Video Article

Evaluation of Respiratory Muscle Activation Using Respiratory Motor Control Assessment (RMCA) in Individuals with Chronic Spinal Cord Injury

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Abstract

During breathing, activation of respiratory muscles is coordinated by integrated input from the brain, brainstem, and spinal cord. When this coordination is disrupted by spinal cord injury (SCI), control of respiratory muscles innervated below the injury level is compromised[1,2] leading to respiratory muscle dysfunction and pulmonary complications. These conditions are among the leading causes of death in patients with SCI[3]. Standard pulmonary function tests that assess respiratory motor function include spirometrical and maximum airway pressure outcomes: Forced Vital Capacity (FVC), Forced Expiratory Volume in one second (FEV_1), Maximal Inspiratory Pressure (PI_{max}) and Maximal Expiratory Pressure (PE_{max})[4,5]. These values provide indirect measurements of respiratory muscle performance[6]. In clinical practice and research, a surface electromyography (sEMG) recorded from respiratory muscles can be used to assess respiratory motor function and help to diagnose neuromuscular pathology. However, variability in the sEMG amplitude inhibits efforts to develop objective and direct measures of respiratory motor function[6]. Based on a multi-muscle sEMG approach to characterize motor control of limb muscles[7], known as the voluntary response index (VRI)[8], we developed an analytical tool to characterize respiratory motor control directly from sEMG data recorded from multiple respiratory muscles during the voluntary respiratory tasks. We have termed this the Respiratory Motor Control Assessment (RMCA)[9]. This vector analysis method quantifies the amount and distribution of activity across muscles and presents it in the form of an index that relates the degree to which sEMG output within a test-subject resembles that from a group of healthy (non-injured) controls. The resulting index value has been shown to have high face validity, sensitivity and specificity[9-11]. We showed previously[9] that the RMCA outcomes significantly correlate with levels of SCI and pulmonary function measures. We are presenting here the method to quantitatively compare post-spinal cord injury respiratory multi-muscle activation patterns to those of healthy individuals.

Video Link

The video component of this article can be found at http://www.jove.com/video/50178/

Protocol

1. Settings

1. Surface electrode heads were placed over the muscle bellies of left (L) and right (R) respiratory muscles: sternocleidomastoid (SC), scalene (S), upper trapezius on midclavicular line (UT), clavicular portion of pectoralis on midclavicular line (P), diaphragm on parasternal line (D), intercostal at 6th intercostal space on anterior axillary line (IC), rectus abdominus at umbilical level (RA), obliquus abdominis on midaxillary line (O), lower trapezius paraspinally at midscapular level (LT), and paraspinal paraspinally on iliac intercrestal line (PS)[6]. The ground electrodes were placed over the acromion processes. A Motion Lab System Back Pack Unit, with attached electrodes, was connected to a Motion Lab EMG Desk Top Unit and Powerlab System (**Figure 1**).
2. T-piece Monitoring Circuit to record the airway pressure was assembled as shown in **Figure 2** and connected to the Low Pressure Transducer (MP45) using air tube.
3. MP45 was connected to CD15 and Powerlab System (**Figure 1** and **Table 1**).

2. RMCA Protocol

1. The respiratory motor tasks consisted of Maximum Inspiratory Pressure Task (MIPT) and Maximum Expiratory Pressure Task (MEPT). To perform MIPT or MEPT, subjects were asked to produce maximum inspiratory effort from residual volume or expiratory efforts from total

lung capacity for 5 sec using a T-piece Monitoring Circuit (**Figures 1 and 2**). Each maneuver was cued by an audible 5-sec long tone and repeated 3x. At least 1 min of rest was allowed between each effort.

2. EMG input was amplified with a gain of 2,000; filtered at 30-1,000 Hz and sampled at 2,000 Hz. Airway pressure input was calibrated at 100 cm of water and sampled at 2,000 Hz. The EMG and airway pressure inputs were converted by the Powerlab acquisition system using 16-bit full scale ADC resolution. Airway pressure, sEMG and marker signals were recorded simultaneously[9].

3. Data Analysis

1. Multi-muscle activity distribution analysis windows of 5 sec each for MIPT or MEPT were determined from the event marker and airway pressure recorded with the cuing tone that signaled the subject when to begin and end the task (**Figure 3**). The sEMG activity for each muscle was calculated using a root mean square (RMS) algorithm[6,12] (**Figure 4**). Three repeated trials for each task were averaged[13] for each muscle (channel).
2. The multi-muscle activation patterns were evaluated based on a vector analysis method known as the Voluntary Response Index (VRI)[8] (**Figures 4-6**) using custom-made Matlab software (MathWorks). For each maneuver, the VRI calculation produces two values, a Magnitude and a Similarity Index (SI) (**Figures 5-6**). The Magnitude parameter, the amount of combined sEMG activity for all muscles within the specific time window, was calculated as a length of the Response Vector (RV) for specific task (**Figure 7**). The Similarity Index (SI) provides a value that expresses how similar the RV of SCI subject is to the Prototype Response Vector (PRV) obtained from healthy subjects during the same task. The SI value was computed for each task as a cosine of the angle between the SCI subject RV and PRV. The SI value ranges between 0 and 1.0 where value of 1.0 represents the best match for compared vectors[9] (**Figure 8**) .

Representative Results

Figure 3 represents the electromyogram and airway pressure (on top) simultaneously recorded during MEPT from a non-injured (left) and SCI (right) individuals. Note decreased airway pressure and absence of sEMG activity in expiratory muscles in an SCI subject when compared to a non-injured individual (marked with gray ellipses). Note also that start of the task, as marked on the bottom, is associated with increased sEMG activity and raising airway pressure.

Figure 4 highlights the main steps of constructing the RV. The beginning and ending of the task (event window) was defined as data points (Step 1) according to the marker. The Root Mean Square (RMS) of sEMG within this event window represents mean sEMG activity for each muscle (Step 2). The RV is assembled using RMSs values for the specific muscle combination (Step 3).

Figure 5 illustrates calculation of the PRV and its Magnitude for a group of non-injured (healthy) individuals. Prototype response matrix was constructed using individual RVs (Step 4). Each column in the prototype response matrix includes data for each individual in the group (n=1,2,..,N) and each row represents quantified sEMG activity (RMSs) of specific muscle from the all individuals in the group. The PRV was calculated by taking the average of each row of the prototype response matrix (Step 5). The Magnitude value represents the length of the RV and was calculated according to the formula shown (Step 6).

Figure 6 shows steps for the SI calculation. The RV (Step 7) and its Magnitude (Step 8) for particular SCI individual were calculated as also shown on **Figures 4 and 5**. The SI was obtained by calculating the inner product of PRV and RV (Step 9).

Figures 7 and 8 illustrate the construction of the vectors and calculations of the outcomes using real data. These calculations can be made by using any appropriate software tool like Mathlab, Excel or others.

Table 1. List of specific equipment and supplies used for the Respiratory Motor Control Assessment.

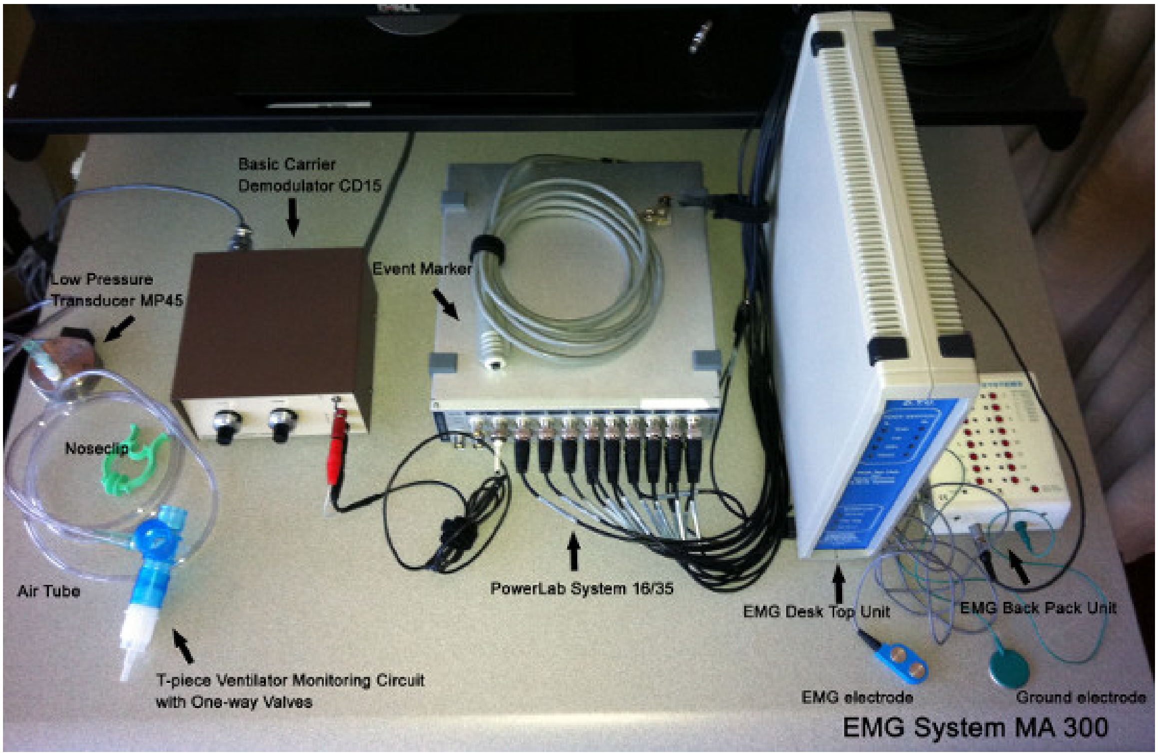

Figure 1. sEMG and airway pressure recording equipment used for the Respiratory Motor Control Assessment. Click here to view larger figure.

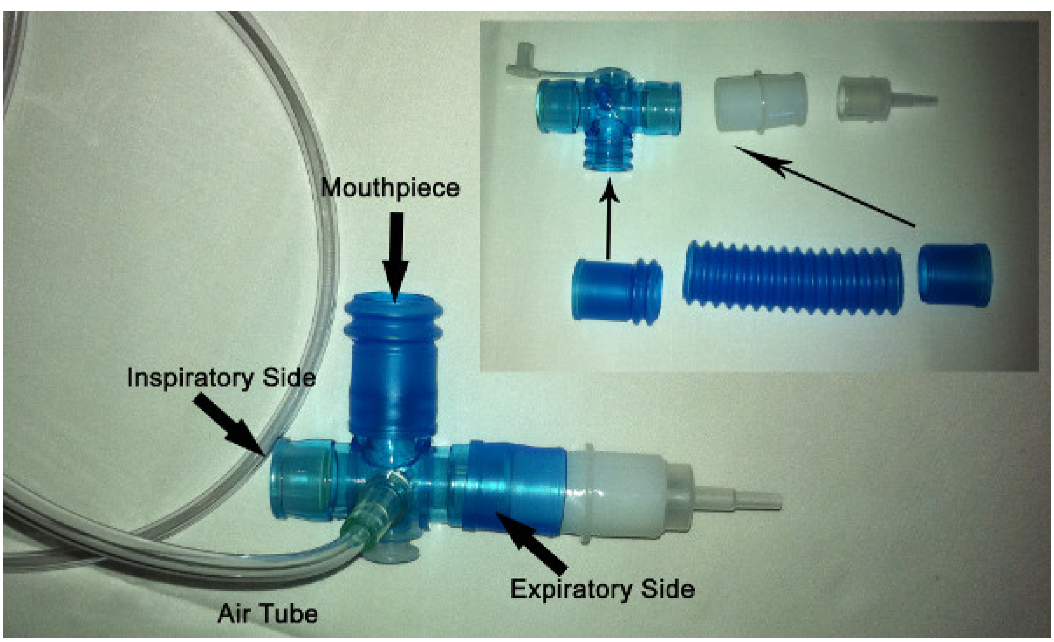

Figure 2. T-piece Monitoring Circuit with air tube assembling used to record the airway pressure during MEPT. Note that for the MIPT, the air leaking part should be flipped to the inspiratory side.

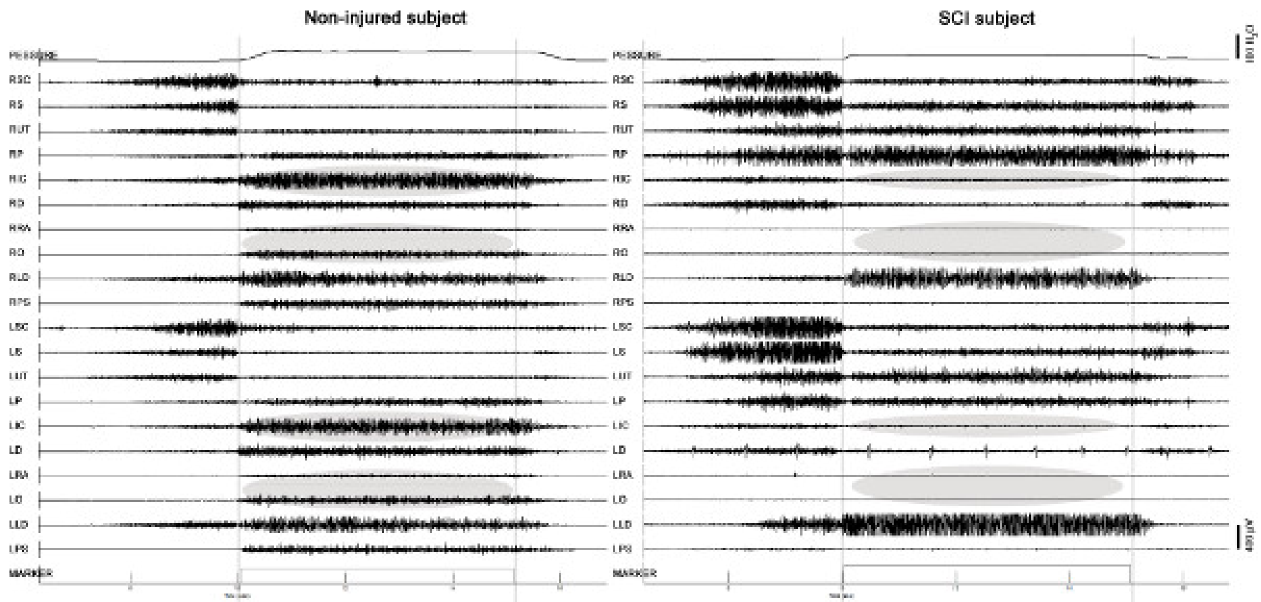

Figure 3. sEMG activity during Maximum Expiratory Pressure Task (MEPT) in a Non-injured Individual and a subject with Spinal Cord Injury (SCI). Air pressure developed is shown on top (PRESSURE) and simultaneously recorded sEMG activity with event mark (MARKER) on the bottom. Vertical gray lines represent the 5-sec analysis windows for VRI calculations. Note decreased airway pressure and absence of activity in expiratory muscles: Right (R) and Left (L) Intercostal (IC), Rectus Abdominus (RA), and Oblique Abdominus (O) in an SCI subject compared to a non-injured individual (marked with gray ellipses). Other muscles shown: Right (R) and Left (L) Sternocleidomastoid (SC), Scalene (S); Upper Trapezius (UT), Pectoralis (P), Diaphragm (D), Lower Trapezius (LT), and Paraspinal (PS). Click here to view larger figure.

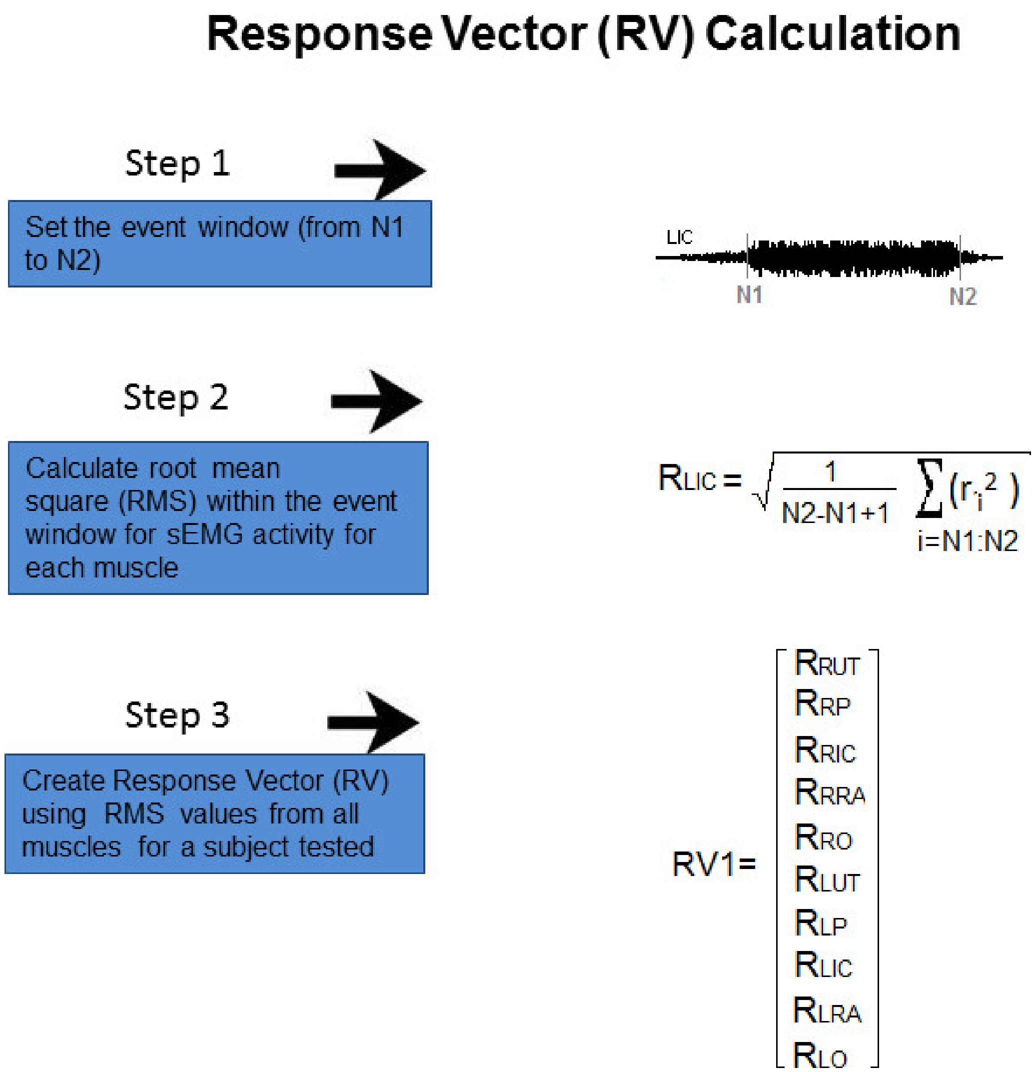

Figure 4. Steps for the calculation of the Response Vector (RV). Note that the RV during the specific task was assembled using Root Mean Square (RMS) values calculated for specific muscles.

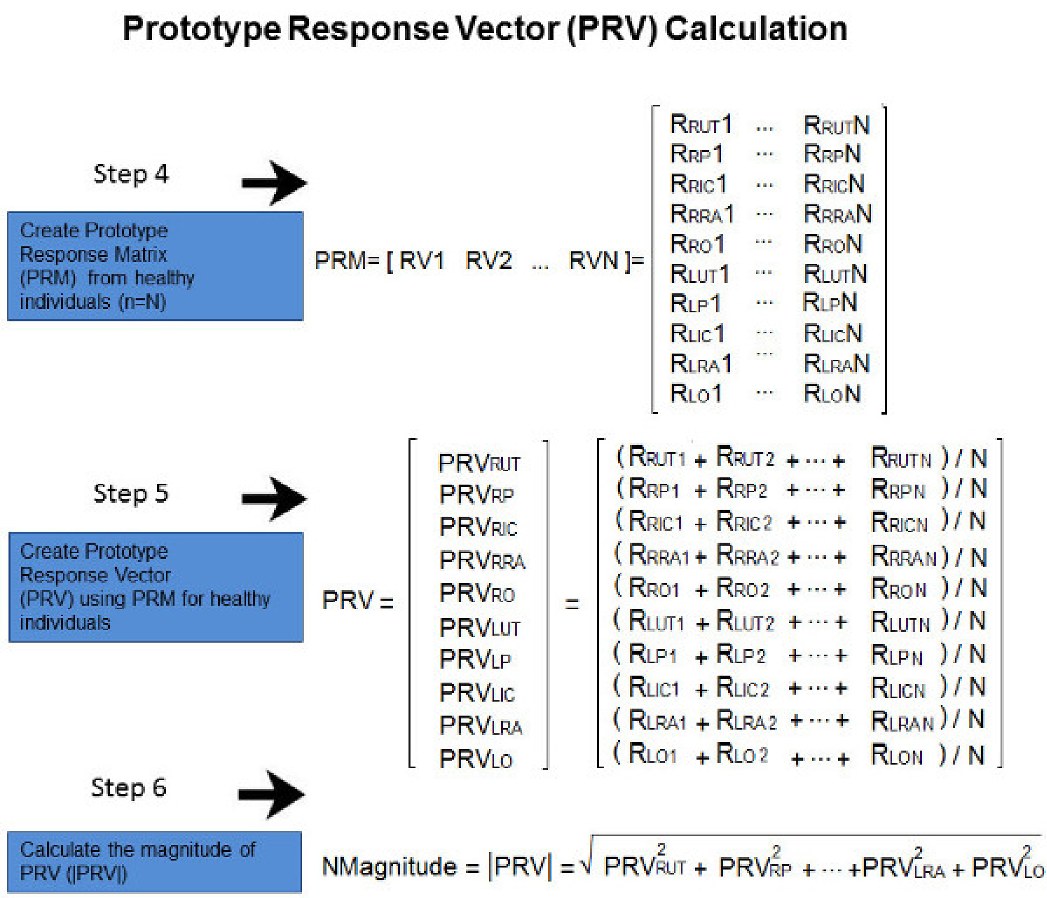

Figure 5. Steps for the calculation of the Prototype Response Vector (PVR). Note that the RV from each healthy individual in the group was used to create the PVR and calculate its Magnitude. Click here to view larger figure.

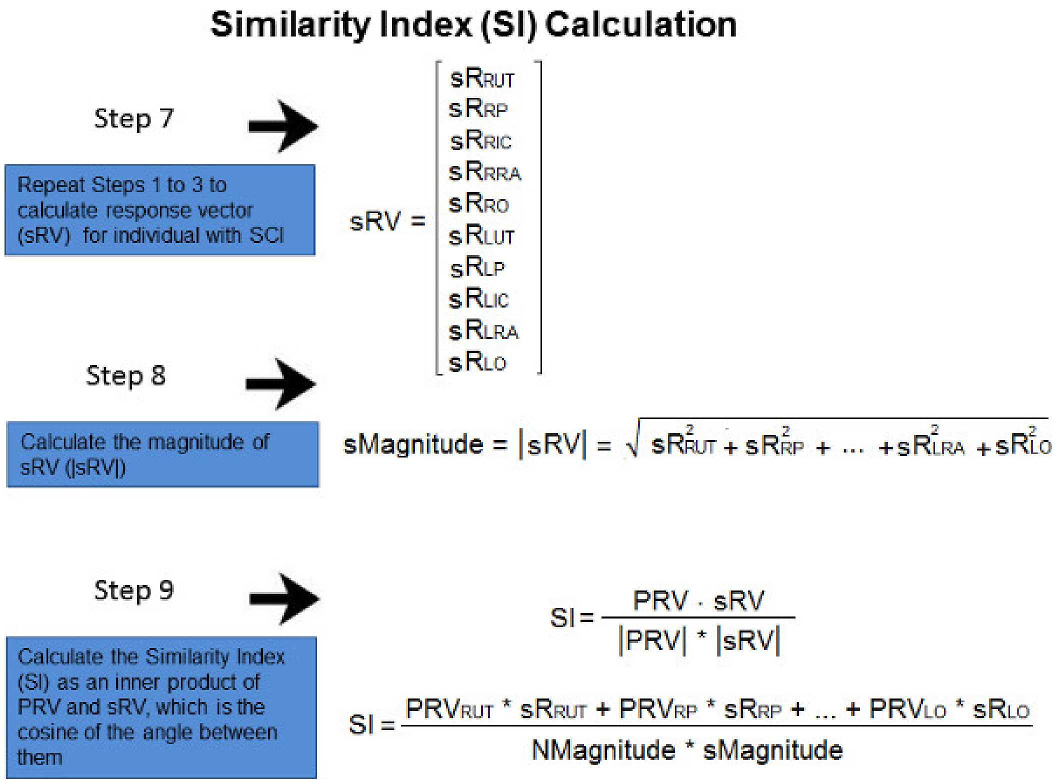

Figure 6. Steps for the calculation of the Similarity Index (SI) and Magnitude. Note that the SI was calculated using PRV and the RV obtained from SCI subject (sRV). Note also that the Magnitude was calculated as the length of the sRV. Click here to view larger figure.

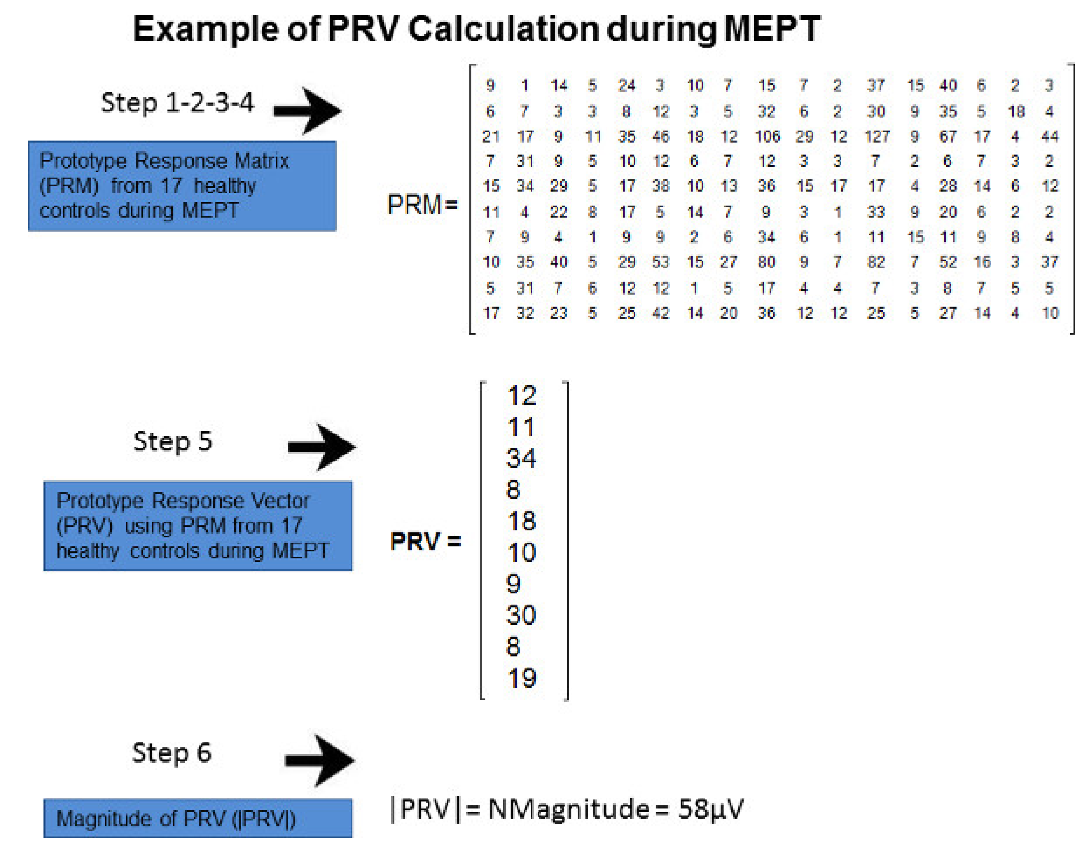

Figure 7. Example of PRV calculations using data obtained during Maximum Expiratory Task (MEPT) in 17 non-injured individuals. Click here to view larger figure.

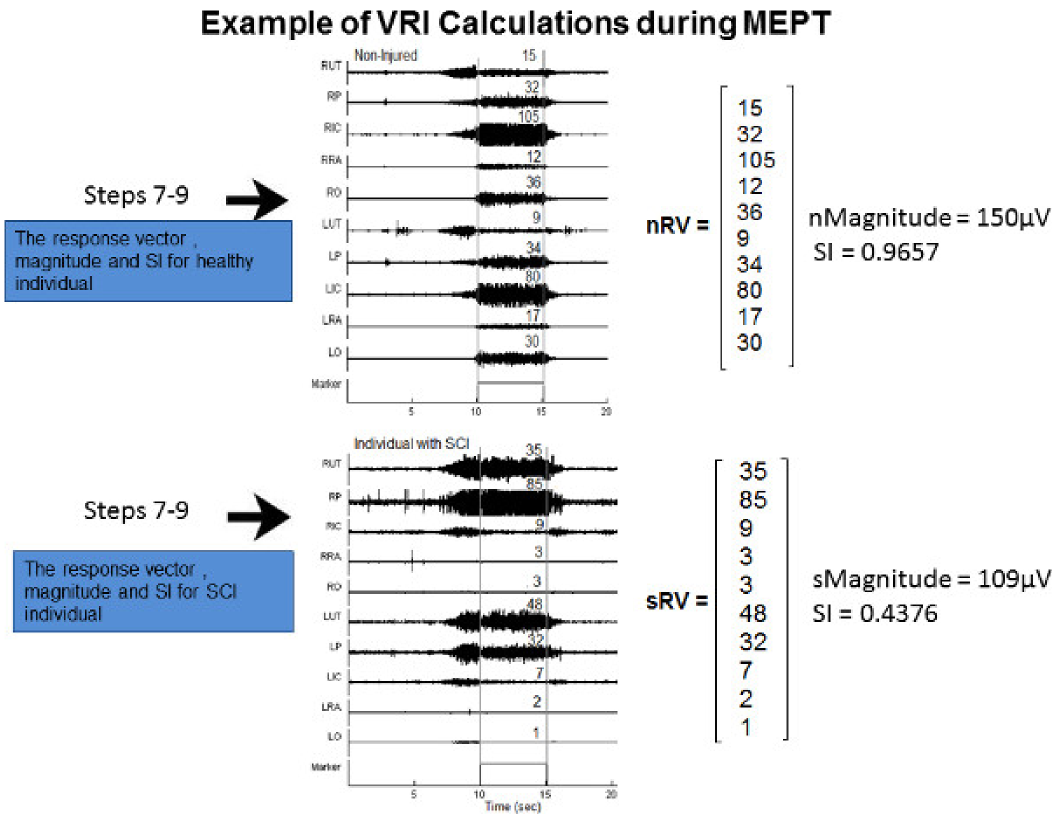

Figure 8. Example of the VRI calculations using data obtained during Maximum Expiratory Task (MEPT) in healthy (non-injured) and SCI individuals. Note that in contrast to the non-injured subject, absence and decreased expiratory muscles activity (IC, RA, and O) in the SCI individual decreased the Similarity Index (SI) value. Also note lower overall muscle activity in an SCI individual associated with lower Magnitude value. Click here to view larger figure.

Discussion

Standard clinical tests to evaluate respiratory motor function after SCI and other disorders include the pulmonary function tests and the American Spinal Injury Association Impairment Scale (AIS) evaluation[14,15]. However, these tools are not designed for quantitative evaluation of the trunk and respiratory motor control. In our previously published work[9], we have shown that the RMCA is a valid method to quantitatively evaluate the respiratory motor function affected by SCI. We have demonstrated that this method can be used despite test-re-test and subject-to-subject EMG amplitude variability.

In order to quantify the degree of difference (SI) in the multi-muscle distribution patterns produced by a tested individual (RV) against the normative vector (PRV), the PRV and RV can be constructed for any combination of muscles. The motor tasks can vary and depend on study design as well as the list of the muscles. In contrast to the SI, Magnitude values, representing the overall sEMG activity, can be modified by subject effort, compensatory muscle activity, and physical properties of body tissues.

The SI, while providing the quantitative measure of how close the multi-muscle activation pattern is to the normative pattern, does not describe in which way the pattern may be different. For this reason, it is essential to qualitatively describe changes in the pattern and individual muscle activation. In addition, further study is needed to examine sEMG signals for additional parameters with which to characterize multi- and single-muscle activation properties.

The method presented here provides a systematic way to evaluate motor control of trunk muscles used to perform respiratory motor tasks in comparison with normative standard measures. In addition to a descriptive sEMG evaluation to investigate in which way the muscle activation pattern is altered, the VRI calculations provide the unified index values from which the severity of disruption can be compared across individuals and changes over time can be monitored. This method allows the evaluation of the respiratory motor control status and the effects of existing and novel interventions on impaired respiratory motor control in persons with SCI and other disorder.

Disclosures

No conflict of interest to declare.

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