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ORIGINAL ARTICLE

The influence of rowing-related postures upon respiratory muscle pressure and flow generating capacity

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Abstract During the rowing stroke, the respiratory muscles are responsible for postural control, trunk stabilisation, generation/transmission of propulsive forces and ventilation (Bierstacker et al. in Int J Sports Med 7:73–79, 1986; Mahler et al. in Med Sci Sports Exerc 23:186–193, 1991). The challenge of these potentially competing requirements is exacerbated in certain parts of the rowing stroke due to flexed (stroke 'catch') and extended postures (stroke 'finish'). The purpose of this study was to assess the influence of the postural role of the trunk muscles upon pressure and flow generating capacity, by measuring maximal respiratory pressures, flows, and volumes in various seated postures relevant to rowing. Eleven male and five female participants took part in the study. Participants performed two separate testing sessions using two different testing protocols. Participants performed either maximal inspiratory or expiratory mouth pressure manoeuvres (Protocol 1), or maximal flow volume loops (MFVLs) (Protocol 2), whilst maintaining a variety of specified supported or unsupported static rowing-related postures. Starting lung volume was controlled by initiating the test breath in the upright position. Respiratory mouth pressures tended to be lower with recumbency, with a significant decrease in P_{Emax} in unsupported recumbent postures (3–9 % compared to upright seated; $P = 0.036$). There was a significant decrease in function during dynamic manoeuvres, including PIF (5–9 %), FVC (4–7 %) and FEV_1 (4–6 %), in unsupported recumbent postures ($p < 0.0125$; Bonferroni corrected). Thus, respiratory pressure and flow generating capacity tended to decrease with recumbency; since lung volumes were standardised, this may have been, at least in part, influenced by the postural co-contraction of the trunk muscles.

Keywords Ventilatory muscle strength · Postural adaptations · Recumbent · Respiratory function

Introduction

The muscles of the trunk have a number of roles, including breathing, stabilisation and postural control. Whilst the respiratory and non-respiratory roles of the trunk muscles can be synergistic, movement can also bring them into conflict, especially during certain sports. Furthermore, the position of the trunk relative to other body parts can also impact negatively upon breathing. The rowing stroke illustrates well how the physical demands of a sport can create such conflicts. For example, experienced rowers tend to inhale just prior to the 'catch' of the stroke (Mahler et al. 1991; Siegmund et al. 1999), a position in which movement of the chest and abdominal walls is impeded by the thighs. The other favoured position for inhalation is the 'finish' (Mahler et al. 1991; Siegmund et al. 1999), and in this position, the rower's hip angle is >90°, necessitating the recruitment of trunk muscles as postural controllers.

Previous investigations into stroke-breathing interrelationships during rowing have shown that peak flow rates and tidal volume (V_T) depended upon the timing of the

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breath during the stroke cycle (Siegmund et al. 1999); in particular, spontaneously generated peak inspiratory flow rate (PIFR) was impaired at the 'finish'. Siegmund et al. postulated that this might be due to impaired diaphragm function, secondary to an increase in intra-abdominal pressure. Further, the authors suggested that limitations to flow and volume generating capacity might be greater in the 'finish' than in the 'catch' position. Their data suggest that the postural role of the trunk muscles may impair the ability of the respiratory muscles to generate flow. All other things being equal, impairment in flow generating capacity is indicative of impairment in the maximal power output of the respiratory muscles. The functional repercussion of such an impairment would be an increased propensity of the respiratory muscles to fatigue, which has a number of detrimental implications for exercise performance (Romer and Polkey 2008).

Thus, the purpose of this study was to examine the influence of the postural engagement of the trunk muscles in the 'catch' and 'finish' positions upon the maximal static respiratory pressures, flow rates, and volume excursions. In addition, the independent influences of postural muscle co-contraction and body position were examined by comparing responses when the trunk was supported and unsupported. We hypothesised that pressure and flow generating capacity would be impaired in the 'finish' position when the trunk is unsupported, but not when it is supported, and that function would not be impaired in the 'catch' position.

Methodology

Participants

Eleven males (mean ± SD: age 25.6 ± 6.5 years, body mass 86.8 ± 18.7 kg, height 182 ± 9 cm) and five females (age 23.6 ± 2.5 years, body mass 71.9 ± 15.7 kg, height 175 ± 8 cm) volunteered to participate in the study. All participants were healthy adults who performed exercise at least 3 times per week and did regular training sessions on a rowing ergometer; seven of the males were competitive oarsmen.

All participants reported to the laboratory on two separate occasions with a 1-week minimum time span between testing sessions. Nine of the participants made four visits; these additional visits were used to collect reliability data to determine inter-test precision of within-subject variation of the testing procedures.

Written informed consent from all participants and local ethics approval were obtained prior to the start of testing sessions. Participants were asked to refrain from vigorous exercise 24 h prior to testing.

General design

Participants completed two different testing protocols, in both instances measurements were preceded by a specific inspiratory warm-up using a pressure threshold-loading device (Volianitis et al. 2001). Testing Protocol 1 (T1) required the participants to perform either maximal inspiratory mouth pressure (P_{Imax}) or maximal expiratory mouth pressure (P_{Emax}) manoeuvres whilst maintaining a variety of specified-static rowing-related postures. Testing Protocol 2 (T2) consisted of maximal flow volume loops (MFVLs) manoeuvres in the same postures used in T1. All participants undertook a familiarisation session prior to the start of testing, during which all respiratory manoeuvres were performed (at moderate efforts) in the various postures.

The 'catch' position was defined as a 75° angle of flexion at the hip (but with legs straight), whilst the 'finish' postures were defined as extended hip angles of 110°, 130° and 150°. Three 'finish' postures were examined to accommodate variations of the 'finish' positions that arise in rowing. The postures were assigned randomly and were either 'supported' (S) by a bench or 'unsupported' (U). 'Unsupported' postures required the participants to sustain the specified posture against gravity during the manoeuvres.

Since respiratory pressure generating capacity influences starting lung volume, which in turn influences maximal pressure and flow generating capacity, starting lung volume was controlled by initiating all test manoeuvres in the upright position. In this way, the influence of body position upon postural co-contraction of the trunk muscles was isolated from the effect of body position upon starting lung volume. Whilst this standardisation reduced external validity, it increased internal validity, and also provided an indication of the 'best case scenario' in terms of the magnitude of any effects of posture upon respiratory muscle function, i.e., any effects would be minimised because they did not include the well established influence of lung volume upon respiratory muscle function.

Procedures

Pulmonary and respiratory muscle function measurements

Inspiratory warm-up

Prior to all testing sessions, participants performed an inspiratory muscle warm-up using a pressure threshold-loading device (POWERbreathe, HaB International Ltd., Southam, UK). With nares occluded, participants performed two sets of 30 breaths, with a 1-min rest break between sets, at a resistance equivalent to 40 % P_{Imax}. The warm-up was performed in an upright standing position; all breaths were initiated from residual volume (RV). Participants were instructed to inhale fully against the set resistance and then to exhale slowly until "empty". This warm-up protocol has been shown to attenuate the effect of repeated measurement upon P_{Imax} and to improve reliability, which can otherwise require repeated efforts in order to obtain a representative maximal value (Lomax and McConnell 2009; Volianitis et al. 2001). To date, there is no evidence to suggest that this procedure influences any other aspect of pulmonary function. No data on the benefits of an expiratory muscle warm-up are currently available, so this was not implemented.

Respiratory muscle strength

Maximal inspiratory and expiratory mouth pressure manoeuvres (P_{Imax} and P_{Emax}, respectively) were measured as surrogates of inspiratory and expiratory muscle strength. Measurements were performed using a portable handheld mouth pressure meter (Micro Medical MPM, Micro Medical Ltd., Kent, UK). Regardless of the manoeuvre, all measurements were initiated in the 90° upright position. Participants were required to either inhale fully [to total lung capacity (TLC)] or exhale fully (to RV) in the upright position and were manually positioned into the specified posture, whereupon they performed the designated manoeuvre. Participants were required to maintain head and neck alignment (head upright looking forward) for all manoeuvres. Participants held the mouth pressure meter with one hand, while the other hand was relaxed by their side. The procedure was repeated until two P_{Imax} or P_{Emax} values were reproduced within 5 cmH_2O. The highest reproducible value was recorded and presented in cmH_2O.

Maximal flow volume loop

Maximal flow volume loop (MFVL) measurements were made using a handheld spirometer (MicroLoop, Micro Medical Ltd., Kent, UK). The following measures were recorded: PIF, PEF, forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV_1). A minimum of three technically acceptable attempts were performed. The highest value achieved for PIF, PEF, FVC and FEV_1 was determined from the usable curves (ATS/ERS 2005). The same preparatory routine was used to standardise starting lung volume as was applied for the measurements of P_{Imax} and P_{Emax}. All MFVL measurements were initiated at full inhalation (TLC) and both the expiratory and inspiratory loops were performed as one continuous manoeuvre.

Imposition of rowing-related postures

The stroke was divided into three distinct phases: the 'catch', sitting upright and the 'finish' (Fig. 1). All participants performed the T1 and T2 protocols on an adjustable table. A universal goniometer was used to measure hip/trunk angle and to adjust the bench. The fixed arm of the goniometer was kept parallel to the longitudinal axis of the femur by fastening it to the supporting bench, whilst the moving arm was adjacent to the lumbar region of the spine to determine the joint angle at the hip. During the rest periods between each respiratory manoeuvre, the goniometers were re-adjusted to the next position.

The rowing-related postures included hip flexion to 75° with legs straight (simulated 'catch' position), sitting upright at 90°, and lumbar extension to 110°, 130° or 150° (the 'finish' position). The 'catch' position was adopted with legs straight to isolate the postural role of the trunk muscles from the effect of abdominal compression by the thighs. Postures >90° are consistent with the normal range of back extension during the drive phase of the rowing stroke (Mahler et al. 1984). An extended range of motion to 150° was utilised to examine the fully extended position.

In summary, participants were positioned on a bench, sitting upright with legs straight. Breathing manoeuvres were performed in either 'supported' (S) or 'unsupported' (U) postures. Eight different postures were examined for each breathing manoeuvre: three 'supported' positions 110°, 130° and 150° (S-110°, S-130° and S-150°, respectively); and five 'unsupported': 75°, 90°, 110°, 130° and 150° (U-110°, U-130° and U-150°, respectively).

Testing protocol

All participants performed two test sessions consisting of either the T1 (respiratory mouth pressures) or T2 (MFVLs) test protocol. Only one test protocol was performed per session. Each testing session required participants to perform three 'blocks' of measurements; a block was defined as one breath per respiratory manoeuvre in each of the eight different postures. The T1 protocol consisted of a total of 16 respiratory manoeuvres per block (i.e. 48

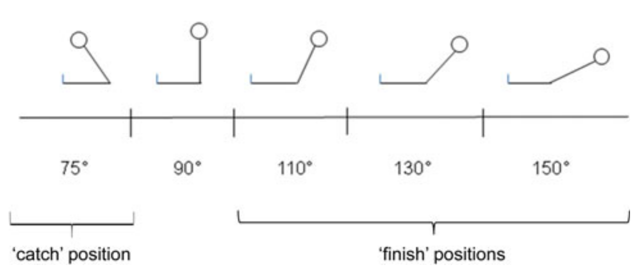

Fig. 1 Schematic diagram of the simulated rowing postures

breaths per testing session) and T2 protocol consisted of eight measurements per block (i.e. 24 measurements per testing session). All postures were randomised and the manoeuvres were alternated allowing a timed 1-min recovery between each breathing manoeuvre. A short rest break was provided between each block of measurements (~15 min).

Statistical analysis

Limits of agreement were used to ascertain the reliability of the percentage change from the 90° position for respiratory pressures and MFVL measurements performed on two separate days (Bland and Altman 1986); these were used to estimate the random and systematic error. These estimates were performed using a bespoke Excel spreadsheet, based upon the calculations of Zar (1998). A repeated measures analysis of variance (ANOVA) was used to determine intra-participant differences in outcome variables between postures measured as a percentage change from upright seated (90°).

Planned pairwise comparisons were performed using paired sample *t* tests to determine within-subject differences in postures compared as a percentage change from upright seated (90°). The Bonferroni adjustment was applied, where appropriate. Pearson's correlation coefficient was used to determine relationships between absolute variables and the percent change from 90° in the various postures. Probability values $\leq$0.05 were considered significant, unless a Bonferroni adjustment was applied. All results are expressed as mean and standard deviation (SD) unless stated otherwise.

Results

Inter-test precision

Measurements of P_{Emax} in the U-110° and U-150° posture, showed the lowest reliability (see Table 1). All other parameters were within 95 % limits of agreement. Where appropriate, the influence of reliability upon statistical power is considered when interpreting data.

Maximal mouth pressures

Percentage change and mean values for all outcome variables are reported in Table 2. Maximal expiratory pressure (P_{Emax}) was lower, compared to P_{Imax}. Both P_{Emax} ($P = 0.036$) and P_{Imax} ($P = 0.085$) tended to decrease with recumbency, and there was a significant main effect for P_{Emax} in unsupported recumbent postures ($P = 0.036$). However, the post hoc analysis did not identify any significant differences in any specific posture.

Maximal flow volume loops

All MFVL measurements decreased with recumbency; but only PIF, FVC and FEV_1 showed statistically significant decreases in the unsupported finish positions ($p < 0.05$; Greenhouse Geiser). There was a within-subject effect between PEF and posture compared to upright seated ($P = 0.039$; Greenhouse Geiser); however, post hoc analysis revealed no significant differences, using the Bonferroni corrected critical value of P ($p < 0.0125$), at any posture. There was a significant decrease in PIF compared to upright seated at U-110° ($P = 0.010$), U-130° ($P = 0.002$), and

Table 1 Random and systematic error for the between day measurements of respiratory pressures and pulmonary function

Variable	RE	SE		RE	SE		RE	SE
P_{Emax} (cm H_2O)			PEF (L min^{-1})			FVC (L)		
75°	0.31	0.09		0.13	0.04		0.13	0.04
S-110°	0.31	0.09		0.05	0.02		0.06	0.02
U-110°	0.23	0.07		0.05	0.01		0.06	0.02
S-130°	0.30	0.09		0.10	0.03		0.07	0.02
U-130°	0.19	0.06		0.09	0.03		0.08	0.02
S-150°	0.25	0.07		0.07	0.02		0.08	0.02
U-150°	0.43	0.14		0.19	0.06		0.10	0.03
P_{Imax} (cm H_2O)			PIF (L min^{-1})			FEV_1 (L)		
75°	0.27	0.08		0.17	0.05		0.16	0.05
S-110°	0.29	0.09		0.11	0.03		0.06	0.02
U-110°	0.22	0.07		0.15	0.04		0.05	0.02
S-130°	0.26	0.08		0.15	0.04		0.06	0.02
U-130°	0.30	0.09		0.13	0.04		0.12	0.04
S-150°	0.31	0.09		0.20	0.06		0.07	0.02
U-150°	0.26	0.08		0.17	0.05		0.07	0.02

Values are for the percentage change from 90°

RE random error, *SE* systematic error

Table 2 Group mean and standard deviation values for respiratory pressures and pulmonary measurements assessed during different rowing trunk angles

	75°	90°	S-110°	U-110°	S-130°	U-130°	S-150°	U-150°
P_{Emax} (cm H_2O)*	−4.8 (3.1)%	115.6 (30.3)	0.5 (10.2)%	−2.9 (2.8)%	−1.3 (5.5)%	−1.9 (4.4)%	−3.4 (2.6)%	−9.1 (1.6)%
	110.2 (33.0)		115.9 (31.3)	111.8 (29.5)	113.6 (28.9)	112.9 (29.0)	112.7 (35.1)	106.9 (32.4)
P_{Imax} (cm H_2O)	−3.9 (2.1)%	122.8 (29.4)	−1.9 (3.4)%	−1.2 (7.5)%	−1.6 (6.2)%	−5.6 (1.4)%	−7.8 (1.6)%	−8.4 (2.0)%
	117.3 (26.9)		120.6 (29.4)	121.2 (29.4)	121.6 (33.3)	115.8 (28.0)	113.1 (29.9)	111.9 (28.0)
PEF (L min^{-1})	−0.6 (5.6)%	542.9 (128.7)	−0.1 (7.1)%	−2.5 (2.8)%	−2.6 (2.4)%	−3.5 (1.7)%	−3.6 (1.5)%	−7.2 (1.6)%
	536.4 (117.9)		540.6 (126.5)	525.7 (116.3)	525.8 (120.7)	522.0 (123.7)	522.1 (125.1)	501.6 (127.9)
PIF (L min^{-1})	−4.0 (1.5)%	472.7 (139.1)	1.0 (13.0)%	−4.7 (1.4)%*	−3.5 (1.9)%	−6.7 (1.0)%**	−6.7 (1.4)%*	−8.9 (1.5)%
	450.3 (124.9)		470.8 (130.7)	448.1 (129.9)	452.9 (128.2)	441.9 (135.6)	434.9 (117.5)	423.2 (118.4)
FVC (L)	−2.2 (1.8)%	5.27 (1.14)	−0.3 (5.1)%	−3.7 (0.8)%**	−1.2 (2.5)%	−4.7 (0.8)%**	−2.4 (3.0)%*	−7.4 (6.5)%**
	5.15 (1.14)		5.25 (1.13)	5.07 (1.12)	5.20 (1.13)	5.03 (1.14)	5.14 (1.13)	4.88 (1.17)
FEV_1 (L)	−2.2 (5.2)%	4.19 (0.91)	0.7 (3.8)%	−2.7 (5.2)%	−1.2 (3.5)%	−3.6 (4.7)%*	−3.3 (4.3)%*	−5.5 (7.0)%**
	4.08 (0.86)		4.21 (0.89)	4.07 (0.87)	4.13 (0.89)	4.03 (0.87)	4.04 (0.87)	3.95 (0.91)

Data expressed as percentage change from upright seated (90°) as mean and SD

* Significantly decreased compared to upright seated ($p < 0.0125$; Bonferroni corrected critical value for P for unsupported posture comparisons)

** Significantly decreased compared to upright seated ($p \leq 0.007$; Bonferroni corrected critical value for P for comparison of all postures)

S-150° ($P = 0.011$) postures. As shown in Table 3, there were significant correlations between the percentage change from 90° for PEF and P_{Emax} at S-130° ($P = 0.023$) and PIF and P_{Imax} at U-110° ($P = 0.043$).

Forced vital capacity (FVC) showed a decrease compared to upright seated at U-110° ($P = 0.000$), U-130° ($P = 0.000$), U-150° ($P = 0.0000$) and S-150° ($P = 0.007$) postures.

Similarly, FEV_1 also decreased in U-110° ($P = 0.008$), U-150° ($P = 0.007$) and S-150° ($P = 0.008$). There were no significant correlations between the percentage change from 90° for mouth pressures and FVC, or FEV_1.

Discussion

Main findings

The aim of this study was to determine whether respiratory pressure and flow generating capacity were impaired in positions that were similar to those of the ‘catch’ and ‘finish’ of the rowing stroke, and to assess the effect of unloading the postural role of the trunk muscles by supporting the trunk in these positions. To isolate the influence of trunk muscle co-contraction, starting lung volume was also standardised. There was a significant interaction effect between posture and respiratory mouth pressure, an impairment of dynamic function (PIF) in the unsupported recumbent postures, as well as a significant impairment of FVC and FEV_1 in most of the recumbent postures. Thus, when starting lung volume is controlled, inspiratory muscles appear to work effectively when generating quasi-static pressures in a wide range of rowing-related postures. However, all other outcome variables were reduced in the recumbent postures, with significant impairment of volumes and flows in extreme recumbency.

Effect of posture on respiratory muscle strength

There was a significant effect of unsupported recumbency upon P_{Emax} as well as some significant interrelationships between physiologically related variables, i.e. significant differences in pulmonary function seemed to be related to changes in respiratory muscle function. For example, respiratory mouth pressures and the MFVL measures were highest in the upright-seated (90°) position and S-110° compared to all other postures. The standardisation of the starting lung volume by initiating each manoeuvre from the upright posture (inhaling or exhaling before adopting the test posture) would have minimised the influence of posture upon the measured pressures. However, this was performed in order to minimise the effect of starting lung

Table 3 Correlations (r) between respiratory pressures and pulmonary function

	75°	S-110°	U-110°	S-130°	U-130°	S-150°	U-150°
P_{Imax}							
PEF	−0.17	−0.25	−0.04	0.33	0.22	−0.06	−0.15
PIF	0.08	−0.16	−0.44*	0.04	0.26	0.09	0.13
FVC	−0.02	−0.33	−0.08	−0.06	−0.20	−0.01	−0.01
FEV_1	−0.14	−0.32	−0.07	0.10	−0.15	−0.35	−0.12
P_{Emax}							
PEF	−0.12	−0.29	0.25	−0.50*	0.16	−0.07	−0.20
PIF	0.04	0.07	−0.15	−0.38	−0.33	−0.02	−0.17
FVC	−0.36	−0.08	−0.26	0.04	−0.05	0.04	−0.09
FEV_1	−0.50	0.02	−0.05	−0.17	−0.19	0.23	−0.26

Values are for the percentage change from 90°. All data are presented as r values

* $p \leq 0.05$

volumes upon the measured pressures, thereby isolating any effect of postural co-contraction of trunk muscles.

Previous studies have shown a tendency for respiratory muscle pressures to decline in recumbent postures (Ogiwara and Miyachi 2002; Talwar et al. 2002). This effect is most likely due to alterations in starting lung volumes in recumbent positions, since the force generating capacity of the respiratory muscles is dependent upon the starting lung volume, which influences both the length-tension relationship and the elastic contribution from the chest wall. Although we did not measure TLC or RV, our data showed a decline in FVC (4–7 %), PIF (5–9 %) and PEF (3–7 %) with recumbent postures compared to upright seated, which supports the notion that posture influenced the ability of the respiratory muscles to generate maximal volume and flow excursions. Thus, it is likely that if starting lung volume had not been standardised, that posture would have exerted a more potent influence upon respiratory mouth pressures than was observed.

Contraction of the diaphragm along with the expiratory muscles assists in maintaining spine stabilisation by increasing intra-abdominal pressure (Hodges and Gandevia 2000; Siegmund et al. 1999). Hence, the co-contraction of the diaphragm and abdominal muscles during simultaneous postural and respiratory manoeuvres in the recumbent positions could conceivably result in a decrease in the ability to generate respiratory muscle pressures. Accordingly, we had anticipated that unsupported recumbent body positions would have a negative impact upon respiratory muscle pressure generating capacity. However, we observed a relatively small difference in respiratory pressures (~5 %) measured in the supported versus unsupported recumbent postures (e.g., S-130° compared to U-130°), suggesting the functional impact was modest. A potential explanation may reside in the nature of maximal mouth pressure measurements, i.e. they are quasi-static efforts. Under conditions of bracing and static co-contraction it is conceivable that P_{Imax} and P_{Emax} are relatively unaffected. However, under conditions where respiratory muscle shortening must take place in the presence of static, stabilising contraction of the trunk musculature, i.e. during production of MFVLs in the recumbent unsupported positions, the competing demands upon the trunk muscles for breathing and postural functions may be greater. Our data suggest that this is indeed the case, since the unsupported postures had a greater effect upon dynamic flow and volume generation than on static pressure generation (see Table 2).

An observation that demands explanation is our finding that P_{Emax} was ~7 % lower than P_{Imax} in all postures. Typically, P_{Emax} is higher than P_{Imax} when measured in both normally seated and standing position. A potential explanation for our observation is the use of an inspiratory muscle 'warm-up' prior to P_{Imax} efforts. Previous studies suggest that this adds 10–12 % (Lomax and McConnell 2009; Volianitis et al. 2001) to the resulting maximal value for P_{Imax}. The influence of an expiratory muscle 'warm-up' has not yet been explored, but there is every reason to believe that such a 'warm-up' would result in a similar enhancement of function were it to be applied.

Effect of posture on MFVL parameters

Generally, flows and volumes tended to decrease in the unsupported recumbent positions (see Table 2). Various degrees of recumbency have been shown previously to induce changes in lung volumes and flow rates (Badr et al. 2002; Castile et al. 1982; D'Angelo and Agostini 1995; Kera and Maruyama 2005; Talwar et al. 2002). However, the influence of a supine posture observed by previous investigators has been attributed to the effects of fluid and organ shifts due to gravity (Kera and Maruyama 2005), which would not have played a part in our observations. We observed a significant decrease in PIF, FVC and FEV_1 in unsupported recumbent postures compared to sitting upright. Since starting lung volume was largely controlled, the influence of unsupported recumbency on MFVL parameters was most likely due to the competing postural role of respiratory muscles. These results are consistent with other research showing a decrease in the ability to generate fast forced expiration in recumbent postures (Meysman and Vincken 1998; Vilke et al. 2000; Tsubaki et al. 2009). It is possible that the compressive expiratory forces generated by the postural activation of trunk muscles during recumbency led to an increase in intra-thoracic pressure, resulting in a slight narrowing of the airways (McCool 2006), thereby impairing FEV_1.

Collectively, our MFVL data are consistent with the notion that co-contraction of the trunk muscles in recumbent positions impairs dynamic pressure and flow generating capacity. Functionally, this would explain the results of Siegmund et al. (1999), who observed a significant decrease in spontaneously generated PIFRs during exercise at the finish position of the rowing stroke, compared to an upright position. These authors also suggested that this decline was likely due to the co-contraction of the diaphragm and abdominal muscles to maintain trunk extension.

We did observe significant correlations between P_{Emax} and PEF ($r = -0.50$) and P_{Imax} and PIF ($r = -0.44$) from the upright position to recumbent postures. It appears that small impairments in respiratory muscle strength during recumbency (presumably due to co-contraction of trunk postural stabilising muscles) may affect the ability to maximise respiratory flow rates. Since P_{Imax} and P_{Emax} were relatively unaffected by changes in posture, it is not entirely surprising that only two significant correlations were identified. In addition, the relatively large variability in the data (see Table 3) makes our correlational analyses difficult to interpret.

Methodological considerations

To remove the influence of chest and abdominal wall compression, the 75° 'catch' position was performed with straight legs (see Fig. 1). It is recognised that during the rowing stroke the 'catch' position is characterised by knees fully bent pressed against the chest and abdomen. Thus, the two positions are not directly comparable. However, this modified position allowed for an uncontaminated assessment of the postural role of respiratory muscles in this position. During the actual rowing stroke, the thighs may limit or prohibit abdominal excursion, which may impair the ability to generate maximal pressures and flows. Hence, the results of this study are not directly applicable to the catch position, and probably represent a best-case scenario in terms of the detrimental influence of this posture upon respiratory function in this position.

Whilst performing recumbent respiratory manoeuvres, participants were required to start the manoeuvre by either inhaling fully or exhaling completely in the upright, seated position. Participants were then assisted to the correct recumbent position before initiating the respiratory manoeuvre, thus maintaining a consistent head and neck posture and assuring participants reached the appropriate lung volume for each manoeuvre. Although we cannot be certain that all participants were able to sustain the achieved lung volume whilst being repositioned, each manoeuvre was performed a minimum of three times, achieving FVC and FEV_1 repeatability within 0.150 L, to maximise reliability. However, it is important to acknowledge there may have been a degree of error in the positioning of the participants to the required postures at specified hip angles.

Conclusion

Significant interaction effects between posture and P_{Emax}, P_{Imax}, PEF and PIF suggest that respiratory function was impaired in the unsupported recumbent positions. Respiratory function tended to be optimised in the seated or more upright postures, and minimised in unsupported recumbent postures. Although these findings are not directly applicable to the dynamic nature of rowing, they demonstrate that involvement of trunk muscles in postural activities impairs maximal function of the respiratory pump muscles.

Conflict of interest AKM declares a beneficial interest in the POWERbreathe® inspiratory muscle trainer in the form of a share of license income to the University of Birmingham, as well as acting as a consultant to HaB International Ltd. LAG has no potential conflicts of interest.

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