Classification of Postural Profiles among Mouth-breathing Children by Learning Vector Quantization

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Methods: By using the LVQ model, five postural profiles for mouth-breathing children could be determined. LVQ showed satisfactory results for mouth-breathing and nose-breathing classification: sensitivity and specificity rates of 0.90 and 0.95, respectively, when using the validation dataset.

Results: The skull, mandible, cervical portion of the spine and upper airways can be regarded as a system in which its parts are positioned in a close interrelationship. Mouth breathing is a physiological abnormality of the correct respiratory process that causes postural changes because of the abnormal, interrelated performance of the muscles in each of the parts of this system [3]. The main characteristics reported in studies on the posture of mouth-breathing children have been forward projection of head and shoulders, lordosis, protruding scapulas, frontal depression of the thorax, and protruding abdomen [4, 5]. The change to normal spinal curvature caused by mouth breathing does not resolve on its own when its etiological factors are eliminated [6].

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1. Introduction

Breathing is the first vital function developed at birth. It becomes the most important body function and, as such, should be cared for. Chronic mouth breathing is associated with pediatric allergy-related and otorhinological complaints [1]. Narrowing of the pharynx has been reported to be associated with forward extension of the neck in order to attempt to straighten the pharyngeal tube and thereby improve the reduced airflow through it [2].
2. Objectives

The present investigation aimed to apply LVQ to determine postural pattern categories among mouth-breathing children, for incorporation into application software for healthcare professionals. This software would also incorporate expert advice on the need for physiotherapeutic treatment for abnormal posture. Thus, it might be possible to use such software as a decision-making support tool that would both save unnecessary referral to orthopedic specialists and emphasize the cases of critical need for such referral.

3. Methods

This study was partitioned into two main tasks. First, LVQ was applied and validated to determine postural profiles among mouth-breathing children. Within this stage, we also proposed a software routine for automatically indicating postural changes. In the second stage, the results achieved using LVQ for automatic classification of mouth breathers and nose breathers were compared with the following other pattern classifiers [25]: SOM, back-propagation applied to multilayer perceptrons (BP) [19], Bayesian networks (BN) [26], naive Bayes (NB) [27], decision trees (J48) [28], k* [29], k-nearest-neighbor classifiers (KNN) [30], and support vector machines (SVM) [31]. The present study was approved by the institutional ethics committee, under procedural number 0997/05.

3.1 Dataset

The study data included the variables used for postural assessments on 84 children (52 mouth breathers and 32 nose breathers).

Table 1 shows the subject composition of each dataset (named DS1 and DS2) used in this study. DS1 and DS2 subjects were randomly included in the applicable databases.

Inclusion criteria: age 5 to 12 years, mouth breathing and free and informed consent form signed by guardian.

Exclusion criteria: craniofacial malformations, musculoskeletal diseases, orthopedic traumas, respiratory diseases and neurological diseases.

4. Nasofibroscopy: carried out in order to assess the nasal cavities, septal displacement, turbinate hypertrophy and nasopharynx; to determine the degree of pharyngeal tonsil hypertrophy in relation to the right and left choanal spaces; and to measure the palatine tonsils that cause pharyngeal constriction.

The criteria for allergic rhinitis were the presence of symptoms such as coryza, nasal obstruction and sneezing, by means of a positive prick test. We included patients with both allergic and non-allergic rhinitis [9].

The clinical examination was of fundamental importance for identifying the obstructive factor and for enabling appropriate treatment. However, the definition of
Thus, children were defined as mouth breathers if they exhibited mouth breathing during consultation, with confirmation from their guardian that they had been predominantly breathing through the mouth for the previous six months, in addition to at least one of the following findings: skeletal crossbite, high-arched palate, anterior open bite, shortened upper and protruding lower lips or lips that did not seal. Children were defined as nose breathers (controls) if the signs and symptoms described above were absent [10].

3.1.2 Variables

Table 2 shows the variables used for postural assessment. DS2 included an extra variable showing the need for physiotherapeutic intervention among mouth-breathing patients. This variable also indicated the class of postural changes occurring among the mouth breathers investigated.

Figure 1 shows points and angles that were used as references for assessing posture, described as follows: a) Cervical lordosis: tragus of the ear, acromion and C7, such that the acromion was the apex of the angle. The larger this angle was, the further forward the position of the head and the lower the degree of cervical lordosis was. b) Thoracic kyphosis: L1, acromion and T7, with an angle drawn from the acromion to L1 and from L1 to T7, such that L1 was the apex of the angle. The larger this angle was, the greater the degree of thoracic kyphosis was. c) Lumbar lordosis was measured using an angle drawn between three anatomical points: L1, anterior superior iliac spine (ASIS) and the greater trochanters, such that ASIS was the apex of the angle. Here, the smaller the angle was, the greater the degree of lumbar lordosis was. d) Position of the pelvis: an angle was drawn between three anatomical points: ASIS, the midpoint of the knee joint on the lateral face and the greater trochanters, such that the midpoint of the joint line was the apex of the angle. The greater the angle was, the further forward the pelvic tilt position was.

All subjects underwent postural assessment with the aid of photographs taken in left lateral view, thereby ensuring that the spinal curvatures were visible in sagittal profile. Small balls of polystyrene, of 8 mm in diameter, were attached to the following specific anatomical points, using double-sided tape: acromion, seventh cervical vertebra (C7), tragus of the ear, seventh thoracic vertebra (T7), first lumbar vertebra (L1), anterior superior iliac spine (ASIS) and greater trochanters.

All participants were photographed wearing swimwear, barefoot, with the feet together and parallel and, when necessary, hair was tied back to ensure that the cervical region was visible. The subjects were instructed to keep their eyes open, looking at the horizon, and there was no verbal interference for postural correction. A 1 m plumb-line was hung on the left side, close to the participants.

Photographs were taken with the children in the orthostatic position, standing on a set of two steps, 42 cm high, 15 cm wide and 34 cm long, in front of a white wall as background. A Sony® Cyber-shot 2.0 megapixel digital camera was fixed at 90° to horizontal in order to focus on the subject lengthways. This camera was positioned 4 m from the wall, on a 1.5 m high tripod and adjusted such that the lower horizontal guideline in the camera viewfinder corresponded to the horizontal line formed by the second step on which the patient was positioned.

Postural analysis was carried out using the SAPO (Software for Postural Analysis) postural analysis package (http://sapo.incubadora.fapesp.br). The analysis on the photographs consisted of the following steps: opening the photograph, zooming to 40%, calibrating the image based on the plumb-line and marking the anatomical points on the photograph.

Figure 2 shows the distribution charts for the variables of thoracic kyphosis, cervical lordosis, lumbar lordosis and pelvis positioning.

In addition, Student’s t-test [33] was performed to compare postural variables between mouth breathers and nose breathers. The means for these two groups were found to be significantly different (p < 0.05), as shown in Table 3.

3.2 Learning Vector Quantization

In addition to performing dimension reduction, thereby enabling representation of the relevant characteristics of the input
pattern (the main SOM property), LVQ also uses class information to make slight changes to the weight of each neuron in the grid, in order to improve the classifier decision [23]. Because of this characteristic, studies have reported that the performance of LVQ in relation to pattern recognition and feature extraction has been significant within the field of biomedicine [34, 39]. Specifically, LVQ uses a competitive learning rule. In this type of learning, the neurons are placed in a grid that is usually one- or two-dimensional. Maps with greater numbers of dimensions are possible but not as common, because visualizing them becomes problematic [19, 35]. For this reason, approaches involving models with other dimensions were rejected and the present study standardized on two-dimensional maps alone. The neurons were connected to adjacent neurons through a neighborhood relationship, thus dictating the map structure. The neurons on the map could be arranged in rectangular or hexagonal shapes [23].

### 3.2.1 Neighborhood Function

The neighborhood function determines how strongly the neurons are connected to each other. A Gaussian function is generally used to implement the neighborhood function [23]:

$$h_{c,i}(t) = \exp \left( -\frac{||c - i||^2}{2\sigma^2(t)} \right),$$

where \(c\) is the vector position of the neuron and \(i\) is the vector position of the winning neuron. The calculation for the winning neuron is shown in Formula 3. The parameter \(\sigma^2(t)\) is the standard deviation of the neighborhood function [12].

The standard deviation of the neighborhood function \(\sigma^2(t)\) decreases with the number of steps \(t\) [23]. One popular choice for the dependence of \(\sigma\) on the discrete time \(t\) is the exponential decay given by the following (19):

$$\sigma(t) = \sigma_0 \exp \left( -\frac{t}{\tau} \right),$$

where \(\tau\) is a time constant.

In addition to the Gaussian function, a rectangular function, a Gaussian function with a cut-off or an Epanechnikov function can also be used as neighborhood functions for LVQ [23].
3.2.2 Training

At each training step, a sample $x$ is chosen at random from the entry pattern, and its similarity is calculated with all the neurons on the map, triggered by $m_i$ in function (3). The best-matching unit (BMU), also known as the winning neuron [12], which is triggered as $m_i$ in Formula 3, is the unit in which the weight of the grid vector has greatest similarity with sample $x$ of the entry vector. The similarity is usually defined by the smallest value of the Euclidean distance between the vector $x$ and all the neurons of the grid, represented by the formula [12, 23]:

$$\|x - m_i\| = \min_j(\|x - m_j\|).$$  \hspace{1cm} (3)

After determining the BMU, the vector values of the SOM neurons are updated. The values for the BMU and its topological neighborhoods move close to the vector for the entry pattern of the entry space. Specifically for the LVQ, there are different rates for updating the neuron weights. If sample $x$ from the entry pattern corresponds to the same neuron class (determined when initializing the LVQ grid), the updating rate is given by the following [23]:

$$m_i(t + 1) = m_i + \eta(t) \cdot h_{c(i)}(t)(x(i) - m_i(t)),$$  \hspace{1cm} (4)

where $t$ is the time, $\eta(t)$ is the learning rate and $h_{c(i)}(t)$ is the neighborhood function around the winning neuron $c$.

Likewise, if sample $x$ from the entry pattern does not correspond to the same neuron class, the updating rate is given by the following [23]:

$$m_i(t + 1) = m_i - \eta(t) \cdot h_{c(i)}(t)(x(i) - m_i(t)),$$  \hspace{1cm} (5)

This updating rule leads to topological ranking of the character maps in the entry space, in the sense that neurons in the same category will tend to have vectors of similar synaptic weight [12].

Specifically, the learning parameter $\eta(t)$ is a variable in time that corresponds to the case of stochastic approximation. In particular, it should start with a value $\eta_0$ and then gradually decrease with increasing time $t$. This requirement can be satisfied by choosing an exponential decay for $\eta(t)$, as shown in the following [12]:

$$\sigma(t) = \sigma_0 \cdot \exp\left(-\frac{t}{\tau_2}\right),$$  \hspace{1cm} (6)

where $\tau_2$ is a time constant.

3.2.3 Classification Process

After adjusting the neuron weights (done during the training stage), classification of a new sample will take place when it is presented to LVQ. A BMU is indicated as represented in Formula 3. Specificity and sensitivity are calculated according to the classification of the neuron (mouth breathing or not) and the classification of the sample that has been presented.

3.3 Leave-one-out

Given a sample with $n$ cases or sets of variables, the leave-one-out algorithm (LOO) consists of using $n - 1$ sets of variables to train the ANN model, with the $n$-th case held out to test the model. This process is repeated $n$ times until each of the $n$ sets of the sample has been used to test the model [36].

3.4 ROC Curve

The ROC curve correlates sensitivity with the complement of specificity attained by any pattern recognition tool for different ranges of values assumed by one or more of the variables/parameters analyzed. In ANN applications, it is used to determine the classifier showing the best performance [37]. The performance of each classifier is measured by computing the area under the curve (AUC) plotted for each classifier. Larger AUCs will determine classifiers with better performance [37].

One critical point when using ROC curves to compare performances is to determine the range of inputs to be analyzed. In this study, each LOO iterative step was proposed as a range for comparison.

3.5 Inter-rater Agreement (Kappa Statistics)

The inter-rater agreement (Kappa statistics) [39] is used to evaluate the agreement level between two classifications on ordinal or nominal scales. The agreement is quantified by the weighted Kappa (WK), which in this study was calculated using a 95% confidence interval. The WK values are presented in Table 4 [39]. The aim in using WK values was to identify the agreement level between the classifiers studied and the gold standard.

3.6 Software

The SOM Toolbox version 2.0 [40] package was used to implement SOM and LVQ neural models and the Neural Networks Toolbox® version 4.0.1 (MathWorks Inc., Natick, MA, USA) was used to implement the perceptron and BP models. Both software packages allow implementation of ANN algorithms through Matlab® version 7.0 (MathWorks Inc., Natick, MA, USA). After performing several tests with different parameters, the final configurations of the SOM Toolbox and ANN Toolbox for ANN models and DS1 that attained best accuracy were:


Table 4: Interpretation of weighted Kappa (WK) values

<table>
<thead>
<tr>
<th>WK value</th>
<th>Agreement strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.20</td>
<td>poor</td>
</tr>
<tr>
<td>0.21–0.40</td>
<td>fair</td>
</tr>
<tr>
<td>0.41–0.60</td>
<td>moderate</td>
</tr>
<tr>
<td>0.61–0.80</td>
<td>good</td>
</tr>
<tr>
<td>0.81–1.00</td>
<td>very good</td>
</tr>
</tbody>
</table>

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Neighborhood function: Gaussian. Running length: 100. Learning rate: 0.001.


Visual Basic 6.0© (Microsoft Corporation) was used to implement a classifier for mouth-breathing children’s posture, and Microsoft Access® 2002 (Microsoft Corporation) was used to create a databank for the data from the present study.

In addition, the Weka program version 3.5.2 [26] was used to implement pattern recognition models. Several tests were performed using different parameters in data mining models, and the final configurations with the best accuracy can be accessed at http://telemedicina6.unifesp.br/projeto/methods.html. Furthermore, Kappa was performed using MedCalc®, version 10.4.8.0 (MedCalc Software, Mariakerke, Belgium).

4. Results

4.1 Postural Profile Determination among Mouth-breathing Children

4.1.1 LVQ Training

As the LVQ model allowed visualization of its neural topology, the labeling of the neurons in the LVQ neural structure was performed using DS1. This labeling reflected the largest number of neuron activations by data referring to either nose-breathing or mouth-breathing children during the training of the ANN model. Figure 3a shows the neuron identification after training: neurons 1, 4 and 7 were characteristic activated by data from nose breathers and neurons 2, 3, 5, 6, 8 and 9 by data from mouth breathers. This labeling reflected the largest number of neuron activations by data referring to either nose-breathing or mouth-breathing children during the training of the ANN model. LVQ attained specificity of 0.95, sensitivity of 0.90 and AUC of 0.92 for the classification of mouth-breathing children.

Figure 3b illustrates the specificity of the LVQ model of the present study for classifying nose-breathing children based on postural data. From among the ten children included in DS2 who had previously been determined to be nose breathers through medical examination, only one had the respective postural data activating one neuron (neuron 2) that was labeled characteristic of mouth-breathing children. The specificity rate for performing the task under analysis was calculated as 0.90.

Figure 3c illustrates the sensitivity of the LVQ model for classifying mouth-breathing children based on postural data. From among the 22 mouth breathers in DS2 that were determined through medical examination, only one had the respective postural data activating one neuron (neuron 7) that was labeled characteristic of nose-breathing children. The specificity rate for performing the task under analysis was calculated as 0.95.

4.1.2 Postural Profile Determination

By feeding the data relating to 22 mouth breathers (who included 15 children with a prescription for spinal rehabilitation treatment) into the LVQ model, five postural classes of mouth-breathing children were determined through analysis of the number of activations of neurons and neuron topology.

Figure 4a shows the LVQ topology for DS2 mouth-breathing children who were not prescribed any spinal rehabilitation treatment and Figure 4b shows the topology for mouth breathers who were prescribed spinal rehabilitation treatment. By comparing the two topological patterns and the numbers of
children with the same diagnosis associated with activation of one neuron, the following classes or postural profiles were established (Fig. 4c):

- **Class A**: mouth-breathing children with critical postural problems needing spinal rehabilitation care (associated with neurons 8 and 9).
- **Class B**: mouth-breathing children with moderate changes to normal posture (associated with neurons 5 and 6).
- **Class C**: mouth-breathing children with posture slightly affected (associated with neurons 2 and 3).

Two other classes were also proposed:

- **Class D and E**: nose breathers with slightly altered posture (associated with neurons 1, 4 and 7).

4.2 LVQ Accuracy Comparison

LVQ accuracy was compared with that of other pattern classification algorithms: SOM, BR, BN, NB, J48, k*, KNN and SVM. DS1 was used as the input pattern and LOO was the validation technique applied. Sensitivity, specificity and AUC and their 95% confidence intervals attained are shown in Table 5.

Kappa statistics were applied to obtain the agreement level between the classifier models and the gold standard. For this test, we used DS1 and LOO. The WK values for each classifier are shown in Table 6.

5. Discussion

One important feature of LVQ and SOM is that, unlike other classifiers, the neural topology (neighboring neurons) allows the developer to have a view of the classification inside a map and help prompt new patterns [39] (Figs. 3 and 4). Although the LVQ specificity rate was lower than in BN and NB models, it should be noted that...
the LVQ sensitivity rate was the same as the BN and NB rates, as seen in Table 5. Moreover, the WK values presented in Table 6 did not reveal any difference in agreement strength (WK > 0.81) between the LVQ and Bayesian approaches. We can thus say not only that LVQ helped in discovering new categories but also that this RNA model showed important results in relation to the task of pattern recognition.

In addition, the results shown in Table 5 suggest that SOM presents lower accuracy for postural classification, compared with the LVQ model. Moreover, although tests with SOM were carried out to determine profiles for mouth-breathing children, the feature extraction for this ANN model was worse than that of LVQ. SOM showed problems while separating relevant postural profiles, and some SOM artificial neurons could not correctly indicate either nose breathers/mouth breathers or visual clusters. Some studies [34, 41] have reported that SOM shows difficulties in classifying biomedical data. In this ongoing work, the ANN model presented the same behavior. Furthermore, we can show that LVQ boosted the feature extraction because of the supervised learning.

As configured in the present study, LVQ showed specificity and sensitivity rates of 0.90 and 0.95, respectively, for recognizing mouth-breathing children by using postural parameters in the model validation. However, some remarks regarding posture need to be made:

- As seen in Figure 3c, LVQ classified one mouth-breathing child as a nose-breathing child. This was a case of a mouth breather who was declared by a specialist as having no problems with his spine.
- Conversely, Figure 3b shows a nose breather classified as a mouth-breathing child. However, this child was classified as needing no spinal rehabilitation (class C).

The above events may constitute evidence that some nose-breathing and mouth-breathing children share the same postural profile, which could be either characteristic of normal spinal curvature or characteristic of slight abnormality of the spine.

Use of the LOO cross-validation algorithm for the first phase has been reported to be a good choice when working with fairly small number of attributes [19, 41], as in the dataset used in the present study.

Furthermore, exploratory use of k-fold (fivefold and tenfold) cross-validation algorithms was also performed. This yielded sensitivity and specificity rates lower than those attained with LOO. Two reasons may account for the lower rates of k-fold sensitivity and specificity obtained with k-fold cross-validation in this study: a) the higher rates attained with LOO may be due to its intrinsic rounding up of the final neuron weight vector during the validation procedure; and b) there may be intrinsic variability of sensitivity and specificity rates in k-fold cross-validation, linked to the variable randomization obtained in each instance of data sampling, on each occasion when a k-fold test is carried out.

Finally, the present study showed that most mouth-breathing children had a characteristic type of posture, and that determination of postural categories was possible through the use of LVQ. Identification of such patterns enabled development of an automatic postural classification tool that would potentially be useful for postural treatment among mouth-breathing children. However, because the database was small, it needs to be determined whether the results shown by LVQ might present any problems of overfitting. Thus, further studies could determine the effectiveness of the present tool in relation to two main approaches:

First, there could be an assessment comparing the classification of the level of postural abnormality provided by the system with the classification made by the medical treatment provider.

Second, there could be an assessment of the effectiveness of postural rehabilitation compliance among mouth-breathing patients. We believe that a tool that can support health providers’ decisions would be able to provide more information and guidance to mouth-breathing patients not only regarding their treatment for nasal obstruction but also their postural rehabilitation therapy, thereby reinforcing a multidisciplinary approach towards treating mouth-breathing children. This approach can be guided by the children’s compliance with postural rehabilitation therapy before and after the implementation of this tool in multidisciplinary centers caring for mouth-breathing children.

6. Conclusion

By using the LVQ model, it was possible to determine postural patterns among mouth-breathing children. The LVQ model showed satisfactory performance in terms of sensitivity and specificity (0.90 and 0.95, respectively). Five postural categories for mouth-breathing children were determined and incorporated into application software for classifying the severity of mouth breathers’ abnormal posture.

Acknowledgments

We would like to thank CAPES for its financial support, the patients and their families involved in this study and all colleagues and friends who, despite not listed as co-authors, in some manner helped to improve the present investigation, especially Vladimir Camelo Pinto and Lidia Bravo de Souza.

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