SHORT COMMUNICATION

The effect of respiratory muscle fatigue on respiratory sensations

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Summary

1. Eight subjects maintained maximal inspiratory pressure as long as possible. The subjects accurately judged the pressure developed, but considered that the sense of effort or motor command increased progressively during the contraction as fatigue developed.

2. A reference inspiratory load was overestimated after maximal inspiratory contractions.

3. These findings are consistent with the hypothesis that awareness of the motor command or effort contributes to the estimation of respiratory loads.

Key words: dyspnoea, fatigue, respiratory sensations, sense of effort.

Introduction

In past years it has been shown that the perceived heaviness of a lifted weight is judged by perceiving the outgoing motor command or 'sense of effort' required to lift it (McCloskey, Ebeling & Goodwin, 1974; Gandevia & McCloskey, 1977a,b, 1978; review McCloskey, 1978). Evidence supporting this hypothesis is that the perceived heaviness of a lifted object increases when the lifting muscles are weakened by fatigue, by neuromuscular block or by paresis without clinically apparent sensory loss. Perceived heaviness increases when the effort of outgoing motor command increases. Signals of achieved muscular tension can be perceived, but are usually disregarded in favour of signals related to the motor command (McCloskey et al., 1974; Gandevia & McCloskey, 1977a).

Addition of small resistive or elastic loads during quiet breathing is reliably detected (Campbell, Freedman, Smith & Taylor, 1961; Bennett, Jayson, Rubenstein & Campbell, 1962; Wiley & Zechman, 1966; Guz, 1977). However, the mechanisms by which the size of a respiratory load is judged are not known. Here we have used fatigue of respiratory muscles to study these mechanisms. If afferent information signals the apparent size of a respiratory load no change will be expected during fatigue, but if the motor command signals apparent size then the subject will overestimate the load.

Methods

Protocol

During sustained maximal contractions of inspiratory muscles subjects signalled their subjective assessment of either the achieved inspiratory pressure (i.e. muscle tension) or the sense of motor command. At the end of each contraction the perceived size of a reference inspiratory load was estimated and compared with estimates of the same load made after voluntary apnoea without inspiratory muscle activity.

Subjects

Eight normal subjects were studied including two of the authors. The other subjects were unaware of the hypothesis being tested.
**Procedure**

Subjects sustained a maximum isometric inspiratory contraction at functional residual capacity after 20 s of hyperventilation on 100% oxygen. They were exhorted constantly to maintain the contraction until it could no longer be tolerated (approx. 30–60 s). Contractions were associated with a feeling of fatigue and usually a reduction in inspiratory pressure (approx. 20%). Two minutes separated the trials.

Mouth pressure was measured continuously during contractions with a modified Hewlett Packard 267 pressure transducer. On alternate contractions the subject signalled his subjective estimate of either achieved inspiratory pressure or motor command by turning a potentiometer. Subjects were asked by the experimenter 'how big is the inspiratory pressure or tension in the muscle?' and 'how big is your command or effort?' respectively.

After subjects signalled the approach of their limit they developed a 5 kPa threshold inspiratory pressure before airflow started (hereafter called 'inspiratory load'). For naive subjects the inspiratory load remained at 5 kPa, but it varied randomly from 2 to 7 kPa in studies on the authors. Loads were produced by switching the inspiratory line to a container partly filled with water. Air entered the container through a tube 50 cm below the water. Subjects chose a number proportional to the size of the inspiratory load (unrestricted magnitude scaling; Stevens, 1957; Marks, 1974). They were asked 'how big is the load?'; no further instructions were given. On average each subject produced 10 maximal inspiratory contractions, five estimates of the load after maximal contractions and three after hyperventilation with oxygen and an equivalent period of breath holding.

Detailed statistical analysis of the subjective scores and potentiometer signals are inappropriate to the design; for example it is not possible to standardize the degree of fatigue in each contraction. Emphasis is placed on the uniformly consistent trend in comparative results in all subjects.

**Results**

**Signalling inspiratory pressure or motor command**

All subjects indicated that the motor command increased monotonically during the contraction, especially towards the end of the contraction when the achieved force declined. When signalling perceived inspiratory pressure, six of the subjects indicated the reduced pressure during the latter part of the contraction. In one subject the perceived pressure remained steady throughout despite a fall in achieved pressure. In the other subject perceived pressure increased during contractions, but at a rate lower than the perceived increase in the motor command. Qualitatively similar performances were given by two subjects tested on two different days. A typical result is shown in Fig. 1.

Subjects often reproduced accurately the fluctuations in the pressure developed by the inspiratory muscles (Fig. 1a).

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![Fig 1](image-url)  
**Fig 1.** Records from one subject for two successive maximal inspiratory manoeuvres are shown.  
(a) The subject was simply asked to signal the perceived 'inspiratory pressure or tension' during the contraction with a potentiometer.  
(b) The subject was asked to signal, in a similar way, the 'motor command or effort' put into the contraction. During a maximal inspiratory contraction the motor command was perceived to increase progressively (b) while the perceived inspiratory pressure remained stable until a slight fall during the last 8 s of the contraction (a). This subject, in whom fluctuations in achieved pressure were particularly marked, perceived several rapid fluctuations in achieved pressure (a).
Perception of an inspiratory load during fatigue

An inspiratory load (see the Methods section) appeared larger when presented at the end of a sustained maximal isometric inspiration than when presented after breath holding. In all individuals all estimates of the inspiratory load received higher scores after the sustained contraction than during the control situation. Thus for the group of subjects, with a total of more than 50 fatiguing contractions, an inspiratory load felt bigger when the inspiratory muscles were fatigued. For example, with the two subjects who differed most in their adopted range of apparent size, the control score in one was 100 ± 0 and the fatigue score 5000 ± 0; in the other the control was 14.2 ± 1.2 and the fatigue score 20.5 ± 1.0 (mean ± SD, n = 4). The fatigue scores consistently exceeded control scores in four subjects studied again on a different day, although the ranges adopted were usually different (Stevens, 1957).

Discussion

We used fatigue as a technique to dissociate the motor command (or effort) put into a maximal inspiratory contraction from the actual muscular tension (or inspiratory pressure) produced by it. Subjects were able to distinguish between their sense of motor command and their sense of achieved muscular tension. An inspiratory load was consistently overestimated when produced by fatigued muscles. Subjects thus preferred a signal of motor command, rather than of achievement, when judging the size of a respiratory load. For the limb muscles signals of motor command and of muscular tension are perceived, but signals of command are usually preferred as indicators of muscular tension (McCloskey et al., 1974; Gandevia & McCloskey, 1977a). Thus contraction of respiratory and peripheral muscles is associated with the same sensations.

Sustained inspiratory contractions were used to reduce the force developed by the inspiratory muscles because these muscles are particularly resistant to fatigue with rhythmic contractions. Rhythmic contractions take many minutes to produce fatigue and limit the number of repetitions that can be tolerated (Roussos, Fixley, Gross & Macklem, 1979). Using continuous inspiratory loading (6 kPa l⁻¹ s⁻¹; Roussos et al., 1979), we were able to maintain fatigue in only one of the eight subjects. In this subject fatigue was associated with a significant increase in the perceived size of a series of resistances.

The origin of the afferent input signalling achieved muscular tension is not revealed by this study. Experiments with anaesthesia of skin and joints combined with muscular weakness suggest an intramuscular origin for this signal in the limb muscles (McCloskey et al., 1974; Roland & Ladegaard-Pedersen, 1977).

Our hypothesis that a respiratory load feels larger when an increased motor command is required to overcome it is supported by a study of normal subjects during partial curarization (Campbell, Gandevia, Killian, Mahutte & Rigg, 1980). Anecdotal reports in the literature have noted difficulty in breathing during partial paralysis [with curare (Smith, Brown, Toman & Goodman, 1947); by disease (Comroe, 1966)]. Similarly patients often report an increased effort required to breathe immediately after prolonged artificial ventilation when respiratory muscles may be weakened by disuse (S. Gandevia & K. Killian, unpublished observations). These observations support our concept.

In patients with a mechanical or neuromuscular impairment to breathing a greater motor command is required to achieve adequate ventilation. This added command may result in the sensation of dyspnoea in certain circumstances, just as the added command to lift a weight with fatigued limb muscles is responsible for the heavy feeling of the weight.

References


