Introduction

Background

Inspiratory muscle training (IMT) has been widespread, particularly in a clinical context, since Delhez *et al.* (1966) demonstrated that the breathing muscles could be strengthened by specific training. Numerous technologies have been described subsequently (Anderson *et al.* 1979; Kim 1981; Nickerson & Keens 1982; Clanton *et al.* 1985; Belman & Shadmehr 1988; Flynn *et al.* 1989; Pardy & Rochester 1992). To date, pressure threshold loading has proved to be the most effective technology, in clinical populations (Smith *et al.* 1992) offering a versatile yet robust means of improving the strength, power and endurance of the inspiratory muscles.

Pressure threshold training permits loading at a quantifiable intensity by providing near flow-independent resistance to inspiration. This is typically achieved with either a weighted plunger or spring loaded valve. Pressure threshold training can be utilised effectively without regulating breathing pattern or gas exchange. In addition, this technology is both portable and easy to use. Unfortunately, the only commercially available device – The Threshold® (Healthscan Products Inc., Cedar Grove, NJ, USA) – was devised for use in clinical populations and thus permits only modest loading (maximum < −50 cm H_2O). This renders it inappropriate for inducing strength based adaptations of the inspiratory muscles in healthy adults.

Until recently, the notion of training the breathing muscles of healthy humans has received little attention. Traditionally, the pulmonary system in its capacity as a mechanical pump has largely been dismissed as a factor limiting exercise capacity in healthy humans (Wasserman *et al.* 1981; Dempsey *et al.* 1982). However, recent studies indicate that the condition of the breathing muscles may be a factor in determining exercise performance. Johnson *et al.* (1996) concluded that respiratory muscle fatigue may limit human performance, whilst suggesting that other factors related to the respiratory muscles (i.e. alterations in the sensation of dyspnoea or mechanical load) may also play an important role in determining exercise tolerance.

Data supporting the notion that inspiratory or respiratory muscle training can engender ergogenic benefits also exists. Most recently, Spengler *et al.* (1999) concluded that endurance training of the respiratory muscles significantly prolonged constant-intensity exercise. Unfortunately, the training technology used in this and other similar studies (Boutellier & Piwko 1992; Boutellier *et al.* 1992) requires regulation of gas exchange and is thus constrained to laboratory use.

The device described in the present paper has been utilised in several studies to examine the effect of inspiratory muscle training upon lung function and exercise in trained individuals. Pressure threshold inspiratory muscle training has been shown to improve the effectiveness of breathing under load, reducing circulating blood lactate concentrations during cycling at high exercise intensities (Sharpe & McConnell 1998; Sharpe 1999). Ergogenic benefits have been observed in cyclists, whereby times to volitional exhaustion have improved significantly following a period of pressure threshold inspiratory muscle training. Moreover, ratings of perceived exertion have been attenuated, with blood lactate concentrations also being significantly reduced post-training. Furthermore, a significant correlation exists between improvement in cycling performance and percentage reduction in blood lactate concentrations (Caine & McConnell 1998). Voliantis *et al.* (1999) also documented improvements in inspiratory muscle function in rowers following a specific inspiratory muscle warm-up using the device. It should be noted, however, that whilst evidence is accruing to support the notion that specific inspiratory muscle training can enhance exercise performance, the mechanisms by which such improvements are engendered remain unclear.

The potential for widespread implementation of IMT in athletic populations has until recently been constrained by the absence of a suitable training device. Thus, the purpose of the present paper is to document the design and development of such a