# Effect of a 1-week intense myofunctional training on obstructive sleep apnoea in children with Down syndrome

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## ABSTRACT

**Background** Obstructive sleep apnoea (OSA) is common in children with Down syndrome (DS), yet difficult to treat. As muscular hypotonia of the upper airway may cause OSA and is also common in DS, we tested whether intense myofunctional therapy improves OSA in children with DS.

**Patients and methods** Forty-two children underwent cardiorespiratory sleep studies immediately before and after a 1-week intensive training camp consisting of three daily 45 min sessions of myofunctional exercises according to Padovan. Primary outcome was the mixed-obstructive-apnoea/hypopnoea index (MOAHI), secondary outcomes the ≤3% oxygen desaturation index ($DI_3$), the ≤90% desaturation index ($DI_{90}$) and the lowest pulse oximeter saturation ($SpO_{2nadir}$).

**Results** Eighteen recordings had ≥3 hours of artefact-free recording in both the pretreatment and post-treatment sleep study and were therefore included in the analysis. Mean age was 6.3 years (SD 2.5); 83% had OSA prior to intervention. Mean MOAHI was 6.4 (SD 8.6) before and 6.4 (SD 10.8) after the intervention ($p>0.05$); the $DI_3$ and $SpO_{2nadir}$ also did not change. Only the $DI_{90}$ decreased significantly from 2.7 (SD 4.5) to 2.1 (SD 3.7) ($p<0.05$).

**Conclusion** The 1-week intense myofunctional training camp evaluated here in children with DS had only a marginal effect on OSA. Whether a longer follow-up period or duration of intervention would yield stronger effects remains to be determined.

### What is already known on this topic?

- Obstructive sleep apnoea is very common in children with Down syndrome.
- Common treatments such as adenotonsillectomy have a high failure rate in these patients.
- Myofunctional exercises helped improve obstructive sleep apnoea in adults.

### What this study adds?

- We evaluated a 1-week intense myofunctional training camp with three daily sessions to improve upper airway muscle tone.
- This led only to a minimal improvement in sleep study results in these children with Down syndrome.

## BACKGROUND

Children with Down syndrome (DS) have an increased risk of obstructive sleep apnoea (OSA).[1] OSA has an estimated prevalence of 1%–3% in healthy children, and of 30%–90% in those with DS.[2 3] Common risk factors for OSA, also highly prevalent in DS, are adenotonsillar hypertrophy, (relative) macroglossia[4] and craniofacial abnormalities[5] related to hypopharyngeal collapse during sleep,[6] reduced orofacial muscle tone and obesity.[4 6 7]

As in the general paediatric population, both sleep disordered breathing (SDB) and OSA may affect neurocognitive outcome of DS children,[8 9] increase morbidity and decrease quality of life.[10 11] They should therefore be avoided or treated early and effectively.

Depending on the underlying cause, several treatment options for OSA exist. Adenotonsillectomy (AT), however, the first-line treatment in children with adenotonsillar hypertrophy,[12] is less effective in children with DS, where OSA persists in up to 55% of patients following AT.[6 13 14] Therefore, additional therapies such as continuous positive airway pressure are required, but the latter is poorly tolerated in patients with DS and may lead to mid-face hypoplasia.[15] Other treatments include intranasal corticosteroids,[16] orthodontic treatment, weight loss programmes and palatal plate therapy[7]; myofunctional therapy (MT) is also widely used.[10 17 18] Some of these treatments may correct the oropharyngeal anomalies, but have little effect on anatomic function or neuromuscular deficits. Several studies have shown that common pathophysiologic aspects related to OSA in DS children do not change after surgical, medical or orthodontic treatment, potentially explaining their lack of effectiveness.[14 17 19] Other interventions are therefore necessary.

MT has repeatedly been reported as an effective OSA treatment in adults. For example, didgeridoo playing provides a training effect on the soft palate, tongue and oropharynx and improved OSA and SDB symptoms in a controlled trial in 25 adults.[20] A meta-analysis with nine adult studies (120 patients) showed that MT decreases apnoea-hypopnoea index by approximately 50% and improves the nadir oxygen saturation, snoring and sleepiness outcomes.[21]

In children with OSA, better and longer lasting postoperative improvement has been reported in those who received MT in addition to AT compared with AT alone. Villa *et al* and Guilleminault *et al* both showed that a combination of oropharyngeal exercises and AT may result in better symptom improvement and less OSA recurrence than performing only an AT.[17 22]

Another study applied MT in nine DS children aged 9–33 months and found less parent-reported snoring and better oral motor function for those who underwent treatment with a palatal plate that contained a stimulation knob and was worn for at least 2 hours/day over 4 years, compared with untreated age-matched controls.[7] In infants, a longitudinal audit from our centre found normalisation in mean mixed-obstructive-apnoea index (MOAI) in 24 DS infants with OSA (defined as MOAI ≥1) after 2 months of treatment with a palatal plate that had a stimulation knob and was worn 24 hours/day.[23] In infants with Robin sequence, we found a major reduction in the MOAI after only 48 hours of MT combined with a palatal plate that shifted the base of the tongue forward.[24]

Thus, it seems that MT may help children with DS clinically, particularly if combined with other interventions, but we are not aware of any study investigating the effects of MT as sole therapy for OSA in older children with DS. Our group has a long-lasting cooperation with a centre for MT that offers 1 week of intense (three sessions/day) training camps for children with DS. Given the paucity of data on such an intervention and its potential, particularly in children with pre-existing muscular hypotonia, we performed sleep studies before and after therapy to test whether it improved OSA severity. Our aim was to assess the effect of a 1-week intense MT programme on the mixed-obstructive-apnoea/hypopnoea index (MOAHI) in patients with DS with OSA.

## PATIENTS AND METHODS

This was a prospective longitudinal study on the effects of a 1-week intense MT intervention on sleep study results in DS children, conducted between January 2015 and September 2016.

Inclusion criteria were DS with frequent snoring, ages between 2 and 11 years and provision of written informed parental consent. Exclusion criteria were concurrent upper respiratory tract infections and a recording time of <3 hours in either sleep study (see below).

Children meeting inclusion criteria underwent two overnight polygraphy (PG) examinations each, one in the night before the start of the therapeutic intervention, the second 1 week later immediately following the intervention week.

## MT ACCORDING TO PADOVAN

MT was performed as three 45 min sessions per day, with two based on the Padovan method. This includes the continuous repetition of selective movement patterns stimulating the entire nervous system, thereby addressing different sensorimotor functions.[25] Exercises are performed both passively and actively, with the active parts increasing across sessions, and begin with physical exercises that aim to strengthen overall muscle tone and improve posture. This is believed to have an effect on the orofacial complex as well as on linguistic development. These exercises are followed by oral exercises, which are targeted to airflow control, lip activity, tongue movements to increase its strength, activation of the buccinator and masseter muscles, and proprioception through chewing exercises. The oral exercises aim at strengthening the orofacial complex and to improve ingestion, articulation and the development of the facial and jawbones.

The third daily session comprised linguistic exercises specific for single sounds, syllables and words combined with behavioural training (https://www.gabriele-iven.de/intensivwoche).

## OVERNIGHT PG

Sleep recordings were performed overnight using a standard digital ambulatory PG device (Embletta PDS, MedCare; Reykjavik, Iceland). The portable device was attached to the patient using an elastic belt. Chest and abdominal wall movements were monitored using piezo sensors (Pro-Tech, Pittsburgh, PA), heart rate was monitored by ECG. Airflow was measured by a nasal pressure transducer (nasal prongs and built-in pressure transducer, MedCare). Arterial oxygen saturation ($SpO_2$) was recorded by pulse oximetry in beat-to-beat mode (Xpod, Nonin Medical, Plymouth, MN), with simultaneous recording of the pulse waveform. Actigraphy and body position were also monitored (built-in actimeter/body position sensor, MedCare).

A trained team member of the therapy centre explained handling of the ambulatory sleep study device to the parents who were asked to mail the recording device to our sleep lab after completing the second recording. In the sleep lab, recordings were downloaded and evaluated without knowledge of the timing of the recordings (before/after intervention) using device-specific software (Somnologica for Embletta, V.3.1.2, MedCare).

Analysis was performed according to the standard criteria of the American Academy of Sleep Medicine.[26] Sleep onset was estimated as the beginning of the first 10 min period not containing changes in body position; morning awakening as the end of the last such 10 min period. The estimated sleep time (EST) was calculated as the period between sleep onset and morning awakening. Within EST, recordings were analysed for (1) movement periods using actigraphy, body position, or movement artefacts on any other channel; and (2) artefactual or uninterpretable readings other than movement periods on the nasal flow, chest and abdominal wall movements or $SpO_2$ signal. Movement periods and artefactual/uninterpretable recording periods were excluded from EST if they lasted for more than 1 min and the corrected EST (CEST) (ie, EST without movement periods or artefactual/uninterpretable recording periods) was calculated.

Central, obstructive and mixed apnoea events were counted. Obstructive apnoeas were defined as the absence of airflow (nasal and oral) with continued chest wall and abdominal movement for two preceding breaths. A central apnoea was scored if no airflow (nasal and oral) was detected and no chest and abdominal wall movements were present. Mixed apnoeas were defined as apnoeas with central and obstructive components. Hypopnoeas were defined as a decrease in airflow by ≥30% (nasal or oral) of the two preceding breaths, with a corresponding decrease in $SpO_2$ ≥3%.[27] The MOAHI was defined as the sum of obstructive and mixed apnoeas and hypopnoeas per hour of CEST. Mild, moderate and severe OSAs were defined as MOAHI ≥1/hour, ≥5 and ≥10/hour of CEST, respectively, while a normal PG was defined as MOAHI <1/hour of CEST.

The lowest oxygen saturation value ($SpO_{2nadir}$) and the number of desaturation events by ≥3% ($D_3$) and to ≤90% ($D_{90}$) were determined. Desaturation event indices, defined as the number of $D_3$ and $D_{90}$ events per hour of CEST, were calculated ($DI_3$ and $DI_{90}$). Events with a disturbed pulse waveform signal were excluded.

## STATISTICAL ANALYSIS

Descriptive statistics are reported as mean, SD and median with IQR. Comparisons before/after intervention were done using

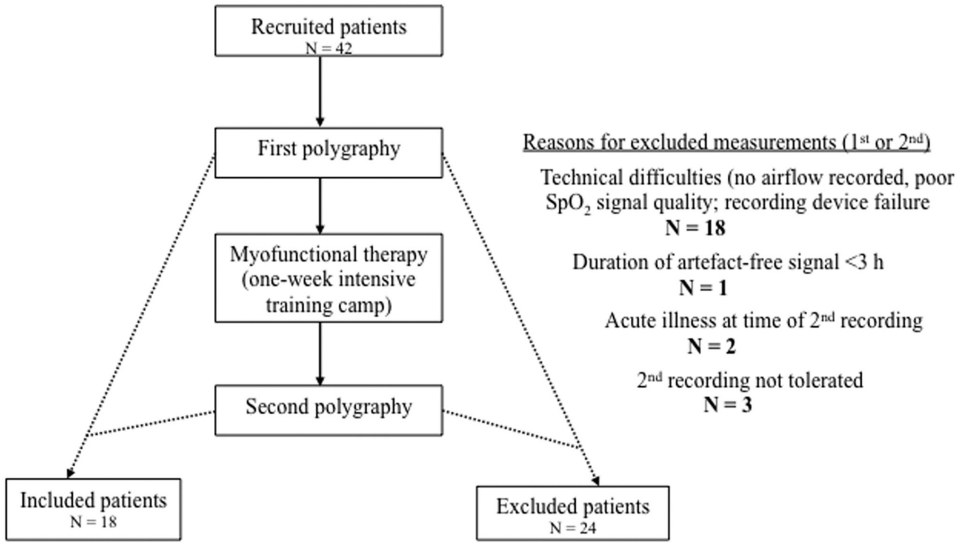


**Figure 1** Patient flow.

the Wilcoxon signed-rank test. A p value <0.05 was considered statistically significant. As this was a pilot study, no sample size estimation was performed.

Statistical analysis was performed using SAS Jump V.13 (SAS Institute).

## RESULTS

### Subject characteristics

Forty-two children were recruited and participated in the study, with 33 having an interpretable sleep study prior to (PG1) and 24 following intervention (PG2); 18 recordings contained analysable data at both time points thus qualifying for inclusion in this study (figure 1). Demographic data for included children were comparable to those from children with complete study data (table 1).

Prior to study intervention, 11 children had received regular speech therapy, 7 had received orthodontic treatment or maxillofacial surgery (eg, upper dentures, braces, maxillary advancement) and 5 ear-nose-throat surgery (AT, tonsillectomy or tonsillotomy).

**Table 1** Demographic data of study participants

| | Patients n=18 (included) | Patients n=24 (excluded) |
|---|---|---|
| Demographic data | | |
| Age (years)* | 6.3±2.5 | 6.8±2.6 |
| Height (cm)* | 110.1±16.1 | 114±16.0 |
| Weight (kg)* | 21.7±7.3 | 22.5±6.7 |
| Gender: male, n | 6 | 15 |
| Smoking father and/or mother, n | 1 | 4 |
| Prior treatment and comorbidities | | |
| Regular speech therapy, n | 11 | 16 |
| Orthodontic treatment or maxillofacial surgery, n | 7 | 5 |
| ENT surgery, n | 5 | 10 |
| Congenital heart defect (without surgery), n | 2 | 4 |
| Congenital heart defect (with surgery), n | 6 | 6 |

*Data are given as mean±SD.
ENT, ear-nose-throat.

Fifteen children had OSA (MOAHI ≥1/hour) in their initial sleep study, with eight (44%) classified as mild, four as moderate and three as severe OSA (table 2).

### Comparison between PG1 and PG2

The interval between PG1 and PG2 was on average 6.3 days (SD 0.8). Individual patient data are shown in the online supplementary tables.

There were no differences in MOAHI, $DI_3$ or $SpO_{2nadir}$ before and after MT (table 3). Only the $DI_{90}$ increased. Also, median MOAHI decreased more in children without prior MT (from 6.1 to 1.5 vs from 2.7 to 2.2), but results from such a subgroup analysis can only be hypothesis generating.

## DISCUSSION

To the best of our knowledge, this is the first study focusing on short-term effects of MT on OSA in children with DS. We found that MT resulted in a significant improvement in the $DI_{90}$, but not in any other sleep parameter. Hence, we only found very little short-term effects of this intense 1-week MT training camp.

Starting point for this study was the very sparse literature in spite of a largely unresolved clinical problem: how to improve the high prevalence of OSA in DS children. Given the data in adults and children without DS, MT seemed a promising option.[10 17 20 22] Why then could we not confirm its effectiveness?

Several potential explanations may be considered. First, the 1-week training camp, despite offering three daily sessions lasting 45 min each, may have been too short an intervention to

**Table 2** Descriptive statistics of data from the first and second ambulatory polygraphy with declaration of corrected estimated sleep time and the distribution of different sleep positions

| Ambulatory polygraphy | Mean±SD (95% CI) | Median (IQR) |
|---|---|---|
| Interval between first and second polygraphy (days) | 6.3±0.8 (5.9 to 6.7) | 6.0 (6.0–7.0) |
| Corrected estimated sleep time of first polygraphy (min) | 439.5±142.8 (373.6 to 505.5) | 489.0 (290.5–558.7) |
| Corrected estimated sleep time of second polygraphy (min) | 413.3±144.1 (346.7 to 479.9) | 395.5 (314.0–530.1) |

Data are given as mean±SD, 95% CI, median and IQR.

**Table 3** Comparison between the first and second polygraphy

| | PG1 (before myofunctional therapy) | | PG2 (after myofunctional therapy) | | |
|---|---|---|---|---|---|
| **Primary parameters** | **Mean±SD (95% CI)** | **Median (IQR)** | **Mean±SD (95% CI)** | **Median (IQR)** | **P values** |
| MOAHI (events/hour) | 6.4±8.6 (2.4 to 10.4) | 2.8 (1.3–8.5) | 6.4±10.8 (1.4 to 11.4) | 1.8 (1.0–5.3) | 0.96 |
| $DI_3$(events/hour) | 12.8±10.1 (8.1 to 17.4) | 11.7 (4.3–19.5) | 12.1±13.2 (6.0 to 18.2) | 7.0 (2.9–17.2) | 0.58 |
| $DI_{90}$(events/hour) | 2.7±4.5 (0.6 to 4.8) | 0.8 (0.2–2.7) | 2.1±3.7 (0.4 to 3.9) | 0.2 (0.0–2.0) | 0.04 |
| $SpO_{2\ nadir}$ (%) | 85.9±4.5 (83.3 to 88.0) | 87.5 (82.3–89.0) | 87.3±4.9 (85.1 to 89.6) | 88.5 (84.3–90.8) | 0.21 |

Data are given as mean±SD, 95% CI, median and IQR. P value determined by Wilcoxon signed-rank test.
$DI_3$, desaturation index ≥3% (events per hour of corrected estimated sleep time); $DI_{90}$, desaturation index <90% (events per hour of corrected estimated sleep time); MOAHI, mixed-obstructive-apnoea/hypopnoea index; $SpO_{2nadir}$, lowest oxygen saturation value.

realise an effect. We had expected a rapid effect given that our functional treatment with a modified palatal plate in infants with Pierre Robin sequence yielded a strong improvement in MOAI after only 48 hours.[24] With those patients, however, the likely mechanism of action was of an anatomical, not functional nature as expected here. Also, a 1-week training camp is the standard setting offered by the MT centre involved, and we assumed that parents would not continue the exercises at the same intensity once having returned home. Thus, we did not expect a stronger effect from a longer interval between the two sleep studies. Poor compliance may be an alternative explanation. Children's compliance was not monitored, but the general feedback given by staff members was that they usually enjoyed the exercises and were happy to participate.

In studies that did report an effect of MT on paediatric OSA, MT was used in addition to other interventions such as AT,[17 22] not as a sole treatment as done here. Thus, MT may perhaps only be effective if used as an adjunct. Also, several children had already received MT for several months on an outpatient basis, thereby mitigating any additional effect that might be expected from a more intense training as evaluated here. This is supported by the fact that children with prior MT showed very little decrease in their MOAHI following the 1-week training course, whereas it was reduced by 75% in those *not* having received prior MT.

Finally, the intensity of the intervention may have been insufficient, but this seems unlikely as 3 hours/day is more than any other MT intervention offers we are aware of.

Our study has additional limitations. Collecting at least 3 hours of artefact-free recording in this patient population turned out to be more difficult than anticipated. Thus, 34% of recordings had to be excluded, a much higher proportion than in previous ambulatory studies using a similar set-up.[28] Performing in-hospital recordings may have avoided this problem, but could not be realised due to financial constraints and because we wanted to keep patient burden to a minimum. Reassuringly, however, there were no demographic variables to suggest that this resulted in skewed population characteristics. Also, we only performed cardiorespiratory recordings, not full polysomnography, but reliability of the former is considered sufficient to identify OSA.[29] Nonetheless, as respiratory events occur more often in rapid eye movement sleep and are associated with arousals that disturb sleep architecture,[30] we may have underestimated the true effect of our intervention, particularly as hypopnoeas associated with arousals but without desaturation could also not be identified. The precise pathophysiology of OSA in DS is yet unclear; it is thus possible that our decision not to document arousals might have reduced our chance of finding a treatment effect if this predominantly involved hypopnoeas.

Participants were not screened for anatomical anomalies likely to interfere with breathing; this happened because ours was a pilot study analysing the effectiveness of an intervention under routine conditions. Finally, as this was a pilot study, we did not perform a formal power calculation and can thus not exclude that we would have seen an effect with a larger sample size. The differences in sleep study results seen before versus after the intervention, however, were so small that it seems unlikely that we missed a clinically relevant improvement in OSA symptoms. Finally, we did not recruit a control group, that is, each patient served as his/her own control.

Study strengths include that all patients were treated according to a standard, well-established protocol, that only objective outcome parameters were used and that analysis was blinded to the intervention.

The only parameter showing some improvement was the $DI_{90}$. In healthy schoolchildren, a high $DI_{90}$ has been associated with impaired school performance and behaviour.[31 32] Nonetheless, the improvement in $DI_{90}$ seen appears too small to be clinically meaningful.

## CONCLUSION

OSA is a common problem in children with DS and often difficult to treat. This study could not show that MT was effective as the sole treatment for OSA in DS. Whether a combination of surgery (eg, AT to enlarge the hypopharyngeal space) with MT would have been more effective remains unclear and should be subject of a future randomised clinical trial.

**Contributors** ML designed the study, performed the analyses, drafted the initial manuscript and revised the manuscript. NH analysed the recordings and contributed to patient recruitment. SR set up the recordings. MQ supervised the analysis of the recordings. GI supervised the myofunctional treatment. CFP initiated and supervised the study. SR, MQ, GI and CFP reviewed and revised the manuscript making important intellectual contributions.

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## REFERENCES

1 Lin SC, Davey MJ, Horne RS, *et al*. Screening for obstructive sleep apnea in children with Down syndrome. *J Pediatr* 2014;165:117–22.
2 Marcus CL, Keens TG, Bautista DB, *et al*. Obstructive sleep apnea in children with Down syndrome. *Pediatrics* 1991;88:132–9.
3 Dyken ME, Lin-Dyken DC, Poulton S, *et al*. Prospective polysomnographic analysis of obstructive sleep apnea in down syndrome. *Arch Pediatr Adolesc Med* 2003;157:655–60.
4 Rosen D. Management of obstructive sleep apnea associated with Down syndrome and other craniofacial dysmorphologies. *Curr Opin Pulm Med* 2011;17:1–6.
5 Fink GB, Madaus WK, Walker GF. A quantitative study of the face in Down's syndrome. *Am J Orthod* 1975;67:540–53.

6 Donnelly LF, Shott SR, LaRose CR, *et al*. Causes of persistent obstructive sleep apnea despite previous tonsillectomy and adenoidectomy in children with down syndrome as depicted on static and dynamic cine MRI. *AJR Am J Roentgenol* 2004;183:175–81.
7 Carlstedt K, Henningsson G, Dahllöf G. A four-year longitudinal study of palatal plate therapy in children with Down syndrome: effects on oral motor function, articulation and communication preferences. *Acta Odontol Scand* 2003;61:39–46.
8 Halbower AC, Degaonkar M, Barker PB, *et al*. Childhood obstructive sleep apnea associates with neuropsychological deficits and neuronal brain injury. *PLoS Med* 2006;3:e301.
9 Mitchell RB, Kelly J. Behavioral changes in children with mild sleep-disordered breathing or obstructive sleep apnea after adenotonsillectomy. *Laryngoscope* 2007;117:1685–8.
10 Guimarães KC, Drager LF, Genta PR, *et al*. Effects of oropharyngeal exercises on patients with moderate obstructive sleep apnea syndrome. *Am J Respir Crit Care Med* 2009;179:962–6.
11 Breslin J, Spanò G, Bootzin R, *et al*. Obstructive sleep apnea syndrome and cognition in Down syndrome. *Dev Med Child Neurol* 2014;56:657–64.
12 Mitchell RB. Adenotonsillectomy for obstructive sleep apnea in children: outcome evaluated by pre- and postoperative polysomnography. *Laryngoscope* 2007;117:1844–54.
13 Shete MM, Stocks RM, Sebelik ME, *et al*. Effects of adeno-tonsillectomy on polysomnography patterns in Down syndrome children with obstructive sleep apnea: a comparative study with children without Down syndrome. *Int J Pediatr Otorhinolaryngol* 2010;74:241–4.
14 Shott SR, Donnelly LF. Cine magnetic resonance imaging: evaluation of persistent airway obstruction after tonsil and adenoidectomy in children with Down syndrome. *Laryngoscope* 2004;114:1724–9.
15 Li KK, Riley RW, Guilleminault C. An unreported risk in the use of home nasal continuous positive airway pressure and home nasal ventilation in children: mid-face hypoplasia. *Chest* 2000;117:916–8.
16 Kheirandish-Gozal L, Bhattacharjee R, Bandla HPR, *et al*. Antiinflammatory therapy outcomes for mild OSA in children. *Chest* 2014;146:88–95.
17 Villa MP, Brasili L, Ferretti A, *et al*. Oropharyngeal exercises to reduce symptoms of OSA after AT. *Sleep Breath* 2015;19:281–9.
18 Mohamed AS, Sharshar RS, Elkolaly RM, *et al*. Upper airway muscle exercises outcome in patients with obstructive sleep apnea syndrome. *Egypt J Chest Dis Tuberc* 2017;66:121–5.
19 Strome M. Obstructive sleep apnea in Down syndrome children: a surgical approach. *Laryngoscope* 1986;96:1340–2.
20 Puhan MA, Suarez A, Lo Cascio C, *et al*. Didgeridoo playing as alternative treatment for obstructive sleep apnoea syndrome: randomised controlled trial. *BMJ* 2006;332:266–70.
21 Camacho M, Certal V, Abdullatif J, *et al*. Myofunctional Therapy to Treat Obstructive Sleep Apnea: A Systematic Review and Meta-analysis. *Sleep* 2015;38:669–75.
22 Guilleminault C, Huang YS, Monteyrol PJ, *et al*. Critical role of myofascial reeducation in pediatric sleep-disordered breathing. *Sleep Med* 2013;14:518–25.
23 Linz A, Urschitz MS, Bacher M, *et al*. Treatment of obstructive sleep apnea in infants with trisomy 21 using oral appliances. *Cleft Palate Craniofac J* 2013;50:648–54.
24 Buchenau W, Urschitz MS, Sautermeister J, *et al*. A randomized clinical trial of a new orthodontic appliance to improve upper airway obstruction in infants with Pierre Robin sequence. *J Pediatr* 2007;151:145–9.
25 Hoke F, Abad Bender N. Die Padovan Methode. *Logos-Fachzeitschrift für akademische Sprachtherapie und Logopädie*. 2011;4:301–7.
26 Iber C A-IS, Chesson A. The AASM manual for the scoring of sleep and associated event: rules, terminology and technical specifications. *Am Acad Sleep Med 1st ed Westchester* 2007.
27 Berry RB, Budhiraja R, Gottlieb DJ, *et al*. Rules for scoring respiratory events in sleep: update of the 2007 AASM Manual for the Scoring of Sleep and Associated Events. Deliberations of the Sleep Apnea Definitions Task Force of the American Academy of Sleep Medicine. *J Clin Sleep Med* 2012;8:597–619.
28 Moss D, Urschitz MS, von Bodman A, *et al*. Reference values for nocturnal home polysomnography in primary schoolchildren. *Pediatr Res* 2005;58:958–65.
29 Alonso-Álvarez ML, Terán-Santos J, Ordax Carbajo E, *et al*. Reliability of home respiratory polygraphy for the diagnosis of sleep apnea in children. *Chest* 2015;147:1020–8.
30 Verginis N, Jolley D, Horne RS, *et al*. Sleep state distribution of obstructive events in children: is obstructive sleep apnoea really a rapid eye movement sleep-related condition? *J Sleep Res* 2009;18:411–4.
31 Goodwin JL, Kaemingk KL, Fregosi RF, *et al*. Clinical outcomes associated with sleep-disordered breathing in Caucasian and Hispanic children–the Tucson Children's Assessment of Sleep Apnea study (TuCASA). *Sleep* 2003;26:587–91.
32 Urschitz MS, Wolff J, Sokollik C, *et al*. Nocturnal arterial oxygen saturation and academic performance in a community sample of children. *Pediatrics* 2005;115:e204–9.