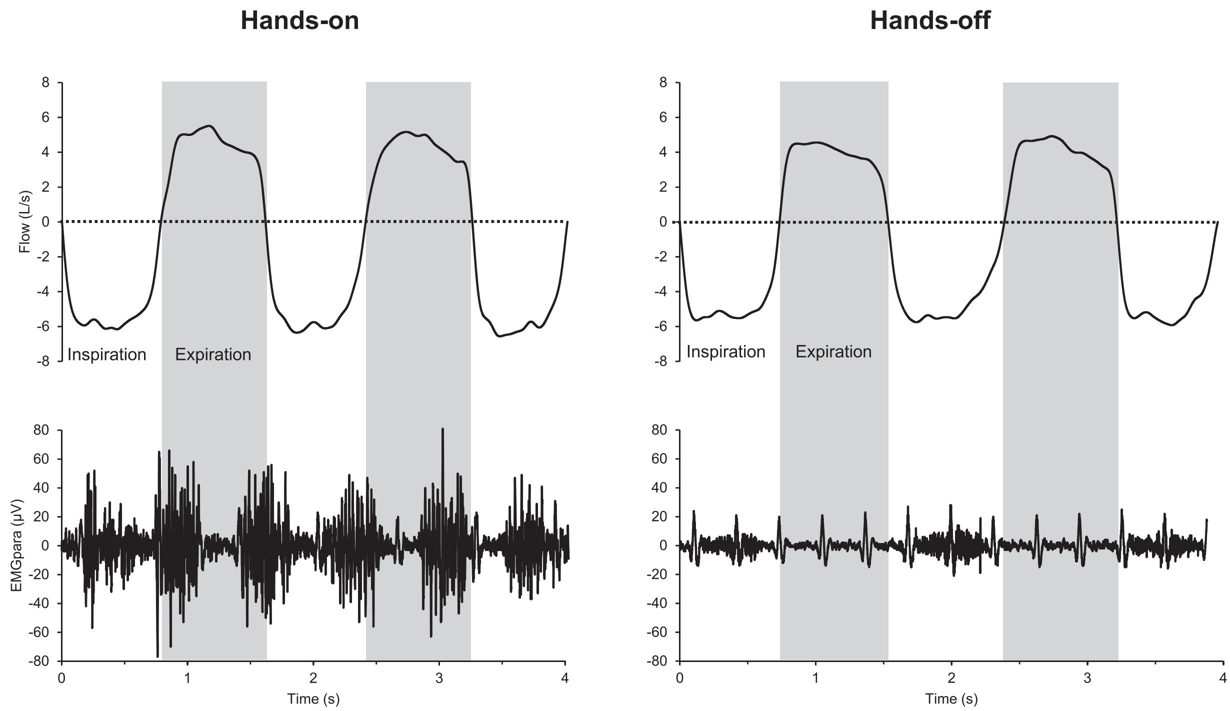

Fig. 1. Raw traces of parasternal intercostal EMG in one subject exercising at 300 W in the hands-on and hands-off condition. Expiration identified as positive flow highlighted in grey bars.

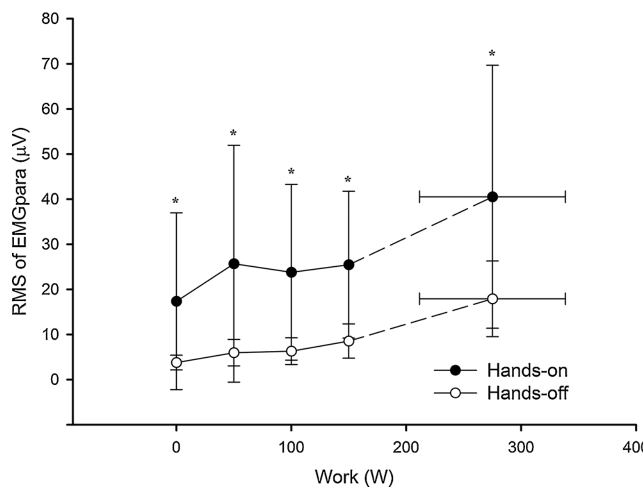

Fig. 2. Absolute expired electromyography (EMG) responses during exercise. *, $p < 0.05$.

EMG techniques such as high-density surface EMG, a technique used previously to differentiate the contribution of neighbouring muscles in the forearm using a grid of closely-spaced surface electrodes (Gallina and Botter, 2013), could be used as a non-invasive means to identify the activation of different muscle groups during upright exercise. However, we are unaware of any high-density surface EMG studies which examine respiratory muscles during vigorous upright cycle exercise at this time. We maintain our original position that EMGpara, measured by bipolar surface electrodes, is not a suitable surrogate for NRD during upright cycle exercise.

Conflicts of interest

None of the authors have any conflicts of interest to report relevant to this manuscript.

Disclosure of funding

AHR was supported by a fellowship from the University of British Columbia and a graduate scholarship from the Natural Sciences and Engineering Research Council of Canada. JAG was supported by a Canadian Institutes of Health Research Clinical Rehabilitation New Investigator Award and Scholar Awards from the Michael Smith Foundation for Health Research, Providence Health Care Research Institute, and St. Paul's Hospital Foundation.

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