Appl Psychophysiol Biofeedback
DOI 10.1007/s10484-008-9052-3

# Evaluation of Breathing Pattern: Comparison of a Manual Assessment of Respiratory Motion (MARM) and Respiratory Induction Plethysmography

**Rosalba Courtney · Jan van Dixhoorn · Marc Cohen**



**Abstract** Altered breathing pattern is an aspect of dysfunctional breathing but few standardised techniques exist to evaluate it. This study investigates a technique for evaluating and quantifying breathing pattern, called the Manual Assessment of Respiratory Motion (MARM) and compares it to measures performed with Respiratory Induction Plethysmography (RIP). About 12 subjects altered their breathing and posture while 2 examiners assessed their breathing using the MARM. Simultaneous measurements with RIP were taken. Inter-examiner agreement and agreement between MARM and RIP were assessed. The ability of the measurement methods to differentiate between diverse breathing and postural patterns was compared. High levels of agreement between examiners were found with the MARM for measures of the upper rib cage relative to lower rib cage/abdomen motion during breathing but not for measures of volume. The measures of upper rib cage dominance during breathing correlated with similar measures obtained from RIP. Both RIP and MARM measures methods were able to differentiate between abdominal and thoracic breathing patterns, but only MARM was able to differentiate between breathing changes occurring as result of slumped versus erect sitting posture. This study suggests that the MARM is a reliable clinical tool for assessing breathing pattern.

**Keywords** Breathing pattern assessment · Dysfunctional breathing · Manual Assessment of Respiratory Motion reliability

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## Introduction

The aim of this study is to determine the utility of a technique called the Manual Assessment of Respiratory Motion (MARM) used to assess and quantify breathing pattern, in particular the distribution of breathing motion between the upper and lower parts of the rib cage and abdomen under various conditions. It is a manual technique that once acquired is practical, quick and inexpensive. Its utility is assessed on the basis of the inter-rater reliability and its ability to differentiate between clearly different breathing patterns.

Non-invasive estimation of breathing movement has been used to derive several respiratory parameters, including time components like breathing frequency, inhalation time, exhalation time and exhalation pauses, as well as volume components like tidal volume and pattern of recruitment of respiratory muscles (Society 2002). Measures of breathing pattern usually involve the assessment of displacement and movement of the two main functional compartments of the body involved in breathing i.e. the upper rib cage and lower rib cage/abdomen.

In the research setting the two main types of instrumentation used to evaluate breathing pattern are Respiratory Induction Plethysmography (RIP) and Magnetometry (Society 2002) whilst in the clinical environment, the cheaper and less time consuming methods of observation and palpation are the mainstay of breathing pattern assessment (Clanton and Diaz 1995). Clinical techniques for evaluating muscle and rib cage movement and recruitment patterns frequently involve manual palpation and visual assessment (Chaitow et al. 2002; Pryor and Prasad 2002) however these procedures have not been standardized or validated.

### The Manual Assessment of Respiratory Movement (MARM)

The MARM is a palpatory procedure based on the examiners interpretation and estimation of motion perceived by their hands at the posterior and lateral lower rib cage. The examiner using the MARM can gauge various aspects of breathing such as rate, regularity, but its particular utility is for assessing breathing pattern and the relative distribution of breathing motion between upper rib cage and lower rib cage and abdomen.

The MARM also takes into account the form of the spinal column, whose extended or flexed form constitutes a third degree of freedom of breathing movement (Smith and Mead 1986). Extension of the spinal column increases the distance between the pubic symphysis and xiphoid process, elevates the ribcage, facilitating upward motion of the sternum/upper thorax (pump-handle motion) as well as abdominal expansion. Thus, it facilitates inhalation in a vertical direction ('length breathing'). By contrast, a slumped posture inhibits the vertical movement of inhalation, increases pressure of abdominal contents to increase diaphragm length and promotes lateral expansion and sideways elevation of the lower ribs or bucket-handle movement. Thus, it facilitates inhalation in a horizontal direction ('width breathing'). The MARM is able to differentiate between these breathing patterns and assess asymmetry between the two sides of the body. In case of scoliosis or sideways distortion of the spinal column there is a marked difference in breathing movement between the left and right sides of the body and this can be registered clearly by the examiners two hands. Such asymmetry adds even more degrees of freedom of breathing movement, but would remain unobserved when one relies on assessment by RIP.

An assumption of the MARM procedure is that breathing is a *global* movement of expansion (inhalation) and contraction (exhalation) of the body. From the manual assessment of motion at the lower ribs the examiner constructs a mental picture of global breathing motion, represented by an upper line and a lower line, originating from the centre of a circle or ellipse, together creating a slice in a pie chart, which represents the area of expansion. Specific features of the global change in form that can be estimated are: the degree that the sternum and upper thorax are lifted upwards, the degree that the lower ribs lift and expand sideways and the degree that diaphragmatic descent expands the abdomen outwards. The predominance of motion in either the upper rib cage/sternum or the lower rib cage/abdomen determines the direction of the global change with inhalation, as either predominantly in an upward or downward direction and the shape as either elongation or widening.

Individuals may differ in their breathing response to postural change. For example when the spine is extended inspiration may result in a general increase in breathing motion with greater involvement of both upper thorax and abdomen or result in upward elevation of the chest with little increase or paradoxical decrease in abdominal motion.

The two lines of MARM are a simplified way of describing the global form of inhalation. The recent technology of opto-electronic plethysmography (OEP) shares the same assumption of MARM and uses between 40 and 80 markers on the body that can be followed by several camera's (Aliverti et al. 2000). From these recordings the form and volume of the 'sphere' is calculated, or mathematically recreated, which corresponds accurately with actual breathing movement. The procedure is much like the creation of animation movies. From OEP research it appears that there are many degrees of freedom in respiratory movement (or form changes), all resulting from more or less successful adaptations of breathing to different circumstances (Aliverti et al. 1997, 2003, 2007).

With the MARM, having the subject intentionally breathe in different ways, the examiner can test the functionality of breathing. The procedure is derived from the practice of breathing therapy, which aims to test and increase the functional adaptability or flexibility of breathing (Dixhoorn 2007). For instance, the subject can be asked to breathe normally and more deeply, to breathe with emphasis on upper thoracic or more abdominal inhalation, to breathe in an upright or easy sitting posture. The range of breathing patterns produced suggests that functional breathing involves flexibility and a range of breathing patterns. This may be operationalised in the MARM as the largest distance between the highest upper line and the lowest lower line across several maneuvers.

The diaphragmatic, abdominal and rib cage muscles all have optimum length tension relationships and co-ordination patterns that make breathing most efficient when all muscle groups are equally involved (De Troyer and Estenne 1988). This suggests that 'optimal' breathing occurs when there is an even distribution of breathing effort between the two main functional compartments of the body involved in breathing i.e. upper rib cage and lower rib cage/abdomen. The distribution of breathing effort can be measured using RIP by determining the % rib cage motion and can be assessed using the MARM by deriving measures of ‘balance’ and % rib cage motion, which indicate the relative contributions of upper and lower half of the body. Efficient breathing occurs when ‘percent rib cage’ is around 50 and ‘balance’, (upper half minus lower half) is minimal. An uneven breathing distribution without good reason may be considered to be unnecessary, effortful and dysfunctional.

The MARM procedure was first developed and applied in a follow-up study of breathing and relaxation therapy with cardiac patients in the 1980s. It appeared that 2 years after breathing therapy the MARM still showed differences between experimental and control patients (Dixhoorn 1994). The experimental group showed more involvement of the lower half of the body and better balance, both at rest and during deep breathing. Later preliminary tests of inter-examiner reliability indicated that the MARM has potential as a clinical and research tool for evaluating breathing pattern (Dixhoorn 2004) and that further investigations are warranted.

In this study we used experienced ‘breathers’ to test the ability of the MARM to differentiate between nine different breathing patterns and postures. We also assessed the validity and inter-examiner reliability of the MARM by comparing the measures made with the MARM to measures made simultaneously with RIP (Vivometrics Lifeshirt system).

Our hypotheses were

1. Different examiners will make similar assessments when using the MARM on the same subject breathing consistently.
2. There will be a significant correlation between MARM and RIP measurements of ‘percent ribcage’.
3. RIP measures of ‘percent ribcage’ and MARM measure of ‘balance’ are able to differentiate between (a) voluntary thoracic and abdominal breathing and (b) breathing with an extended and slumped spinal column.
4. Experienced breathers have ‘percent ribcage’ values of about 50, ‘balance’ values approaching zero and a large total range of MARM across the different procedures.

The study was undertaken at RMIT University, Biomedical Sciences Laboratory in Melbourne Australia. Ethics approval was received from RMIT University ethics committee and all subjects gave written consent.

## Method

### Examiners

The tests were done by three experienced osteopaths all of who had several years of clinical experience in manual therapy. One of them (RC), the principle investigator, was personally trained in MARM by Van Dixhoorn while the other examiners all had 2 h of instruction and practice using the MARM during which time subjects altered their posture and breathing pattern with each examiner being given appropriate feedback about their palpation technique and findings. RC did the MARM on all subjects and her data were used to compare with the Lifeshirt and the other examiners.

### The MARM

The examiners received the following instructions on how to perform and record the MARM:

> Sit behind the subject and place both your hands on the lower lateral rib cage so that your whole hand rests firmly and comfortably and does not restrict breathing motion. Your thumbs should be approximately parallel to the spine, pointing vertically and your hand comfortably open with fingers spread so that the little finger approaches a horizontal orientation. Note that the 4th and 5th finger reach below the lower ribs and can feel abdominal expansion. You will make an assessment of the extent of overall vertical motion your hands feel relative to the overall lateral motion. Also decide if the motion is predominantly upper rib cage, lower rib cage/abdomen or relatively balanced. Use this information to determine the relative distance from the horizontal line of the upper and lower lines of the MARM diagram. The upper line will be further from the horizontal and closer to the top if there is more vertical and upper rib cage motion. The lower line will be further from the horizontal and closer to the bottom if there is more lateral and lower rib cage/abdomen motion. Finally get a sense of the overall magnitude and freedom of rib cage motion. Place lines further apart to represent greater overall motion and closer for less motion.

Examiners were required to draw two lines to form a ‘pie chart’ for each event. The MARM graphic notion which is drawn by the examiner can be seen in Fig. 1. The MARM variables are calculated by measuring angles determined from the 2 lines drawn by examiners, based on their palpatory impressions, with the top taken to be 180° and the bottom at 0°. An upper line (A) represents the “highest point of inhalation” and is made by the examiners perception and estimation of the relative contribution of upper rib cage particularly the extent of vertical motion of sternum and upper rib cage. The lower line (B) represents the “lowest part of inhalation” and this corresponding to examiners perception and estimation of the relative contribution of lower rib motion and abdominal motion particularly the

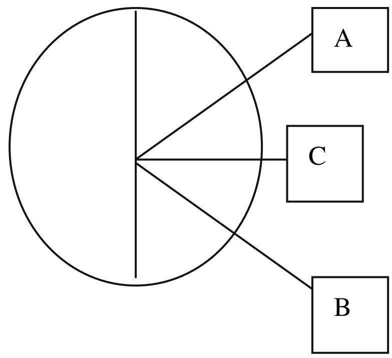


**Fig. 1** The MARM graphic notation

extent of lateral expansion. With more thoracic breathing the upper line A is placed higher and when breathing is more abdominal with greater lateral expansion of the lower rib cage the lower line B is placed lower.

The 3 MARM measurement variables are:

(1) Volume = angle formed between upper line and lower line (area AB).
(2) Balance = difference between angle made by horizontal axis (C) and upper line (B) and horizontal and lower line (AC–CB).
(3) Percent rib cage motion = area above horizontal/total area between upper line and lower line × 100 (AC/AB × 100).

## Subjects

Subjects were 12 "experienced breathers", who were yoga or breathing therapy teachers and included 7 females and 5 males aged between 25–65 years (average 37 years). Subjects were requested to manipulate their breathing pattern and keep the pattern for some minutes, to allow for each measurement. They were taken through a trial run of breathing and posture requirements to confirm their ability to comply with instructions.

While wearing the Lifeshirt, the subjects were instructed to follow a sequence of nine different posture and breathing combinations. These instructions were displayed on a computer screen and explained verbally in the same order to each person (Table 1). They were asked to keep the same breathing and posture pattern until a digital timer signalled the time to stop after 3 min. During each 3 min interval examiners performed the MARM procedure and recorded their findings without consultation with each other or the subject. The onset of each breathing period was recorded on a handheld electronic diary which is part of the LifeShirt™ system. This enabled subsequent identification and analysis of data for each separate period.

## Data Collection

### *Respiratory Induction Plethysmography (RIP)*

The LifeShirt™ (Vivometrics, Inc. California, USA) was the RIP device used to record electronic data. After measurement of chest dimensions, the subjects were asked to put on the correct size LifeShirt vest to ensure that there was correct body contact with the RIP bands. The motion detecting RIP bands embedded in the LifeShirt vest surround the circumference of the body at the thoracic region under the axilla and around the abdomen. Three ECG electrodes were also attached to the chest wall. Calibration was performed at the start of each session using a fixed volume calibration bag.

LifeShirt measures were recorded on the Lifeshirt flash card and later downloaded into the Vivologic software (Vivometrics, Inc. California, USA) and data exported for analysis in SPSS.

The Lifeshirt measures a large number of cardiorespiratory variables, most of which are not comparable to MARM measures. Lifeshirt variables with expected correspondence to MARM measures were: Percentage rib cage motion (%RC) and Mean Phase Relation of Total Breath (MPRTB). For exploratory purposes we also analysed: Mean Inspiratory Flow (Vtti), Peak Inspiratory Flow (PifVt), Peak Inspiratory Flow of Rib Cage (PifRC), Peak Inspiratory Flow of Abdomen (PifAB), Ventilation/Peak Inspiratory Flow Ratio (Ve Pif), Inspiratory Tidal Volume (ViVol).

## Data Analysis

Pearsons correlation coefficient and intra-class correlations were calculated to check for agreement between examiners and between Lifeshirt and the MARM.

**Table 1** Order of 9 breathing & posture instructions

| | | |
|---|---|---|
| 1. Breathe normally-sit in your normal posture (BN-NP) | 4. Breathe normally-sit in slumped posture (BN-SP) | 7. Breathe abdominally-sit in slumped posture (BA-SP) |
| 2. Breathe thoracically-sit in your normal posture (BT-NP) | 5. Breathe normally-sit in erect posture (BN-EP) | 8. Breathe thoracically-sit erect posture (BT-EP) |
| 3. Breathe abdominally-sit in your normal posture (BA-NP) | 6. Breathe thoracically-sit in slumped posture (BT-SP) | 9. Breathe abdominally-sit erect posture (BA-EP) |

To test the ability of the MARM and the Lifeshirt to differentiate between the 9 different breathing patterns and postures we performed a within-subject analysis of variance for these jointly and then individually for each measurement method.

## Results

We were able to extract artefact free raw data of each of the 9 events for at least 2 min.

### Agreement Between Examiners Using MARM Measures

Pearson's correlation coefficients indicated that examiners using the MARM were in good agreement with each other for MARM balance measure, $r = .851$, $p = .01$ and MARM % rib cage motion, $r = .844$, $p = .01$. There was no statistically significant agreement between examiners on MARM volume measure, $r = .134$.

Intra-class correlation coefficients calculated for MARM measures using 2 way random effects model and absolute agreement definition suggest that examiners showed agreement for MARM balance, ICC = .850, $p = .0001$, CI(0.788, 0.895) and for MARM percent rib cage motion, ICC = .844, $p = .0001$, CI(0.780, 0.891).

### Agreement Between MARM and RIP (LifeShirt Measures)

The values for Pearson's correlations coefficient between MARM and Lifeshirt measures are shown in Table 2. There was a high and statistically significant correlation between the two measures of 'percent rib cage', $r = .597$, $p = .01$ while the Life shirt 'percent rib cage' correlated equally strongly with MARM balance, $r = .591$, $p = .01$, but much less with MARM volume, $r = 0.21$, $p < 0.05$.

**Table 2** Correlations between MARM measures and selected Lifeshirt variables

| | MARM%RC | MARM balance | MARM volume |
|---|---|---|---|
| LS%RC | *.597*** | *.59*** | *.21** |
| MPRTB | *.202** | *.20** | .081 |
| VTti | .063 | .074 | −.051 |
| PifVt | .027 | .039 | −.037 |
| PifRC | *.31*** | *.32*** | .020 |
| PifAB | *−.45*** | *−.44*** | −.111 |
| VePif | .022 | −.011 | −.050 |
| ViVol | −.045 | −.032 | −.071 |

* $p < 0.05$; ** $p < 0.01$

LS%RC—Percentage rib cage motion; MPRTB—Mean Phase Relation of Total Breath; VTti—Mean Inspiratory Flow; PifVt—Peak Inspiratory Flow; PifRC—Peak Inspiratory Flow of Rib Cage; PifAB—Peak Inspiratory Flow of Abdomen; VePif—Ventilation/Peak Inspiratory Flow Ratio; ViVol—Inspiratory Tidal Volume

As to the other life shirt variables, there was a small correlation between Life Shirt MPRTB and the MARM %RC measure and Balance measure, implying that as rib cage involvement increased there was a tendency for breathing to become more asynchronous. Also, there were positive correlations between peak inspiratory flow and the two principle MARM measures. Inspiratory flow resulting from rib cage expansion correlated positively with MARM percent rib cage and balance, whereas inspiratory flow resulting from abdominal expansion correlated negatively with them. Thus, the MARM's assessment of thoracic or abdominal breathing movement confirmed the degree of estimated air flow achieved by thorax or abdomen.

Intraclass correlation was calculated for consistency of agreement for single measures. For MARM% RC motion, ICC = .595, $p = .0001$ and for MARM Balance, ICC = .554, $p = .0001$.

### Ability of MARM and Lifeshirt to Differentiate Between Normal, Abdominal and Thoracic Breathing

The means and standard deviations are given in Table 3.

A within-subject analysis of variance using 3 factors (breathing, posture and measurement method) showed significant differences between normal, abdominal and thoracic breathing across all 9 events ($F(2,16) = 78.6$, $p = .0001$, $\eta^2 = .908$).

As can be seen in Fig. 2, for all 3 types of measurement methods, instructions to breathe thoracically in the 3 postures (normal, erect and slumped) resulted in more rib cage involvement than instructions to breathe normally or breath abdominally. Similarly, instructions to breathe abdominally in all 3 postures resulted in lesser rib cage involvement that that seen in normal or thoracic breathing.

Separate analysis of the 3 measurement methods using within-subject analysis of variance with 2 factors (breathing and posture) showed that each of the measurement methods was able to detect the voluntary breathing changes. For the MARM percentage rib cage measure ($F(2,22) = 191.2$, $p = .0001$, partial $\eta^2 = .946$) and for the MARM balance measure ($F(2,22) = 189.4$, $p = .0001$, partial $\eta^2 = .945$) the ability to differentiate between breathing patterns was very high. For the Lifeshirt percentage rib cage measure ($F(2,16) = 12.89$, $p = .0001$, partial $\eta^2 = .617$), however, the ability was less. This suggests that both the MARM and Lifeshirt are able to differentiate between breathing patterns, with the MARM's being markedly better.

**Table 3** Average values of the measurements

| Posture/breathing instruction | MARM "percentage rib cage" measure | RIP "percentage rib cage" measure | MARM "balance" measure |
|---|---|---|---|
| 1. Normal posture, normal breathing | 56 (±8)[a] | 44 (±6) | 6 (±12) |
| 2. Normal posture, thoracic breathing | 73 (±7) | 57 (±15) | 29 (±11) |
| 3. Normal posture, abdominal breathing | 32 (±13) | 35 (±17) | −20 (±16) |
| 4. Slumped posture, normal breathing | 41 (±14) | 39 (±7) | −11 (±17) |
| 5. Erect posture, normal breathing | 55 (±8) | 41 (±10) | 8 (±12) |
| 6. Slumped posture, thoracic breathing | 72 (±8) | 54 (±13) | 26 (±10) |
| 7. Slumped posture, abdominal breathing | 32 (±8) | 35 (±14) | −23 (±11) |
| 8. Erect posture, thoracic breathing | 76 (±7) | 52 (±12) | 32 (±8) |
| 9. Erect posture, abdominal breathing | 30 (±9) | 31 (±22) | −25 (±10) |

[a] Mean and standard deviation

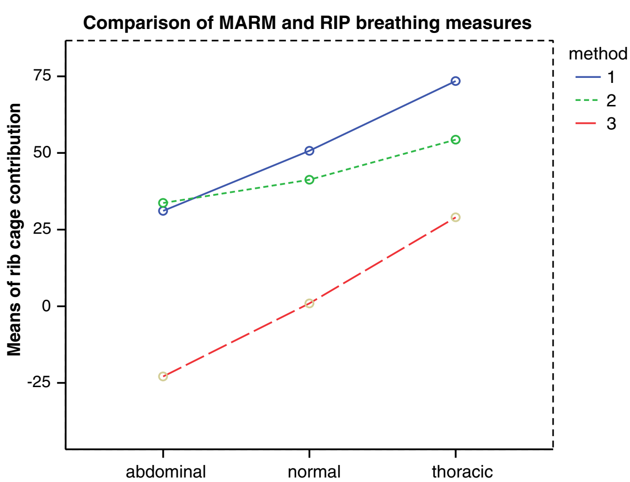


**Fig. 2** Effects of abdominal, normal and thoracic breathing for the 3 measurement methods. Method 1 = MARM percentage rib cage, Method 2 = Lifeshirt percentage rib cage, Method 3 = MARM balance

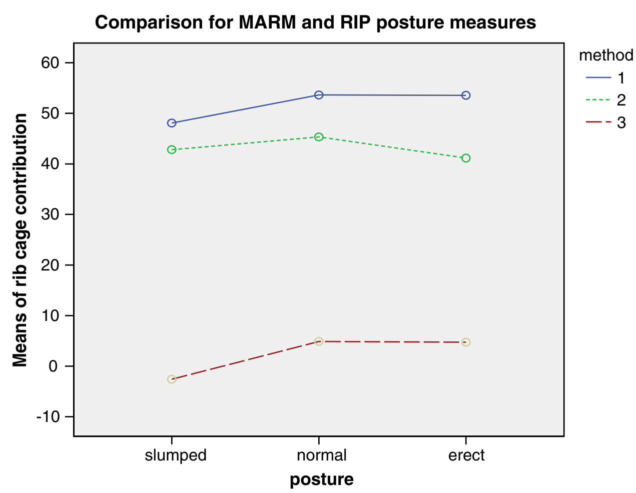


**Fig. 3** Effect of slumped, normal and erect sitting posture for three measurement methods. Method 1 = MARM percentage rib cage, Method 2 = Lifeshirt percentage rib cage, Method 3 = MARM balance

## MARM and Lifeshirt Differentiation of Effects of Postural Change on Breathing

The within-subject analysis of variance using 3 factors (breathing, posture and measurement method) showed that no overall significant difference resulted from changes in posture ($F(4,32) = 2.8$, $p = .091$, partial $\eta^2 = .258$). Investigation by analysis of variance of the individual measurement methods showed that the MARM measure of % rib cage motion was able to detect differences in breathing that resulted from changes in posture ($F(2,22) = 6.29$, $p = .007$, $\eta^2 = .364$) and the MARM measure of balance was also able to detect these differences ($F(2,22) = 189.4$, $p = .006$, $\eta^2 = .371$). Figure 3 shows the differences in breathing measures brought about by changes in posture, for the 3 measurement methods.

As can be seen in Figs. 4 and 5, for both MARM measures the change in posture from slumped to erect had positive effects in combination with the instruction "breathe thoracically", less so with the instruction "breathe normally" and an opposite effect with the instruction to breathe abdominally. Thus, sitting upright stimulated thoracic breathing movement, and lessened abdominal breathing movement.

With respect to the Lifeshirt, analysis of variance showed that it only marginally differentiated between postural effects on breathing ($F(2,16) = 3.3$, $p = .062$, partial $\eta^2 = .294$). The results of the Lifeshirt percentage rib cage motion can be seen in Fig. 6. Interestingly, the results of the Lifeshirt with posture change are quite different from the results obtained with the MARM. With the Lifeshirt the erect posture did not result in a greater measure of thoracic breathing, rather it recorded a decrease in the measurement of ribcage motion.

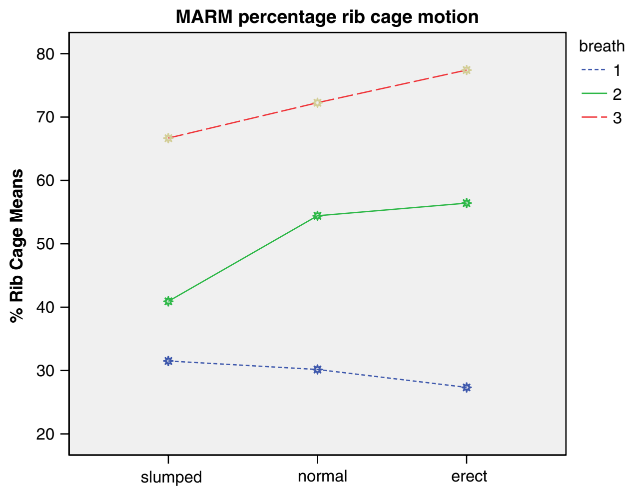


**Fig. 4** MARM% rib cage measures for slumped, normal and erect posture and three different types of breathing instruction. Breath 1 = abdominal, Breath 2 = normal, Breath 3 = Thoracic

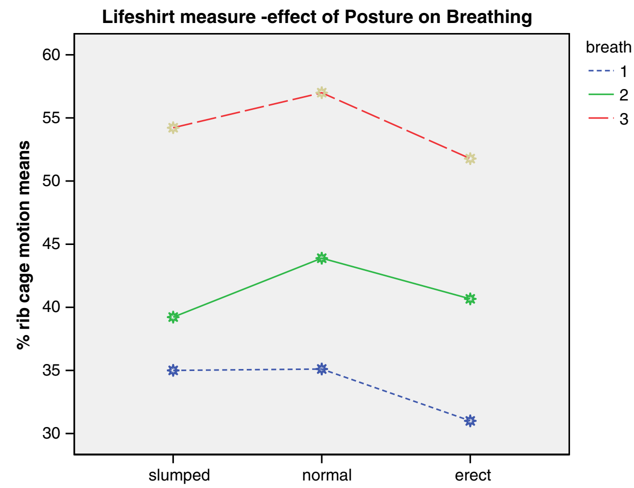


**Fig. 6** Breath 1 = abdominal, Breath 2 = normal, Breath 3 = Thoracic. This figure shows Lifeshirt percentage rib cage motion measures for effects of posture on change in relative rib cage motion with different types of breathing instruction

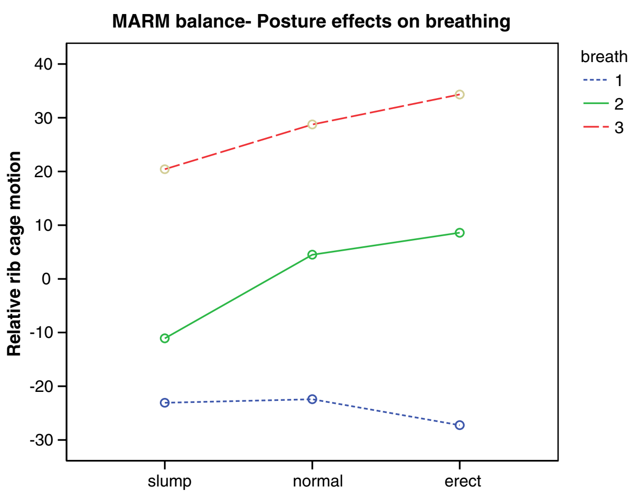


**Fig. 5** MARM balance measures for slumped, normal and erect posture and three different types of breathing instruction. Breath 1 = abdominal, Breath 2 = normal, Breath 3 = Thoracic

**Table 4** MARM functional breathing parameters for each subject

| Subject | Mean | sd | Minimum | Maximum | Range |
|---|---|---|---|---|---|
| 1 | 94.2 | 31.8 | 40 | 140 | 100 |
| 2 | 93.9 | 34.2 | 50 | 145 | 95 |
| 3 | 87.5 | 35.2 | 35 | 140 | 105 |
| 4 | 95.3 | 35.9 | 47 | 148 | 101 |
| 5 | 93.6 | 32.6 | 48 | 140 | 92 |
| 6 | 84.4 | 34.1 | 35 | 132 | 97 |
| 7 | 89.6 | 34.2 | 45 | 150 | 105 |
| 8 | 93.1 | 33.9 | 50 | 140 | 90 |
| 9 | 90.7 | 34.2 | 40 | 144 | 104 |
| 10 | 91.7 | 38.3 | 35 | 150 | 115 |
| 11 | 85.3 | 35 | 35 | 140 | 105 |
| 12 | 89.9 | 32.7 | 45 | 140 | 95 |
| Mean | 90.77 | 34.34 | 42.08 | 142.42 | 100.33 |
| sd | 3.56 | 1.70 | 6.11 | 5.21 | 7.00 |

## Functional Breathing Parameters

An assumption of the MARM is that functional breathing consists of a balance between upper and lower compartments of breathing. This would result in average values of ‘percent ribcage’ of around 50 and of ‘balance’ of around zero. Another assumption is that functionality of breathing implies a responsiveness to changes in breathing and posture. This would result in a large total range of MARM lines across the different procedures.

In Table 4 the values for each subject and the grand mean for all subjects are given. The first column shows the average values of all upper and lower MARM lines, based on their position on the semi-circle, ranging from 0 to 180° across the 9 events. Its grand mean is 90.8 and it ranges between subjects from 84.4 to 95.3. This corresponds to almost exactly the middle value and horizontal line of the half circle that is used in MARM notation. It implies that the percentage of top half (section AC) to total range (Section AB) is indeed close to 50. Likewise, the bottom half minus the top half is approaching zero.

As to the range of MARM values, Table 4 shows the lowest lower line (minimum) and highest upper line (maximum) and the distance between them (range). The average range between lowest and highest MARM line is about 100. In all subjects the maximal range is 90 or larger, which is more than half of the total range of a half circle of 180°.

## Discussion

The good agreement between examiners and between the MARM and comparable Lifeshirt measures along with the MARM's ability to differentiate clearly divergent patterns of breathing and posture suggest that the MARM is a useful and reliable tool for the assessment of breathing pattern with good inter-rater reliability. This confirms previous results (Dixhoorn 2004).

It appears that the MARM is a global assessment in the double meaning of global: general and spherical. The MARM provides a general indication of distribution of breathing pattern in its three dimensional form and was better able to distinguish between thoracic and abdominal breathing than RIP.

All four specific hypotheses relating to the utility of MARM were confirmed. Its ability to distinguish between more thoracic and more abdominal breathing was even greater than the Lifeshirt.

Given the fact that the subjects were 'experienced breathers', practiced in breath control, we may assume their MARM values to represent optimal breathing. The results confirmed that under resting and normal conditions the values of MARM, which theoretically range between 0 and 180, have an average of the almost exact middle value of 90. This implies a percent ribcage of about 50 and an even distribution of breathing between the two main compartments, which is expressed in the measure of 'balance' approaching zero.

As a measure of functionality MARM can be used to test flexibility of breathing pattern by assessing the response to sufficiently divergent postural and respiratory instructions and by determining the maximum difference between upper and lower lines. The present data suggest that the maximum difference between upper and lower lines of MARM across several instructions should be at least 90. In theory, upward breathing moves fully vertically to lift the sternum and downward breathing moves fully vertically to press on the pelvic floor. The assessor's hands however are placed at the middle of the body and this limits the information acquired. The values of around 100 therefore seem to represent the limits of the range that can be assessed by the MARM. The variation between subjects is remarkably small for all parameters. This indicates that subjects may be taken as a sample of truly experienced breathers who are able to modify their breathing pattern as far as is feasible without creating undue effort.

More studies are needed to establish optimal cutoff scores by comparing the outcome to untrained and less experienced subjects as well as to patients with breathing or other difficulties. Re-analysis of one data set from a previous study showed that 12 subjects performing 3 different breathing events had comparable average values.

One option for future studies to assess functionality is to have subjects bend sideways, in order to imitate a scoliotic C-curve and test the adaptability of the ribcage to these posture changes. A strong characteristic of the MARM is its ability to distinguish differences between the left and right side of the chest. In case of even slight scoliosis, which is quite common, there may be marked differences between the two sides which remain unnoticed by traditional instrumental recordings. Such distortions may give rise to both disturbance of breathing movement as well as a sense of dyspnoea. Only OEP gives an accurate image of the exact shape of the breathing movement in all its variations (Aliverti et al. 2000).

Several limitations of this study should be noted. One is the low reliability of the absolute distance between the two lines. We called it 'volume' but it may be more accurate to call it 'area'. The exact place and distance of the two lines on the half circle appears to depend on the assessor's personal preference. There was no inter-rater agreement on the distance between the lines and it correlated only to a small degree with the Lifeshirt measures. Given the high agreement between assessors across the nine events on the other MARM measures, however, it seems probable that the assessor's preference of the placement of the lines is stable. Thus, it is likely that in clinical practice the clinician may compare his assessment on one occasion with his assessment at another occasion. This remains to be tested in a future study. Possibly, more intensive training is necessary including specific focus on the placement of the lines to increase reliability of 'area' assessment.

Another potential limitation is the requirements to perform the MARM correctly. In applying the MARM one forms a mental picture of the general change in shape of the body with in- and ex-halation. It requires sensitive hands as well as imagination. The assessors were all three trained and experienced osteopaths who were clearly able to perform the MARM correctly. It is not sufficient to simply put one's hands on another person's body and record any movement that one notices locally. The touch should be clear and firm but not intrusive or constrictive or in any way inhibit free breathing movement. The hands need to follow respiratory motion and the assessor should try to picture the origin and direction of the locally experienced movement. Possibly the MARM is particularly useful for clinicians who are experienced in touching other subject's bodies in a sensitive and perceptive way. The first two authors who are experienced practitioners have now taught the MARM to many subjects, with good practical success. However it remains to be seen how less experienced examiners are able to perform.

A limitation of the design of this study is the possibility of observer bias, because of the fixed order of the events and the possibility of visual information to establish posture. In future studies the order of events could be random. However, there is a natural sequence in difficulty of the events, which should not be ignored. In this study the examiners were not aware of any expected changes in breathing from posture. However they may have responded to visual cues, the assessor may have expected to feel more thoracic breathing when the subject was seen straightening up and the spine was extended. The experience of the author most familiar with this technique (JvD) is that the upper line of MARM can indeed be expected to rise in extended posture and examiners may have quickly discovered this. In future studies it may be advisable to use a random order of events, undisclosed to the assessor. Still, the act of extending the spine will always be noticeable by the hands on the back and some bias is inevitable even if assessors are blindfolded. The effect of spinal extension on the lower line is open, however, and cannot be firmly predicted. When the distance between symphysis pubis and sternum is increased there is also more space for abdominal expansion. Some subjects may use this space and increase abdominal expansion whereas others may predominantly lift the chest and show decreased abdominal expansion. Thus, it is important for the assessor to be as neutral as possible and observe the actual movements perceived by the hands, and not try to guess the breathing pattern.

The study used a relatively small number of subjects and compared results of only two examiners; this was another limitation of this study.

The correlation between the MARM and the Lifeshirt at 0.60 was not very high for a reliability assessment. We believe this is because the Lifeshirt only measures lateral expansion while the MARM also measured vertical motion. It is interesting that RIP measurement did not respond to spinal extension as MARM did. In fact, RIP showed a decrease of ribcage motion while the MARM showed an increase. This may reflect the fact that when the ribcage is lifted upwards ‘pump-handle’ or vertical motion of the rib cage dominates and there is a loss of some of its sideways expansion or ‘bucket-handle’ motion. MARM is apparently able to register the real upward motion, whereas RIP is limited to purely sideways expansion.

In future studies the MARM may be used to clarify the concept of ‘dysfunctional breathing’. This concept refers on the one hand to functional respiratory complaints, like disproportionate breathlessness and can be measured for instance by Nijmegen Questionnaire for hyperventilation complaints (Thomas et al. 2001). On the other hand it refers to disturbances in the biological function of breathing, without real physical causes. Signs include asynchrony of breathing movement between thorax and abdomen, predominantly upper-thoracic breathing, frequent or deep sighs, mouth breathing, exaggerated use of auxiliary respiratory muscles (Chaitow et al. 2002). It is still unclear to what degree the two definitions overlap. Functional respiratory complaints may be caused by uneven distribution of breathing movement, but also by other causes, like stress or anxiety (Morgan 2002). The MARM can be used to measure breathing movement and help to elucidate its role in the etiology of respiratory complaints. More specifically, as a tool in breathing therapy, the MARM is useful to quantify the effect of breathing therapy on the quality of respiratory movement. If such effects are related to improvements in complaints, it may be argued that they were due to disturbances in breathing movement.

## Conclusion

The MARM appears to be a valid and reliable clinical and research tool for assessing breathing movement with good inter-examiner and a greater ability to distinguish vertical ribcage motion than RIP. Further studies to confirm its clinical utility are warranted.

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