The Effect of Myofunctional Therapy in Anterior Open Bite Patients Measured by Electropalatography

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2. Abstract

Anterior open bite (AOB) and tongue thrust swallowing are frequently associated, but the relationship between the two remains unclear. Anterior tongue posture may prevent the eruption of the anterior teeth, and myofunctional therapy (MFT) is often prescribed for the correction of tongue thrust swallowing, with the expectation that AOB will reduce spontaneously if a more posterior tongue posture is learned. However, the effectiveness of MFT has not been subjected to systematic evaluation. Electropalatography (EPG), which is widely used in speech pathology to measure dynamic tongue function for diagnostic, therapeutic and research purposes, is a suitable technique for the assessment of MFT.

This prospective clinical study examined dento-facial pattern and tongue function in AOB and non-open bite children, and assessed the effect of tongue re-education therapy on dento-facial form and tongue function in AOB patients. EPG recordings of speech and swallowing, and lateral head radiographs were obtained from 8 ten year old boys with tongue thrust swallowing behaviour and AOB, and 8 age matched non-open bite controls.

Analysis of data from the two groups indicated that although differences were small, the open bite children displayed trends for longer face morphology and greater upper incisor proclination, less consistent production of closures during speech, a more posterior pattern of EPG contact, and relatively sparse EPG contact during swallowing.

Comparison of the condition of the AOB children before and after a course of tongue re-education therapy showed little cephalometric change, but there was some evidence of a trend for upper and lower incisor eruption, with concomitant reduction of the AOB. A trend for more consistent, and more anterior pattern of EPG contact after therapy was also found. After therapy, the experimental children more closely resembled the controls, implying that the therapy was at least partially successful.

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This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

A S Cayley June 9th, 1998

4. Introduction & Aims

4.1 Introduction

Anterior Open Bite (AOB) and fronted tongue posture are frequently associated, but despite much work the relationship between the two is not completely understood (Proffit, 1993; Proffit & Ackerman, 1994). Although in the past tongue thrust was thought to be the main ætiological factor in many AOB cases in young children, more recent evidence suggests that tongue thrust swallowing is an adaptation to open bite rather than its cause (Proffit, 1993).

The effect of different orthodontic and non-orthodontic treatment modalities on AOB, fronted tongue posture, and speech have not been clearly established. Further investigation into the effects of treatment on these conditions would be beneficial, and a reproducible method of measurement of tongue activity is necessary to assess such change.

The intra-oral measurement of tongue position during function is extremely difficult. Currently available measurement techniques are either limited to being able to record static rather than dynamic information, such as the early 'wipe-off' palatograms, or interfere with function, as with electropalatography (EPG). In this technique an acrylic palatal baseplate fitted with a number of electrodes is used to record the location and timing of tongue contacts with the hard palate (or, more accurately, the acrylic baseplate) during continuous speech (Hardcastle *et al.*, 1991a).

Another study is already in progress within the department to assess the suitability of EPG for the measurement of tongue function in a group of 8 non-open bite patients. To extend this work it is proposed that a further study should be undertaken, using similar equipment and methodology to assess a group of 8 AOB patients treated with swallowing re-education therapy, and to compare the results before and after therapy with those from the non-open bite control group. The combination of the two studies will:

- compare tongue function in open bite and non-open bite patients.
- assess the effect of swallowing re-education therapy on tongue function.
- produce a core of experimental data for future research using this technique.

4.2 Aims

The aims of this project are therefore to:

- to review the published literature relating to AOB, tongue thrust, and EPG.
- to recruit a sample group of 8 children with AOB and tongue thrust.
- to assess each child clinically, radiographically, and with EPG before and after a course of swallowing re-education therapy to assess the effect of the therapy on tongue function.
- to examine the findings from the control group with findings before and after swallowing re-education therapy to compare tongue function in open bite and non-open bite patients.
- produce a core of experimental data for future research.

4.3 Null hypotheses

The null hypotheses under test are that:

- no differences in tongue function will be found between children with clinical anterior open bite and children with normal anterior occlusion.
- no differences in tongue function will be found between children with clinical anterior open bite before and after a course of swallowing re-education therapy.

5. Literature Review

5.1 Anterior open bite

5.1.1 Features

Anterior open bite is defined by Moyers as the failure of the teeth to meet antagonists in the opposite arch (Moyers, 1988). Patient selection criteria for studies of anterior open bite (AOB) have differed, and some of these are set out below:

- the absence of contact between the maxillary and mandibular incisors in centric relation (Worms *et al.*, 1971).
- a definite lack of contact, in the vertical direction, between opposing segments of teeth (Subtelny & Sakuda, 1964).
- the dental relationship for which the vertical overlap between the central incisors is less than 0.0mm, measured perpendicular to the palatal plane (Wardlaw *et al.*, 1992).
- a linear distance greater than 3mm from the incisal edge of the most anterior mandibular incisor to the contact point of the opposing hard tissue structure projected along the long axis of the mandibular incisor, measured from a lateral head radiograph (Lopez-Gavito *et al.*, 1985). However, this is not a reliable indicator of the presence or extent of AOB; a deep bite with a large antero-posterior discrepancy can produce the same situation. Furthermore, inclined incisors can inflate the extent of the vertical discrepancy (Katsaros & Berg, 1993).
- the vertical distance between the incisal edges of the upper and lower incisors with posterior teeth in the retruded contact position (O'Brien, 1994).

From a review of the literature (Lopez-Gavito *et al.*, 1985) a partial list of features associated with AOB was compiled, including:

- excessive gonial, mandibular and occlusal plane angles.
- decreased palatal plane angle.
- small mandibular body and ramus.
- increased lower anterior face height.
- decreased upper anterior face height.
- shorter nasion-basion distance.

- retrusive mandible.
- increased anterior and decreased posterior face height.
- Class II tendency.
- divergent cephalometric planes.
- steep anterior cranial base.

These features are widely reported in the literature (Subtelny & Sakuda, 1964; Gellin, 1966; Worms *et al.*, 1971; Klechak *et al.*, 1976; Fränkel & Fränkel, 1983; Haymond *et al.*, 1991; Kuster & Ingervall, 1992). Several other features of AOB have also been reported, including:

- increased maxillary vertical dento-alveolar dimensions (Subtelny & Sakuda, 1964; Lopez-Gavito *et al.*, 1985; Haymond *et al.*, 1991; Mason, 1994).
- increased molar and incisor eruption (Subtelny & Sakuda, 1964; Worms *et al.*, 1971; Rönning *et al.*, 1994).
- thinner, longer alveolar processes (Subtelny & Sakuda, 1964).
- increased incidence of temporo-mandibular disorder (Pullinger *et al.*, 1993).
- invariable presence of tongue thrust swallowing (Proffit & Ackerman, 1994).
- shorter upper incisor roots with increased apical resorption, and less facial bony support in the upper anterior region (Harris & Butler, 1992).
- increased vertical airway length (Pae *et al.*, 1997).

As mentioned above, dento-alveolar compensation is a recognised feature in patients with AOB. Marked dento-alveolar compensation can produce a normal overbite in patients who have a skeletal open bite pattern, and such people may therefore have normal speech and tongue function. Many individuals with AOB who seek treatment for abnormal function are those who cannot adapt their muscular function sufficiently to compensate for their open bite deformity (Turvey *et al.*, 1976).

5.1.2 Prevalence

The prevalence of anterior open bite reported in various sample populations is reproduced in Table 1. There is broad agreement that AOB occurs in less than 5% of children, with the notable exception that black American children have a much higher prevalence of AOB than their white compatriots (Proffit & Mason, 1975; Proffit

Table 1 Prevalence of anterior open bite reported in the literature

Author	Prevalence (%)	Age (years)	Sex
Korkhaus, 1928 (Worms et al., 1971)	4.2	6	♂ & ♀
	2.5	14	♂ & ♀
Mills, 1966	4.2	8 - 18	♂
	7.6	8 - 18	♀
Helm, 1968	2.3	6 - 18	♂
	1.8	6 - 18	♀
Tulley, 1969	0.6	11	♂ & ♀
Roder & Arend, 1972	3.51	3	♂
	2.33	3	♀
	1.27	4	♂
	3.15	4	♀
	3.25	5	♂
	2.73	5	♀
Kelly, 1973 (Proffit & Mason, 1975)	5.7	6 - 11	♂ & ♀
	1.4 (white)	6 - 11	♂ & ♀
	9.6 (black)	6 - 11	♂ & ♀
Kamp, 1991	2.3	< 4.5	♂ & ♀
O'Brien, 1994	4	9	♂ & ♀
	3	10	♂ & ♀
	2	11 - 14	♂ & ♀
	3	15	♂ & ♀

& White, 1991). Variation in reported prevalence may reflect the numerous definitions and criteria used in epidemiological studies of AOB (Subtelny & Sakuda, 1964). No clear trend for a difference in prevalence of AOB between the sexes has been reported (Roder & Arend, 1972).

Prevalence reduces markedly between 7 and 9 years of age because of the eruption of the permanent incisors, and again between 10 and 12 years of age as a result of skeletal growth, transition to the permanent dentition, and maturation of the swallowing reflex. Approximately 80% of AOBs correct spontaneously during this period (Worms *et al.*, 1971).

Very high prevalences of AOB in Duchenne's muscular dystrophy (57.1%) and in other myopathies (14.3%) have been reported (Ertürk & Dogan, 1991), and the anomaly is also common in Down's syndrome (Scully & Cawson, 1993) and Beckwith-Wiedemann syndrome (David *et al.*, 1987).

5.1.3 Ætiology

The ætiology of anterior open bite (AOB) remains uncertain (Pae *et al.*, 1997), although it is recognised to be multifactorial (Ricketts, 1968; Haymond *et al.*, 1991; Arat & Iseri, 1992; Haydar & Enacar, 1992; Proffit, 1993; Noar *et al.*, 1996), with a complex interaction between the various contributory ætiological factors (Subtelny & Sakuda, 1964). These factors may be divided into several categories, and these are reviewed below.

Developmental factors

Age

Although the pattern of vertical growth is thought to be established early in post-natal life (Tourne, 1990), the prevalence of AOB reduces with age, as does the prevalence of non-nutritive sucking habits (Fields, 1993). The age gradient is said to be an important factor in open bite malocclusion (Subtelny & Sakuda, 1964).

Growth deficiency

AOB is often associated with long face morphology (Kuster & Ingervall, 1992), and an unfavourable growth pattern has been cited as a cause of AOB (Subtelny & Sakuda, 1964; Gellin, 1966; Arat & Iseri, 1992). Hellman suggested that the primary cause of AOB is skeletal deficiency, although as he noted, the percentage of self-correcting AOB patients was equal to the percentage corrected by active treatment (Worms *et al.*, 1971), implying that treatment conferred little, if any, benefit. Worms *et al.* also cite Björk's work, which states that if anterior and posterior mandibular growth are not equal, mandibular rotation, and AOB may result (Björk, 1969). Excessive eruption of posterior teeth predisposes any individual to AOB, and downward posturing of the mandible and tongue can allow excessive posterior eruption (Proffit, 1993).

Genetic influences

Craniometric, or skeletal variables have high heritability, whereas almost all occlusal variability is acquired (Harris & Johnson, 1991), implying that the ætiology of AOB can be genetic or environmental. Many authors describe a strong genetic influence over AOB (Proffit & White, 1991; Haydar & Enacar, 1992; Proffit, 1993), however, if Harris and Johnson are correct the reported alterations in tongue function following closure of AOB (Subtelny, 1965; Turvey *et al.*, 1976; Proffit & Mason, 1975) should not occur unless the soft tissues are not amenable to adaptation.

Developmental anomalies

Although AOB is commonly found with developmental anomalies such as Beckwith-Wiedemann and Laband syndromes, the ætiological mechanism is unknown (David *et al.*, 1987; Pullinger *et al.*, 1993; Chadwick *et al.*, 1994).

Functional factors

Soft tissue

The effect of soft tissue on the ætiology of AOB is the subject of much discussion in the literature. Many authors assume that the soft tissues can cause AOB (Straub, 1960; Kydd *et al.*, 1963; Subtelny & Sakuda, 1964; Turvey *et al.*, 1976; Arat & Iseri, 1992). Conversely, in a review of the literature (Cleall, 1965), Cleall cites Scott, who says that the form of the dental arches is based on the growth of the alveolar processes, and that the pressure of the adjacent muscles is probably of minor importance in arch form determination. Cleall's own work also supports the hypothesis that form determines function (Cleall, 1965). However, other workers (Moyers, 1988; Proffit & Ackerman, 1994) suggest that the truth lies somewhere between these two opposing opinions, and that there is an association, rather than a simple cause and effect relationship between the soft tissues and arch form, including AOB.

It has been shown that although functional pressures are of limited importance, resting soft tissue pressures are implicated in the ætiology of AOB (Proffit & Mason, 1975; Fröhlich *et al.*, 1991; Proffit & White, 1991; Proffit, 1993).

Habits

The ætiological role attributed to thumb-sucking and other habits is a recurring theme in the literature on AOB malocclusion (Subtelny & Sakuda, 1964; Subtelny & Subtelny, 1973; Arat & Iseri, 1992; Haydar & Enacar, 1992; Proffit & Ackerman, 1994). Subtelny and Sakuda found that in a sample of 36 children with habits, 10 (28%) also had an AOB. The authors attributed a primary causative role to the habit activity, which they suggest prevented eruption of the anterior teeth (Subtelny & Sakuda, 1964), and Fields states that non-nutritive sucking can also cause alveolar deformation (Fields, 1993). A child with a moderate AOB should be presumed to have a sucking habit until proved otherwise (Proffit, 1993), and when caused by a habit, an AOB is often maintained by associated tongue thrust swallow after the sucking habit is corrected (Proffit *et al.*, 1969). Rather than being causative, differences in patterns of swallowing reflect the presence of the AOB (Wallen, 1974; Proffit & Mason, 1975).

Tongue thrust swallowing

Straub's seminal work on the adverse influence of bottle feeding indicated that an abnormal swallowing habit could cause AOB (Straub, 1960), although AOB can also occur without the presence of tongue thrust swallowing or a sucking habit (Gellin, 1966). The general consensus of opinion, however, is that tongue thrust swallowing is an adaptive response to the presence of an AOB (Subtelny & Sakuda, 1964; Subtelny & Subtelny, 1973; Wallen, 1974; Proffit & Mason, 1975; Turvey *et al.*, 1976; Proffit, 1993).

Work on the dynamics of swallowing by Kydd showed that the mean muscular pressure on the dentition during swallowing in children with AOB and tongue thrust was twice that in the control group. However as the normal children swallowed twice as often, the total force expended was about equal (Kydd & Neff, 1964). The duration of swallow in the AOB children was one third of a second longer than in controls. Over a whole day, this was said to amount to an 18% increase in pressure duration in the AOB subjects as compared with the normal group (Kydd *et al.*, 1963).

Tongue size

Although most open bites are not related to macroglossia (Wolford & Cottrell, 1996), an enlarged tongue can cause AOB (Turvey *et al.*, 1976). It has been demonstrated that resting tongue pressures are greater in subjects with macroglossia, and that after reduction glossectomy designed to normalise tongue size, values are comparable with normal controls (Fröhlich *et al.*, 1993).

Tongue posture

Abnormal resting tongue posture, secondary to true macroglossia or a tumour can cause AOB (Turvey *et al.*, 1976). Anterior resting posture of the tongue is thought to be a more important ætiological factor than functional tongue activity (Proffit, 1975; Proffit & Mason, 1975; Ertürk & Dogan, 1991; Fröhlich *et al.*, 1991; Proffit & White, 1991; Proffit, 1993). The lower threshold for genioglossus activity found in AOB patients may reflect a predisposition to forward tongue posture with mandibular rotations as small as 0.5mm. The anterior tongue posture may be sufficient to prevent vertical eruption of the anterior teeth (Lowe & Johnston, 1979).

Head posture

Head posture has been implicated by several authors as an ætiological factor in AOB (Arat & Iseri, 1992; Haydar & Enacar, 1992). In his work on respiratory obstruction syndrome, Ricketts noted that children tend to lower their head posture following adenoidectomy or tonsillectomy. He suggested that pre-operatively these children had been adapting their head posture in order to increase their airway space, and that the post-operative change occurred because there was no longer any need to posture in this way (Ricketts, 1968).

Respiration

Although mouth-breathing is thought by some to be an important factor in the ætiology of AOB (Haydar & Enacar, 1992; Proffit & Ackerman, 1994) and skeletal open bite (Sassouni *et al.*, 1985), Tourne concluded from a review of the literature that the mode of breathing has little impact on the dentition and skeletal morphology (Tourne, 1990), and Linder-Aronson found no evidence of AOB in his sample of mouth-breathers (Linder-Aronson, 1970). However, much of the controversy may result from a lack of objective criteria for the assessment of facial morphology and respiratory function (Ngan & Fields, 1997).

Speech

Lisping, the most common speech articulation error, may be caused in part by irregularities of the anterior teeth. There is no evidence, however, that lisping can cause dental problems (Proffit & Ackerman, 1994).

Wind instruments

Herman found that playing woodwind instruments increases overbite, whereas playing brass instruments decreases overbite. He recommends that playing the correct type of wind instrument can be used as an adjunct to orthodontic therapy in selected cases (Herman, 1981). However, Proffit and Ackerman state that wind instruments have little or no impact on the dentition unless played for many hours per day (Proffit & Ackerman, 1994). A study comparing non-musician controls with professional woodwind and brass musicians, who could be expected to play daily for many hours, found few differences between the two groups of musicians, or between the musicians and the controls (Rindisbacher *et al.*, 1990). None of these authors mention the effect of tongue activity during instrumental playing.

Pathological factors

Nasal obstruction

There is conflicting evidence for the role of nasal obstruction as a cause of AOB. Harvold and co-workers demonstrated that forcing Rhesus monkeys to breathe through their mouths produced a variety of adaptive responses among the experimental animals. A different type of malocclusion developed in accordance with the individual animal's chosen adaptive response to the nasal obstruction. Although AOB was induced in some animals (Harvold *et al.*, 1981), it was neither a consistent nor prominent finding (Tourne, 1990; Proffit & White, 1991).

Although children with enlarged adenoids have been found to have increased facial height and SN-GoGn angles, AOB was not reported (Linder-Aronson, 1970; Sassouni *et al.*, 1985; Behfelt, 1990). In fact, it was noted that an overbite is often found in these cases (Linder-Aronson, 1970), although it is smaller than that found in nose-breathing controls (Behfelt, 1990). Follow up work has shown that adenoidectomy often results in labialisation of the incisor teeth, tending to decrease overbite (Linder-Aronson *et al.*, 1993). Ricketts, however, found that children with enlarged adenoids do exhibit AOB (Ricketts, 1968), and several other workers support the view that nasal obstruction is an important cause of AOB (Arat & Iseri, 1992; Joondeph, 1993; Proffit, 1993).

Joint disease

Inflammatory joint disease, such as juvenile chronic arthritis, is known to cause posterior rotation of the mandible, which may produce an AOB (Svensson *et al.*, 1993), although other workers report no increase in the frequency of open bite (Rönning *et al.*, 1994). If the destruction of the joint is slow, dento-alveolar compensation can occur, with a resulting normal anterior occlusion (Pullinger *et al.*, 1993).

It has been said that increased genioglossus activity, as a reflex response to a temporo-mandibular disorder (TMD), can result in a slightly open mandibular posture. In this case the tongue may be protruded into the space resulting from the teeth apart resting posture, and maintain an AOB (Lowe & Johnston, 1979; Lee, 1993).

Muscle disease

Weakened musculature influences cranio-facial morphology and occlusal development. Myopathies, or peripheral neuromuscular diseases, such as Duchenne's muscular dystrophy and myotonic dystrophy, are pathological conditions which weaken muscle tissue. In a study of patients with neuromuscular diseases, AOB was not seen in patients with neurogenic disorders, but was found in 57% of patients with Duchenne's muscular dystrophy. It should be noted, however, that another feature of Duchenne's disease is macroglossia, which may also contribute to the open bite. (Ertürk & Dogan, 1991).

AOB is known to be associated with reduced biting force, perhaps by allowing over-eruption of the posterior teeth (Proffit, 1978), and it is known that individuals with a long face morphology have weak masticatory musculature (Kuster & Ingervall, 1992). Reduced muscle strength can lead to a disposition to overload and tenderness of the masticatory muscles; it is suggested that a different elevator muscle structure may be responsible for these observations (Bakke & Michler, 1991). Evidence of variation in the composition of myosin fibres in human masseter muscle may support this theory, and has been implicated in the ætiology of the facial pattern in long and short faced individuals (Sciote *et al.*, 1994).

5.1.4 Effect on speech

Although it has been reported that occlusal defects can influence articulation and contribute to speech abnormalities (Rathbone & Snidecor, 1959), other workers have found no correlation between articulatory ability and incisor position (Oliver & Evans, 1986). In a study of the effect of facial osteotomy on speech defects, almost half of the sample had normal speech pre-operatively despite their occlusal defects (Witzel *et al.*, 1980).

In her review of the literature, Laine points out that increased frequencies of articulatory speech disorders have been reported with Class II and Class III malocclusions, and with open and deep bites (Laine, 1992). Witzel also found a relationship between the severity of AOB in combination with mandibular retrognathism or prognathism and the frequencies of sibilant and overall articulation errors. Greater numbers of labio-dental errors were found in mandibular prognathism, and bilabial errors in mandibular retrognathism (Witzel *et al.*, 1980). In an electropalatographic study of a group of patients with mandibular prognathism, it was found that the observed articulatory disorders were attributable to anterior displacement of the tongue (Satoh, 1990).

Although the cause and effect relationship between speech defects and malocclusion remains unclear, AOB may be an exception (Klechak *et al.*, 1976). AOB is associated with the formation of abnormal sibilants, although these usually occur when AOB is combined with other malocclusions. Abnormal sibilant formation is mild in cases where AOB exists without other associated occlusal defects (Laine, 1992). Sibilant formation is particularly sensitive to air stream direction and tongue position (Witzel *et al.*, 1980), which moves anteriorly during sibilant formation in the presence of AOB (Klechak *et al.*, 1976, Mason, 1994). Linguo-dental or interdental production of /ʃ/, /ʧ/, /ʤ/, and /ʒ/ may be encouraged by this structural disharmony (Zimmerman, 1994).

An orthodontic or surgical correction of a malocclusion may contribute to improved speech (Witzel *et al.*, 1980) and even without adjunctive speech therapy, closure of an AOB can lead to the spontaneous improvement of lisping and abnormal tongue behaviour (Turvey *et al.*, 1976), although some residual errors may persist (Rathbone & Snidecor, 1959).

5.1.5 Treatment

There is broad agreement throughout the literature that the treatment of AOB is one of the most difficult problems facing orthodontists, and discussion has included emotive adjectives such as "annoying", "challenging", and even "most perplexing" (Kydd *et al.*, 1963; Subtelny & Sakuda, 1964; Ricketts, 1968; Turvey *et al.*, 1976; Lowe & Johnston, 1979; Fränkel & Fränkel, 1983; Kiliaridis *et al.*, 1990; Arat & Iseri, 1992; Kuster & Ingervall, 1992; Goto *et al.*, 1994; Sarver & Weissman, 1995). There are many reports of unsuccessful treatment, particularly during the later stages of development (Arat & Iseri, 1992), and if the underlying skeletal discrepancy is severe, a functional and æsthetic occlusion may not be attainable by orthodontic treatment alone (McCance *et al.*, 1992). According to Hellman, a good prognosis for treatment can be expected if the growth pattern is favourable, but if it is not, the outcome is questionable. He also recognises that if there is a favourable growth pattern, no treatment may be needed because spontaneous closure may occur (Subtelny & Sakuda, 1964).

Spontaneous closure of AOB has been reported in 62% of children by the end of the mixed dentition (Gellin, 1966), and in 80% of 7 to 9 year olds (Worms *et al.*, 1971), and has been associated with the transition to an adult swallowing pattern (Proffit *et al.*, 1969). When a sucking habit is eliminated, spontaneous closure may occur even at 12 years of age (Subtelny & Sakuda, 1964; Subtelny & Subtelny, 1973). Spontaneous correction may also be attributable to continuing growth of the lower face, which provides space for a lower tongue posture (Gellin, 1966).

Despite considerable efforts to find reliable predictors of AOB treatment outcome, there has been little success in this area (Lopez-Gavito *et al.*, 1985; Katsaros & Berg, 1993).

Given that a high proportion of AOBs of non-skeletal ætiology close spontaneously during the mixed dentition (Gellin, 1966; Worms *et al.*, 1971), it has been suggested that correction should be postponed until after the tenth birthday (Gellin, 1966), while correction of skeletal open bites should be performed during or before active growth periods (Toutountzakis & Haralabakis, 1991).

Many treatment modalities have been used for AOB, and various degrees of success have been reported. These modalities can be divided three groups: myofunctional, orthodontic and surgical therapies.

Myofunctional therapy

Correction of AOB has been reported following the elimination of sucking habits (Straub, 1960; Subtelny & Sakuda, 1964; Subtelny & Subtelny, 1973), and as a result of the transition to an adult swallowing pattern (Proffit *et al.*, 1969). When temporo-mandibular disorder (TMD) is an ætiological factor in the existence of an AOB, it has been recommended that the TMD should be addressed before any corrective therapy for the open bite itself (Williamson *et al.*, 1990; Lee, 1993).

The association of AOB with weak masticatory musculature leads to another type of corrective therapy; it has been shown that training of the muscles by the use of tough chewing gum increases muscle strength by as much as 33%, and results in AOB closure by forward mandibular rotation of up to 6° (Bakke & Siersbæk-Nielsen, 1990), although only the abstract was published, making critical appraisal of the results impossible.

Orthodontic therapy

Functional regulators are able to correct some dento-facial deformities in skeletal open bite cases, and have been reported to be capable of achieving closure even in patients with relapsed AOB (Fränkel & Fränkel, 1983), although they produce mainly dento-alveolar rather than skeletal change, and have a masking rather than a corrective effect on the skeletal discrepancy (Arat & Iseri, 1992; Haydar & Enacar, 1992).

Posterior bite blocks produce a similar intrusion of the posterior teeth to surgical posterior maxillary impaction; the intrusion results in autorotation of the mandible and AOB correction. In order to maximise this effect, stimulation of the vertical growth of the condyle is desirable, but this has not been demonstrated (Kuster & Ingervall, 1992).

The incorporation of magnets into posterior bite blocks reliably produces a greater degree of intrusion more rapidly than bite blocks alone (Dellinger, 1986), although the therapeutic force is less easily controllable, particularly in the transverse direction (Kiliaridis *et al.*, 1990).

Both Begg and Edgewise appliances are used for the treatment of AOB. However, both systems produce an undesirable backwards rotation of the mandible and increased anterior face height by extrusion of the posterior teeth (Arat & Iseri, 1992). Control of the height of the posterior dento-alveolar regions during fixed appliance therapy is extremely important (Prosterman *et al.*, 1995).

Playing certain types of musical instrument has been recommended as an adjunct to orthodontic correction of AOB (Herman, 1981), although this is not supported by other workers (Rindisbacher *et al.*, 1990; Proffit & Ackerman, 1994).

Surgical therapy

The surgical correction of open bite by the intrusion of the maxillary buccal segments was pioneered by Schuchardt (Schuchardt, 1959). More recently, the Le Fort I intrusion osteotomy with or without the extraction of selected teeth has been used to correct an AOB malocclusion (Witzel *et al.*, 1980; Haymond *et al.*, 1991). Stability is improved if the maxillary surgery is combined with a mandibular sagittal osteotomy (Poswillo & Foster, 1992).

Pseudomacroglossia is defined as displacement of the tongue created by anatomic factors other than tongue size alone, as occurs when the tongue is positioned anteriorly by hypertrophied tonsillar tissue. In such cases surgical removal of the primary cause may lead to an increased oro-pharyngeal volume sufficient to accommodate the tongue. True macroglossia, which is not a common cause of AOB, may cause instability of any orthodontic or orthognathic surgical treatment. Partial median glossectomy is a recognised method of reducing tongue volume in cases of true macroglossia, and open bite closure has been seen when performed with tonsillectomy (Wolford & Cottrell, 1996). Spontaneous closure of an AOB has been reported after a partial median glossectomy alone, although it should be noted that the patient was a Rhesus monkey which spontaneously developed an anterior open bite (Bernard & Simard-Savoie, 1987). Congenital absence of part of the tongue or surgical excision of tongue tissue leads to a characteristic collapse in the dental arch (Proffit, 1991a).

5.1.6 Relapse

Ballard realised that the new patterns of muscular activity which occur after treatment must be physiologically economical if they are to be stable (Ballard, 1962). However, there has been little success in finding specific predictors of AOB treatment relapse

(Lopez-Gavito *et al.*, 1985; Katsaros & Berg, 1993), although posterior rotation of the mandible due to growth following treatment is one factor which can adversely affect stability (Katsaros & Berg, 1993).

The tongue adapts to its environment, but it is not possible to predict whether it will adapt to the corrected environment or contribute to relapse (Bernard & Simard-Savoie, 1987). After the surgical correction of open bite, relapse is likely to occur if tongue function cannot be controlled (Poswillo & Foster, 1992), and if the tongue is still positioned forward (Turvey *et al.*, 1976; Goto *et al.*, 1994).

Post-retention relapse of 3mm or more has been reported in over 35% of orthodontically treated AOB patients (Lopez-Gavito *et al.*, 1985). In a study comparing the effects of springs with magnets for intruding the posterior teeth, the cases treated with magnetic bite blocks relapsed more than those treated with the spring loaded bite blocks, although the length of treatment was not the same for both groups (Kuster & Ingervall, 1992).

Surgical correction appears to be more stable than orthodontic treatment, with 5 year follow up of AOB correction using small plate fixation showing relapse in only 14% of 38 treated cases (Haymond *et al.*, 1991).

5.2 Tongue thrust

5.2.1 Features

Tongue thrust is variously referred to as tongue thrust swallow, visceral swallow, infantile swallow, reverse swallow, deviant swallow, perverted swallow, and tongue thrust syndrome (Proffit & Mason, 1975). Swallowing is a complex process in which the tongue, lips and mandible function as a unit (Cleall, 1965). Normal and abnormal types have been described in detail by many authors (Straub, 1960; Andersen, 1963; Cleall, 1965), but swallowing patterns are variable, and are recognised to be capricious and unpredictable (Hanson *et al.*, 1969).

Tongue thrust has been classified on the basis of the resulting deformity (Brauer & Holt, 1965), and according to ætiology (Tulley, 1969). Brauer & Holt's classification is set out in Table 2, and Tulley's in Table 3.

Table 2 Brauer & Holt's classification of tongue thrust

Type I (non-deforming tongue thrust)	
Type II (deforming anterior tongue thrust)	Subgroup 1: anterior open bite
	Subgroup 2: associated procumbency of anterior teeth
	Subgroup 3: associated posterior crossbite
Type III (deforming lateral tongue thrust)	Subgroup 1: posterior open bite
	Subgroup 2: posterior crossbite
	Subgroup 3: deep overbite
Type IV (deforming anterior and lateral tongue thrust)	Subgroup 1: anterior and posterior open bite
	Subgroup 2: associated procumbency of anterior teeth
	Subgroup 3: associated posterior crossbite

Brauer & Holt, 1965

Table 3 Tulley's classification of tongue thrust

Habitual tongue thrust	not common beyond 11 years of age
Endogenous (innate) tongue thrust	familial pattern, marked lisping
Adaptive tongue thrust	adaptation to effect anterior oral seal
Pathological tongue thrust	such as macroglossia - extremely rare

Tulley, 1969

Definitions of tongue thrust swallowing vary among different authors. According to Proffit and Mason, the diagnostic features of tongue thrust swallowing most frequently quoted in the literature are protrusion of the tongue against or between the anterior dentition, and excessive circumoral muscle activity during swallowing (Proffit & Mason, 1975). However, Proffit and Mason themselves suggest that tongue thrusting is one or a combination of three conditions:

- during swallowing, a forward gesture of the tongue between the anterior teeth so that the tongue tip contacts the lower lip during the initiation of the swallow.
- during speech, fronting the tongue between or against the anterior teeth with the mandible hinged open.
- at rest, movement of the tongue forward in the oral cavity with the mandible hinged slightly open and the tongue tip against or between the anterior teeth.

These conditions can be found in individuals with and without speech and dental problems.

Proffit and Mason do not include activity of the facial muscles in their diagnostic features, whereas this is considered to be important by other authors (Straub, 1960; Rogers, 1961; Hanson *et al.*, 1970b). However, they do agree with several earlier authors that the interposition of the tongue between the teeth constitutes a tongue thrust swallow (Straub, 1960; Brauer & Holt, 1965; Tulley, 1969).

Tongue thrust swallowing has been associated with a high palate (Straub, 1960), lingual crossbite (Hanson *et al.*, 1970a), enlarged tonsils (Brauer & Holt, 1965; Hanson *et al.*, 1970a), increased prevalence within families, infantile muscle activity, oro-pharyngeal constriction, ankyloglossia, macroglossia (Brauer & Holt, 1965), habits (Straub, 1960; Brauer & Holt, 1965; Proffit *et al.*, 1969), and open bite (Straub, 1960; Rogers, 1961; Andersen, 1963; Kydd *et al.*, 1963; Brauer & Holt, 1965; Cleall, 1965; Tulley, 1969;

Proffit & Mason, 1975). Although Rogers reported that tongue thrust swallowing is associated with open bite, he observed that many of his deep bite patients also exhibit a similar pattern of swallowing (Rogers, 1961).

In Rogers' literature review of tongue thrust swallowing, he notes conflicting opinions on the effects of abnormal swallowing. For example, it has been associated both with a narrow maxilla, and with diastemas. Similarly, he notes that protruded upper anterior teeth, and lingual displacement of the anterior teeth have been associated with tongue thrust swallowing (Rogers, 1961).

5.2.2 Prevalence

The prevalence of tongue thrust, like the prevalence of AOB, varies widely throughout the literature, partly because different age groups have been assessed, and partly because the definitions used by different workers has varied (Andrianopoulos & Hanson, 1987). Hanson recommends clinical observation as being the best method of diagnosing tongue thrust (Hanson *et al.*, 1970b).

Prevalences as low as 2.7% have been reported for 11 year old children (Tulley, 1969), and as high as 56.9% in a group of 5 to 12 year olds (Rogers, 1961). Tongue thrust is known to decrease with age. In a review of the literature, Hanson cites the work of Lewis and Counihan who, in 1965 found that 97% of neonates displayed a tongue thrust swallowing pattern, of Bell and Hale in 1963, who found 82% in a group of 5 to 6 year olds, and of Fletcher who, in 1961 reported prevalences of 52.3% at 6 years, 38.5% at 8 years, 41.9% at 9 years, and 34.0% at 10 years of age (Hanson *et al.*, 1969).

Table 4 Prevalence of tongue thrust swallow by age (percent)

	Mean age (years & months)						
Criteria	4y 9m	5y 8m	6y 7m	7y 5m	8y 2m	12y	18y
Conservative	57.9	43.8	51.7	35.4	35.0	48.9	42.6
Liberal	86.5	79.2	79.2	72.5	70.8		

Hanson & Cohen, 1973

In a later longitudinal study the subjects were followed until 18 years of age. One conservative and one liberal set of criteria for the diagnosis of tongue thrust were used, and Hanson found a similar trend downward with age. The results are reproduced in Table 4 (Hanson & Cohen, 1973). An unexpected reversal in the downward trend occurred at the age of 12 years, when 48.9% of the sample exhibited tongue thrusting. By the age of 18 years, the figure had dropped to 42.6% (Andrianopoulos & Hanson, 1987).

Although the prevalence of abnormal swallowing varies with age, there appears to be no difference between the sexes (Kydd & Neff, 1964).

5.2.3 Ætiology

Despite the amount written on the subject, the ætiology of tongue thrust remains uncertain (Hanson *et al.*, 1969). Although the tongue functions as an integrated unit (Hanson *et al.*, 1970b), it may be considered to be composed of several different functional components, including the tip, the dorsum, the root and the lateral borders. The tip of the tongue is important in the production of sibilants and all alveolar sounds. It is relatively independent of the other parts, and is capable of rapid movement (Dagenais *et al.*, 1994), so much so that the fingers of the most efficient pianist cannot move as fast as the human tongue during conversation (Straub, 1960).

Developmental factors

Age

Tongue behaviour during swallowing undergoes a gradual transition from an infantile pattern to an adult swallow (Andersen, 1963; Proffit *et al.*, 1969; Hanson *et al.*, 1970a; Proffit & Mason, 1975; Turvey *et al.*, 1976); it has been suggested that tongue thrusting may be related to the aggressive gesture of sticking the tongue out which is seen in young children (Bloomer, 1963). During the second or third year of life, the oral cavity enlarges, the neck elongates, the hyoid bone descends, and the tongue moves down and back from the infantile to the mature position and function (Hanson *et al.*, 1970a). A similar morphological change in the mixed dentition is associated with the onset of puberty. A further increase in the size of the oro-pharyngeal space occurs with a further increase in ramal height, neck length, and a decrease in the size of tonsillar tissue. The tongue moves down and back, in association with the change to the adult swallowing pattern (Proffit & Mason, 1975; Turvey *et al.*, 1976).

Proffit describes four stages in the maturation of the process. The first, the infantile swallow is characterised by contact of the tongue tip with the lower lip, low mandibular position (jaws apart), and active contraction of the lips and facial musculature. In the fourth stage, the adult swallow, the tongue tip is against the alveolar ridge behind the central incisors, the mandible is raised to bring the teeth into occlusion, and the lips are relaxed. Intermediate swallowing patterns, teeth apart swallow, followed by a teeth together swallow, arise if all the features of the adult swallow are not acquired simultaneously. This transition is achieved early in most children, but the persistence of a sucking habit delays the natural transition and causes an intermediate pattern. Proffit argues that this hypothesis is supported by the observation that it is easier to treat a teeth together than a teeth apart swallow (Proffit *et al.*, 1969). In a later publication, Proffit and Mason maintain that the teeth together swallow is transitional, rather than being a learned abnormal pattern (Proffit & Mason, 1975).

The tongue often protrudes into the space left by exfoliated deciduous teeth, but this phenomenon is probably adaptive, and usually disappears on eruption of the permanent successor (Subtelny, 1965).

Skeletal pattern

The evidence for a skeletal ætiology of tongue thrust is ambivalent, with support in the literature for the view that forward tongue posture causes AOB, and conversely that the skeletal pattern predisposes to tongue thrusting (Moyers, 1988). Hanson is of the opinion that anything that restricts the space available to the tongue may lead to tongue thrusting (Hanson & Cohen, 1973; Andrianopoulos & Hanson, 1987).

Although accurate measurement is difficult, the tongue seems to grow steadily, approaching maximum size at or near 8 years of age. The mandible, however, grows more slowly, and may even continue beyond 20 years of age. This leads to a growth differential between the size of the tongue and mandible, with the large tongue positioned high and forward in the mouth in the early years of growth (Proffit & Mason, 1975).

Genetic influences

The role played by heredity and environment in the ætiology of tongue thrust is not clear. Although a child and parent may share a pattern of tongue thrusting, it is impossible to be sure whether this is inherited, or whether the child is imitating the parent's way of swallowing and speaking (Andersen, 1963).

Functional factors

Habits

Opinions vary as to whether non-nutritive sucking habits, such as thumb sucking, contribute to the ætiology of tongue thrust. Habits have been reported to be causative of tongue thrust swallowing by several authors (Straub, 1960; Andersen, 1963; Brauer & Holt, 1965), although Straub notes that it is not a simple cause and effect relationship (Straub, 1960). Although Hanson did not find thumb sucking to be related to tongue thrust swallowing (Hanson *et al.*, 1969), the children in the sample were of pre-school age and may therefore be expected to have a high prevalence of both infantile swallowing pattern, and digit sucking. An infantile swallow is found in a high percentage of children with habits, but also in many children without a history of digit sucking (Andersen, 1963).

It is rare to find such a habit without a tongue thrust swallow, and it may be that the habit causes an orthodontic problem to which the tongue adapts (Subtelny & Sakuda, 1964). The transition from infantile to adult swallowing usually occurs early, and habits may delay this normal developmental process. When digit sucking is stopped, spontaneous transition towards the adult pattern often occurs (Proffit *et al.*, 1969; Proffit & Mason, 1975).

Respiration

Upper respiratory restriction resulting from enlarged tonsillar and adenoidal tissues has been suggested to cause displacement of the tongue to a more anterior position and tongue thrust swallow (Subtelny & Sakuda, 1964; Brauer & Holt, 1965; Ricketts, 1968; Proffit & Mason, 1975; Moyers, 1988), and the removal of inflamed tonsils results in posterior positioning of the tongue (Behfelt *et al.*, 1990)

In a study of pre-school children it was found that nasal breathing was related to tongue thrust swallowing. The authors were unable to explain this finding, but it should be noted that they relied on the opinion of the parents in determining the habitual breathing pattern of the children (Hanson *et al.*, 1969).

Bottle feeding

The histories obtained from the mothers of children with abnormal swallowing led Straub to believe that the condition was caused by bottle feeding. Of 478 children seen over a period of 17 years, only 2 were breast fed (Straub, 1960). However, apart from Rogers, whose work neither confirms nor denies this hypothesis (Rogers, 1961), Straub appears to be alone; other authors have found that bottle feeding cannot account for tongue thrust swallowing (Andersen, 1963; Hanson *et al.*, 1969; Hanson & Cohen, 1973).

Swallowing

Andersen cites the work of Glaser, who suggested in 1951 that abnormal swallowing may be caused by drinking liquids with meals; the reasoning behind this theory is that swallowing dry food requires more effort, leading to stronger muscles. Glaser also suggested that the feeding of puréed foods to infants might delay the transition to a normal swallowing pattern (Andersen, 1963). There is some association between tongue thrust swallowing and the medium being swallowed. Saliva is the least likely to be swallowed with a tongue thrust pattern, whereas swallowing liquids and solids is more positively associated with tongue thrust swallowing (Hanson *et al.*, 1969).

Adaptive behaviour

Tongue thrust swallowing occurs as a transient adaptation to enlarged tonsils (Moyers, 1988), and as a long term adaptation in the long face syndrome. Normal tongue position in this situation would occlude the naso-pharynx, and the tongue is therefore postured down and forwards (Ricketts, 1968). In the presence of an AOB, adaptive tongue thrust swallowing provides an anterior oral seal, an example of function adapting to form (Tulley, 1969; Subtelny & Subtelny, 1973; Wallen, 1974; Proffit & White, 1991).

Pathological factors

Central nervous system

Cerebellar trauma may cause a tongue thrust swallow (Bloomer, 1963), although this is rare (Proffit & Mason, 1975). Tongue thrust swallow, seen in one of a pair of monozygotic twins, was attributed to faulty muscular control and co-ordination impairment (Andersen, 1963).

Airway obstruction

Inflammation of the tonsils, causing pain during swallowing, is recognised to cause a transient adaptive anterior positioning of the tongue (Moyers, 1988). Andersen cites Andrews, who in 1960 thought that chronically inflamed tonsils may lead to a longer term anterior tongue position becoming established, which may continue after the tonsillar inflammation resolves. Andersen himself, however, points out that chronic inflammation is not usually painful, and that the acute phase is relatively short. Chronic tonsillar enlargement might be an ætiological factor, but he notes that many people with chronic tonsillar enlargement do not exhibit tongue thrusting (Andersen, 1963). Prominent tonsils are associated with forward tongue posture (Ricketts, 1968; Proffit & Mason, 1975), and can even cause the tongue to lie between the teeth (Subtelny & Sakuda, 1964).

Mandibular position

Mandibular rotation and forward tongue posture resulting from airway obstruction may allow eruption of the posterior teeth, and lead to anterior open bite. The increased genioglossus activity found in AOB patients may explain the anterior tongue posture (Lowe & Johnston, 1979).

It has been suggested that in patients with temporo-mandibular disorder (TMD) noxious stimuli from mechanoreceptors in the periodontal ligament and temporo-mandibular joint may cause an open jaw posture with an associated anterior resting tongue position. This might explain the increased prevalence of AOB observed in TMD patients (Williamson *et al.*, 1990).

5.2.4 Effect on speech

The production of sibilants is sensitive to tongue position, and air stream direction (Witzel *et al.*, 1980), and lisping is twice as common in tongue thrusters. Tongue thrusting can occur without speech problems and *vice versa*, and tongue thrust appears to be concomitant rather than a causative factor. It remains unproven that re-education of swallowing pattern leads to an improvement in speech or malocclusion (Subtelny, 1965). When there is a tongue thrust without a speech problem, there is no evidence that speech problems will develop subsequently (Proffit & Mason, 1975).

5.2.5 Treatment

Over the years a wide variety of therapies have been suggested for tongue thrust swallowing, including reading aloud (Andersen, 1963), hypnotherapy, swallowing therapy, speech therapy, reminder appliance therapy (Andrianopoulos & Hanson, 1987), myofunctional therapy (Subtelny, 1965; Proffit & Mason, 1975; Andrianopoulos & Hanson, 1987), as well as orthodontics (Subtelny, 1970; Hanson & Cohen, 1973; Proffit & Mason, 1975; Proffit & Ackerman, 1994) and orthognathic surgery (Turvey *et al.*, 1976; Moyers, 1988; Proffit & White, 1991).

Andrianopoulos and Hanson cite work by Stansell in 1969 in which 54 patients with tongue thrust, overjet and lisping were divided into three groups of 18, and each group received either swallowing therapy, speech therapy, or no therapy. The results indicated that speech therapy decreased overjets, and swallowing therapy prevented an increase in overjet, while overjets increased in several untreated patients (Andrianopoulos & Hanson, 1987). Unfortunately, no assessment of AOB was made in this study.

According to Tulley, early treatment for tongue thrust swallowing may be undesirable because the problem may appear to be worse than it really is during the mixed dentition (Tulley, 1969). This is supported by Proffit, who recommends the following protocol:

- in cases of tongue thrust alone, there is no need for treatment.
- when tongue thrust is seen with speech problems only, spontaneous correction is likely and therefore treatment is unnecessary.

- if tongue thrust and malocclusion are present, the tongue thrust may be addressed first, but Proffit recommends treatment of the malocclusion as a better choice.
- cases where tongue thrust is present with malocclusion and speech problems should be treated similarly to those without speech problems, but additional supportive speech therapy should be included in the treatment (Proffit & Mason, 1975).

Myofunctional therapy

According to Moyers, the principal purpose of myofunctional therapy (MFT) is the creation of normal oro-facial muscular function to aid growth and the development of normal occlusion, but not to increase the size or strength of muscles. However, in practice it is difficult for patients to maintain a regime of myotherapy. Brass instruments are recommended to increase lip tonicity, and single reeded instruments should be avoided (Moyers, 1988).

It has been recommended that MFT should be instituted after orthodontic treatment if adverse tongue and lip patterns persist (Subtelny & Subtelny, 1973).

Closure of anterior open bite

Closure of anterior open bite induces a spontaneous correction of adaptive tongue thrust swallowing in many instances, and this can be achieved either by orthodontic treatment (Cleall, 1965; Tulley, 1969; Subtelny, 1970; Proffit & Mason, 1975; Proffit & Ackerman, 1994), or by orthognathic surgery (Turvey *et al.*, 1976; Moyers, 1988; Proffit & White, 1991). Reminder and crib appliances are also recommended to re-educate tongue behaviour (Rogers, 1961; Subtelny & Sakuda, 1964; Cleall, 1965).

5.2.6 Relapse

In a review of the literature on the effectiveness of therapy for tongue thrust swallowing, all six of the long term studies quoted produced results supportive of therapy. For example, in a study by Robson in 1963, 666 subjects were followed for up to 31 months, and 78.1% retained a corrected swallowing pattern. However, none of these studies provide information on predictive indicators of stability. From the results of their own work, Andrianopoulos and Hanson concluded that it was not possible to predict the development or persistence of future tongue thrust behaviour (Andrianopoulos & Hanson, 1987).

5.3 Relationship between anterior open bite & tongue thrust

The prevalence of tongue thrust in AOB children is over 90% (Rogers, 1961), and this association has been confirmed by other workers (Speidel *et al.*, 1972; Hanson & Cohen, 1973; Andrianopoulos & Hanson, 1987). There is also evidence for a relationship between digit sucking habits and AOB (Andrianopoulos & Hanson, 1987), and it is rare to find a child with an AOB and such a habit who has no tongue thrust swallowing pattern (Subtelny & Sakuda, 1964). AOB has been related to an anterior inferior tongue position (Ertürk & Dogan, 1991), and with a teeth together tongue thrust swallow (Proffit *et al.*, 1969), and with macroglossia (Turvey *et al.*, 1976). Although heavy tongue pressures have been found in teeth together tongue thrust swallowing, and light pressures in teeth apart swallows, resting pressures are thought to be more important than functional pressures (Proffit & Mason, 1975; Fröhlich *et al.*, 1991; Proffit & White, 1991).

Subtelny noted that it had not been conclusively shown that re-education of swallowing has an appreciable effect on malocclusion (Subtelny, 1965). Uncertainty still exists over the fundamental relationships between tongue function and malocclusion (Andrianopoulos & Hanson, 1987). There appears to be an association, but an association is not proof of cause and effect (Proffit & Mason, 1975).

Essentially the evidence falls into two, with some workers suggesting that function dictates form, and other authors suggesting the opposite. Straub was of the opinion that form is determined by function, and he stated that an abnormal swallowing habit usually produces an open bite (Straub, 1960). It is recognised that digit sucking can cause AOB, indicating that function can influence form (Subtelny & Sakuda, 1964; Proffit *et al.*, 1969). Furthermore, an established malocclusion can be maintained by a tongue thrust swallowing pattern (Proffit *et al.*, 1969).

Although the tongue occasionally fails to adapt to local change brought about by surgery to the jaws (Moyers, 1988), the correction of an AOB is generally accepted to eliminate a tongue thrust swallowing pattern (Subtelny, 1965; Turvey *et al.*, 1976; Proffit & Mason, 1975), with the tongue adapting to the altered form (Subtelny & Sakuda, 1964; Subtelny, 1970). This concept of form dictating function is confirmed by other workers (Cleall, 1965; Tulley, 1969; Subtelny, 1970; Speidel *et al.*, 1972; Subtelny & Subtelny, 1973).

The presence of an AOB necessitates an adaptive tongue thrust swallowing pattern in order to effect an anterior oral seal (Subtelny & Subtelny, 1973; Wallen, 1974).

5.4 Measurement of tongue function

Serial cephalograms, cineradiography and cinefluorography are no longer commonly used in the measurement of tongue function and swallowing because of the deleterious effects of exposure to ionising radiation (Cleall, 1965; Subtelny, 1965; Tulley, 1969; Subtelny, 1970; Subtelny & Subtelny, 1973), although videofluoroscopy and manofluorography have been used in more recent work (Hamlet, 1989; Kahrilas *et al.*, 1993). Cinephotography has also been used, but is of little value because it provides little information about intra-oral function (Tulley, 1969).

Electromyography (EMG) has also been used. Andrianopoulos quotes an experiment reported in 1975 by Overstake in which the characteristics of tongue thrust patterns were not found on the EMGs of corrected thrusters, whose patterns closely matched those of the normal swallowers (Andrianopoulos & Hanson, 1987). However, it is not clear what patterns were being assessed. Although Tulley states that "it is quite impossible to study the tongue musculature by electromyography" (Tulley, 1969), later work showed that it is indeed possible to monitor genioglossus activity with electromyography (Lowe & Johnston, 1979).

The lingometer, a device for measuring forward movement of the tongue tip during swallowing, has been used as a diagnostic tool for the assessment of tongue thrust (Fink, 1986). Although simple and inexpensive, the lingometer is bulky, affecting tongue function by its very presence. Furthermore, it can only measure the most anterior position of the tongue during swallowing, rather than a dynamic recording of lingual activity.

Electromagnetic articulography, which tracks the movements of induction coils positioned in the midline of the dorsum of the tongue, appears to be safe, and non-invasive, and does not interfere with speech movements. It has been used in the evaluation of speech impaired patients (Schönle *et al.*, 1987), and in the diagnosis of tongue thrust (Horn *et al.*, 1996). Unfortunately, only an abstract of the latter work is available, and the conclusions of the research are unclear.

Intra-oral pressure transducers have been used for the assessment of the pressures generated by the tongue during swallowing (Proffit *et al.*, 1969), but although they are not too bulky, they too produce limited information on the dynamics of tongue function. More recent work with a less intrusive intra-oral system using an open ended cannula connected to an extra-oral pressure transducer has demonstrated that negative pressures are generated within the oral cavity during normal function (Fröhlich *et al.*, 1991). Although this equipment is more sensitive, it still yields little dynamic information about tongue function.

Two- and three-dimensional 30kHz ultrasound images of tongue function have been used, but unfortunately ultrasound does not penetrate bone (Kahrilas *et al.*, 1993; Byrd *et al.*, 1995). Magnetic resonance imaging has also been used, but it is not practical to obtain simultaneous recordings of speech during the scan, and the time taken for each slice precludes its use for the measurement of speech (Byrd *et al.*, 1995).

Palatography was designed to record the positions of lingual contact for isolated speech sounds. The surface of the hard palate was sprayed with a dry powder (usually a mixture of charcoal and chocolate), and the area of 'wipe-off' caused by tongue contact after the sound had been produced was photographed (Hardcastle *et al.*, 1991a). Palatography has been shown to be able to differentiate between the swallowing patterns of tongue thrusters and normals (Andrianopoulos & Hanson, 1987). However, palatography is also unable to record the dynamic aspects of palatal tongue contact.

5.4.1 Electropalatography (EPG)

Electropalatography (EPG), which evolved from the older static palatographic techniques, was introduced in the early 1970s. In electropalatography tongue to palate contact is monitored with a specially constructed acrylic palatal baseplate containing electrodes exposed to the lingual surface. As the technique records contact only, the proximity and shape of the tongue must be inferred from the contact patterns alone (Hamlet *et al.*, 1986; Hardcastle *et al.*, 1991a), and it is impossible to make inferences about gestural trajectory and articulator velocity (Byrd *et al.*, 1995). Although the exact part of the tongue contacting the EPG plate cannot be known precisely, it has been reported that, under certain circumstances it may be possible to infer changes in mandibular position from EPG data (Lundqvist *et al.*, 1995). Using EPG, it has been possible to demonstrate antero-posterior changes in articulatory placement following maxillary advancements and mandibular setbacks (Wakumoto *et al.*, 1996).

EPG can provide detailed spatio-temporal information on contacts during continuous speech and other functional activities of the tongue. Because it is a safe, relatively non-invasive, simple and easy-to-use technique, EPG has become an attractive laboratory tool for the investigation of dynamic lingual activity in normal and pathological speech (Hardcastle, 1987), and has been used to analyse tongue activity in many languages (Hardcastle, 1989). However, constructing EPG plates for subjects to be representative of a larger population is expensive and inconvenient. As a diagnostic aid, EPG produces objective, detailed and accurate information on articulatory behaviour, and can reveal patterns and tendencies which cannot be obtained by other commonly used methods such as auditory based transcription (Hardcastle *et al.*, 1991a; 1991b; Byrd *et al.*, 1995). On-screen visual feedback of tongue activity allows EPG to be used as a therapeutic aid, enabling patients to develop a precise idea of how their tongue movement patterns need to change in order to resemble normal patterns (Hardcastle *et al.*, 1991a; 1991b). The ability to connect two palates simultaneously enables a speech therapist to give real-time demonstrations and instruct patients in more appropriate patterns of tongue activity (Gibbon & Hardcastle, 1987); EPG is particularly useful for helping hearing-impaired patients to learn the normally hidden tongue-palate contacts essential for intelligible speech (Fletcher *et al.*, 1991). EPG is also used as a tool for the assessing the efficacy of speech therapy regimes, both for clinical research and for cost benefit analysis (Hardcastle *et al.*, 1991a; 1991b). More recently, EPG has been used for the assessment of tongue function during swallowing with particular reference to the effects of bolus size and consistency (Chi-Fishman & Stone, 1996).

It is necessary to provide subjects with a 'dummy' plate, to allow their speech to accommodate to wearing the EPG plate during recordings. There is disagreement in the literature on the length of time necessary to ensure adaptation. Lundqvist required day and night time wear for two weeks prior to recordings (Lundqvist *et al.*, 1995), whereas Haydar found that within seven days of wearing maxillary retainers, articulatory distortions had disappeared, and patients had adapted completely to the plates (Haydar *et al.*, 1996), and Proffit found that after three days wear, trained listeners could not detect differences in speech quality with and without an appliance (Proffit *et al.*, 1969). Allen found that with a thin well-adapted palate approximately 1mm thick, his subjects were able to enunciate properly after only a few minutes of practice (Allen, 1958), and Byrd cites Flege who, in 1976 found that even with an EPG plate, only 5 minutes of practice was necessary to eliminate perceptible interference with normal speech (Byrd *et al.*, 1995). Hardcastle, who pioneered the Reading EPG system, recommended four hours wear before recordings to reduce hypersalivation (Hardcastle, 1989), but elsewhere suggests that the practice plate should be worn for increasing period of time including at least one 2 hour period, so as to become accustomed to the feel of the device in the mouth (Hardcastle & Edwards, 1992). Byrd and co-workers required the EPG plate to be worn for only an hour (Byrd *et al.*, 1995).

5.5 Corrective therapy

Normal development of speech sounds occurs gradually throughout the early years and perfect production of the entire range need not be expected until the seventh birthday (Rathbone & Snidecor, 1959). Tongue agility, also known as diadochokinesia, increases with age at least until the end of the second decade of life. A lack of ability to perform rapid tongue movements is known as dysdiadochokinesia (Bloomer, 1963).

5.5.1 Myofunctional therapy

Besides altering the anatomy by means of orthodontic or surgical intervention, myofunctional therapy (MFT) is used to improve swallowing patterns by changing tongue function. This technique is often practised by speech therapists as there is a considerable overlap with therapies designed to modify tongue behaviour during speech. Both approaches are capable of repositioning the tip of the tongue more posteriorly, although there is some evidence that MFT does not change the swallowing pattern significantly (Proffit & Mason, 1975). A protocol for such therapy is presented (Rogers, 1961) consisting of several stages:

- evaluation, including assessment of oro-pharyngeal, lingual and facial muscle function.
- explanation of the problem to the parent and patient.
- demonstration of the correct palatal contact point for the tongue during swallowing.
- instruction in swallowing.
- home practice regime.
- monthly review until the therapist is satisfied that the patient is swallowing correctly without conscious effort.

Some authors have advocated the use of MFT and orthodontic therapy together, indicating that success is enhanced by a combination approach (Proffit & Mason, 1975; Turvey *et al.*, 1976). It has also been recommended that speech therapy be delayed until after orthodontic treatment is complete or well advanced (Rathbone & Snidecor, 1959), and then only in the rare cases in which the tongue does not adapt to its new environment (Speidel *et al.*, 1972). However Proffit suggests that in cases of tongue thrust swallowing, malocclusion, and abnormal speech, therapy should not be delayed until the start of orthodontic treatment (Proffit & Mason, 1975). There is also evidence that patients treated with tongue thrust therapy before orthodontic treatment will retain correct tongue function (Andrianopoulos & Hanson, 1987).

MFT is unnecessary to correct tongue thrust swallowing occurring without a malocclusion or abnormal speech (Proffit & Mason, 1975; Turvey *et al.*, 1976). Even where there is a malocclusion, MFT should not be prescribed before puberty as spontaneous change may occur at this stage (Turvey *et al.*, 1976). MFT may be beneficial before puberty where abnormal speech, tongue thrust swallowing and a malocclusion are all present (Proffit & Mason, 1975), and in any case should be instigated if spontaneous change has not occurred by the onset of puberty (Turvey *et al.*, 1976).

Most children adapt rapidly to the reduction in articulatory proficiency which may occur with orthodontic treatment (Proffit & Mason, 1975; Proffit & Ackerman, 1994). However, speech therapy and MFT may be provided in cases where difficulty is encountered (Proffit & Mason, 1975). The effectiveness of speech therapy before 9 years of age is questionable (Gellin, 1966).

5.5.2 Reminder appliance therapy

The placement of cemented palatal crib appliances is a recognised technique both for eradicating digit sucking (Subtelny & Sakuda, 1964; Subtelny & Subtelny, 1973; Haskell & Mink, 1991), and for the modification of tongue behaviour (Rogers, 1961; Cleall, 1965), although in the latter case they have been found to be only partially successful (Rogers, 1961).

In a group of tongue thrusting children, the placement of a crib was associated with a more posterior resting position, and a more posterior and superior functioning position of the tongue after a period of 6 months. The appliances were removed, and after 2 months there was slight evidence that the tongue tip was functioning in a more superior position than before the appliance placement. The upper incisors, however, moved lingually, and this change appeared to be stable (Cleall, 1965).

5.6 Summary

Anterior Open Bite

The prevalence of AOB is probably less than 5%. The ætiology remains uncertain, but genetic, functional and pathological factors have been implicated. Differences in the composition of masticatory musculature, and resting tongue posture are thought to be important ætiological factors. AOB can be also caused by functional activities such as non-nutritive digit sucking. There is also an association with the abnormal production of sibilant speech sounds.

Although treatment is notoriously difficult, spontaneous closure is common, perhaps resulting from the development of normal swallowing activity, the transition to the permanent dentition, and the elimination of non-nutritive sucking activity, which may all occur at around the same age. Myofunctional therapy, orthodontics and surgery have all been used to correct AOB, but if anterior tongue posture persists after correction of the open bite, relapse is likely.

Tongue thrust swallowing

A wide variation in prevalence has been reported, partly because of the profusion of definitions of abnormal tongue thrust behaviour; tongue thrust swallowing is a normal feature of suckling. Lisping is often associated with tongue thrust swallowing, but many tongue thrust patients do not show altered sibilant production. The ætiology is uncertain although, genetic, functional, and pathological factors, and anterior open bite have been cited. A tongue thrust swallow is commonly found with AOB, facilitating an anterior oral seal; tongue behaviour in these cases is therefore probably adaptive.

Tongue thrust has been treated by anterior open bite closure, which often results in spontaneous correction of tongue thrust swallowing, and with myofunctional therapy. Myofunctional therapy is used to reposition the tongue tip posteriorly during speech and swallowing, but its effects have not been subjected to systematic evaluation.

Electropalatography

Electropalatography provides a convenient method of measuring dynamic tongue function. It is extensively used in the diagnosis and treatment of speech disorders, and also as an investigative tool, although it has not been used widely in orthodontic research.

6. Materials & Methods

6.1 Introduction

The aim of this study was to assess the effect of tongue re-education therapy on tongue function. Measurement was by comparison of clinical and electropalatographic (EPG) data obtained before and after therapy.

6.2 Sample

6.2.1 Experimental patient selection

Dental Officers from the South Australian Dental Service (SADS) clinics in and around Adelaide were briefed about the nature of the study, and subsequently referred 8 patients for treatment. In order to be eligible for inclusion in the study, children were required to fulfil certain criteria. They were to:

- be male.
- be over 9, but less than 11 years of age at the time of examination.
- have either an anterior open bite, or an incomplete overbite of 3mm or more.
- exhibit a tongue thrust swallowing pattern with interposition of the tongue between the teeth.

6.2.2 Experimental patient assessment

Clinical assessment

By means of a clinical examination, each child was checked for suitability according to the above criteria by ASC and another orthodontist in the Orthodontic Department at the Adelaide Dental Hospital. The child's tongue thrust swallowing pattern was demonstrated, and the association between tongue thrust swallowing and AOB were explained to the child and parent. The aims of the study were outlined, and the need for a course of tongue re-education therapy was discussed.

Extra-oral and intra-oral photographs, and upper and lower alginate impressions for plaster study models were taken at the initial visit.

Speech pathology assessment

Suitable children were also assessed by either of two speech therapists attending the Adelaide Dental Hospital to confirm the presence of a tongue thrust swallowing pattern, and the existence of any abnormal speech sounds.

Radiographic assessment

Lateral head radiographs were taken before and after completion of the tongue re-education therapy. A post-therapy radiograph was not taken for child A because of parental refusal, and therefore lateral head radiographs were available for only 7 of the 8 experimental group children. The films were viewed on a light box in a darkened room, and traced on acetate with an 0.5mm pencil using shielding as necessary to assist in the location of landmarks; all films were traced and measured using 400mm 2x magnification loupes.

The landmarks defined in Table 5 were used to determine the angular and linear measurements listed in Table 6. A graphical representation of the landmarks and angular and linear measurements can be found in Figure 1. These measurements were selected to facilitate comparison of the vertical and horizontal facial patterns of the subjects, and to assess any change in incisor position occurring between the beginning and end of the course of tongue re-education therapy.

6.2.3 Control group

The control group consisted of 8 male children aged between 9 and 11 years of age with no tongue thrust swallowing pattern or AOB, who were the subjects of previous research by Dr Andrew Tindall in the University of Adelaide Orthodontic Department (Tindall, 1998).

Radiographic assessment

Lateral head radiographs were taken at the initial visit, and these were traced and measured by ASC as described above. Radiographs were not taken for 2 children because of parental refusal, and therefore lateral head radiographs were available for only 6 of the 8 control group children.

Table 5 Cephalometric landmarks used & their definitions

S	Sella	The centre of the hypophyseal fossa (sella turcica)
N	Nasion	The fronto-nasal suture at its most superior point on the curve at the bridge of the nose
ANS	Anterior Nasal Spine	The most anterior point on the maxilla at the level of the palate
PNS	Posterior Nasal Spine	The most posterior point on the bony hard palate in the sagittal plane
A	Subspinale (A Point)	The most posterior point of the curve between ANS & Supradentale
B	Supramentale (B point)	The most posterior point of the bony curvature of the mandible below Infradentale and above Pogonion
Gn	Gnathion	The most anterior inferior point on the lateral shadow of the chin
Me	Menton	The lowest point on the symphyseal outline of the chin
Go	Gonion	The most posterior inferior point at the angle of the mandible
Is	Incision superius	The incisal tip of the most anterior maxillary central incisor
Ii	Incision inferius	The incisal tip of the most anterior mandibular central incisor
UIA		Upper incisor apex
LIA		Lower incisor apex
Ss	Stomion superius	The most inferior point on the upper lip
Si	Stomion inferius	The most superior point on the lower lip

Moyers, 1988; Enlow & Hans, 1996

Table 6 Angular & linear measurements used in cephalometric analysis

SN-MP	°	Cranial base to mandibular plane angle (Go-Gn)
SN-PP	°	Cranial base to palatal plane angle (ANS-PNS)
SNA	°	Antero-posterior position of maxilla to cranial base
SNB	°	Antero-posterior position of mandible to cranial base
ANB	°	Antero-posterior relationship between maxilla and mandible
N-PP	mm	Upper face height perpendicular to palatal plane
PP-Me	mm	Lower face height perpendicular to palatal plane
AFH	mm	Anterior face height (N-Me) perpendicular to palatal plane
Is-PP	mm	Distance from maxillary incisal edge to palatal plane perpendicular to palatal plane
Ii-MP	mm	Distance from mandibular incisal edge to mandibular plane along lower incisor axis
AOB	mm	Distance from mandibular incisal edge to upper incisor along lower incisor axis
U1-SN	°	Angle of maxillary incisor to cranial base
U1-PP	°	Angle of maxillary incisor to palatal plane
IMPA	°	Angle of mandibular incisor to mandibular plane
IIA	°	Inter-incisal angle
ILG	mm	Inter-labial gap perpendicular to palatal plane
NLA	°	Naso-labial angle

Owen, 1984; Lopez-Gavito *et al.*, 1985; Proffit, 1991b

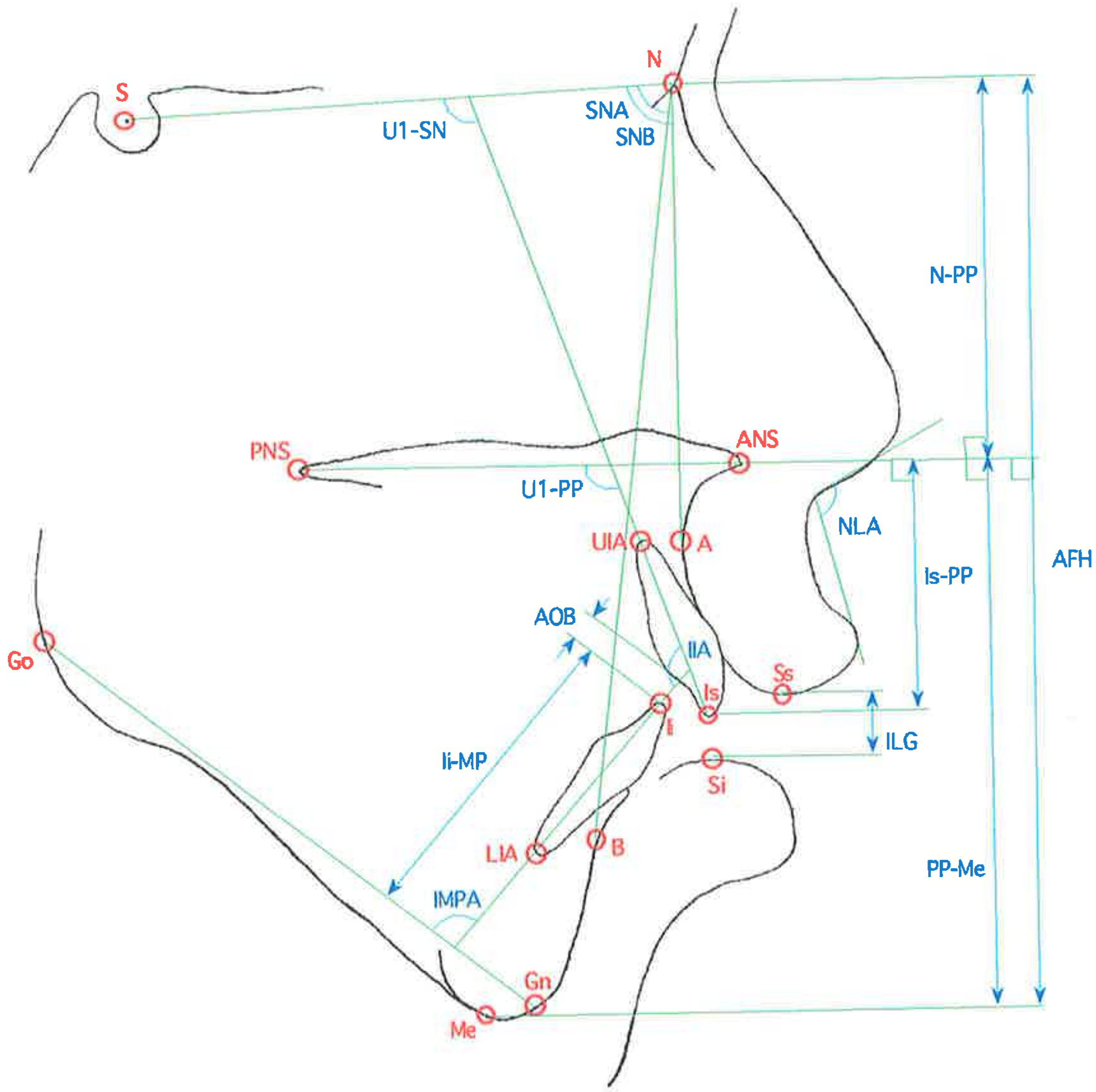


Figure 1 Cephalometric landmarks with linear & angular measurements

6.3 Plate construction

At the initial visit an indelible pencil was used to mark the junction of the hard and soft palates before a second upper alginate impression was taken. The impression was acceptable only if the indelible pencil mark was visible on the impression material, indicating adequate distal extension. This impression was used for the construction of two acrylic baseplates with Adams clasps on the second deciduous molars. One baseplate was used as the 'dummy' trainer plate, and the other was used as the acrylic baseplate for the EPG plate, as shown in Figure 2 on the following page. The construction of the EPG plate is described in detail in the Reading University Electropalatograph EPG3 manual, from which the following is taken:

> "An essential component of the EPG system is an artificial palate. This is made from acrylic, moulded to fit the upper palate and teeth, and contains 62 miniature silver electrodes exposed to the lingual surface. These are arranged according to a predetermined scheme based on anatomical landmarks. This ensures adequate coverage of the entire palate including phonetically important areas, such as the region near the junction between the hard and soft palates and the lateral margins close to the side teeth. The procedure involves first marking the positions for the electrodes on a plaster model of the subject's ... palate and teeth. Three reference lines are then traced out on the surface:
>
> 1 a line drawn horizontally across the top of the model through the palatal junctures of the upper ... incisors.
>
> 2 a line drawn horizontally through the mid point of the juncture between the hard and soft palate.
>
> 3 a line drawn vertically down the centre of the palate.
>
> The 62 electrode positions are arranged in eight horizontal rows with eight electrodes in each row, except the first (the most anterior) which has six. The most anterior and most posterior rows constitute the two horizontal reference lines, 1 & 2 above. Along these lines the electrode positions are marked out at equidistant intervals with the most lateral ones just inside the side teeth. The remaining rows are arranged so that the spacing between the front four rows is half that of the back four rows. As with the first (most anterior) and eighth (most posterior) rows, the contact positions are equally spaced across the rows. The electrode positions are marked out on the plaster model and used as a guide for placing the electrodes during the palate manufacture process. The electrodes themselves are thin silver discs 1.4mm in diameter, each connected to a 46cm length of 41 s.w.g. enamelled copper wire. The bundles of wire from the electrodes are brought to the posterior corner of the palate, ... and are fed out of the mouth via the buccal surfaces of the maxillary dentition. The wires are protected by soft heat-shrink tubing.

The choice of anatomically-based reference lines and the proportional spacing of the electrodes ensure that different palate sizes and shapes can be compared with reference to specific rows and electrode positions. Thus for example, row number 3 (third from the edge of the alveolar ridge) will stand in more or less the same relationship to the palate and teeth in different subjects.

It is important that the palate interferes as little as possible with normal speech production. It should be as thin as possible, but at the same time robust enough to tolerate frequent use and thick enough to keep its shape accurately. An exact fit is essential and the palate should not move even when considerable pressure is exerted on the posterior edge, as may happen for example during the closure for a velar stop. It is a routine procedure to issue clients with a 'practice plate'. This is a duplicate plate, without the electrodes and wires, or connector, which can be taken home and worn for increasing periods of time prior to clinical sessions."

Each child attended again for fitting of the two plates, and after any adjustments, the trainer plate was taken home. The child was requested to wear the trainer plate full time for 3 days prior to the EPG recording session.

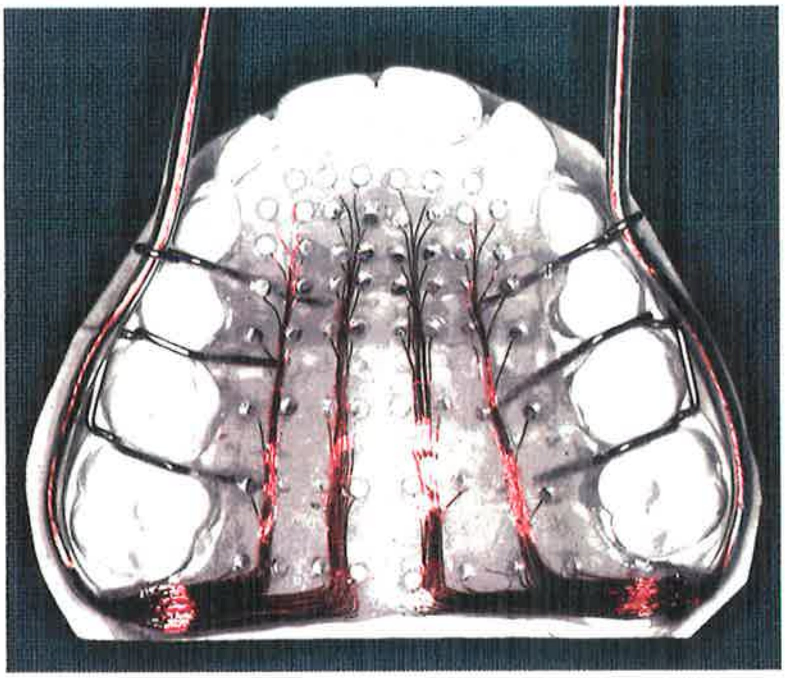


Figure 2 EPG plate

6.4 First electropalatographic (EPG) recording

6.4.1 Equipment

The apparatus for EPG recording consisted of the EPG plate, a microphone, a hand held electrode, a multiplexer, the EPG3 unit, and an IBM compatible PC containing an EPG3 interface card, and monitor, keyboard, mouse, and headphones. All connections were made as directed in the EPG3 manual. The system was switched on, and the EPG3 programme started. The equipment was tested to check that all components were properly connected and functioning correctly. With the child speaking into the microphone, the gain was adjusted to peak below maximum level to avoid distortion. The EPG palate was inserted, and the hand held electrode given to the child to hold. With the EPG3 programme in the 'HOLD' mode, which 'remembers' and displays any electrode touched by the tongue, the child was asked to try to make all the contacts 'light up' on the monitor. Any that could not be made to work were inspected, and any excess acrylic was removed. The palate was then tested in the mouth again. All 62 contacts were functioning properly before a recording session was started.

6.4.2 Procedure

A phonetically balanced list of test words was compiled to provide a wide range of consonant articulations in initial, medial and final positions within words, and in association with different vowels. This word list, which is shown in Appendix 1 beginning on page 155, was used to assess dynamic tongue activity during speech. Each child was asked to read each group of 4 phrases into the microphone, and a group was saved only if the words were read fluently and without mistakes. This resulted in 37 files corresponding to the 37 groups of 4 words.

Recordings of swallowing activity were also made; because no sound was recorded during swallowing, these files contained EPG data only. Each swallow was recorded in a separate file. The child was asked to take a mouthful of water and to hold it until the recording was started. When the command was given to the EPG3 programme to initiate the recording, the child swallowed the water. In the same way a second recording was made with the child swallowing saliva instead of water to obtain a recording of a 'dry' swallow. This process was repeated two further times, producing six files consisting of three pairs of recordings of water and saliva swallows.

The 43 files created in each session were saved in a folder bearing the child's name. Each entire recording session lasted approximately an hour.

The procedure described above was also used by Dr Andrew Tindall for the EPG recordings of the 8 control group subjects (Tindall, 1998).

6.5 Tongue re-education therapy

Each child visited the speech therapist for an initial assessment of speech and tongue function before the first EPG recording session. For each child the speech therapist confirmed the diagnosis of tongue thrust swallowing pattern.

A set protocol of therapy, consisting of four twenty minute sessions spaced fortnightly, was used for all children. The EPG system was not used as a therapeutic aid. Treatment was instituted as soon as possible after the first EPG recording. When no clinical appointments were available, or when attendance was not possible for some other reason, the closest suitable appointment was given.

The first stage of therapy was directed towards developing new muscle patterns necessary as a foundation for correct swallow and correct lip and tongue postures. This was followed by instruction and practice in the use of a normal swallow using liquid and semi-solid materials (Zante, 1994).

6.6 Second electropalatographic (EPG) recording

Each patient was seen again after completion of the course of tongue re-education therapy. After checking the fit of the two plates, and adjusting the clasps and baseplates as necessary, an appointment was arranged for the second EPG recording within a month of completion of the course of tongue re-education therapy. The second recording was conducted in exactly the same way as the first recording for both the control and experimental group subjects.

A second lateral head film, upper and lower alginate impressions for study models, and photographs were taken for the experimental group subjects at the same visit as the second EPG recording.

6.7 Analysis

6.7.1 Cephalometric data

Differences between mean values of the cephalometric variables listed in Table 6 were calculated for the control group and the experimental group before tongue re-education therapy, and for the experimental group before and after therapy. Comparisons were made using Student's *t*-tests. Statistical significance was pre-determined at $p < 0.05$.

6.7.2 Electropalatographic data

The data obtained from the EPG recordings were analysed according to the methods described in detail in previous work from the Orthodontic Department at the University of Adelaide (Tindall, 1998). The EPG data was analysed with the EPG3 programme and with additional programmes written by John Henderson, Chris Wallace and Andrew Tindall. From the raw EPG data, these programmes were designed to extract details of the frequency of occurrence, duration, and average notional row number (ANR, a nominal average representing tongue position derived from the number of contacts per row over time weighted towards the front of the palate) of all closures, and ANR and symmetry of whole words and swallows.

Closure data

Each word from each EPG recording session was examined for closures. A closure was defined as an EPG event in which continuous contact occurred from one side of the palate to the other, thus preventing the passage of air. Examples of speech sounds involving closure are /d/, the voiced, and /t/ the voiceless alveolar stops, and the velar stop /k/ (Clark & Yallop, 1995).

Phonemes are represented throughout this text in the conventional manner, for example, the velar closure, /k/, in the word suit/k/ase. This notation is simple and easy to understand, although as in the example given, the conventional phonemic symbol may differ from the normal consonant in the written word. The test words and their phonemic notations are included in Appendix 2 on page 157.

The forty-two closures listed in Table 8 were chosen to provide a selection of different closure types for analysis. As can be seen from Table 8, examples of initial, medial and final positions are present for many closures, and a mixture of singletons and clusters was included.

It should also be noted that the word 'box' ends with 2 phonemes, /k/ followed by /s/, within the 'x' consonant. To differentiate between the two component articulations, these are denoted as either 'bo/k/s' or 'bok/s/' where relevant. The /s/ phoneme does not normally constitute a closure. However, it was made occasionally by children from both the control and the experimental groups.

Table 8 also contains details of the location of production of each closure, the classification of each closure type according to the manner of articulation, the position of each closure within the word, and the context in which the closure occurs. A simple closure occurs in isolation from other consonants, as for example in la/d/er, whereas a coarticulated closure is closely related to, and can even overlap another consonant, as in /d/redger, where the /r/ may affect the production of the initial /d/ closure. In complex coarticulations two closures can occur simultaneously; for example, in 'cocktail' the velar stop /k/ at the end of the first syllable often persists beyond the start of the alveolar stop /t/ at the beginning of the second. In such cases the data for the overlapping frames was duplicated and edited so that the two closures could be analysed separately.

Closure frequency

Each closure was recorded 3 times for each of the 8 subjects, and therefore the maximum possible number of usable recordings at each recording session was 24. However, some recordings of closures could not be analysed; for example, if the child released the hand held electrode during the recording, no EPG data was recorded. Therefore, the number of usable recordings referred to subsequently represents the number of recordings for which analysis was possible. The closure frequency is the number of actual occurrences of the closure expressed as a percentage of the potentially usable recordings of closures.

Although a closure was defined as an EPG event in which continuous contact occurred from one side of the palate to the other, thus preventing the passage of air, some closures can be made without complete occlusion of airflow. For example, the alveolar lateral /l/ is produced by allowing lateral airflow to occur while the apical region of the tongue is held against the alveolar ridge; depending on the breadth of the contact between the tongue and the palate, an EPG closure may be seen although air is still passing. Furthermore, it is possible to make sounds which are recognisable as stopped consonants without EPG closure occurring. For example, the medial alveolar stop /t/ in tro/t/er can be made by a glottal stop, with no EPG contact. In order to measure this variability the frequency of occurrence of each of the 42 closures was calculated.

Closure duration, average notional row (ANR), and closure intensity index

A smaller set of closures which were made consistently in both the control and experimental groups was selected for more detailed analysis. The criteria used to select these closures for the control group specified that they occur in more than 83% of the usable instances, and that for each child no more than one repetition was missing in each recording session. Fourteen closures met these criteria in the control group, whereas only two closures fulfilled these criteria for the experimental group before tongue re-education therapy. It was therefore necessary to alter the criteria for the selection of closures in the experimental group. The frequency of occurrence of the fourteen control group closures was compared with the frequency found in the experimental group before therapy. The most frequently occurring example of each closure type in the experimental group was selected for further analysis. Thus the resulting eight closures, which are listed in Table 7, and marked in Table 8, were the most reliably produced examples of each closure type in both the control group and the experimental group before therapy. As can be seen from Table 8, this subset of eight closures includes a wide variety of closure types.

Duration

The frame numbers limiting each closure were used to calculate the closure duration in frames. One frame = 10 milliseconds.

Average notional row (ANR)

The front and rear rows involved in each frame were used to calculate the average notional row number for each closure.

Closure index

The closure index, or index of intensity of a closure is the product of the mean number of rows involved in a closure and the mean percentage of contacts in those rows; it is a measure of the amount of linguo-palatal contact in a closure (Tindall, 1998).

Word data

Each phrase in the word list used for the recordings begins with 'it's a...' which contains a /t/ closure. The starting frame for each subject word was the frame in which the end of the 'it's a...' closure occurred. The duration of each word in hundredths of a second was found by subtracting the starting frame number from the last frame number.

The thirty-two words listed in Table 9 were selected from the list in Appendix 1 for whole word analysis. Using the EPG3 programme together with the programmes written by John Henderson, Chris Wallace and Andrew Tindall, the pattern and symmetry of EPG contact were examined, and average notional row number (ANR) for each word was calculated for the selected words.

Swallow data

The EPG data for the saliva and water swallows was examined, and the duration of the propulsive phase of each swallow in frames was estimated. The frame in which the posterior extrusion of the bolus commenced was the starting frame. The final frame was the frame in which maximum contact occurred. The pattern and symmetry of EPG contact were examined, and ANR for each swallow was calculated.

Statistical analysis

The EPG data consists of three repetitions of each closure, word or swallow obtained from the first recording and three from the second recording. EPG results from the control group and the experimental group before the course of tongue re-education therapy were compared to check for differences in tongue activity between the groups. Any treatment effect was assessed by comparing results from the experimental group before and after therapy.

Recordings of particular closures, words or swallows could not be used if the child released the hand-held electrode during the recording; no EPG data was registered when this occurred. Recordings were also unusable if more than 5 closures were made within a word, or if the duration of a closure was over 5 seconds; these limits were predetermined by the software used for analysis.

In order to prevent unusable repetitions from skewing the results, a repeated measures analysis of variance with 'within child' factors of session and replication within session was used. A compound symmetric error structure was assumed. Programme "5V" (unbalanced repeated measures) from the BMDP Statistical Software package was used. This programme allows for missing data such as the unusable repetitions in the EPG recordings.

Because the number of values obtained for each EPG parameter was so large, statistical significance was pre-determined at $p < 0.01$.

Table 7 Subset of closures subjected to detailed analysis

/ʧ /ain
/d/oor
/ʤ/oke
/l/eg
le/g/
/n/ose
suit/k/ase
/t/eam

Table 8 Classification & description of closures selected for analysis

Location	Closure	Type	Position	Context	Word
alveolar	t	voiceless plosive	initial	simple	/t/ack
			initial	simple	/t/eam §
			medial	simple	tro/t/er
			medial	coarticulated	cock/t/ail
			medial	coarticulated	s/t/retcher
			medial	coarticulated	sui/t/case
			final	simple	kitka/t/
			final	simple	squashki/t/
			final	simple	star/t/
	d	voiced plosive	initial	simple	/d/esk
			initial	simple	/d/oor §
			initial	coarticulated	/d/redger
			medial	simple	la/d/er
			final	simple	swor/d/
			final	simple	threa/d/
	l	lateral	initial	simple	/l/eg §
			medial	coarticulated	c/l/ock
			medial	coarticulated	s/l/ipper
			final	simple	cocktai/l/
	n	nasal	initial	simple	/n/ose §
			final	simple	chai/n/
	s	voiceless fricative	final	coarticulated	bok/s/
palato-alveolar	ʧ	voiceless affricate	initial	simple	/ʧ/ain §
			medial	simple	stre/ ʧ/er
			medial	coarticulated	wi/ʧ/craft
			medial	coarticulated	deck/ʧ/air
			final	simple	ca/ʧ/
	ʤ	voiced affricate	initial	simple	/ʤ/oke §
			medial	simple	dre/ ʤ/er
velar	k	voiceless plosive	initial	simple	/k/astle
			initial	simple	/k/itkat
			initial	coarticulated	/k/lock
			medial	coarticulated	bo/k/s
			medial	coarticulated	co/k/tail
			medial	coarticulated	de/k/chair
			medial	coarticulated	suit/k/ase §
			medial	coarticulated	witch/k/raft
			final	simple	ta/k/
			final	simple	mathsboo/k/
			final	simple	des/k/
	g	voiced plosive	final	simple	le/g/ §
	ŋ	nasal	final	simple	tho/ŋ/

Clark & Yallop, 1995

§ closure selected for further analysis (see text)

Table 9 Words selected for analysis

biscuit
box
castle
catch
chain
clock
desk
door
dredger
feather
flash
joke
ladder
leg
measure
nose
razor
saddle
seesaw
shack
shore
skate
slipper
star
sword
tack
team
thong
thread
tooth
tune
zip

6.8 Assessment of reproducibility

6.8.1 Radiographic error study

In order to assess the reproducibility of the identification and measurement of the cephalometric values, eight lateral head films were selected from the pre-therapy and control groups using random numbers (Campbell & Machin, 1993). The selected films were traced and measured a second time by the same method, and by the same observer. The standard deviation of a single determination was calculated using the following equation:

$$S = \sqrt{\frac{\sum d^2}{2n}}$$

where S = the error of a single measurement, d = the difference between the two readings, and n = the number of differences (Dahlberg, 1940).

7. Results

7.1 Introduction

The results consist of cephalometric and electropalatographic (EPG) data from eight boys with anterior open bite who underwent a course of therapy aimed at re-education of swallowing behaviour, and eight normal boys who form a control group. Following the sections describing the tongue re-education therapy, and the radiographic error study, the data are arranged in four further sections. The first compares cephalometric data from the control and experimental group before therapy, the next compares cephalometric data from experimental group before and after therapy, the third compares EPG data from the control and experimental group before therapy, and the last compares EPG data from experimental group before and after therapy. A short summary follows each of these four sections.

Initial lateral head radiographs were taken for the control and experimental group children, and a further radiograph was taken for the experimental group subjects after completion of the course of therapy. Within each section the data are arranged in subsections which refer to vertical, antero-posterior, dental and soft tissue change. The cephalometric data are summarised to illustrate group effects. However, for reference, the values for all cephalometric measurements for each child are reproduced in full in Appendix 3 on pages 158 - 161.

The electropalatographic data refer to initial recordings made by children in the experimental and control groups, and a second recording made by the experimental subjects after the course of tongue re-education therapy. Within each section the data are arranged in subsections which refer to closures, words and swallows. Palatograms summarising the electropalatographic data are reproduced in Appendix 4 on pages 162 - 171, and are also included in the text were relevant.

At the first EPG recording the mean age of the children in the experimental group was 9.93 ± 1.02 years ranging from 9.08 - 11.75 years. The mean age of the children in the control group was 10.23 ± 0.53 years ranging from 9.35 - 10.84 years.

One subject in the experimental group (child D) was over 11 years old at the time of his first EPG recording. Although at his initial visit he was under 11 years of age, and his EPG plate was constructed within a fortnight, family circumstances precluded his attendance for the first recording session until 9 months later, by which time his age fell outside the selection criteria. However, he was included in the sample.

7.2 Tongue re-education therapy report

The 8 children in the experimental group underwent a course of therapy designed to alter tongue function during swallowing. The therapy sessions were spaced fortnightly. When this was not possible, appointments were made as close to two weekly intervals as possible. Table 10 shows the time in weeks which elapsed between the first EPG recording, tongue re-education therapy visits & second EPG recording.

As can be seen from Table 10, child B did not attend for tongue re-education therapy for more than six months after the first EPG recording.

Child C was withdrawn from tongue re-education therapy after three sessions as his mother felt that no benefit was being gained from the therapy. This is represented by § in Table 10. A period of 10 weeks elapsed between this child's third tongue re-education therapy appointment and the second EPG recording.

For child D, the learned swallowing pattern was generalised by the fourth tongue re-education therapy appointment.

In the case of four children (B, E, F & H), the learned swallowing pattern was generalised after only three therapy sessions; it was therefore decided that the fourth session was unnecessary, and this is represented by a hyphen in Table 10.

In the case of two children (A & G), the new swallowing behaviour was not generalised by the fourth session, and further therapy sessions were needed after the second EPG recording. This is represented by * in Table 10.

Table 10 Time elapsed between first EPG recording, tongue re-education therapy visits & second EPG recording (in weeks from the first EPG recording)

Child	Tongue retraining therapy visits				Second EPG recording
	First	Second	Third	Fourth	
A	1	2	3	5*	8
B	29	31	35	–	38
C	11	15	17	§	27
D	1	2	4	5	7
E	4	6	8	–	11
F	10	17	19	–	21
G	1	5	7	9*	11
H	3	6	8	–	11

– final therapy visit unnecessary
§ child withdrawn from therapy
* further therapy necessary

7.3 Radiographic error study

A radiographic error study was performed to assess the reproducibility of determination of the selected cephalometric landmarks. The results of the cephalometric error study are shown in Table 11, which shows the standard deviation of a single determination (Dahlberg, 1940) for each variable for the two tracings of each radiograph, the means and standard deviations of the differences, and the results of a Student's *t*-test together with the level of significance of the result.

The values for standard deviation of a single determination show that all linear measurements were accurate to within 1mm, and, except for the naso-labial angle, all angular measurements were accurate to within 2°.

The differences between values from the two determinations were statistically significant ($p < 0.05$) for only two variables (SN-MP and PP-Me). For all other variables, differences failed to reach significance.

Table 11 Results of cephalometric error study

Variable (units)	Standard deviation of a single determination	Mean of differences (standard deviations)	*t* (n = 8)	Significance
SN-MP (°)	0.86	0.94 (0.82)	3.23	*
SN-PP (°)	0.94	0.56 (1.29)	1.23	ns
SNA (°)	0.54	0.31 (0.75)	1.17	ns
SNB (°)	0.38	0.31 (0.46)	1.93	ns
ANB (°)	0.50	0.00 (0.76)	0.00	ns
N-PP (mm)	0.60	0.44 (0.78)	1.59	ns
PP-Me (mm)	0.61	0.63 (0.64)	2.76	*
AFH (mm)	0.28	0.19 (0.37)	1.43	ns
Is-PP (mm)	0.56	0.38 (0.74)	1.43	ns
Ii-MP (mm)	0.71	0.63 (0.83)	2.12	ns
AOB (mm)	0.45	0.19 (0.65)	0.81	ns
U1-PP (°)	1.43	0.75 (2.00)	1.06	ns
IMPA (°)	1.79	0.13 (2.71)	0.13	ns
IIA (°)	1.56	0.25 (2.35)	0.30	ns
ILG (mm)	0.38	0.06 (0.56)	0.31	ns
NLA (°)	6.14	4.69 (7.81)	1.70	ns

* $p < 0.05$
ns $p > 0.05$ (not significant)

7.4 Control & pre-therapy cephalometric data

The cephalometric values for the control group and experimental group before therapy are summarised in Table 12. Initial lateral head films were obtained for all children in the experimental group, but were only available for six of the eight control group subjects.

Initial cephalometric values for all children are included in Appendix 3 on pages 158 - 161.

7.4.1 Vertical assessment

Control group

In the control group the SN-MP angle for one child was less than 28°, indicating a brachyfacial vertical pattern, and for another was greater than 36° indicating a dolichofacial pattern. The SN-MP angles for the remaining four children for whom lateral head radiographs were available fell within the normal range of 28 - 36° indicating a mesofacial vertical pattern (Steiner, 1960). The mean total anterior face height was 108.8mm, which is 6mm lower than the figure quoted by Wylie, who measured a group of ninety seven 11 - 13 year old boys whose mean age was 11.5 years (Wylie, 1952); it was also lower than the corresponding value of 116.6 ± 3.6mm for 10 year old boys in the Michigan Growth Study (Riolo *et al.*, 1974). However, the value of 108.8mm is close to the mean anterior face height of 108.1 ± 3.5mm found for long-faced 10 year old males in the University of Iowa longitudinal facial growth study (Bishara & Jakobsen, 1985).

Experimental group

In the experimental group before therapy, the SN-MP angle for five children was greater than 36°, indicating a dolichofacial pattern. The SN-MP angles for the remaining three children fell within the normal range of 28 - 36°. The mean total anterior face height of 114.1 ± 4.0 was slightly below both the normal value of 114.9 ± 6mm from the California analysis (Wylie, 1952), and the value of 116.6 ± 3.6mm for 10 year old boys in the Michigan Growth Study (Riolo *et al.*, 1974), but 6mm higher than the value from long-faced 10 year old males from the University of Iowa growth study (Bishara & Jakobsen, 1985).

Comparison of groups

Five children in the experimental group had SN-MP angles over 36°, indicating a dolichofacial vertical pattern, whereas there was only one dolichofacial child in the control group. As can be seen from Table 12, no differences in means of the variables measuring vertical dimension reached statistical significance ($p < 0.05$), although the differences for SN-MP, AFH and PP-Me almost reached significance. Although the results of the cephalometric error study (see Table 11) show that SN-MP and PP-Me were the least reproducible cephalometric measurements, the higher values for SN-MP, AFH and PP-Me in the experimental group, while not statistically significant, may indicate a trend towards longer face morphology in the experimental group subjects before therapy.

7.4.2 *Antero-posterior assessment*

Control group

The mean value for SNA of 80.4° is within the normal range of 82 ± 2° (Steiner, 1960). However, three of the control group children had an SNA value of 79.5°, which is slightly below normal. Similarly, the mean value for SNB of 77.2° is within the normal range of 78 ± 2°. Of the two children who had SNB values less than 76°, one had an ANB of 6.5° confirming a Class II skeletal relationship. The remaining five children had normal ANB angles between 1° and 5° (Vaden *et al.*, 1994).

Experimental group

The mean value for SNA of 81.9° is within the normal range of 82 ± 2° according to Steiner. However, the range of values in the experimental group children was wide. Three children had SNA values lower than 80°, and three had values higher than 84°. Similarly, the mean value for SNB of 76.9° is within the normal range of 78 ± 2°, but three children had SNB values less than 76°, and two had values higher than 80°. Four children had normal ANB values between 1° and 5°, while the remaining four had ANB values above 5° indicating a Class II skeletal relationship (Vaden *et al.*, 1994).

Comparison of groups

Four of the experimental subjects had Class I skeletal base relationships, while the other four were Class II. Of the control group subjects for whom lateral head radiographs were available, one was Class II, and the remaining five had Class I skeletal bases. No differences in variables measuring antero-posterior skeletal relationship reached statistical significance.

7.4.3 *Dental assessment*

Control group

The mean anterior open bite of the control group was 0.7 ± 0.8mm. All subjects had a Class I incisor relationship, but only three of the six children had a complete overbite.

The mean angulation of the upper incisor to SN was 103.8°, which is close to the Steiner normal value of 104 ± 4° (Steiner, 1960). The mean IMPA and mean inter-incisal angle of the control group subjects were also within the normal range of 95 ± 5° (Owen, 1984) and 135 ± 6° (Downs, 1956) respectively.

Experimental group

The criteria for participation in the study specified that subjects should have either an anterior open bite or an incomplete overbite of 3mm or more. Although the mean anterior open bite of the experimental group was 4.1 ± 1.4mm, cephalometric measurements indicated that two children had an open bite less than 3mm.

Although the mean IMPA was close to normal (Tweed, 1954), the mean U1-SN angle was 109.6 ± 5.7°, which is higher than Steiner's normal value of 104 ± 4°. The mean inter-incisal angle of the experimental group subjects was below 120°, which is considerably less than the normal value of 135 ± 6° (Downs, 1956).

Comparison of groups

The mean difference in anterior open bite between the groups was the only variable measured which reached statistical significance ($p < 0.05$).

Differences in the angulation of the upper incisors to SN, and inter-incisal angle between the two groups just failed to reach significance, but may indicate a trend towards more proclined upper incisors in the experimental group subjects.

7.4.4 *Soft tissue assessment*

Control group

The mean value for the naso-labial angle was slightly above the upper limit of the normal range of 105 ± 8° (Owen, 1984), but the range and standard deviation were large. The inter-labial gap also varied widely (0 to 5.0mm).

Experimental group

The mean naso-labial angle was within the normal range of 105 ± 8° (Owen, 1984), but the range and standard deviation were large. The inter-labial gap also varied widely (0 to 8.5mm).

Comparison of groups

The mean differences in naso-labial angle and inter-labial gap between the two groups failed to reach significance. Wide variation was found for both measurements in both groups of children. As the children were not directed either to keep their lips together or apart while the radiographs were taken, this variation is probably related to lip contact during the radiographic exposure.

7.4.5 *Summary*

Before therapy, the control and experimental groups were similar for all cephalometric variables measured except for anterior open bite, for which the difference between mean values reached statistical significance ($p < 0.05$).

There was, however, some evidence of a trend towards longer face morphology in the experimental group subjects before therapy.

Similarly, there was some evidence of a trend towards upper incisor proclination in children in the experimental group.

Wide variation in the values of the soft tissue measurements was found for both groups of children.

Table 12 Means & standard deviations of cephalometric variables for control group & experimental group before therapy

Variable	Mean (standard deviation) Control	Pre-therapy	Mean Difference	*t* (*n* = 14)	Significance
SN-MP (°)	30.4 (4.3)	35.8 (3.7)	5.4	2.14	ns
SN-PP (°)	6.9 (1.9)	5.4 (3.1)	1.5	1.02	ns
SNA (°)	80.4 (1.4)	81.9 (4.3)	1.5	0.81	ns
SNB (°)	77.2 (1.7)	76.9 (3.4)	0.3	0.20	ns
ANB (°)	3.3 (2.1)	5.0 (2.3)	1.8	1.40	ns
N-PP (mm)	49.0 (2.3)	49.9 (1.6)	0.9	0.84	ns
PP-Me (mm)	59.8 (3.8)	64.2 (4.0)	4.4	1.86	ns
AFH (mm)	108.8 (5.8)	114.1 (4.0)	5.3	1.82	ns
Is-PP (mm)	26.8 (1.9)	28.1 (3.5)	1.3	0.82	ns
Ii-MP (mm)	35.6 (2.9)	37.1 (3.6)	1.5	0.87	ns
AOB (mm)	0.7 (0.8)	4.1 (1.4)	3.4	3.04	*
U1-SN (°)	103.8 (3.8)	109.6 (5.7)	5.8	1.89	ns
U1-PP (°)	110.7 (3.7)	115.0 (5.5)	4.3	1.56	ns
IMPA (°)	96.8 (3.1)	95.4 (7.4)	1.4	0.44	ns
IIA (°)	129.2 (4.3)	119.9 (8.2)	9.2	2.11	ns
ILG (mm)	0.9 (2.0)	2.0 (3.0)	1.1	0.77	ns
NLA (°)	114.4 (7.0)	108.9 (6.0)	5.5	1.49	ns

* $p < 0.05$
ns $p > 0.05$ (not significant)

7.5 Pre- & post-therapy cephalometric data

The cephalometric values for the experimental group before and after therapy are summarised in Table 13. Lateral head films were obtained for all children in the experimental group before therapy, and for all except child A after therapy. The cephalometric data was therefore analysed only for the 7 children for whom pre- and post-therapy films were available. This accounts for the different values for the pre-therapy children which appear in Table 12 and Table 13.

7.5.1 Vertical assessment

Pre-therapy condition

In the experimental group before therapy, the SN-MP angle for four children was greater than 36°, indicating a dolichofacial pattern. The SN-MP angles for the remaining three children fell within the normal range of 28 - 36°. The mean total anterior face height of 114.1 ± 4.4 was slightly below both the normal value of 114.9 ± 6mm from the California analysis (Wylie, 1952), and the value of 116.6 ± 3.6mm for 10 year old boys in the Michigan Growth Study (Riolo *et al.*, 1974), but 6mm higher than the mean total anterior face height of 108.1 ± 3.5mm found for 10 year old males in the University of Iowa growth study (Bishara & Jakobsen, 1985).

Post-therapy condition

The SN-MP angle for three children was greater than 36°, indicating a dolichofacial pattern. Values for the remaining four children for whom lateral head films were available fell within the normal range of 28 - 36°. The mean anterior face height of the group after therapy was 115.7 ± 5.1mm, which is still slightly lower than the value of 116.6 ± 3.6mm found for 10 year old boys in the Michigan Growth Study (Riolo *et al.*, 1974), but slightly higher than the California analysis normal value of 114.9 ± 6mm (Wylie, 1952), and 7.6mm higher than the value for long-faced 10 year old males from the University of Iowa study (Bishara & Jakobsen, 1985).

Comparison of pre- & post-therapy condition

Initially, four children were dolichofacial, and yet after therapy only three children in the experimental group had an SN-MP angle over 36°. The value for SN-MP for child F decreased by 0.5° to 36°, and he therefore ceased to be classed as dolichofacial, although the difference of 0.5° is below the measurement error of 2°.

Of the five children for whom the SN-MP angle increased (B, D, E, G & H), only for child E was the difference greater than the measurement error of 2°. Interestingly, his SN-MP increased by 2.5°, while his anterior face height remained constant. SN-MP for child C fell by 3° during the observation period, however, this child appears to have protruded his mandible during the second radiographic exposure. Growth may also have accounted for some of this apparent change, but it should be noted that SN-MP was shown to be poorly reproducible in the cephalometric error study.

Although two children (E & G) maintained the same anterior face height between the two lateral head radiographs, AFH increased by more than 1mm for the other children (B, C, D, F & H). AFH for child D increased by 4mm.

Although mean values for SN-MP, SN-PP, N-PP, PP-Me and AFH increased slightly after therapy, none of these differences even approached statistical significance.

7.5.2 Antero-posterior assessment

Pre-therapy condition

The mean value for SNA of 82.1° is within the normal range of 82 ± 2° according to Steiner (Steiner, 1960). However, the range of values in the experimental group children before therapy was wide. Three children had SNA values lower than 80°, and three had values higher than 84°. Similarly, the mean value for SNB of 77.3° is within the normal range of 78 ± 2°, but two children had SNB values less than 76°, and two had values higher than 80°. Four children had normal ANB values between 1° and 5°, while the remaining three had ANB values above 5° indicating a Class II skeletal relationship.

Post-therapy condition

The mean value for SNA did not change during the observation period, but the range remained wide. Three children had SNA values lower than 80°, and three had values higher than 84°. The mean value for SNB of 77.6° is within the normal range of 78 ± 2°, but three children had SNB values less than 76°, and two had values higher than 80°. Five children had normal ANB values between 1° and 5°, while the remaining two had ANB values of 7°, indicating a Class II skeletal relationship.

Comparison of pre- & post-therapy condition

Initially, three subjects had Class II skeletal relationships, and this number dropped to two after therapy. Of these three, and child C appears to have postured his mandible forward during the post-therapy radiographic exposure (see below).

The mean value for SNA decreased by 0.3°, the mean value for SNB increased by the same amount, and ANB decreased by 0.6°. However, these small differences are within measurement error, and fell well short of statistical significance.

For all children, SNA either remained the same during the observation period, or changed by less than 2°. The same was true for SNB, except for child C, whose SNB value increased by 3°. As his mandibular length did not change between radiographs, and his overjet was 3mm less on the second film, this increase in SNB is probably attributable to forward mandibular posture during the exposure of the post-therapy radiograph, although growth may also have contributed to this change.

7.5.3 Dental assessment

Pre-therapy condition

The criteria for participation in the study specified that subjects should have either an anterior open bite or an incomplete overbite of 3mm or more. Although the mean anterior open bite of the experimental group was 4.0 ± 1.5mm, cephalometric measurements indicated that two children had an open bite less than 3mm.

Although the mean IMPA was close to normal (Tweed, 1954), the mean U1-SN angle was 109.8 ± 6.2°, which is higher than Steiner's normal value of 104 ± 4°. The mean inter-incisal angle of the experimental group subjects was 120.5°, which is considerably less than the normal value of 135 ± 6° (Downs, 1956).

Post-therapy condition

After therapy the mean anterior open bite of the experimental group was 3.1 ± 2.3mm, with an open bite of less than 3mm in three children.

The mean IMPA was 96.6 ± 7.1°, which is within the normal range of 76 - 99° (Tweed, 1954), but the mean angulation of the upper incisor to SN was 109.1 ± 7.7°, which is higher than Steiner's normal value of 104 ± 4°. The mean inter-incisal angle of the experimental group subjects was below 120°, which is considerably less than the normal value of 135 ± 6° (Downs, 1956).

Comparison of pre- & post-therapy condition

Mean values for both Is-PP and Ii-MP increased slightly after therapy, indicating a trend towards further eruption of these teeth. The mean value for AOB decreased slightly after therapy, but neither the mean difference in AOB nor the change in any other variable measured reached statistical significance.

AOB increased by 1mm in child D, remained the same in child G, and decreased for the remaining five children for whom lateral head radiographs were available (B, C, E, F & H). In three children (E, F & H), the AOB decreased by 1mm or less, but in two (B & C), the open bite reduced by 2.5mm during the observation period. For these two children, eruption of both the upper and lower incisors contributed to the reduction in open bite, while for the remaining children no clear pattern was seen.

The inter-incisal angle for two children (D & H) changed by less than 2°. For the remaining children, IIA changed by more than 2°. Only in child G did it increase (by 2.5°), while in the other children (B, C, E & F), IIA decreased by between 2.5° and 9°.

7.5.4 Soft tissue assessment

Pre-therapy condition

The mean naso-labial angle was within the normal range of 105 ± 8° (Owen, 1984), but the range and standard deviation were large. The inter-labial gap also varied widely.

Post-therapy condition

The mean naso-labial angle was still within the normal range of 105 ± 8° (Owen, 1984), but the range and standard deviation were large. The inter-labial gap also varied widely.

Comparison of pre- & post-therapy condition

The mean differences in naso-labial angle and inter-labial gap before and after therapy failed to reach statistical significance.

There was a wide variation in differences between inter-labial gap measurements for individual children before and after therapy. As the children were not directed either to keep their lips together or apart while the radiographs were taken, these differences are probably related to lip contact during the radiographic exposure.

Although the mean difference between the values for the naso-labial angle before and after therapy was only 1.9°, values varied widely for individual children in the two radiographic examinations. This is consistent with the standard deviation of a single determination of 6.14° for the measurement of the naso-labial angle found in the error study.

7.5.5 Summary

Very little cephalometric change was found in the experimental subjects during the observation period. Differences for vertical and antero-posterior skeletal parameters did not even approach statistical significance.

There was, however, some evidence of a trend towards reduction of the AOB, and further eruption of the upper and lower incisor teeth, although these differences failed to reach statistical significance.

Wide variation was found in soft tissue measurements for both groups of children.

Table 13 Means & standard deviations of cephalometric variables for experimental group before & after therapy

Variable	Mean (standard deviation) Before therapy	After therapy	Mean Difference	t (n = 14)	Significance
SN-MP (°)	35.5 (3.8)	36.1 (4.1)	-0.6	0.32	ns
SN-PP (°)	5.6 (3.3)	6.0 (3.5)	-0.4	0.21	ns
SNA (°)	82.1 (4.6)	81.9 (4.4)	0.3	0.13	ns
SNB (°)	77.3 (3.4)	77.6 (4.3)	-0.3	0.14	ns
ANB (°)	4.9 (2.5)	4.3 (2.2)	0.6	0.48	ns
N-PP (mm)	49.9 (1.8)	50.9 (1.5)	-1.1	1.22	ns
PP-Me (mm)	64.3 (4.3)	64.8 (4.5)	-0.5	0.23	ns
AFH (mm)	114.1 (4.4)	115.7 (5.1)	-1.6	0.65	ns
Is-PP (mm)	28.1 (3.8)	28.4 (3.3)	-0.4	0.20	ns
Ii-MP (mm)	37.0 (3.9)	38.4 (3.8)	-1.4	0.70	ns
AOB (mm)	4.0 (1.5)	3.1 (2.3)	0.9	0.92	ns
U1-SN (°)	109.8 (6.2)	109.1 (7.7)	0.7	0.20	ns
U1-PP (°)	115.4 (5.8)	115.1 (7.2)	0.4	0.11	ns
IMPA (°)	94.9 (7.9)	96.6 (7.1)	-1.6	0.43	ns
IIA (°)	120.5 (8.7)	118.4 (6.3)	2.1	0.56	ns
ILG (mm)	1.7 (3.1)	4.1 (3.3)	-2.4	1.36	ns
NLA (°)	108.8 (6.5)	106.9 (10.4)	1.9	0.44	ns

ns $p > 0.05$ (not significant)

7.6 Control & pre-therapy electropalatographic data

7.6.1 Closure data

The frequency of closure data below refers to the forty-two closures chosen from the word list to provide a selection of different closure types for analysis. From these forty-two, 8 closures were selected for more detailed analysis, the results of which are set out in the 3 subsections which follow the frequency data. These subsections refer to the duration, the average notional row (ANR) number, and the closure index of the 8 selected closures.

Closure frequency

Control group

Table 14 shows the frequency of occurrence of each closure for the control group, together with the number of recordings which were usable for analysis. The method of determining the frequency of closures is explained in '*Closure frequency*' on page 56. The words are arranged in order of decreasing frequency of occurrence of the closures.

As can be seen from Table 14, four of the selected closures were made in all instances, and sixteen were made more frequently than 90%. Four closures were never made.

Table 16 shows the frequency of closures for the control and pre-therapy experimental group, arranged by closure. The words are arranged according to the position of the closure within the word, so that for instance, the frequency of medial /t/ closures can be readily examined. The occurrence of alveolar closures of between 0% and 100% was highly variable. The frequency of medial /t/ closures varied between 0% and 96.02%. Initial /d/ closures were made with similar frequency to initial /t/ closures. Final /d/ closures were made more frequently than medial /d/, and final /t/ closures. The final /l/ closure was never made, while the initial /l/ closure was more frequently made than the medial /l/ closures. All palato-alveolar closures occurred in more than 40% of usable closures, but no clear pattern emerged when their position within words was examined. Apart from the final /ŋ/ closure, all velar closures were made in more than 50% of cases, but no clear pattern emerged from the figures.

Experimental group

Details of the frequency of closures made during the pre-therapy recordings is summarised in Table 15, which shows the frequency with which each closure was made, and the number of recordings which were usable in the analysis. The frequency is the number of occurrences of the closure expressed as a percentage of the usable closures. Closures are arranged in order of decreasing frequency of occurrence.

As can be seen from Table 15 none of the closures were made in all instances, and the final /t/ in squashki/t/ and kitka/t/ were never made. The most frequently occurring closures were /ʤ/oke and /d/oor, which were each made in 91.67% of the usable recordings. No other closures were made in more than 90% of instances, while 5 closures occurred in less than 10% of possible instances.

Table 16 also shows the frequency of closures made by the experimental group subjects before therapy, expressed as a percentage of the usable closures, but grouped by closure. From the table, it can be seen that the occurrence of alveolar closures of between 0% and 91.67% was highly variable. Initial /t/ closures were made more frequently than medial /t/ closures, and initial /d/ closures were made with similar frequency to initial /t/ closures. Final /d/ closures were more frequently made than final /t/ closures and the medial /d/ closure. The final /l/ closure was made rarely, while other /l/ closures occurred with similar frequency. All palato-alveolar closures were made in over 65% of usable closures, but no clear pattern emerged when their position within words was examined. The occurrence of velar closures was also highly variable, but no clear pattern was discernible in the figures.

Comparison of groups

Table 16 shows the frequency of closures for the control and pre-therapy experimental group, arranged by closure. For squashki/t/ and kitka/t/, too few closures were made by any child during any session for statistical comparison to be possible. This is denoted by § in Table 16.

In the case of 8 of the 42 closures, differences were less than 5%; of the other 34 closures, only 4 (sui/t/case, tro/t/er, s/l/ipper & wi/ʧ/craft) were made more frequently in the experimental group, while the remaining 30 closures occurred more frequently in the control group.

Of the 42 closures examined, mean differences for 14 were greater than 20%. Of these, only wi/ʧ/craft occurred more frequently in the experimental group. The greatest difference (41.67%) was found for both /k/astle and /k/lock. Differences for these closures, and for /t/eam and swor/d/ reached statistical significance ($p > 0.01$). These 4 closures occurred more frequently in the control group, indicating a trend towards more consistent production of closures in the control group than in the experimental group before therapy.

Of the 12 initial closures examined, differences for /d/oor, /d/redger and /ʤ/oke were below 5%. The remaining 9 closures were made more frequently by the control group.

Of the 14 final closures analysed, differences between the groups was less than 5% for 3 closures (kitka/t/, squashki/t/, & cocktai/l/), while all others were made more frequently by the control group.

For alveolar and palato-alveolar medial closures, no clear pattern was discernible for differences between the groups. However, of the 5 medial velar closures analysed, 4 were made more frequently by the control group, while the difference between groups for the remaining closure (de/k/chair) was below 5%.

For many closures the standard error was high compared with the mean difference. This indicates high variability in the occurrence of closures, and this is reflected in the small number of differences which reached statistical significance.

Table 14 Closure frequency of control group (by frequency)

Closure	Number made	Number usable	Frequency (%)
/d/esk	22	22	100.00
/n/ose	24	24	100.00
/t/eam	24	24	100.00
suit/k/ase	24	24	100.00
cock/t/ail	21	22	96.02
/d/oor	23	24	95.83
/k/itkat	23	24	95.83
le/g/	23	24	95.83
/k/astle	23	24	95.83
chai/n/	22	23	95.73
/ʧ/ain	22	23	95.58
/t/ack	21	22	94.88
/l/eg	22	24	91.67
/d/redger	22	24	91.67
ca/ʧ/	21	23	91.04
deck/ʧ/air	16	18	90.98
/ʤ/oke	21	24	87.50
witch/k/raft	19	22	85.98
dre/ ʤ/er	20	24	83.33
swor/d/	20	24	83.33
stre/ ʧ/er	18	22	82.67
threa/d/	19	23	82.43
des/k/	18	22	80.77
/k/lock	19	24	79.17
co/k/tail	18	23	78.94
s/t/retcher	17	22	76.37
ta/k/	16	22	72.65
de/k/chair	13	18	71.67
s/l/ipper	16	24	66.67
c/l/ock	15	24	62.50
bo/k/s	14	24	58.33
mathsboo/k/	13	24	54.17
la/d/er	13	24	54.17
tro/t/er	12	23	52.33
wi/ʧ/craft	9	22	43.24
tho/ŋ/	9	24	37.50
star/t/	7	24	29.17
bok/s/	4	24	16.67
kitka/t/	0	24	0.00
cocktai/l/	0	24	0.00
squashki/t/	0	24	0.00
sui/t/case	0	24	0.00

Table 15 Closure frequency of experimental group before therapy (by frequency)

Closure	Number made	Number usable	Frequency (%)
/ʤ/oke	22	24	91.67
/d/oor	22	24	91.67
/d/redger	21	24	87.50
/d/esk	21	24	87.50
/k/itkat	20	23	86.44
/t/ack	20	24	83.33
/n/ose	20	24	83.33
suit/k/ase	19	23	82.58
/t/eam	19	24	79.17
/ʧ/ain	19	24	79.17
deck/ʧ/air	15	19	77.61
threa/d/	17	22	77.42
s/l/ipper	18	24	75.00
de/k/chair	15	19	74.03
/l/eg	17	23	73.95
dre/ ʤ/er	17	24	70.83
stre/ ʧ/er	17	24	70.83
chai/n/	17	24	70.83
cock/t/ail	16	23	69.26
ca/ʧ/	16	23	69.25
s/t/retcher	16	24	66.67
le/g/	15	23	65.99
tro/t/er	15	23	65.39
wi/ʧ/craft	15	23	65.31
c/l/ock	15	24	62.50
witch/k/raft	14	23	60.70
des/k/	14	24	58.33
ta/k/	14	24	58.33
/k/astle	13	24	54.17
swor/d/	12	24	50.00
la/d/er	11	24	45.83
co/k/tail	9	23	39.65
bo/k/s	9	24	37.50
/k/lock	9	24	37.50
mathsboo/k/	8	24	33.33
tho/ŋ/	6	24	25.00
star/t/	5	23	21.07
sui/t/case	2	23	8.51
bok/s/	1	24	4.17
cocktai/l/	1	24	4.17
kitka/t/	0	23	0.00
squashki/t/	0	23	0.00

Table 16 Closure frequency for control group & experimental group before therapy (by closure type)

Location	Closure	Frequency (%)		Mean difference	*t*	Significance
		Control	Pre-therapy	(std. err.)	(n=16)	
alveolar	/t/ack	94.88	83.33	11.55 (10.85)	0.29	ns
	/t/eam	100.00	79.17	20.83 (7.65)	0.01	*
	cock/t/ail	96.02	69.26	26.75 (14.03)	0.06	ns
	s/t/retcher	76.37	66.67	9.70 (13.62)	0.48	ns
	sui/t/case	0.00	8.51	8.51 (6.51)	0.19	ns
	tro/t/er	52.33	65.39	13.07 (13.94)	0.35	ns
	kitka/t/	0.00	0.00	0.00 (§)	§	§
	squashki/t/	0.00	0.00	0.00 (§)	§	§
	star/t/	29.17	21.07	8.10 (16.81)	0.63	ns
	/d/esk	100.00	87.50	12.50 (7.04)	0.08	ns
	/d/oor	95.83	91.67	4.17 (5.84)	0.48	ns
	/d/redger	91.67	87.50	4.17 (10.88)	0.70	ns
	la/d/er	54.17	45.83	8.33 (15.17)	0.58	ns
	swor/d/	83.33	50.00	33.33 (12.78)	0.01	*
	threa/d/	82.43	77.42	5.02 (12.08)	0.69	ns
	/l/eg	91.67	73.95	17.72 (13.69)	0.20	ns
	c/l/ock	62.50	62.50	0.00 (18.11)	1.00	ns
	s/l/ipper	66.67	75.00	8.33 (17.51)	0.63	ns
	cocktai/l/	0.00	4.17	4.17 (5.29)	0.43	ns
	/n/ose	100.00	83.33	16.67 (10.74)	0.12	ns
	chai/n/	95.73	70.83	24.90 (11.73)	0.03	ns
	bok/s/	16.67	4.17	12.50 (11.66)	0.28	ns
palato-alveolar	/ʧ/ain	95.58	79.17	16.41 (10.23)	0.11	ns
	deck/ʧ/air	90.98	77.61	13.37 (17.88)	0.45	ns
	stre/ʧ/er	82.67	70.83	11.84 (14.07)	0.40	ns
	wi/ʧ/craft	43.24	65.31	22.07 (16.98)	0.19	ns
	ca/ʧ/	91.04	69.25	21.97 (13.33)	0.10	ns
	/ʤ/oke	87.50	91.67	4.17 (8.25)	0.61	ns
	dre/ʤ/er	83.33	70.83	12.50 (10.73)	0.24	ns
velar	/k/astle	95.83	54.17	41.67 (13.20)	0.00	*
	/k/lock	79.17	37.50	41.67 (15.44)	0.01	*
	/k/itkat	95.83	86.44	9.39 (8.99)	0.30	ns
	bo/k/s	58.33	37.50	20.83 (16.87)	0.22	ns
	co/k/tail	78.94	39.65	39.29 (18.55)	0.03	ns
	de/k/chair	71.67	74.03	2.36 (19.63)	0.90	ns
	suit/k/ase	100.00	82.58	17.42 (6.91)	0.01	ns
	witch/k/raft	85.98	60.70	25.28 (12.43)	0.04	ns
	des/k/	80.77	58.33	22.44 (15.33)	0.14	ns
	mathsboo/k/	54.17	33.33	20.83 (16.06)	0.19	ns
	ta/k/	72.65	58.33	14.31 (15.49)	0.36	ns
	le/g/	95.83	65.99	29.84 (12.15)	0.01	ns
	tho/ŋ/	37.50	25.00	12.50 (15.91)	0.43	ns

§ no details available (see text) ns $p > 0.01$; * $p < 0.01$

Closure duration

Table 17 summarises the values from the control and the experimental group before therapy for the mean durations of the 8 closures selected for more detailed analysis. Values are in milliseconds. Also included in the table are standard errors, mean differences and the significance of the differences.

Control group

Two closures, the alveolar plosive /d/ and the nasal /n/, were longer than 100ms, and only one, the palato-alveolar affricate /ʧ/, was less than 80ms in length. The remaining 5 closures, the alveolar plosive /t/, and lateral /l/, the palato-alveolar affricate /ʤ/, and the velar plosives, /k/ and /g/, lasted between 80 and 100ms.

Variability in duration was similar for all 8 closures examined, ranging from 7.8 to 12.0ms.

Experimental group

Durations of more than 110ms were found for 4 closures, the alveolar plosives, /t/ and /d/, and the palato-alveolar affricates /ʧ/ and /ʤ/. The nasal and lateral closures, /n/ and /l/, were fastest with durations of less than 80ms. The duration of the 2 velar closures, /k/ and /g/, was between 80 and 100ms.

Variability in duration was similar for all 8 closures examined, ranging from 7.9 to 12.6ms.

Comparison of groups

From Table 17 it can be seen that although there were differences between the mean durations of the selected closures produced by the two groups, none of these differences reached statistical significance. However, some differences did approach significance ($p < 0.1$). In particular, both the alveolar lateral /l/ and the nasal /n/ closures were of shorter duration in the experimental group, and both the palato-alveolar affricates, /ʧ/ and /ʤ/, were shorter in the control group.

Palatograms showing the contact patterns for these closures are reproduced in Figure 3 on pages 87 - 88. Where electrodes are coloured red in one palatogram (indicating contact for more than 80% of the duration of the recording), but blue in another (indicating less than 80% contact), this suggests greater variability of contact in the latter palatogram. Similarly, yellow electrodes suggest greater variability than blue.

Although differences were small, close examination of the palatograms for the selected closures suggests that the /t/, /d/, /l/, /n/, /k/ and /g/ closures were more variable in the experimental group. For the /t/, /d/, /k/ and /g/ closures, no clear pattern was seen in the numerical data. The pattern of contact for the 2 palato-alveolar closures was similar, with a deeper anterior contact pattern seen in the experimental group subjects. However, this pattern was different from that seen in the control group subjects, making interpretation of closure duration from the palatograms difficult.

It can also be seen from Table 17 that the variability in the duration of the 8 closures was similar in the two groups, although values for the pre-therapy experimental group were slightly higher.

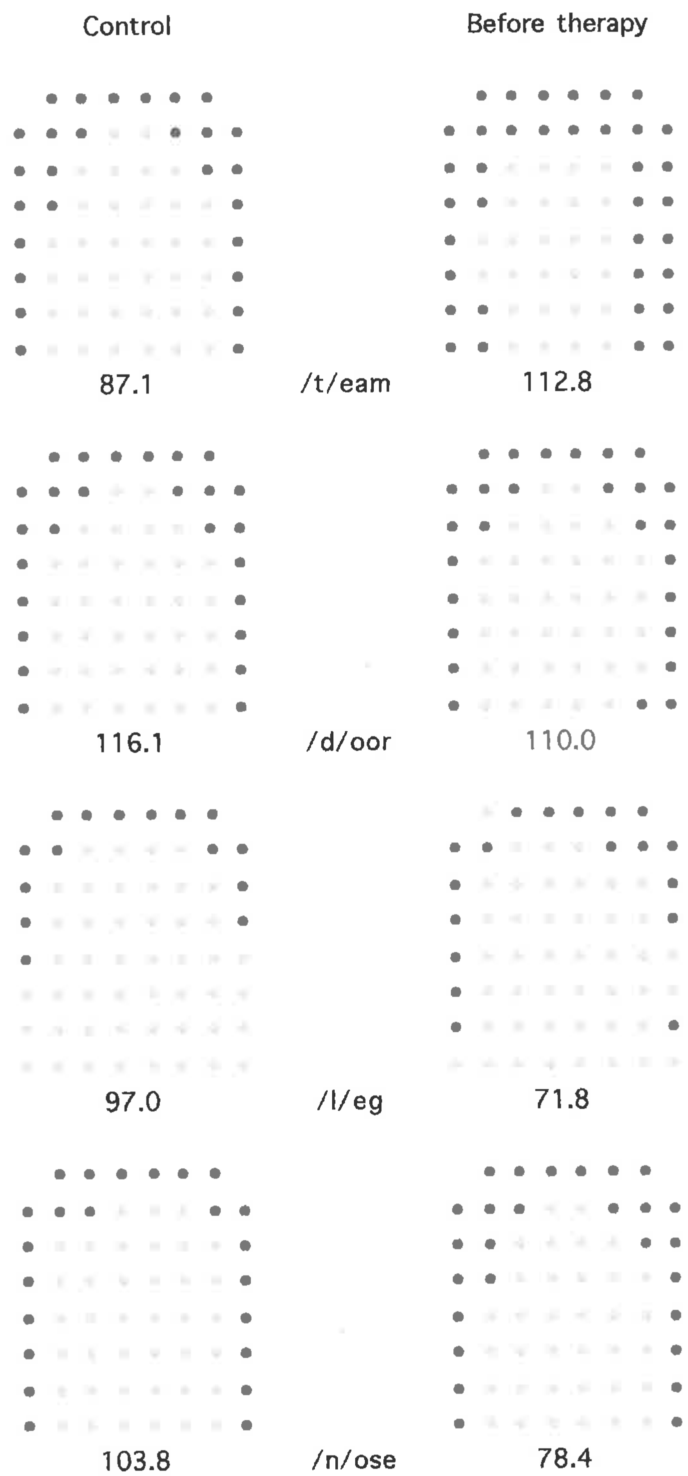
Table 17 Mean durations of selected closures for control group & experimental group before therapy (standard errors in parentheses)

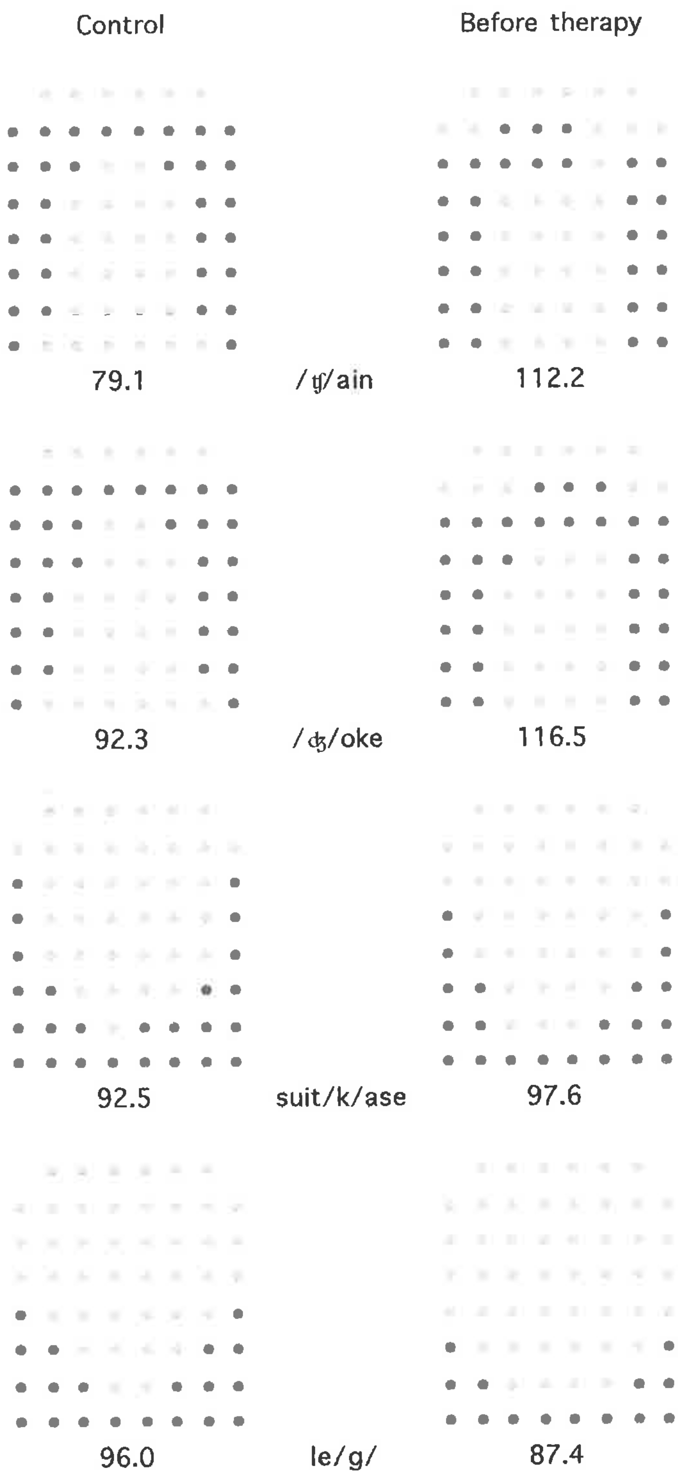
Closure	Mean duration in milliseconds		Mean difference	t (n=16)	Significance
	Control	Pre-therapy			
/t/eam	87.1 (10.0)	112.8 (10.8)	25.7 (14.8)	0.08	ns
/d/oor	116.1 (7.8)	110.0 (7.9)	6.1 (11.2)	0.59	ns
/l/eg	97.0 (7.8)	71.8 (8.8)	25.2 (11.8)	0.03	ns
/n/ose	103.8 (8.6)	78.4 (8.9)	25.3 (12.4)	0.04	ns
/ʧ /ain	79.1 (12.0)	112.2 (12.6)	33.2 (17.4)	0.06	ns
/ʤ /oke	92.3 (10.2)	116.5 (10.1)	24.2 (14.3)	0.09	ns
suit/k/ase	92.5 (8.3)	97.6 (9.2)	5.1 (12.4)	0.68	ns
le/g/	96.0 (9.5)	87.4 (11.3)	8.6 (14.7)	0.56	ns

ns $p > 0.01$ (not significant)

Figure 3 **Palatograms with mean duration values in milliseconds for 8 selected closures for control & pre-therapy experimental groups (continued on following page)**

- electrode contact > 80% of duration of closure
- electrode contact > 60% of duration of closure
- electrode contact < 60% of duration of closure




Control
Before therapy
79.1
/tʃ/ain
112.2
92.3
/dʒ/oke
116.5
92.5
suit/k/ase
97.6
96.0
le/g/
87.4

Average notional row of closures

Table 18 summarises the mean average notional row (ANR) values for the control and the experimental group before therapy for the 8 closures selected for more detailed analysis. The table also includes standard errors, mean differences and the significance of the differences.

Control group

The highest mean ANR values occurred with the velar closures, /k/ and /g/. Values for the palato-alveolar closures, /ʧ/ and /ʤ/ were slightly higher than those for the alveolar plosives, /t/ and /d/, and the lowest values were obtained with the lateral /l/ and nasal /n/ closures.

Experimental group

The highest values occurred with the velar closures, /k/ and /g/. Values for the palato-alveolar closures, /ʧ/ and /ʤ/ were slightly higher than those for the alveolar plosives, /t/ and /d/, and the lowest values were obtained with the lateral /l/ and nasal /n/ closures.

The alveolar plosive closures, /t/ and /d/, showed noticeably greater variability than the other closures.

Comparison of groups

Values for variability in the ANR of the 8 closures were virtually identical in the two groups.

Although no differences in ANR actually reached statistical significance, differences for 4 closures, /l/ and /n/, and /ʧ/ and /ʤ/, almost reached significance ($p < 0.1$). For these closures, and in fact, for all 8 except suit/k/ase, the mean ANR values were higher in the experimental group before therapy, indicating a trend towards more anterior palatal contact in the control subjects.

From the palatograms reproduced in Figure 4 on pages 91 - 92, it can be seen that in the pre-therapy group, the pattern of contact for the /l/ and /n/ closures was deeper laterally. Interestingly, in the /n/ closure, a lower percentage of contact was found in the posterior row lateral contacts. This has the effect of decreasing the ANR value, which lessens the difference between the groups.

For the /ʧ/ closure, the pattern of contact in the experimental group, particularly in rows 2 and 3, is quite different. The control and pre-therapy patterns and differences for the /ʧ/ and /ʤ/ closures are similar.

The pattern of contact for the /d/ closure is similar between the groups. The presence of three blue electrodes in the anterior row of the pre-therapy palatogram supports the lower ANR value for the control group.

The pattern of contact in the pre-therapy palatogram for the /t/ closure is broader and deeper than for the control group, also supporting the lower ANR value found in the control group.

From the palatograms for the velar closures, /g/ and /k/, it can be seen that the pattern of contact is more anterior in the control group, with noticeably more electrodes coloured yellow in the pre-therapy palatograms. In contrast, the numerical ANR value for the /k/ closure suggests that the pattern of contact for the control group is more posterior.

Examination of the palatograms in Figure 4 suggests that a more posterior pattern of contact was found for all 8 closures in the experimental group, rather than in 7 as suggested by the numerical ANR values.

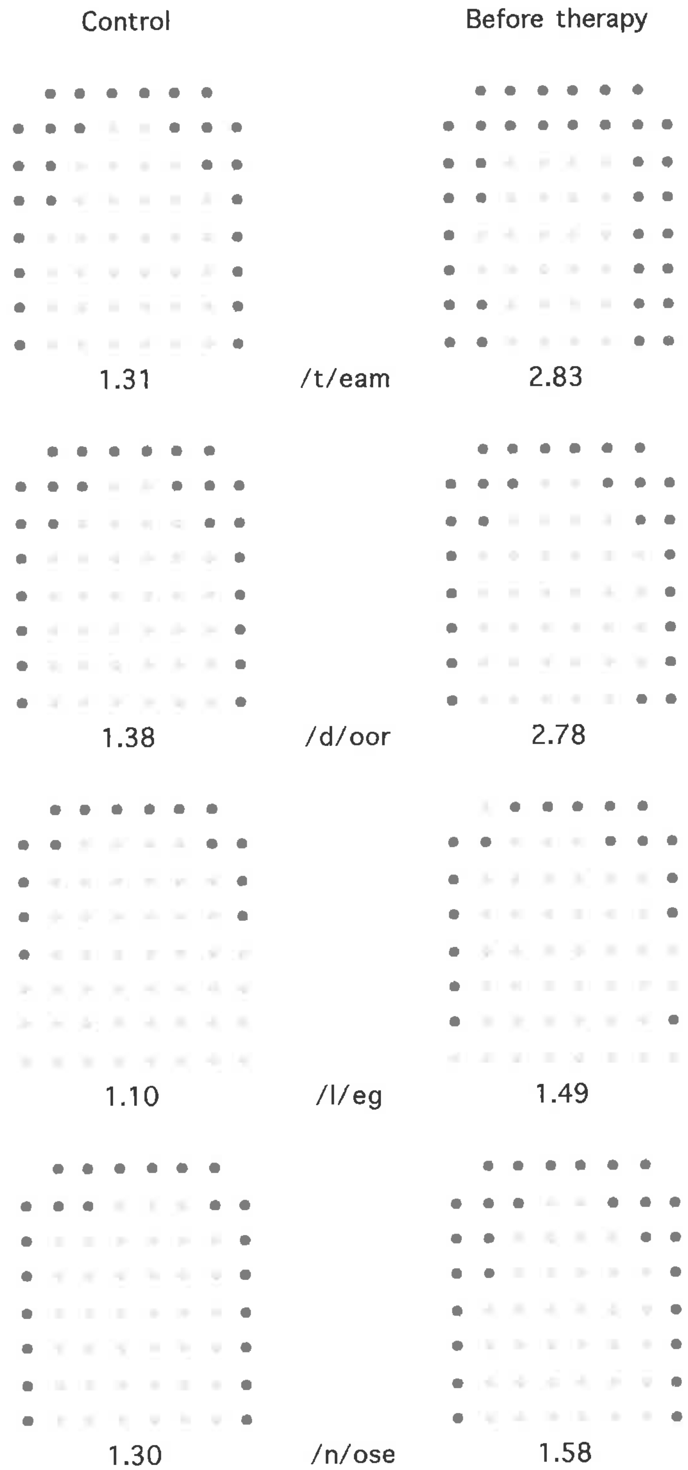
Table 18 Mean ANR of selected closures for control group & experimental group before therapy (standard errors in parentheses)

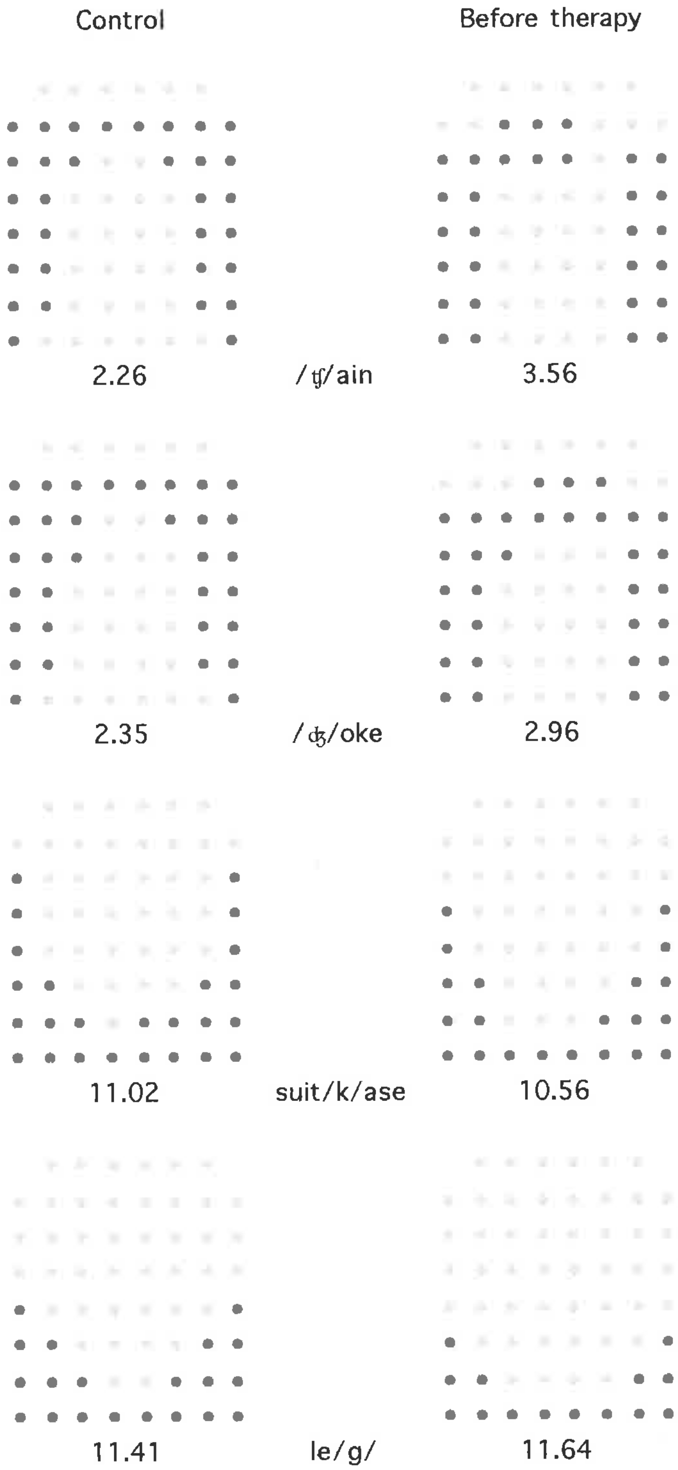
Closure	Mean ANR		Mean difference	t (n=16)	Significance
	Control	Pre-therapy			
/t/eam	1.31 (0.76)	2.83 (0.76)	1.52 (1.08)	0.16	ns
/d/oor	1.38 (0.83)	2.78 (0.83)	1.40 (1.18)	0.23	ns
/l/eg	1.10 (0.13)	1.49 (0.14)	0.40 (0.20)	0.04	ns
/n/ose	1.30 (0.11)	1.58 (0.11)	0.28 (0.15)	0.06	ns
/ʧ /ain	2.26 (0.42)	3.56 (0.44)	1.29 (0.61)	0.03	ns
/ʤ /oke	2.35 (0.26)	2.96 (0.26)	0.61 (0.37)	0.10	ns
suit/k/ase	11.02 (0.41)	10.56 (0.42)	0.46 (0.59)	0.44	ns
le/g/	11.41 (0.17)	11.64 (0.19)	0.23 (0.26)	0.38	ns

ns $p > 0.01$ (not significant)

Figure 4 Palatograms & mean ANR values for 8 selected closures for control & pre-therapy experimental groups (continued on following page)

- electrode contact > 80% of duration of closure
- electrode contact > 60% of duration of closure
- electrode contact < 60% of duration of closure




Control
Before therapy
2.26
/tʃ/ain
3.56
2.35
/dʒ/oke
2.96
11.02
suit/k/ase
10.56
11.41
le/g/
11.64

Closure index

Table 19 summarises the mean values for the closure index (see page 57) for the control and the experimental group before therapy for the 8 closures selected for more detailed analysis. The table also includes standard errors, mean differences and the significance of the differences.

Control group

The alveolar lateral /l/ and nasal /n/ closures scored lower indices than the remaining 6 closures for which no clear pattern emerged.

The variability of the closure index was approximately 10% for all 8 closures.

Experimental group

The palato-alveolar and alveolar plosive closures both scored high closure indices, although values for the alveolar closures were not as high. The remaining 4 closures scored similarly.

The variability of the closure index was approximately 10% for all 8 closures.

Comparison of groups

Both velar closures reached higher values in the control group, while values for all other closures were higher in the experimental group. No differences reached statistical significance, although /tʃ/ain and le/g/ almost did ($p > 0.1$).

Values for the variability in the closure indices of the 8 closures were similar in both groups.

Table 19 Mean closure indices of selected closures for control group & experimental group before therapy (standard errors in parentheses)

Closure	Mean closure index: Control	Mean closure index: Pre-therapy	Mean difference	t (n=16)	Significance
/t/eam	154.93 (15.06)	186.48 (16.13)	31.55 (22.07)	0.15	ns
/d/oor	160.79 (15.60)	169.85 (15.70)	9.05 (22.14)	0.68	ns
/l/eg	116.35 (9.18)	135.40 (10.22)	19.04 (13.74)	0.17	ns
/n/ose	141.52 (13.92)	157.70 (14.47)	16.18 (20.08)	0.42	ns
/ʧ /ain	165.52 (18.34)	224.07 (19.06)	58.55 (26.45)	0.03	ns
/ʤ /oke	188.89 (23.66)	231.20 (23.28)	42.30 (33.20)	0.20	ns
suit/k/ase	175.28 (19.02)	140.48 (19.58)	34.81 (27.29)	0.20	ns
le/g/	144.72 (11.75)	114.37 (13.16)	30.35 (17.64)	0.09	ns

ns $p > 0.01$ (not significant)

7.6.2 Word data

Table 20 summarises the mean average notional row (ANR) values for the control and the experimental group before therapy for the 32 words selected for analysis. Words are arranged in order of increasing difference. The table also includes standard errors, mean differences and the significance of the differences.

Control group

As can be seen from Table 20, values ranged from 5.65 to 8.71, but no obvious pattern was seen. The standard error for all measurements was below 10%.

Experimental group

ANR values ranged from 6.26 to 8.49, but no obvious pattern was seen. The standard error for all measurements was below 10%.

Comparison of groups

From the table it can be seen that differences ranged from -1.27 to 1.33. Values for the standard error of the difference were often high compared with the differences themselves.

Mean ANR values for the control group were higher for 9 of the 32 words analysed, although none of these differences reached statistical significance ($p < 0.01$). However, of the 23 words for which values were higher in the experimental group, differences for 5 words (desk, measure, tooth, tune & zip) did reach significance ($p < 0.01$), indicating a more anterior pattern of palatal contact for these words in the control group children.

Palatograms summarising the mean whole word electrode contact patterns of the 5 words for which differences in ANR were statistically significant are set out in Figure 5 on pages 97 - 98. Examination of these palatograms confirms the tendency to a more anterior pattern of contact in the control group children.

The palatograms for 'box' and 'castle' show a broader pattern of lateral contact in the control subjects. A deeper anterior contact pattern is seen in the control group for 'chain', whereas a deeper anterior pattern occurs in the experimental group in 'dredger'. The control group subjects showed more anterior and posterior contact during 'clock' and 'leg' than the experimental group. Palatograms for these words are reproduced in Figure 6 on pages 99 - 100.

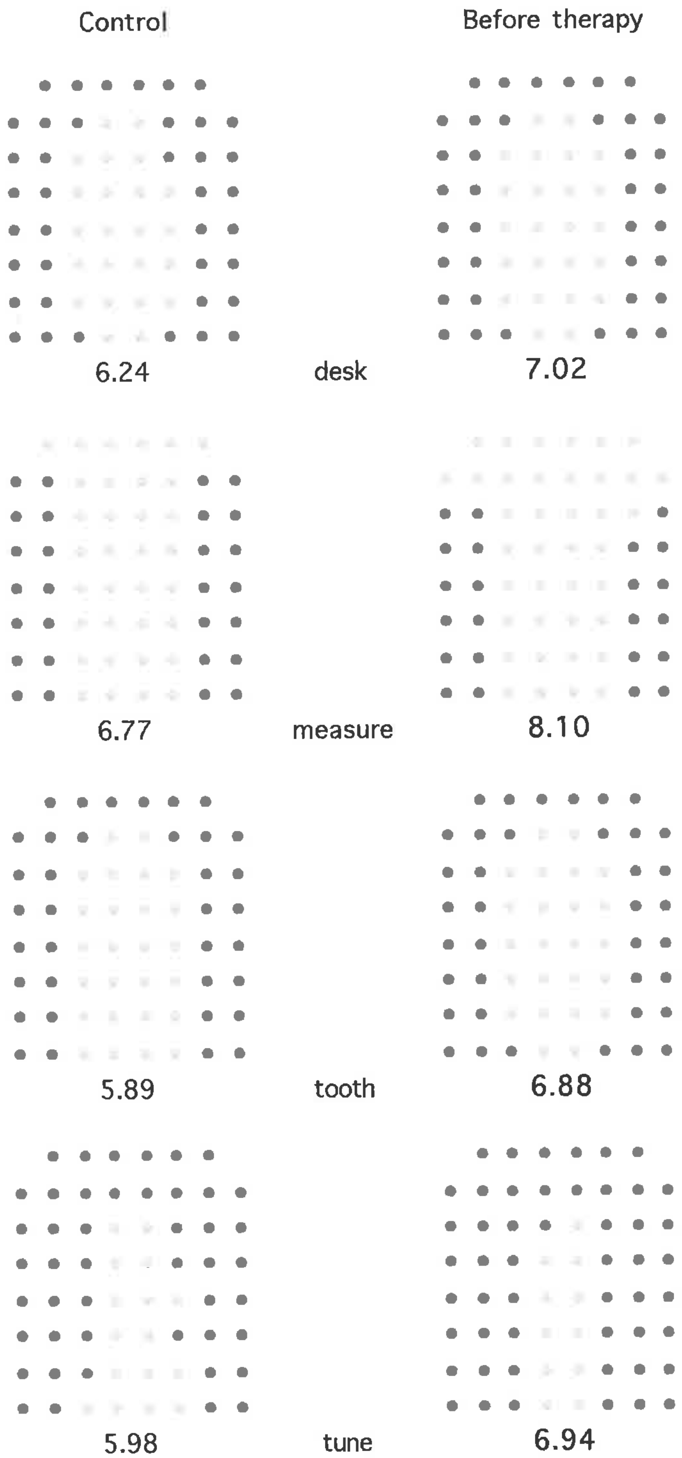
Table 20 Mean ANR of selected words for control group & experimental group before therapy (standard errors in parentheses)

Word	Mean ANR Control	Mean ANR Pre-therapy	Mean difference	*t* (n=16)	Significance
box	8.57 (0.57)	7.30 (0.57)	-1.27 (0.81)	0.11	ns
thong	7.79 (0.57)	6.73 (0.57)	-1.06 (0.80)	0.19	ns
castle	8.71 (0.31)	8.05 (0.31)	-0.65 (0.44)	0.14	ns
star	6.85 (0.54)	6.26 (0.54)	-0.58 (0.76)	0.44	ns
clock	7.16 (0.40)	6.96 (0.40)	-0.20 (0.57)	0.72	ns
sword	7.11 (0.34)	7.04 (0.34)	-0.07 (0.48)	0.89	ns
catch	8.06 (0.33)	8.00 (0.33)	-0.06 (0.47)	0.90	ns
flash	7.24 (0.39)	7.18 (0.39)	-0.06 (0.55)	0.91	ns
tack	7.92 (0.37)	7.89 (0.36)	-0.04 (0.51)	0.94	ns
slipper	6.68 (0.39)	6.73 (0.39)	0.05 (0.55)	0.93	ns
shore	8.33 (0.32)	8.38 (0.33)	0.06 (0.46)	0.90	ns
nose	6.53 (0.34)	6.72 (0.34)	0.18 (0.49)	0.70	ns
seesaw	6.64 (0.30)	6.93 (0.30)	0.28 (0.42)	0.50	ns
ladder	6.63 (0.46)	6.92 (0.46)	0.28 (0.66)	0.66	ns
feather	7.35 (0.56)	7.74 (0.56)	0.39 (0.80)	0.63	ns
thread	6.67 (0.32)	7.17 (0.32)	0.50 (0.45)	0.27	ns
joke	7.36 (0.38)	7.87 (0.38)	0.51 (0.53)	0.34	ns
saddle	7.03 (0.24)	7.57 (0.25)	0.54 (0.35)	0.12	ns
shack	7.94 (0.33)	8.49 (0.34)	0.54 (0.47)	0.25	ns
leg	7.06 (0.36)	7.64 (0.36)	0.57 (0.51)	0.26	ns
skate	7.27 (0.29)	7.96 (0.30)	0.69 (0.42)	0.10	ns
dredger	6.53 (0.25)	7.23 (0.25)	0.70 (0.35)	0.05	ns
chain	6.76 (0.24)	7.54 (0.24)	0.78 (0.34)	0.02	ns
desk	6.24 (0.19)	7.02 (0.18)	0.79 (0.26)	0.00	*
team	6.26 (0.27)	7.10 (0.27)	0.84 (0.39)	0.03	ns
door	7.44 (0.57)	8.31 (0.57)	0.87 (0.81)	0.28	ns
biscuit	6.53 (0.28)	7.46 (0.29)	0.93 (0.40)	0.02	ns
razor	7.26 (0.33)	8.19 (0.33)	0.93 (0.46)	0.05	ns
tune	5.98 (0.20)	6.94 (0.20)	0.96 (0.29)	0.00	*
tooth	5.89 (0.19)	6.88 (0.19)	0.99 (0.26)	0.00	*
zip	5.65 (0.29)	6.87 (0.29)	1.22 (0.41)	0.00	*
measure	6.77 (0.36)	8.10 (0.36)	1.33 (0.51)	0.01	*

ns $p > 0.01$ (not significant)
* $p < 0.01$

Figure 5 **Palatograms & mean ANR values for 'desk', 'measure', 'tooth', 'tune' & 'zip' for control & pre-therapy experimental groups (continued on following page)**

- electrode contact > 25% of duration of word
- electrode contact > 15% of duration of word
- electrode contact < 15% of duration of word



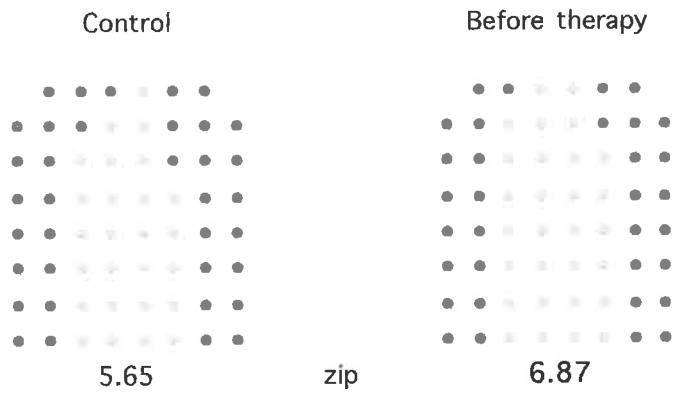
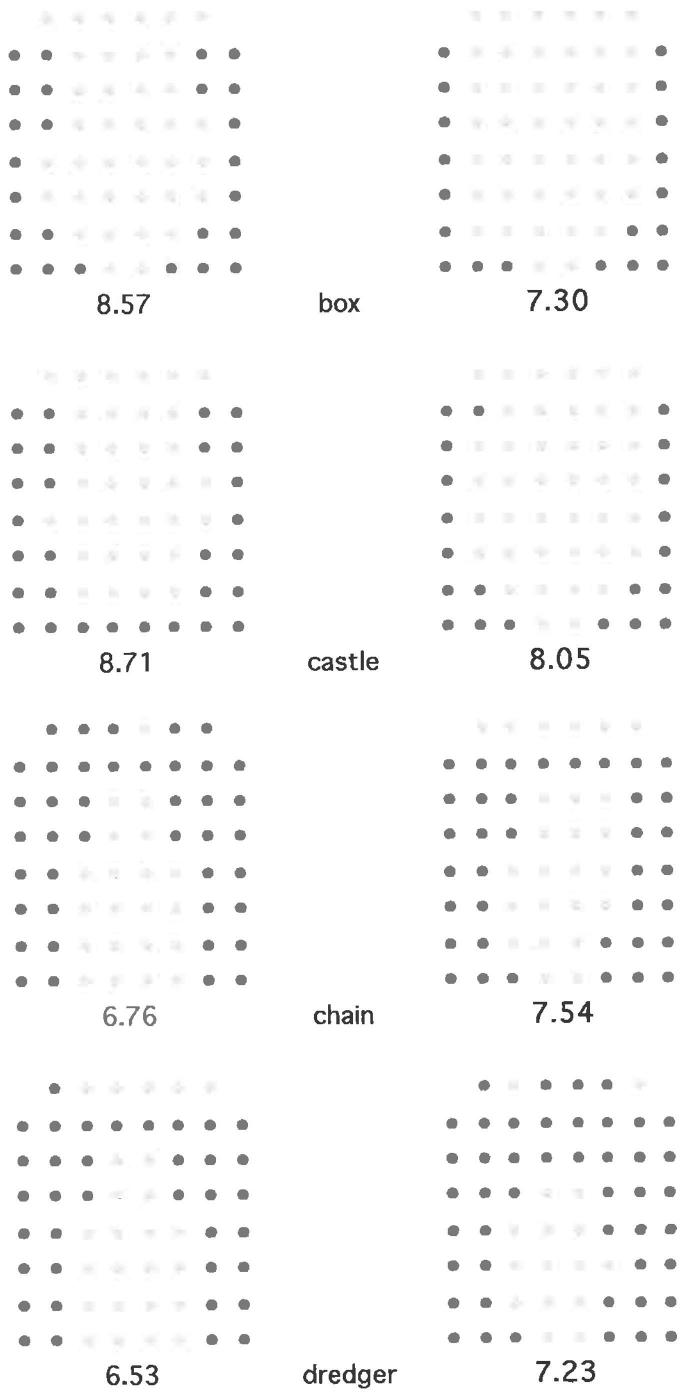
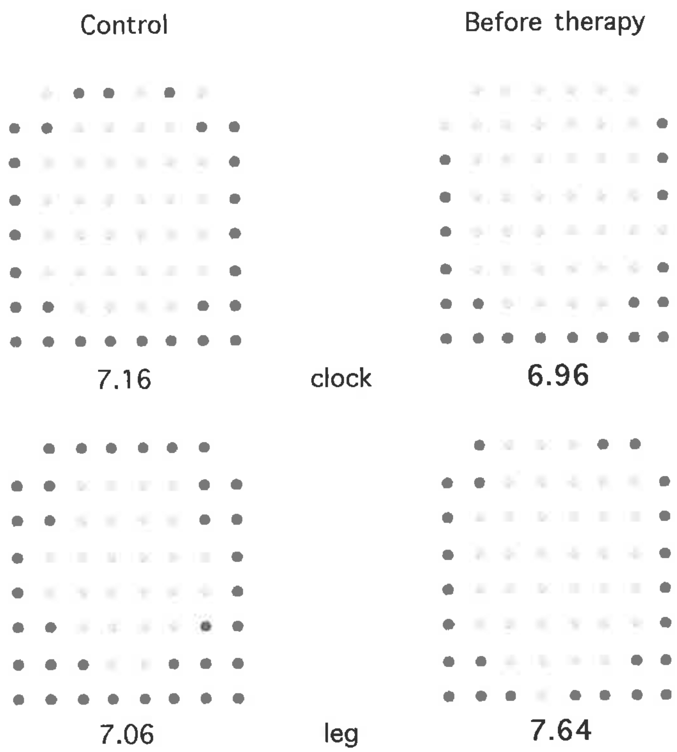

Control
Before therapy
5.65
zip
6.87

Figure 6 **Palatograms & mean ANR values for 'box', 'castle', 'chain', 'dredger', 'clock' & 'leg' for control & pre-therapy experimental groups (continued on following page)**

- electrode contact > 25% of duration of word
- electrode contact > 15% of duration of word
- electrode contact < 15% of duration of word

Control | Before therapy




Control
Before therapy
7.16
clock
6.96
7.06
leg
7.64

7.6.3 *Swallow data*

Table 21 summarises the mean average notional row (ANR) values for the control and the experimental group before therapy for the saliva and water swallows. The table also includes standard errors, mean differences and the significance of the differences.

Control group

Values for both saliva and water swallows were similar, and the standard error values were very small.

Experimental group

Values for both saliva and water swallows were similar, and the standard error values were very small.

Comparison of groups

The difference of 0.49 ± 0.16 between the groups for the water swallow was statistically significant ($p < 0.01$), indicating more anterior palatal contact in the control group. The difference between the saliva swallows was also in the same direction, but did not reach significance.

Palatograms of the saliva and water swallows are reproduced in Figure 7 on page 102. From these it can be seen that before therapy, there was relatively sparse contact for both swallows. In the water swallows, none of the electrodes reached 90% contact, and the distribution of the blue electrodes followed no obvious pattern. In the saliva swallows, there was over 75% peripheral electrode contact, and a distinguishable posterior palatal bolus cavity. Palatograms of the control group swallows, on the other hand, show a high percentage of lateral and anterior contact, with a well defined posterior palatal bolus cavity.

The evidence from the palatograms and the numerical ANR data both support the finding that a more anterior pattern of contact was made by the control group subjects.

Table 21 Mean ANR of saliva & water swallows for control group & experimental group before therapy (standard errors in parentheses)

Word	Mean ANR: Control	Mean ANR: Pre-therapy	Mean difference	*t* (n=16)	Significance
saliva	4.70 (0.15)	5.01 (0.15)	0.31 (0.21)	0.14	ns
water	4.69 (0.11)	5.18 (0.12)	0.49 (0.16)	0.00	*

ns $p > 0.01$ (not significant)
* $p < 0.01$

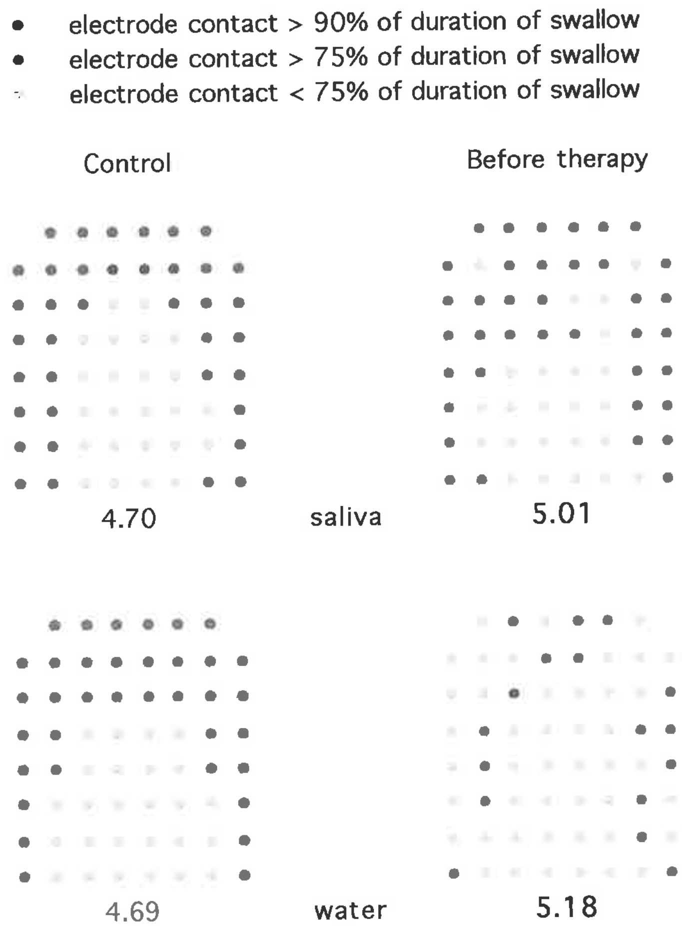


Figure 7 Palatograms & mean ANR values for saliva & water swallows for control & pre-therapy experimental groups

7.6.4 *Summary*

Closure data

The frequency data on the 42 closures analysed indicate a trend towards more consistent production of closures in the control group than in the experimental group before therapy. Both groups exhibited high variability in production of closures.

Data on the duration of the 8 closures analysed in more detail showed that variability in length of closures was similar for both groups. Although the palato-alveolar closures were shorter in the control group, and the alveolar lateral and nasal closures were shorter in the experimental group, these differences did not reach significance. Palatograms of the palato-alveolar closures, /tʃ/ and /ʤ/, showed a different anterior pattern of contact in the two groups, making interpretation of closure duration more difficult for these closures. Palatographic evidence suggests that the remaining selected closures were more variable in the experimental group subjects, although the differences were small.

Mean ANR values were lower in the control group, perhaps indicating a trend towards more posterior palatal contact in the experimental subjects before therapy. Further evidence for this trend was found in the palatographic representations of the data. Values for the variability in the ANR of the 8 closures were virtually identical in the two groups.

No differences in closure indices reached statistical significance although values for the velar closures reached higher values in the control group, while values for all other closures were higher in the experimental group. Variability in the indices of the 8 closures were similar in both groups.

Word & swallow data

Numerical and palatographic evidence from the analysis of the 32 selected words suggested that the children in the control group had a more anterior pattern of palatal contact.

Similarly, the data on both saliva and water swallows indicated more anterior palatal contact in the control group. Palatograms of the swallows show relatively sparse patterns of contact in the experimental group children compared with the control subjects, in whom a stronger pattern of peripheral contact, and a well defined posterior palatal bolus cavity were found.

7.7 Pre- & post-therapy electropalatographic data

7.7.1 Closure data

The frequency of closure data below refers to the forty-two closures chosen from the word list to provide a selection of different closure types for analysis. From these forty-two, 8 closures were selected for more detailed analysis, the results of which are set out in the 3 subsections which follow the frequency data. These subsections refer to the duration, the average notional row (ANR) number, and the closure index of the 8 selected closures.

Closure frequency

Pre-therapy condition

Details of the frequency of closures made during the pre-therapy recordings are summarised in Table 22 (reproduced from Table 15 for convenience), which shows the frequency of occurrence of each closure before therapy, together with the number of recordings which were usable for analysis. The method of determining the frequency of closures is explained in '*Closure frequency*' on page 56. The words are arranged in order of decreasing frequency of occurrence of the closures.

As can be seen from Table 22 none of the closures were made in all instances, and the final /t/ in squashki/t/ and kitka/t/ were never made. The most frequently occurring closures were /ʤ/oke and /d/oor, which were each made in 91.67% of the usable recordings. No other closures were made in more than 90% of instances, while 5 closures occurred in less than 10% of possible instances.

Table 24 also shows the frequency of closures made before therapy, expressed as a percentage of the usable closures, but grouped by closure. The words are arranged according to the position of the closure within the word, so that for instance, the frequency of medial /t/ closures can be readily examined. Where more than one example of a closure in a similar position occurs, they are arranged alphabetically.

From Table 24 it can be seen that the occurrence of alveolar closures of between 0% and 91.67% was highly variable. Initial /t/ closures were made more frequently than medial /t/ closures, and initial /d/ closures were made with similar frequency to initial /t/ closures. Final /d/ closures were made more frequently than final /t/ closures and the medial /d/ closure. The final /l/ closure was made rarely, while other /l/ closures occurred in approximately 70% of possible occasions. All palato-alveolar closures were made in more than 65% of possible occasions, but no clear pattern emerged when their position within words was examined. The occurrence of velar closures was also highly variable, but no clear pattern was discernible in the figures.

Post-therapy condition

Table 23 shows the frequency with which each closure was made during the post-therapy recordings, and the number of recordings which were usable in the analysis. As can be seen from the table, none of the selected closures were made in all instances, and squashki/t/ and kitka/t/ were never made. The most frequently occurring closures were /ʤ/oke and /t/eam, which were made in 95.83% of the usable recordings. Five closures were made in more than 90% of instances, and 5 in less than 10%.

Table 24 shows the frequency of closures made after therapy, grouped by closure. The occurrence of alveolar closures of between 0% and 95.83% was highly variable. Initial /t/ closures were made more frequently than medial /t/ closures, and initial /d/ closures were made with similar frequency to initial /t/ closures. Final /d/ closures were made more frequently than final /t/, medial /t/, and medial /d/ closures. The final /l/ closure was made rarely, while other /l/ closures occurred between 70 and 75% of occasions. All palato-alveolar closures were made in more than 40% of occasions, but no clear pattern emerged when their position within words was examined. The occurrence of velar closures was highly variable, but no clear pattern emerged from the figures.

Comparison of pre- & post-therapy condition

Table 24 shows the frequency of closures for the experimental group before and after therapy, arranged by closure. For squashki/t/ and kitka/t/, too few closures were made by any child during any session for statistical comparison to be possible. This is denoted by § in Table 24.

In the case of 23 of the 42 closures, differences were below 5%. Of the remaining 19 closures, 8 occurred more frequently before, and 11 were made more frequently after therapy.

Differences between pre- and post-therapy recordings were larger than 20% for 2 closures. The largest difference seen was a reduction in frequency of occurrence of 36.53% for deck/ʧ/air ($p = 0.0007$). The frequency of occurrence for swor/d/ increased by 25% between pre- and post-therapy recordings, but this difference did not reach statistical significance.

Mean differences for only 2 closures (/t/eam & deck/ʧ/air) reached statistical significance ($p > 0.01$). For /t/eam, frequency increased, while for deck/ʧ/air, frequency decreased between recording sessions.

No clear pattern was evident in the differences for initial, medial or final closures, except that all 5 velar medial closures analysed were made more frequently after therapy.

From Table 24 it can be seen that for many closures the standard error was high compared with the mean difference, indicating high variability in the occurrence of closures.

Table 22 Closure frequency of experimental group before therapy (by frequency)

Closure	Number made	Number usable	Frequency (%)
/ʤ/oke	22	24	91.67
/d/oor	22	24	91.67
/d/redger	21	24	87.50
/d/esk	21	24	87.50
/k/itkat	20	23	86.44
/t/ack	20	24	83.33
/n/ose	20	24	83.33
suit/k/ase	19	23	82.58
/t/eam	19	24	79.17
/ʧ/ain	19	24	79.17
deck/ʧ/air	15	19	77.61
threa/d/	17	22	77.42
s/l/ipper	18	24	75.00
de/k/chair	15	19	74.03
/l/eg	17	23	73.95
dre/ ʤ/er	17	24	70.83
stre/ ʧ/er	17	24	70.83
chai/n/	17	24	70.83
cock/t/ail	16	23	69.26
ca/ʧ/	16	23	69.25
s/t/retcher	16	24	66.67
le/g/	15	23	65.99
tro/t/er	15	23	65.39
wi/ʧ/craft	15	23	65.31
c/l/ock	15	24	62.50
witch/k/raft	14	23	60.70
des/k/	14	24	58.33
ta/k/	14	24	58.33
/k/astle	13	24	54.17
swor/d/	12	24	50.00
la/d/er	11	24	45.83
co/k/tail	9	23	39.65
bo/k/s	9	24	37.50
/k/lock	9	24	37.50
mathsboo/k/	8	24	33.33
tho/ŋ/	6	24	25.00
star/t/	5	23	21.07
sui/t/case	2	23	8.51
bok/s/	1	24	4.17
cocktai/l/	1	24	4.17
kitka/t/	0	23	0.00
squashki/t/	0	23	0.00

Table 23 Closure frequency of experimental group after therapy (by frequency)

Closure	Number made	Number usable	Frequency (%)
/ʤ/oke	23	24	95.83
/t/eam	23	24	95.83
/d/oor	22	24	91.67
/d/redger	22	24	91.67
suit/k/ase	22	24	91.67
/d/esk	21	24	87.50
dre/ ʤ/er	21	24	87.50
/t/ack	20	23	85.44
/k/itkat	20	24	83.33
/ʧ/ain	20	24	83.33
de/k/chair	17	21	79.86
stre/ ʧ/er	19	24	79.17
witch/k/raft	19	24	79.17
/n/ose	18	24	75.00
threa/d/	18	24	75.00
c/l/ock	18	24	75.00
swor/d/	18	24	75.00
/l/eg	17	23	73.95
s/l/ipper	17	24	70.83
cock/t/ail	17	24	70.83
s/t/retcher	17	24	70.83
le/g/	16	23	70.34
chai/n/	16	24	66.67
ca/ʧ/	15	24	62.50
des/k/	15	24	62.50
tro/t/er	14	24	58.33
/k/astle	13	23	55.61
wi/ʧ/craft	12	24	50.00
co/k/tail	12	24	50.00
bo/k/s	11	24	45.83
/k/lock	10	24	41.67
deck/ʧ/air	9	21	41.08
ta/k/	9	23	39.36
la/d/er	9	24	37.50
mathsboo/k/	8	23	36.33
star/t/	5	24	20.83
bok/s/	3	24	12.50
tho/ŋ/	2	23	8.74
cocktai/l/	2	24	8.33
sui/t/case	1	24	4.17
kitka/t/	0	24	0.00
squashki/t/	0	24	0.00

Table 24 Closure frequency for experimental group before & after therapy (by closure type)

Location	Closure	Frequency (%) Before	Frequency (%) After	Mean difference (std. err.)	t (n=16)	Significance
alveolar	/t/ack	83.33	85.44	2.11 (6.05)	0.72	ns
	/t/eam	79.17	95.83	16.67 (5.89)	0.00	*
	cock/t/ail	69.26	70.83	1.57 (9.28)	0.87	ns
	s/t/retcher	66.67	70.83	4.17 (12.33)	0.74	ns
	sui/t/case	8.51	4.17	4.34 (4.00)	0.28	ns
	tro/t/er	65.39	58.33	7.06 (14.48)	0.63	ns
	kitka/t/	0.00	0.00	0.00 (§)	§	§
	squashki/t/	0.00	0.00	0.00 (§)	§	§
	star/t/	21.07	20.83	0.24 (10.38)	0.98	ns
	/d/esk	87.50	87.50	0.00 (6.79)	1.000	ns
	/d/oor	91.67	91.67	0.00 (6.57)	1.00	ns
	/d/redger	87.50	91.67	4.17 (6.83)	0.54	ns
	la/d/er	45.83	37.50	8.33 (13.58)	0.54	ns
	swor/d/	50.00	75.00	25.00 (11.52)	0.03	ns
	threa/d/	77.42	75.00	2.42 (10.25)	0.81	ns
	/l/eg	73.95	73.95	0.00 (7.08)	1.00	ns
	c/l/ock	62.50	75.00	12.50 (10.69)	0.24	ns
	s/l/ipper	75.00	70.83	4.17 (9.94)	0.68	ns
	cocktai/l/	4.17	8.33	4.17 (4.73)	0.38	ns
	/n/ose	83.33	75.00	16.67 (10.74)	0.12	ns
	chai/n/	70.83	66.67	4.17 (9.64)	0.67	ns
	bok/s/	4.17	12.50	8.33 (7.50)	0.27	ns
palato-alveolar	/ʧ/ain	79.17	83.33	4.17 (9.58)	0.66	ns
	deck/ʧ/air	77.61	41.08	36.53 (10.83)	0.00	*
	stre/ ʧ/er	70.83	79.17	8.33 (11.24)	0.46	ns
	wi/ʧ/craft	65.31	50.00	15.31 (13.03)	0.24	ns
	ca/ʧ/	69.25	62.50	6.75 (11.88)	0.57	ns
	/ʤ/oke	91.67	95.83	4.17 (7.06)	0.55	ns
	dre/ ʤ/er	70.83	87.50	16.67 (9.85)	0.09	ns
velar	/k/astle	54.17	55.61	1.44 (9.66)	0.88	ns
	/k/lock	37.50	41.67	4.17 (10.27)	0.68	ns
	/k/itkat	86.44	83.33	3.11 (7.23)	0.67	ns
	bo/k/s	37.50	45.83	8.33 (10.90)	0.44	ns
	co/k/tail	39.65	50.00	10.35 (8.89)	0.24	ns
	de/k/chair	74.03	79.86	5.83 (7.11)	0.41	ns
	suit/k/ase	82.58	91.67	9.09 (6.72)	0.18	ns
	witch/k/raft	60.70	79.17	18.46 (10.76)	0.09	ns
	des/k/	58.33	62.50	4.17 (10.25)	0.68	ns
	mathsboo/k/	33.33	36.33	2.99 (12.42)	0.81	ns
	ta/k/	58.33	39.36	18.97 (11.47)	0.10	ns
	le/g/	65.99	70.34	4.35 (8.82)	0.62	ns
	tho/ŋ/	25.00	8.74	16.26 (10.46)	0.12	ns

§ no details available (see text) ns $p > 0.01$; * $p < 0.01$

Closure duration

Table 25 shows the mean durations of the 8 closures selected for more detailed analysis from the pre- and post-therapy recordings made by the experimental group subjects. Also included are standard errors, mean differences and level of significance of the differences.

Pre-therapy condition

Table 25 shows the mean duration of the eight closures selected for more detailed analysis in milliseconds. Durations of more than 110ms were found for 4 closures, the alveolar plosives, /t/ and /d/, and the palato-alveolar affricates /ʧ/ and /ʤ/. The 2 nasal and lateral closures, /n/ and /l/ were fastest with durations of less than 80ms. The duration of the 2 velar closures was between 80 and 100ms.

Variability in duration was similar for all 8 closures examined, ranging from 7.9 to 12.6ms.

Post-therapy condition

As can be seen from Table 25, four closures, the alveolar plosives /t/ and /d/, the velar plosive /k/, and the palato-alveolar affricate /ʧ/, lasted for more than 100ms. Two closures, the nasal closure /n/ and the velar plosive /g/, lasted for less than 80ms. The remaining closures, the palato-alveolar affricate /ʤ/ and the lateral /l/, lasted between 80 and 100ms.

Variability in duration was similar for all 8 closures examined, ranging from 8.0 to 12.3ms.

Comparison of pre- & post-therapy condition

From Table 25 it can be seen that although there were differences between the mean durations of the selected closures produced in the two recordings, none of these differences reached statistical significance.

For 2 closures, the lateral /l/ and the affricate /ʤ/, the differences did approach significance ($p < 0.1$). Both the alveolar lateral /l/ and the nasal /n/ closures increased in length between the recordings, while the palato-alveolar affricates, /ʧ/ and /ʤ/, and the alveolar plosives, /t/ and /d/, were shorter at the post-therapy recording. For /k/ and /g/, the velar closures, no pattern was obvious.

From the palatograms shown in Figure 8 on pages 112 - 113, several differences in the variability of contact before and after therapy can be seen. However, it must be stressed that these differences are small.

For the alveolar plosives, /t/ and /d/, the number of red electrodes decreased after therapy, with a corresponding increase in the number of blue electrodes. This indicates that contact with these electrodes was more variable after therapy.

For both palato-alveolar closures, /ʧ/ and /ʤ/, the number of blue electrodes decreased, and there was a corresponding increase in the number of yellow electrodes, indicating that these closures too were more variable after therapy than before.

For the alveolar lateral /l/ and the nasal /n/ closures, and the velar closures, /k/ and /g/, the palatographic evidence was not clear.

Values for the variability in the duration of the 8 closures were similar in both groups.

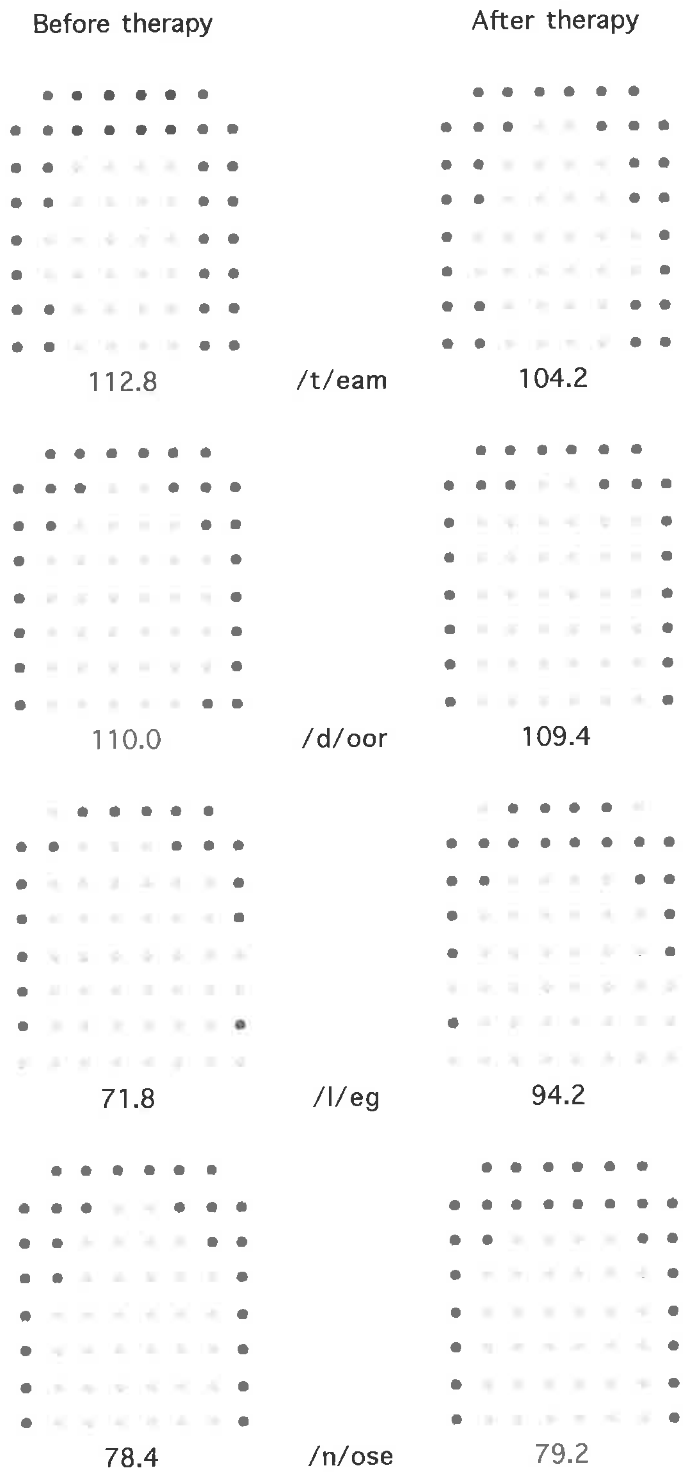
Table 25 Mean durations of selected closures for experimental group before & after therapy (standard errors in parentheses)

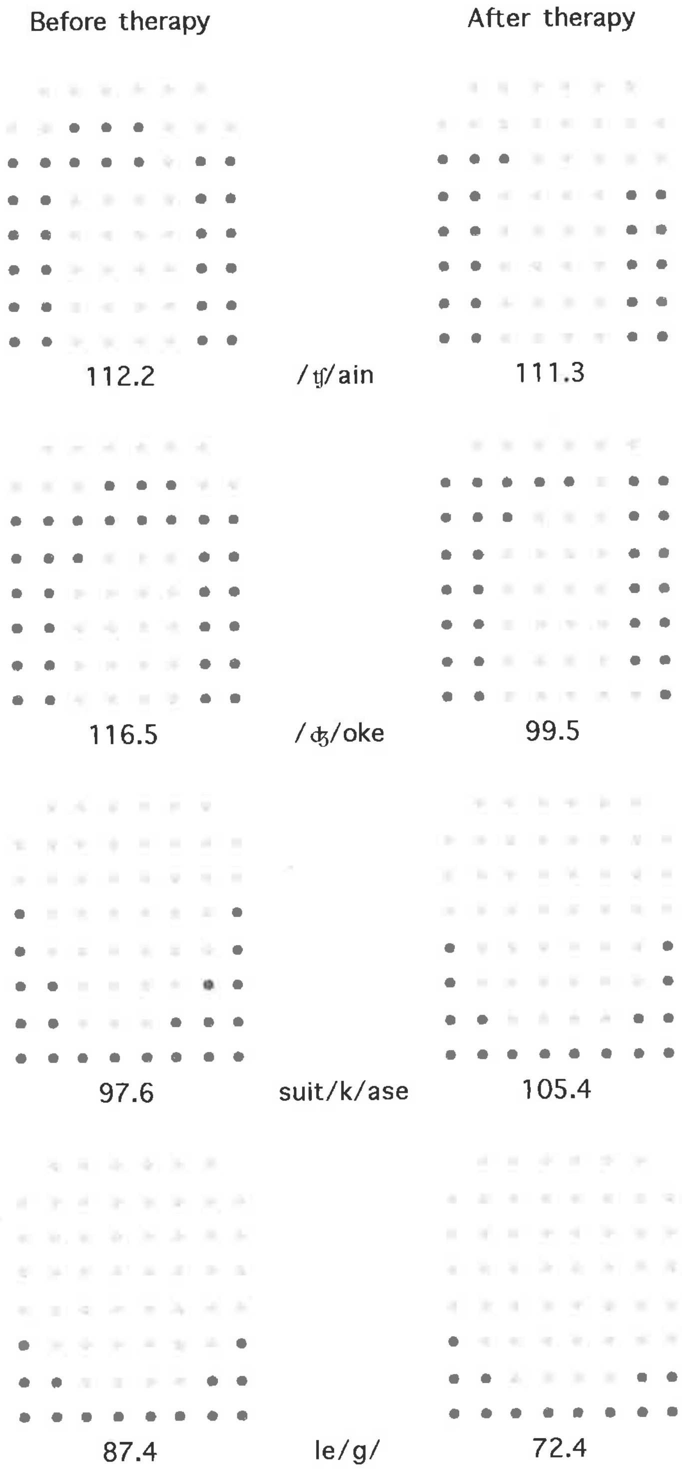
	Mean duration (milliseconds)				
Closure	Pre-therapy	Post-therapy	Mean difference	*t* (n=16)	Significance
/t/eam	112.8 (10.8)	104.2 (10.1)	8.5 (10.3)	0.41	ns
/d/oor	110.0 (7.9)	109.4 (8.0)	0.6 (10.7)	0.96	ns
/l/eg	71.8 (8.8)	94.2 (8.8)	22.4 (10.8)	0.04	ns
/n/ose	78.4 (8.9)	79.2 (9.1)	0.8 (6.6)	0.90	ns
/ʧ /ain	112.2 (12.6)	111.3 (12.3)	0.9 (13.2)	0.94	ns
/ʤ /oke	116.5 (10.1)	99.5 (10.0)	16.9 (9.3)	0.07	ns
suit/k/ase	97.6 (9.2)	105.4 (8.6)	7.9 (11.2)	0.48	ns
le/g/	87.4 (11.3)	72.4 (11.0)	15.0 (13.4)	0.26	ns

ns $p > 0.01$ (not significant)

Figure 8 Palatograms with mean duration values in milliseconds for 8 selected closures for experimental group before & after therapy (continued on following page)

- electrode contact > 80% of duration of closure
- electrode contact > 60% of duration of closure
- electrode contact < 60% of duration of closure





Before therapy
After therapy
112.2
/tʃ/ain
111.3
116.5
/dʒ/oke
99.5
97.6
suit/k/ase
105.4
87.4
le/g/
72.4

Average notional row of closures

Table 26 summarises the mean average notional row (ANR) values for the experimental group before and after therapy for the 8 closures selected for more detailed analysis. The table also includes standard errors, mean differences and the significance of the differences.

Pre-therapy condition

The highest values occurred with the velar closures, /k/ and /g/. Values for the palato-alveolar closures, /tʃ/ and /ʤ/ were slightly higher than those for the alveolar plosives, /t/ and /d/, and the lowest values were obtained with the lateral /l/ and nasal /n/ closures.

The alveolar plosive closures, /t/ and /d/, showed noticeably greater variability than the other closures.

Post-therapy condition

From Table 26 it can be seen that the highest values occurred with the velar closures, /k/ and /g/. Values for the palato-alveolar closures, /tʃ/ and /ʤ/ were slightly higher than those for the alveolar plosives, /t/ and /d/, and the lowest values were obtained with the lateral /l/ and nasal /n/ closures.

The alveolar plosive closures, /t/ and /d/, showed noticeably greater variability than the other closures.

Comparison of pre- & post-therapy condition

Values for the variability in the ANR of the 8 closures were virtually identical in the two groups.

No differences in the mean ANR of the selected closures between sessions reached statistical significance, and the values for all closures changed little.

Differences for 2 closures, /n/ and /k/, almost reached significance ($p < 0.1$), but the mean differences of 0.19 ± 0.10 and 0.59 ± 0.26 respectively were small. For the 2 velar closures, the mean ANR values were slightly lower before therapy, although the differences were small; for the other closure types no pattern could be seen.

From the palatograms shown in Figure 9 on pages 116 - 117, several differences between the contact pattern before and after therapy can be seen.

Examination of the palatograms for the velar closures, /k/ and /g/, suggests that the pattern of contact after therapy was more posterior, but the differences were very small. This supports the evidence from the numerical ANR data.

The contact pattern for both the alveolar lateral closure, /l/, and the nasal closure, /n/, were also slightly more posterior after therapy. While for the /l/ closure, the mean ANR did rise after therapy, the lower post-therapy ANR value for the /n/ closure is at variance with this finding.

For both alveolar plosive closures, /t/ and /d/, the pattern of post-therapy contact appears to be slightly more anterior; this is supported by the numerical ANR data for the /t/, but not for the /d/ closure.

The palatographic evidence for changes in contact pattern for the palato-alveolar closures was not clear.

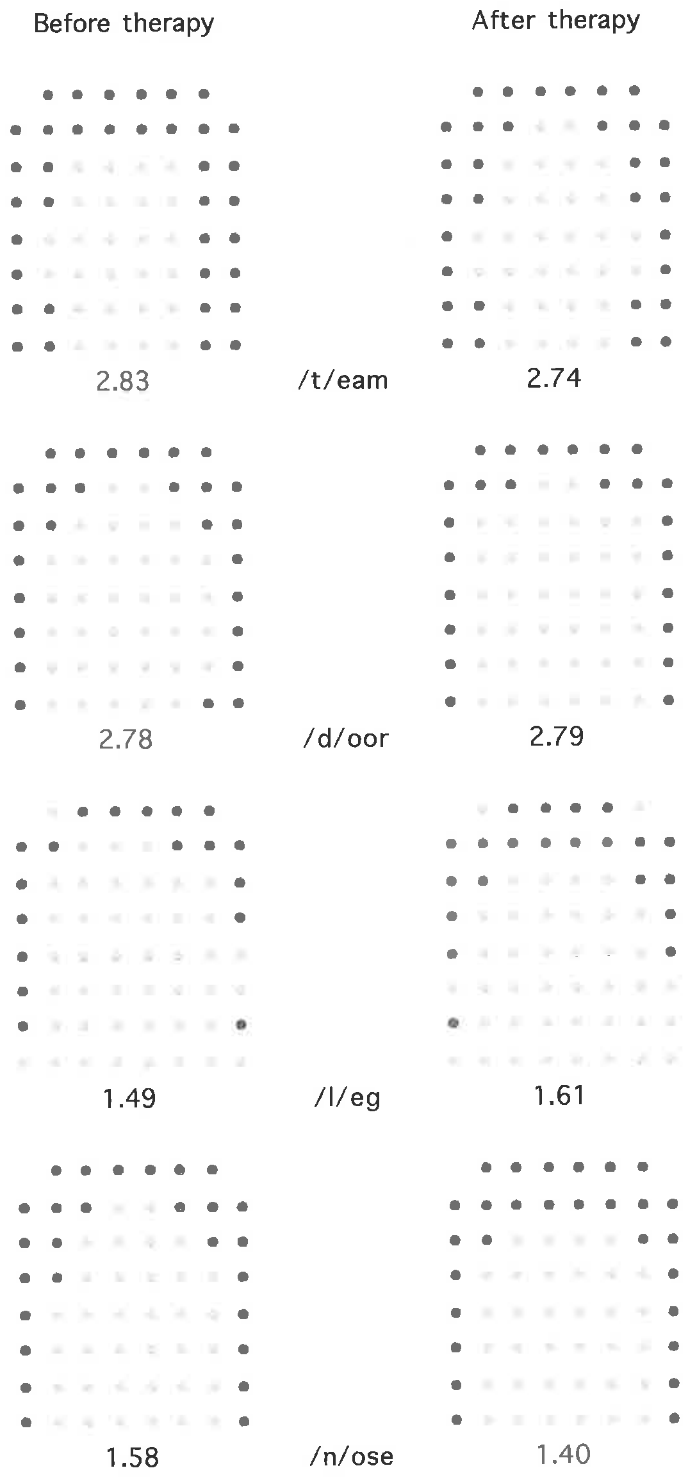
Table 26 Mean ANR of selected closures for experimental group before & after therapy (standard errors in parentheses)

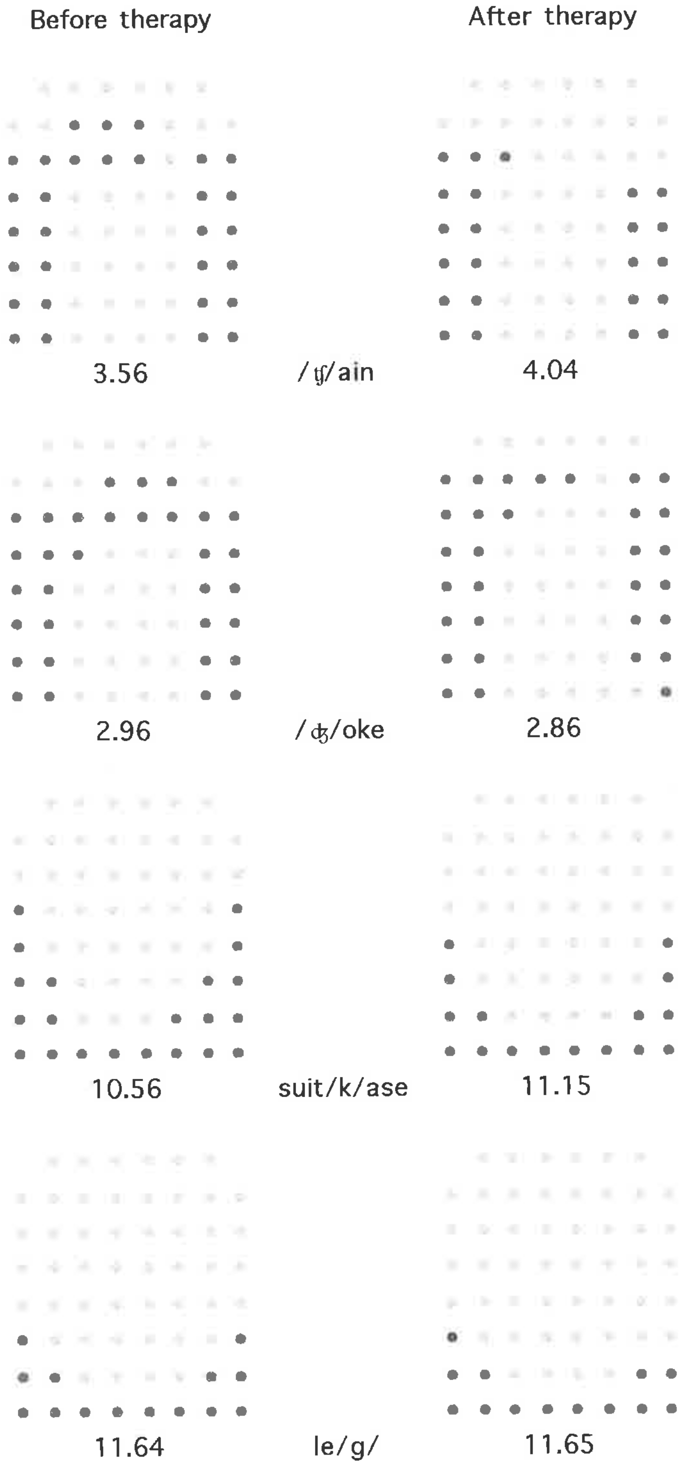
Closure	Mean ANR		Mean difference	*t* (n=16)	Significance
	Pre-therapy	Post-therapy			
/t/eam	2.83 (0.76)	2.74 (0.76)	0.09 (0.11)	0.38	ns
/d/oor	2.78 (0.83)	2.79 (0.83)	0.01 (0.09)	0.90	ns
/l/eg	1.49 (0.14)	1.61 (0.14)	0.11 (0.10)	0.28	ns
/n/ose	1.58 (0.11)	1.40 (0.11)	0.19 (0.10)	0.06	ns
/ʧ /ain	3.56 (0.44)	4.04 (0.43)	0.48 (0.53)	0.37	ns
/ʤ /oke	2.96 (0.26)	2.86 (0.25)	0.10 (0.28)	0.73	ns
suit/k/ase	10.56 (0.42)	11.15 (0.42)	0.59 (0.26)	0.02	ns
le/g/	11.64 (0.19)	11.65 (0.19)	0.01 (0.14)	0.96	ns

ns $p > 0.01$ (not significant)

Figure 9 **Palatograms & mean ANR values for selected closures for experimental group before & after therapy (continued on following page)**

- electrode contact > 80% of duration of closure
- electrode contact > 60% of duration of closure
- electrode contact < 60% of duration of closure




Before therapy
After therapy
3.56
/ʧ/ain
4.04
2.96
/ʤ/oke
2.86
10.56
suit/k/ase
11.15
11.64
le/g/
11.65

Closure index

Table 27 summarises the mean values for the closure index for the experimental group before and after therapy for the 8 closures selected for more detailed analysis. The table also includes standard errors, mean differences and the significance of the differences.

Pre-therapy condition

The palato-alveolar and alveolar plosive closures both scored high closure indices, although values for the alveolar closures were not as high. The score for the remaining 4 closures was lower, ranging from 114.37 to 157.70.

The variability of the closure index was approximately 10% for all 8 closures.

Table 27 Mean closure indices of selected closures for experimental group before & after therapy (standard errors in parentheses)

Closure	Mean closure index		Mean difference	*t* (n=16)	Significance
	Pre-therapy	Post-therapy			
/t/eam	186.48 (16.13)	172.60 (15.20)	13.88 (14.48)	0.34	ns
/d/oor	169.85 (15.70)	159.58 (15.70)	10.27 (11.48)	0.37	ns
/l/eg	135.40 (10.22)	142.25 (10.17)	6.85 (9.56)	0.47	ns
/n/ose	157.70 (14.47)	143.82 (14.85)	13.89 (12.08)	0.25	ns
/tʃ /ain	224.07 (19.06)	167.47 (18.75)	56.60 (18.20)	0.002	*
/dʒ /oke	231.20 (23.28)	220.42 (23.03)	10.78 (22.04)	0.62	ns
suit/k/ase	140.48 (19.58)	139.35 (19.19)	1.12 (12.41)	0.93	ns
le/g/	114.37 (13.16)	120.43 (13.04)	6.06 (10.55)	0.57	ns

ns $p > 0.01$ (not significant)
* $p < 0.01$

Post-therapy condition

The palato-alveolar and alveolar plosive closures both scored higher indices than the remaining 4 closures.

The variability of the closure index was approximately 10% for all 8 closures.

Comparison of pre- & post-therapy condition

From Table 27, it can be seen that for /l/eg and le/g/, values increased between the two recordings. For the remaining 6 closures, the mean closure index fell, indicating a smaller area of linguo-palatal contact, perhaps associated with more precise articulatory control after therapy. For /tʃ/ain, this difference reached statistical significance, while for the remaining 5 closures, values were statistically similar in both recordings.

For all closures except /tʃ/ain, variability of the difference in values between the two sessions was near to, or greater than the mean difference itself.

7.7.2 Word data

Table 28 summarises the mean average notional row (ANR) values for the experimental group before and after therapy for the 32 words selected for analysis. Words are arranged in order of increasing difference in ANR between the two recordings. The table also includes standard errors, mean differences and the significance of the differences.

Pre-therapy condition

As can be seen from Table 28, values ranged from 6.26 to 8.49, but no obvious pattern was seen. The standard error for all measurements was below 10%.

Post-therapy condition

ANR values after therapy ranged from 5.92 to 8.21, but no obvious pattern was seen. The standard error for all measurements was below 10%.

Comparison of pre- & post-therapy condition

From Table 28, it can be seen that differences ranged from -1.32 to 0.61. Values for the standard error of the difference were often high compared with the differences themselves.

Mean ANR values after therapy were lower for 17 of the 32 words analysed; of these 17, the difference for 'box' & 'slipper' reached statistical significance ($p < 0.01$) indicating more anterior palatal contact after therapy. Of the 15 words for which pre-therapy values were lower, only the difference for 'desk' reached significance ($p < 0.01$), indicating more posterior palatal contact after therapy.

Palatograms summarising the mean whole word electrode contact patterns for 9 words are set out in Figure 10 on pages 122 - 123. For several words, there was notable change between the pre- and post-therapy palatograms. Interestingly, the words for which differences in ANR were greatest (those at the top and bottom of Table 28) did not necessarily show the greatest change on the palatograms.

There was noticeably less anterior contact during 'team', 'tune', 'nose', 'dredger' and 'joke' after therapy, as shown by the reduction in the number of red in favour of blue electrodes, and the reduction in the number of blue in favour of yellow electrodes in the anterior rows. In the case of 'dredger', 'team' and 'tune' the palatographic information was in agreement with the numerical data, but for 'joke' and 'nose' the mean ANR fell between sessions, implying a more anterior pattern of contact after therapy.

In the case of 'thong', although the pattern of contact was similar before and after therapy, the percentage contact along the lateral borders of the palate fell noticeably between sessions.

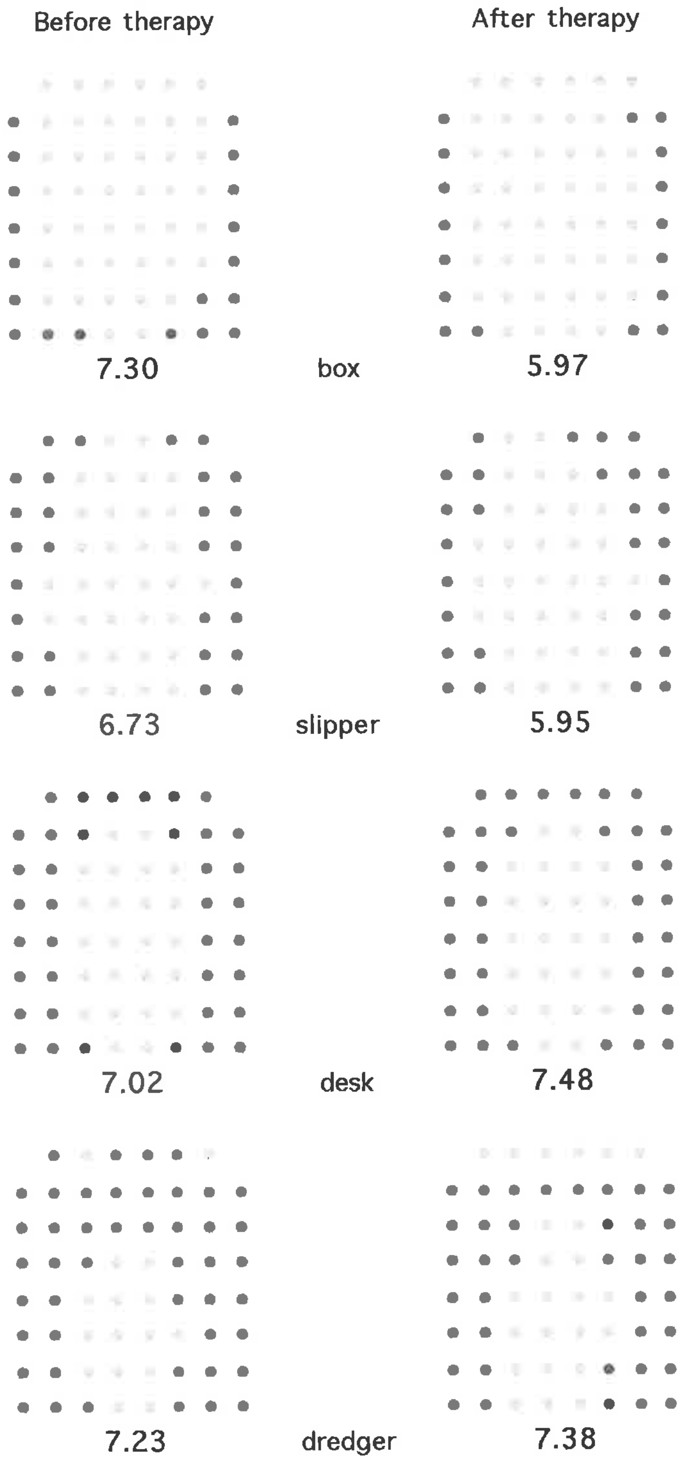
Table 28 Mean ANR of selected words for experimental group before & after therapy (standard errors in parentheses)

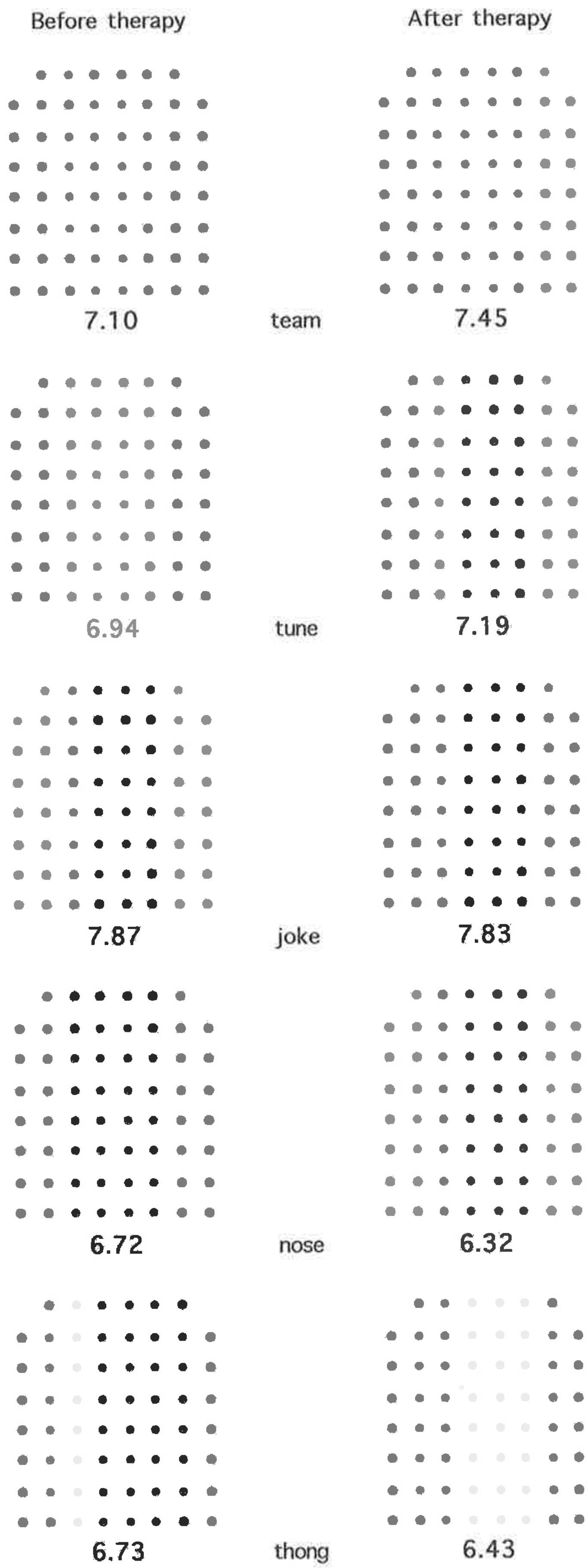
Word	Mean ANR Pre-therapy	Mean ANR Post-therapy	Mean difference	*t* (n=16)	Significance
box	7.30 (0.57)	5.97 (0.57)	-1.32 (0.37)	0.00	*
slipper	6.73 (0.39)	5.95 (0.39)	-0.78 (0.29)	0.01	*
door	8.31 (0.57)	7.64 (0.57)	-0.66 (0.35)	0.06	ns
razor	8.19 (0.33)	7.73 (0.33)	-0.45 (0.24)	0.06	ns
zip	6.87 (0.29)	6.45 (0.29)	-0.42 (0.19)	0.02	ns
nose	6.72 (0.34)	6.32 (0.34)	-0.39 (0.34)	0.25	ns
shack	8.49 (0.34)	8.10 (0.33)	-0.38 (0.33)	0.25	ns
measure	8.10 (0.36)	7.76 (0.36)	-0.34 (0.25)	0.16	ns
star	6.26 (0.54)	5.92 (0.54)	-0.34 (0.39)	0.38	ns
ladder	6.92 (0.46)	6.61 (0.46)	-0.31 (0.30)	0.30	ns
thong	6.73 (0.57)	6.43 (0.57)	-0.30 (0.43)	0.49	ns
chain	7.54 (0.24)	7.29 (0.24)	-0.25 (0.21)	0.23	ns
flash	7.18 (0.39)	6.95 (0.39)	-0.24 (0.33)	0.48	ns
shore	8.38 (0.33)	8.16 (0.32)	-0.22 (0.24)	0.34	ns
tack	7.89 (0.36)	7.73 (0.36)	-0.15 (0.29)	0.60	ns
castle	8.05 (0.31)	7.94 (0.32)	-0.11 (0.25)	0.65	ns
joke	7.87 (0.38)	7.83 (0.38)	-0.05 (0.33)	0.88	ns
saddle	7.57 (0.25)	7.61 (0.24)	0.04 (0.24)	0.85	ns
skate	7.96 (0.30)	8.02 (0.30)	0.06 (0.25)	0.82	ns
thread	7.17 (0.32)	7.27 (0.32)	0.10 (0.21)	0.64	ns
dredger	7.23 (0.25)	7.38 (0.25)	0.15 (0.18)	0.39	ns
catch	8.00 (0.33)	8.16 (0.33)	0.16 (0.31)	0.60	ns
tune	6.94 (0.20)	7.19 (0.20)	0.25 (0.15)	0.10	ns
tooth	6.88 (0.19)	7.14 (0.19)	0.26 (0.13)	0.05	ns
clock	6.96 (0.40)	7.25 (0.41)	0.28 (0.40)	0.48	ns
seesaw	6.93 (0.30)	7.22 (0.30)	0.30 (0.30)	0.32	ns
leg	7.64 (0.36)	7.96 (0.36)	0.32 (0.17)	0.06	ns
team	7.10 (0.27)	7.45 (0.27)	0.35 (0.25)	0.17	ns
biscuit	7.46 (0.29)	7.83 (0.28)	0.37 (0.21)	0.08	ns
desk	7.02 (0.18)	7.48 (0.18)	0.45 (0.15)	0.00	*
feather	7.74 (0.56)	8.21 (0.57)	0.47 (0.35)	0.19	ns
sword	7.04 (0.34)	7.65 (0.34)	0.61 (0.33)	0.06	ns

ns $p > 0.01$ (not significant)
* $p < 0.01$

Figure 10 Palatograms & mean ANR values for 'box', 'slipper', 'desk', 'dredger', 'team', 'tune', 'joke', 'nose' & 'thong' for experimental group before & after therapy (continued on following page)

- electrode contact > 25% of duration of word
- electrode contact > 15% of duration of word
- electrode contact < 15% of duration of word




Before therapy
After therapy
7.10
team
7.45
6.94
tune
7.19
7.87
joke
7.83
6.72
nose
6.32
6.73
thong
6.43

7.7.3 *Swallow data*

Table 29 summarises the mean average notional row (ANR) values for the experimental group before and after therapy for the saliva and water swallows. The table also includes standard errors, mean differences and the significance of the differences.

Pre-therapy condition

Pre-therapy values for both types of swallow were similar, and the standard error values were very small.

Post-therapy condition

Post-therapy ANR values for both swallows were similar, and the standard error values were very small.

Comparison of pre- & post-therapy condition

Although the mean ANR for both swallows fell between sessions, indicating more anterior pattern of contact after therapy, the difference between the groups for neither the water nor saliva swallows reached statistical significance ($p < 0.01$).

Palatograms of the saliva and water swallows are reproduced in Figure 11. From these it can be seen that before therapy, relatively sparse contact occurred for both swallows.

For the pre-therapy saliva swallow, peripheral electrode contact was over 75%, and a distinguishable posterior palatal bolus cavity was present. After therapy, the pattern of contact was similar, but higher contact percentages are evident, particularly in the anterior region.

For the water swallow, none of the electrodes reached 90% contact before therapy; the distribution of the blue electrodes was sparse, and followed no obvious pattern. After therapy, the pattern of contact was still sparse, but over 75% contact was achieved in all electrodes in the most anterior row and antero-laterally, indicating more consistent peripheral contact.

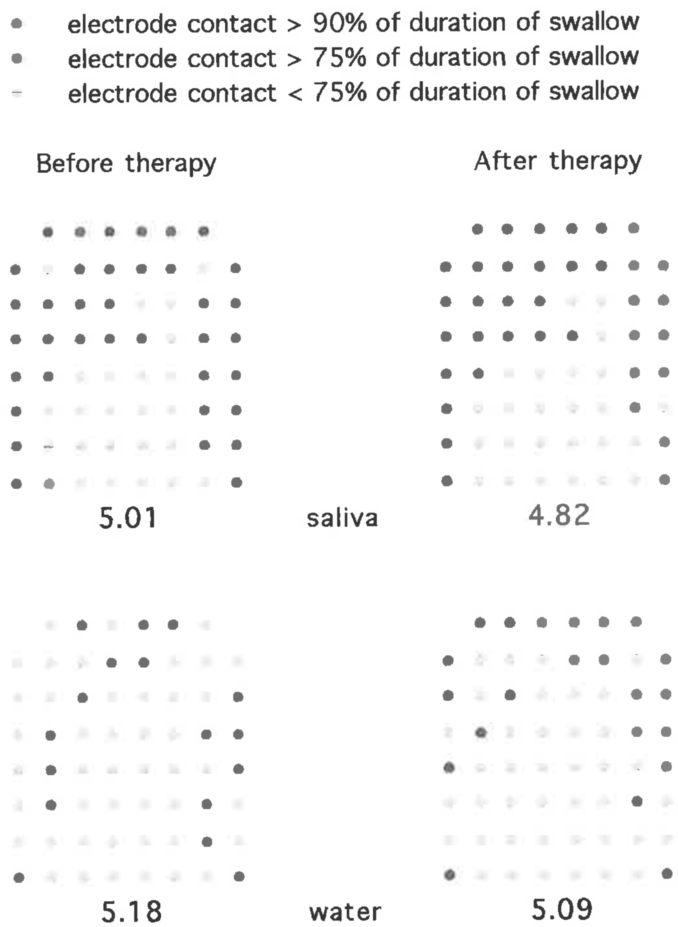
The evidence from the palatograms and the numerical ANR data both indicate a more anterior pattern of palatal contact after therapy. Examination of the palatograms suggests a more consistent and definite pattern of contact for both water and saliva swallows after the course of therapy.

Table 29 Mean ANR of saliva & water swallows for experimental group before & after therapy (standard errors in parentheses)

Word	Mean ANR: Pre-therapy	Mean ANR: Post-therapy	Mean difference	t (n=16)	Significance
saliva	5.01 (0.15)	4.82 (0.15)	0.20 (0.15)	0.18	ns
water	5.18 (0.12)	5.09 (0.12)	0.08 (0.11)	0.46	ns

ns $p > 0.01$ (not significant)

Figure 11 Palatograms & mean ANR values for saliva & water swallows for experimental group subjects before & after therapy



7.7.4 *Summary*

Closure data

The frequency data from the 42 closures analysed revealed no clear pattern of differences over the observation period. Differences for only 2 closures reached statistical significance, one occurring more frequently before, the other occurring more frequently after therapy. However, all 5 velar medial closures analysed occurred more frequently after therapy, although none of these reached statistical significance. Variability in the frequency of occurrence of closures was high both before and after therapy.

None of the differences in duration of the 8 closures selected for further analysis reached statistical significance between sessions. However, both the alveolar lateral, /l/, and the nasal, /n/, closures increased in length between the recordings, and both the alveolar plosives, /t/ and /d/, and the palato-alveolar affricates, /ʧ/ and /ʤ/, were shorter at the post-therapy recording. For the velar closures, no pattern was obvious. Variability in the duration of the 8 closures were similar in both groups.

Numerical ANR data and palatograms indicated that the pattern of contact after therapy for the velar closures was more posterior, but differences were small. For the remaining closures, no clear pattern emerged from the numerical ANR data or from examination of the palatograms. No differences in ANR reached statistical significance, and the values for all closures changed little between sessions. Variability in the ANR of the 8 closures was virtually identical in the two groups.

Closure indices for 2 closures, /l/eg and le/g/, increased between the two recordings. However, for the remaining 6 closures, the mean closure index fell. For /ʧ/ain, this difference reached statistical significance, while for the remaining 5 closures, values were statistically similar in both recordings. For all closures except /ʧ/ain, variability of the difference in values between the two sessions was near to, or greater than the mean difference itself.

Word & swallow data

No pattern of change was evident for the 32 words studied, and the numerical and palatographic evidence was often conflicting. Variability was high for both groups.

For the swallows, differences were small, and failed to reach statistical significance, but evidence from the palatograms and the numerical ANR data both indicate a more anterior pattern of palatal contact after therapy. Examination of the palatograms suggests a more consistent and definite pattern of contact for both water and saliva swallows after the course of therapy.

8. Discussion

This study used cephalometric and electropalatographic methods to compare an experimental group of 9 - 11 year old male anterior open bite (AOB) children with a group of non-open bite controls of similar age. Secondly, using the same methodology, the effect of swallowing re-education therapy on anterior open bite was investigated in the experimental group.

A review of the literature showed that although electropalatography (EPG) has been widely used as a diagnostic, therapeutic and research tool in various situations (Gibbon & Hardcastle, 1987; Fletcher *et al.*, 1991; Hardcastle *et al.*, 1991a; 1991b), to date it has not been applied specifically to AOB patients. Neither has it been used to compare two group of subjects with potential differences in linguo-palatal function, or to assess the effectiveness of the swallowing re-education therapy commonly prescribed for children who exhibit tongue thrust swallowing. EPG has been applied, however, to the quantification of tongue contact patterns during swallowing, and has been shown to be potentially useful in this area (Chi-Fishman & Stone, 1996). Unfortunately, this research was published too late to have been useful during the planning of the present study.

As this was primarily an electropalatographic investigation, a limited number of cephalometric variables was selected to provide an overview of the skeletal and dental morphology of the subjects. The use of a small number of measures has the additional benefit that it decreases the likelihood of statistically significant findings occurring by chance (Tulloch *et al.,* 1997).

A large number of statistical comparisons was obtained from analysis of the EPG data, and it may be expected that some of these would reach statistical significance by chance. The level of significance was therefore pre-determined at $p \leq 0.01$ in order to reduce this statistical 'noise'. For the cephalometric data, however, there were fewer comparisons, and therefore the level of significance was set at $p \leq 0.05$.

Recruitment of patients for the study proved to be difficult, and it was not possible to find more than eight children who met the selection criteria within the time allowed. Although the prevalence of AOB has generally been reported to be less than 5%, depending on the diagnostic criteria used, it may be that the prevalence of AOB in the local population is lower than elsewhere. However, no evidence for such a difference has been found. It is probably more likely that the difficulty in finding subjects is a reflection of the local referral mechanism.

No difference has been shown in the prevalence of AOB in boys and girls (Roder & Arend, 1972), and therefore girls could have been included in the sample. It would undoubtedly have been easier to recruit a larger sample if girls had not been excluded.

However, the incisor teeth erupt a few months earlier in girls than in boys (Bailit, 1975), and therefore it would have been necessary to select slightly younger girls in order to maintain a homogeneity of dental maturity within the sample.

The children in the control and experimental groups were matched for chronological age. More precise matching, for instance for vertical and antero-posterior skeletal, and dental patterns, might have yielded more detailed information on the differences between the control and experimental groups, and on the effects of therapy. However, this was not possible with the small number of subjects available.

If the criteria for inclusion in the sample group had specified dental rather than chronological age, girls could have been included, which would have increased the pool of potential experimental subjects, and the sample could have been more closely matched with respect to the eruptive state of the incisor teeth.

The control group of non-open bite children had normal vertical incisor relationships, whereas the subjects in the experimental group had AOB. Spontaneous closure of AOB occurs in approximately 80% of 10 to 12 year old children (Worms *et al.*, 1971). As mentioned above, recruitment of sufficient numbers of subjects for the experimental group was difficult, and therefore there was no control group of AOB children to assess how much closure of AOB would have occurred without therapeutic intervention; the (non-open bite) control group was used for this purpose. However, growth changes and alterations in incisor position in the experimental and control group subjects may well have been different.

The mean time interval between the pre- and post-therapy lateral head radiographs taken for the experimental group subjects was 16.75 weeks, or approximately one third of a year. Normative values for PP-Me predict that an increase of approximately 1mm per year will occur for 10 year old boys (McNamara, 1984). The mean change during the observation period was an increase of 0.6mm for PP-Me, which is therefore double that predicted by McNamara. However, in the radiographic error study, PP-Me was identified as one of the least reproducible cephalometric measurements, and furthermore, values for both the measured difference from the present study, and the expected difference from the McNamara's normative data are small. It is probable that some growth did take place in the experimental group children, and that any treatment effect attributable to the therapy provided was superimposed upon the change due to growth. Unfortunately, no normative values for growth in children with AOB are available for comparison.

For five of the children who received swallowing re-education therapy, this was judged to be successful; the newly learned swallowing pattern had been generalised either after 3 or 4 sessions of therapy. For these children, the mean time interval which elapsed between the completion of the course of therapy and the second lateral head radiograph was 2.6 weeks. Although this is probably insufficient time for any skeletal anatomical modification attributable to the therapy to be detectable, some evidence was found for a trend for further eruption of the upper and lower incisor teeth, and a reduction in AOB during the observation period. However, these differences were small and failed to reach statistical significance.

The cephalometric results indicate that before treatment, the experimental group were different from the control group. This is to be expected as the criteria for inclusion in the experimental group specified that subjects should have an anterior open bite, and furthermore, no AOB subjects were allowed in the control group. However, although AOB was the only variable that was statistically significantly different between the control and experimental groups before therapy, several measurements of vertical facial height almost reached statistical significance. As can be seen from Table 12 on page 72, differences between the control group and the experimental group before therapy for SN-MP, AFH and PP-Me approached statistical significance, indicating a possible trend towards a longer facial morphology in the experimental group subjects. It should be noted, however, that in the error study, SN-MP and PP-Me were the least reproducible of the cephalometric measurements used. Nonetheless, the association of these morphological features with AOB has been reported widely in the literature (Lopez-Gavito *et al.*, 1985).

From Table 12 it can also be seen that differences between mean values of U1-SN, U1-PP and IIA between the experimental and control groups were high, but the differences were not statistically significant. Table 30 on page 132 shows the mean values and standard deviations for the upper incisor to cranial base, and inter-incisal angles from the long faced group in the University of Iowa longitudinal facial growth study (Bishara & Jakobsen, 1985), and from the control group and experimental group before and after therapy in the present study. The mean anterior face height for the Iowa long faced group was similar to that of the control group in the present study, but was 6mm less than the mean of the experimental group, thus placing the latter well into the long faced category as described by Bishara & Jakobsen. From the table, it can be seen that the mean value for U1-SN for the control group was 3.1° higher than that found in the Iowa long faced group. However, for the experimental group before therapy, the upper incisor to cranial base angle was almost 9° higher than that of the Iowa long faced group.

Similarly for the inter-incisal angle, the mean value for the control group from the present study is comparable with values from the Iowa study, whereas the mean IIA for the pre-therapy group was almost 10° lower than the long faced Iowa group. These various pieces of evidence may indicate a trend towards greater upper incisor proclination in subjects with AOB, which has also been reported in mouth-breathers with enlarged tonsils (Behfelt, 1990). Forward resting tongue posture, which was also noted by Behfelt, could account for this phenomenon, and it may be that if the sample group had been larger, these small differences may have reached statistical significance.

Table 30 Means & standard deviations of U1-SN & IIA from University of Iowa growth study & present study (standard deviations in parentheses)

	Iowa study	Present study		
	Long faced	Control	Pre-therapy	Post-therapy
U1-SN (°)	100.7 (7.0)	103.8 (3.8)	109.6 (5.7)	109.1 (7.7)
IIA (°)	129.5 (7.8)	129.2 (4.3)	119.9 (8.2)	118.4 (6.3)

Bishara & Jakobsen, 1985

Table 31 shows the mean values and standard deviations for the soft tissue cephalometric variables inter-labial gap (ILG) and naso-labial angle (NLA) for the control group, and the experimental group before and after therapy. Standard deviations for ILG and NLA are both large compared with their respective mean values, indicating high variability. Several children, whose lips were normally apart at rest, had large values for ILG on one radiograph, but had a value of zero on the other because they had held their lips together during the exposure. The cephalometric technique was not standardised with regard to lip posture, and the children were not told whether to relax or tense their lips.

Table 31 Mean values & standard deviations of soft tissue variables for control group & experimental group before & after therapy

	Control		Pre-therapy		Post-therapy	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
ILG (mm)	0.9	2.0	2.0	3.0	4.1	3.3
NLA (°)	114.4	7.0	108.9	6.0	106.9	10.4

The first session of the course of swallowing re-education therapy was directed towards developing new muscle patterns, which are necessary as a foundation for a correct swallow, and for correct lip and tongue postures (Zante, 1994). Good progress at this stage enabled the child to move on to learning the new swallow, even during the same session, if this was felt to be appropriate by the speech therapist. However, there would be little benefit in attempting to teach the new swallow if the child had difficulty in grasping these new muscle patterns. Therefore, whilst every attempt was made to standardise the course of swallowing re-education therapy, it was necessary to vary the therapy according to the child's response. From Table 10 on page 65, it can be seen that only for child D was four sessions the correct number, and while some children achieved a successful outcome in three sessions, others needed more than the four sessions originally planned.

As previously mentioned, for five of the experimental group subjects the corrective therapy was judged to be successful. The criteria for success were that the child was able to use the new and old swallows on command, and that the new swallow was generalised, meaning that the new swallow was used in normal function. Assessment of generalisation by the speech therapist is difficult. Partly, this is because the child is likely to be reminded of the new learned swallow simply by being in the speech therapy clinic. In addition, there may be some halo effect, with the child making more effort during the therapy session because of a desire to please the speech therapist.

For three children the therapy was not successful by the end of the four sessions. For two of these, (A & G), further therapy sessions were required. Child C, however, was withdrawn as his mother could see no benefit from the therapy. Indeed, it proved impossible to motivate this child, and therefore it is not surprising the outcome of his course of therapy was not ideal. Practice is a very important aspect of this type of therapy, and motivation and treatment success go hand-in-hand (Zimmerman, 1994).

The therapeutic regime prescribed for the children in the experimental group focused on correction of their abnormal tongue function. Although EPG recordings were made of dry and liquid swallows, the vast majority of EPG data collected came from recordings of the phrases listed in Appendix 1 on pages 155 - 156. In retrospect, as the therapy was directed at retraining errant swallowing behaviour, it may have been more instructive to have investigated changes in swallowing in more detail, rather than placing so much emphasis on the assessment of tongue function during speech. It may have been more useful, perhaps, to have recorded more than six swallows at each recording session, and to have varied the bolus size for the liquid swallows, as in the work of Gloria Chi-Fishman and Maureen Stone in Maryland, USA (Chi-Fishman & Stone, 1996).

The children in the present study received swallowing re-education therapy but no speech therapy, and yet some changes were found in EPG contact patterns during speech over the observation period, although no clear pattern was evident. Some of the observed change might be attributable to alterations in the position of the anterior teeth or dento-facial growth, but as discussed above, little change would be expected in such a short time, and indeed little was found. In the past, it has been noted that it has not been proven that the re-education of swallowing activity affects speech (Subtelny, 1965). It is possible that the observed change is evidence of such a crossover effect, with the altered swallowing pattern causing change in EPG contact patterns during speech.

In the present study, the course of therapy was directed at the alteration of tongue activity during function. However, the resting posture of the tongue is considered to be more important than functional activity in the ætiology of AOB (Proffit & Mason, 1975; Fröhlich *et al.*, 1991; Proffit & White, 1991). Although some changes in function were demonstrated after therapy, resting tongue posture was not investigated, and therefore no evidence for a change in resting tongue posture was found. Any morphological changes over the course of therapy might constitute evidence that resting posture was changed by therapy aimed at altering function. Although after therapy there was a trend towards eruption of the upper and lower anterior teeth, with a concomitant reduction in AOB, none of the changes in cephalometric variables reached statistical significance. It must be noted, however, that the post-therapy lateral head radiographs were probably taken too soon after therapy for anatomical adjustments to have been seen.

Several EPG systems are currently in use, with varying numbers and configurations of electrodes. As there is considerable inter-speaker variability in palate size and shape, the position of a given electrode in systems which use a preformed electrode grid may bear no consistent relationship to physiological landmarks, or the area of articulation for a particular sound (Byrd *et al.*, 1995). In the Reading system, which was used in the present study, the 62 electrodes are arranged according to a predetermined scheme based on anatomical landmarks. This ensures that the spatial relationship of any given electrode to the adjacent oral structures is similar for different palate sizes (Hardcastle *et al.*, 1989), thus minimising the inter-individual variation attributable to the EPG recording system itself. Chi-Fishman and Stone used a Kay Elemetrics EPG system, which is based on a 96 contact grid (Chi-Fishman & Stone, 1996); relating the results of their work to the findings from the present study is therefore difficult.

Previous investigations of tongue function have used an x-ray source to locate metal pellets affixed to the dorsal surface of the tongue (Hamlet, 1989). Electromagnetic articulography, a more modern adaptation of this technique, avoids the use of ionising radiation, and instead uses small coils attached to the surface of the tongue in the midline. The position of the coils can be tracked by the measuring the signal induced in receiver coils placed outside the mouth, and thus the contour of the dorsal surface of the tongue can be deduced (Schönle *et al.*, 1987). Whereas the part of the tongue contacting the palate can only be guessed with EPG, electromagnetic articulography has the advantage that the exact site of the tongue surface in contact with the palate is known. A combination of the two techniques might yield even more precise information on tongue function.

Before recording EPG data, it has been found necessary for subjects to use a 'dummy' plate in order to allow speech to accommodate. Various lengths of accommodation have been used ranging from full-time wear for two weeks (Lundqvist *et al.*, 1995), through three days (Proffit *et al.*, 1969), to a mere 5 minutes used by Flege (Byrd *et al.*, 1995). There is also some individual variation in the ability to accommodate to the presence of an intra-oral device of this type (Allen, 1958). In the present study, although the subjects were asked to wear the plate for three days prior to the recording session, in practice, they may not have managed full-time wear. Byrd and co-workers required their subjects to wear the EPG plate for one hour prior to the recording (Byrd *et al.*, 1995), and in the recent work in the United States, subjects wore their 'dummy' plates for 20 minutes while the recording equipment was set up (Chi-Fishman & Stone, 1996). These methods have two distinct advantages over the technique used in the present study. Firstly, the accommodation time can be supervised, and secondly, the accommodation time is standardised, thus removing a potential source of variation from the EPG data.

Electropalatography generates massive amounts of binary data, which is difficult to analyse quantitatively (Fontdevila *et al.*, 1994), and must therefore be reduced in some way in order to be meaningful (Byrd *et al.*, 1995). Established methods for summarising EPG data utilise spatial and temporal reduction (Fontdevila *et al.*, 1994). In spatial reduction, the electrodes are analysed in groups, with contacts averaged within the group. In temporal reduction, contacts of individual electrodes are averaged over time. An extreme example of temporal data reduction is the analysis of a single frame of EPG data, which ignores time altogether (Byrd *et al.*, 1995). It is possible to use both forms of reduction together to reduce the amount of data further. However, either the dynamic or quantitative aspects of the data, or both, can be lost in such data reduction (Butcher, 1989). In the present study, temporal data reduction was used in the production of the palatograms reproduced in Appendix 4 on pages 162 - 171, and both spatial and temporal reduction were used in the numerical analysis involving average notional row (ANR) numbers.

Wide variation between individuals has been found in tongue contact during speech using both conventional palatography (Allen, 1958) and electropalatography (Hamlet *et al.*, 1986; Lundqvist *et al.*, 1995). In the present study, similar inter-individual variation may have been present in all EPG parameters measured. However, in order to reduce the amount of information, EPG data was pooled and analysed for whole groups of subjects, so that inter-individual variation was masked. Although such loss of information on individual variation has been regarded as a contra-indication to the pooling of EPG data from different individuals (Hamlet *et al.*, 1986), it has nevertheless been used elsewhere (Dagenais *et al.*, 1994; Tindall, 1998), and may be seen as a further EPG data reduction method. In EPG studies which analyse subjects individually, the amounts of EPG data used are relatively small, perhaps 120 to 150 discrete EPG events (Lundqvist *et al.*, 1995; Chi-Fishman & Stone, 1996; Wakumoto *et al.*, 1996). Group analysis has been used where larger volumes of EPG data have been examined, for example 3,600 EPG events (Dagenais *et al.*, 1994), and the present study which, in conjunction with the work of Dr Andrew Tindall, analysed over 10,000 discrete EPG events (Tindall, 1998). Group EPG data reduction was also necessary in the present study in order to compare tongue function in open bite and non-open bite samples of patients, which was one of the aims of the investigation.

As discussed above, the average notional row (ANR) number is derived from the combination of both spatial and temporal data reduction, and is a convenient measure of average tongue to palate contact over a given time span. Palatograms are also a convenient metaphor for the visual representation of linguo-palatal contact. However, as noted previously, the greater data reduction used to produce the numerical value does mask useful information.

Figure 12 on page 137 shows the control group and pre-therapy experimental group palatograms and mean ANR values for the whole words 'chain', 'dredger' & 'clock'. As can be seen from the figure, there is a relatively deep pattern of anterior contact in the control group for 'chain', and in the experimental group for 'dredger', while the pattern in the experimental group for 'chain' and the control group for 'dredger' amounts to a single row only. Although the experimental group palatograms for both words do show a slight increase in posterior contact, as indicated by the appearance of 3 blue contacts in the two posterior rows of electrodes, the ANR values convey little information on the change in the pattern of anterior contact, which is quite different between the two words.

Despite the fact that the mean ANR values for the pre-therapy and control groups for 'clock' differ by only 0.20, the pattern of contact in the palatograms is dissimilar. As can be seen from Figure 12, the control group made more consistent postero-lateral contact, and noticeably more anterior contact than the experimental group.

These results confirm that data is lost when spatial and temporal data reduction are combined (Butcher, 1989), but suggest that palatograms may be more informative. It would appear that although the mean ANR values may be useful, they should be used in conjunction with palatograms.

- electrode contact > 25% of duration of word
- electrode contact > 15% of duration of word
- electrode contact < 15% of duration of word

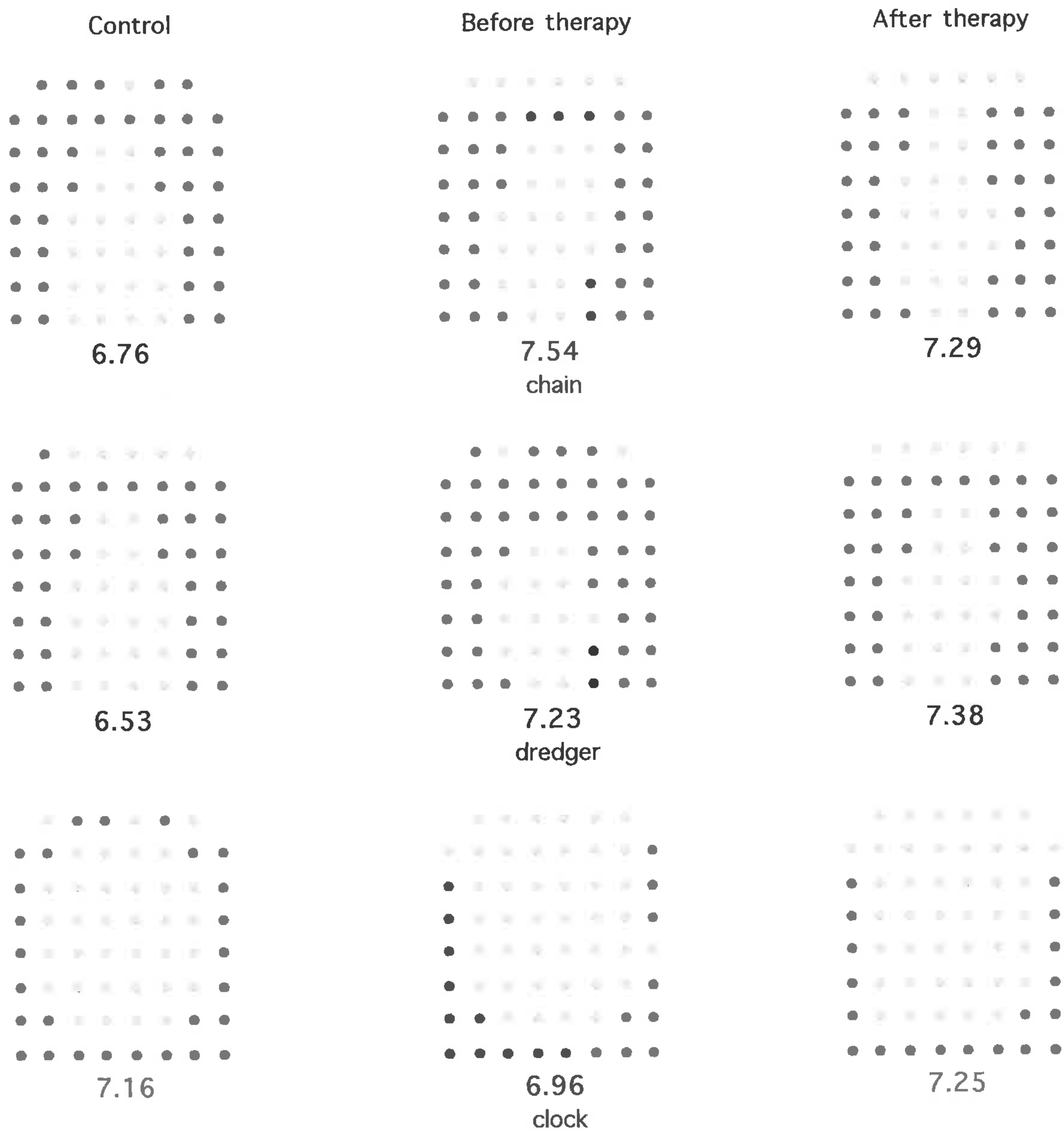


Figure 12 Palatograms & mean ANR values for 'chain', 'dredger' & 'clock' from control group & experimental group before & after therapy

Close examination of the numerical and palatographic data obtained from the control group and the experimental group before therapy (see Table 32 & Figure 13) indicates that for the palato-alveolar affricate phonemes /ʧ/ and /ʤ/, the differences between the groups, although small, were large enough to constitute a distinguishing feature between the groups. As can be seen from Table 32, the mean values for duration and ANR of the /ʧ/ and /ʤ/ closures were higher in the experimental group children. These findings may indicate a more ponderous execution of these sounds with a noticeably different pattern of tongue activity, which confirms the impression that it is indeed possible to detect these differences clinically in open bite children. However, the predictive value of these sounds remains to be systematically tested. With this caveat, it is nonetheless suggested that the /ʧ/ and /ʤ/ phonemes may be of assistance in the diagnosis of tongue thrust, and should be included in any list of test words used for this purpose. In the other closures examined in detail, no general distinguishing characteristics were found, and any useful diagnostic information contained in the whole word data may have been masked by the presence of other phonemes within the words.

Table 32 Mean duration & ANR values for control & experimental group subjects before therapy for /ʧ/ & /ʤ/ closures

	Mean duration (ms)		Mean ANR	
Group	Control	Pre-therapy	Control	Pre-therapy
/ʧ/	79.1	111.2	2.26	3.56
/ʤ/	92.3	116.5	2.35	2.96

Although the production of the /s/ sound has been investigated with EPG in non-open bite individuals (Lundqvist *et al.*, 1995), and with lateral head radiographs in tongue thrusters (Subtelny, 1965), it would appear that to date the production of this sound by tongue thrusters has not been studied with EPG. Because the /s/ phoneme does not usually contain a closure, it was not specifically investigated in the present study. Examination of the numerical and palatographic data for words containing the /s/ phoneme (see Figure 14 on pages 140 - 141) showed no detectable antero-posterior differences between the control group and the experimental group before therapy, but as mentioned above, the presence of other phonemes within words may have masked information relating to the /s/ phoneme. However, the palatograms in Figure 14 do show that the central groove was wider in the experimental subjects, possibly indicating palatal contact by a different area of the tongue for these words.

Figure 13 Palatograms for /ʧ/ & /ʤ/ closures from control & pre-therapy experimental groups

- ● electrode contact > 80% of duration of closure
- • electrode contact > 60% of duration of closure
- – electrode contact < 60% of duration of closure

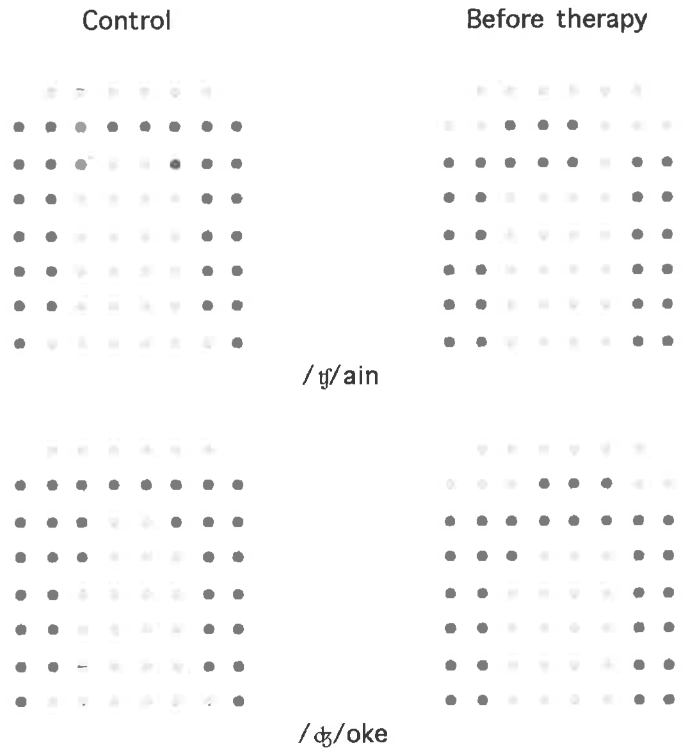
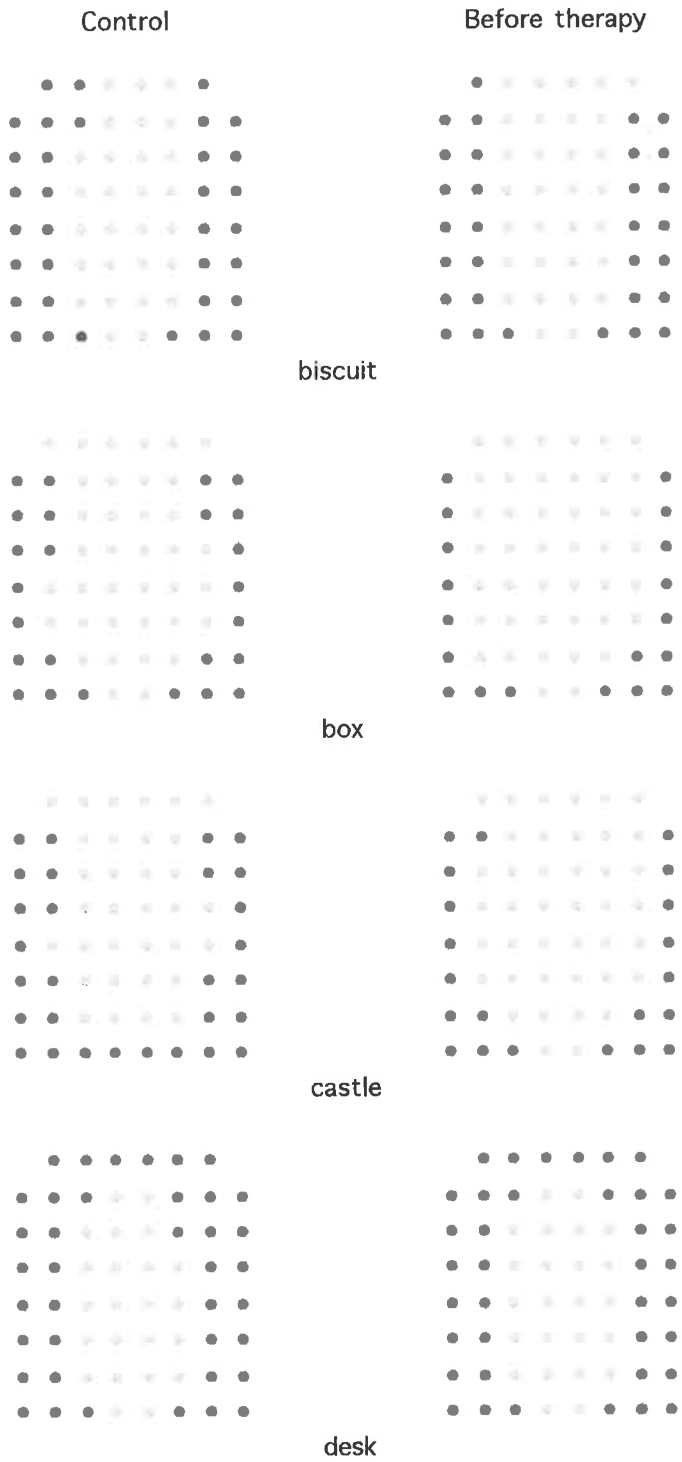
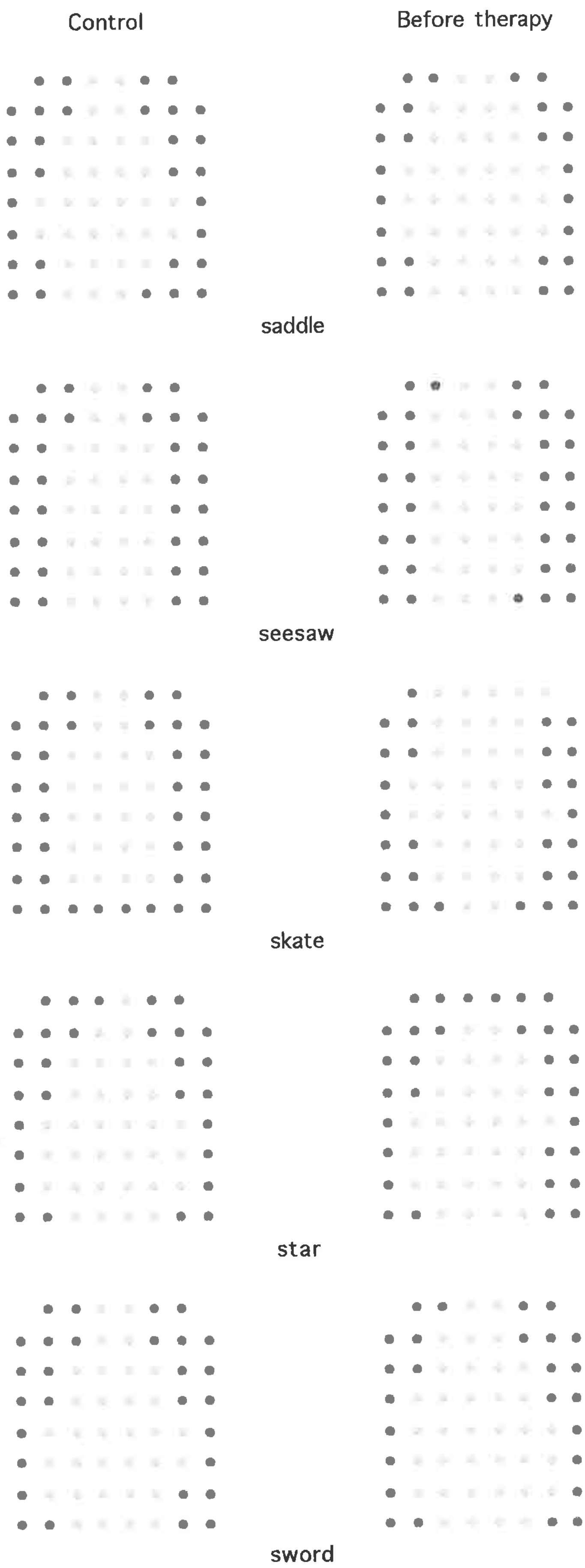


Figure 14 Palatograms for words containing the /s/ phoneme for control & pre-therapy experimental groups (continued on following page)

- electrode contact > 25% of duration of word
- electrode contact > 15% of duration of word
- electrode contact < 15% of duration of word




Control
Before therapy
saddle
seesaw
skate
star
sword

The length of a closure is dependent on the phonetic context, and is therefore variable, but may last from 40 to 150ms (Clark & Yallop, 1995). The mean closure durations found in the present study were all well within these limits, ranging from 71.8 to 116.5ms. Clark and Yallop also note that the duration of a closure is often shorter when voiced than when voiceless. Table 33 shows the mean durations of 6 of the subset of 8 closures selected for further analysis from the present study. In the table, the closures are arranged in pairs, with the voiceless closure below its voiced counterpart. Because the 2 velar closures occur at different positions within the words, they are not strictly comparable with each other. Nevertheless, as can be seen from the table, voiced closures were often shorter, but in contrast to Clark and Yallop's observation all three voiceless closures were shorter in the 'normal' control group.

Velar closures are initiated by contact between the back of the tongue and the soft palate. During the closure, contact extends forwards to the hard palate before 'peeling' away again near the end of the closure. Therefore it is probable that the durations of the velar closures were actually artificially short because the EPG plate only extends distally as far as the junction of the hard and soft palate, and any linguo-palatal contact behind this was not registered.

Table 33 Mean durations of voiced & voiceless closure pairs for control group & experimental group before & after therapy

		Mean duration (milliseconds)		
Closure	Phonation mode	Control	Pre-therapy	Post-therapy
/d/oor	voiced	116.1	110.0	109.4
/t/eam	voiceless	87.1	112.8	104.2
/ʤ/oke	voiced	92.3	116.5	99.5
/ʧ /ain	voiceless	79.1	112.2	111.3
le/g/	voiced	96.0	87.4	72.4
suit/k/ase	voiceless	92.5	97.6	105.4

From the forty-two closures chosen from the word list, a smaller subset was selected for more detailed examination. From Table 14 (page 82) and Table 15 (page 83), it can be seen that many of the original 42 closures were made infrequently, and inclusion of these would have skewed the analysis. Therefore, only closures which were made consistently were included in this subset. Arbitrary criteria were used to select the most reliably produced examples of each closure type in both the control group and the experimental group before therapy, and also to ensure that this subset of eight closures included a wide variety of closure types.

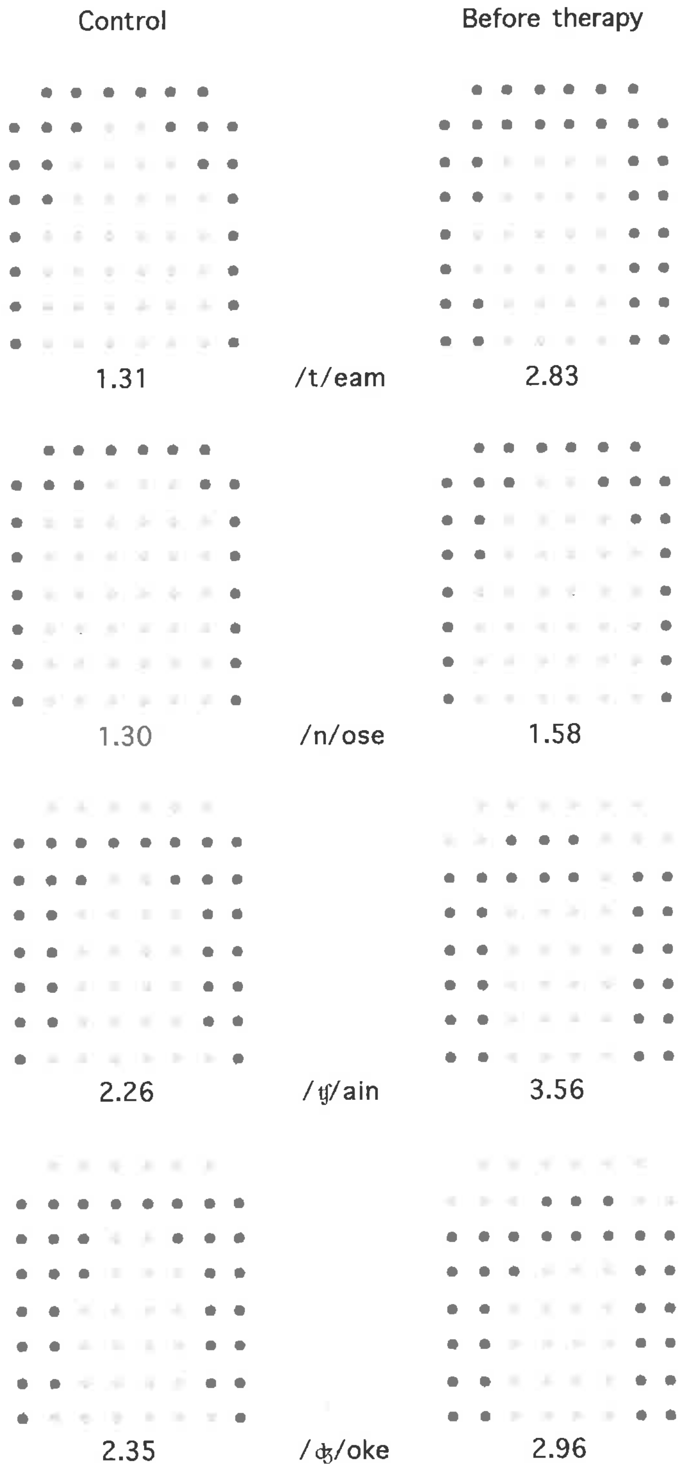
Examination of the palatographic and numerical data for the control and experimental groups before therapy indicates that there were some differences between the two groups. These differences, although small, were evident in the data from closures, words and swallows, and indicated a trend for more posterior palatal contact in the experimental subjects. This finding has not been reported before, but would seem to contradict the hypothesis that during swallowing, the tongue adapts to the presence of the AOB by functioning more anteriorly (Wallen, 1974). However, the front of the EPG plate only extends to the palatal gingival margins of the upper incisors, and cannot therefore quantify tongue function beyond this limit. It may be, therefore, that the tongue does protrude to effect an anterior oral seal, but the EPG system fails to register its position.

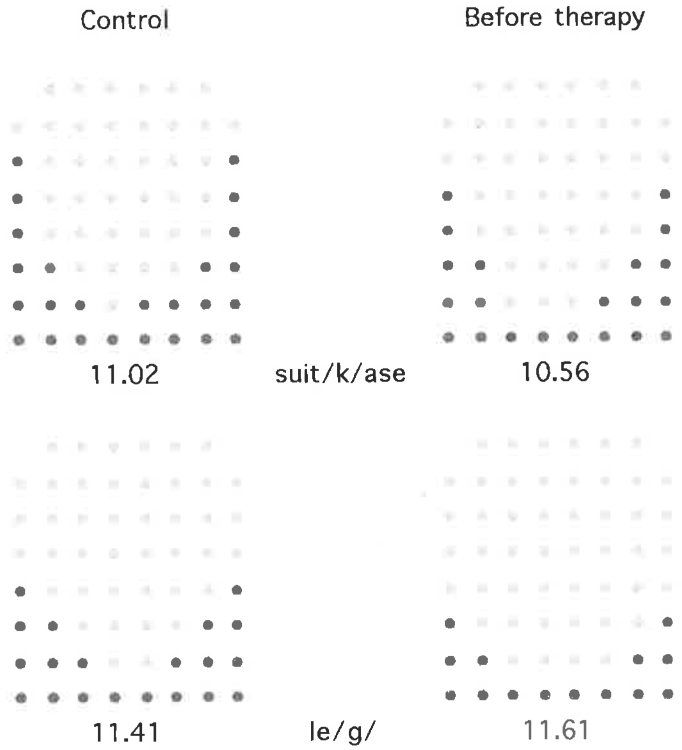
The production of the alveolar and palato-alveolar closures normally involves the apical region or tip of the tongue, and the area of contact is small. Figure 15 on page 144 shows the palatograms and mean ANR values for the /t/, /n/, /ʧ/ and /ʤ/ closures for the control and pre-therapy experimental subjects. As can be seen from the palatograms, in the control group the midline anterior contact for these closures was confined to a single row, whereas before therapy, the children in the experimental group exhibited a deeper pattern of midline anterior contact. In accordance with Wallen's hypothesis, this may be because the tongue was protruded into the open bite; consequently, a more posterior part of the dorsal surface of the tongue, the laminal region, was brought into contact with the palate during the production of these sounds. The laminal region of the tongue, which is also known as the blade, is larger than the tip, and would therefore be expected to produce a larger EPG contact area, as can be seen in the pre-therapy palatograms in Figure 15.

The higher mean ANR values found in the experimental subjects suggest that before therapy, the AOB children had a more posterior contact pattern. However, where the control group children exhibited a small anterior contact pattern, as in these 4 closures, the deeper anterior contact pattern found in the experimental subjects may account for these higher values. Thus, although the tongue is protruded into the open bite, and is actually positioned anteriorly, the deep EPG contact pattern associated with lamino-palatal contact in the anterior region results in a higher mean ANR, implying a more posterior pattern of contact in the AOB subjects. Again, it appears that palatographic representation of EPG data may be more informative than numerical ANR values.

Figure 15 Palatograms & mean ANR values for /t/, /n/, /ʧ/, /ʤ/, /k/ & /g/ for control group & experimental group before therapy (continued on following page)

- electrode contact > 80% of duration of closure
- electrode contact > 60% of duration of closure
- electrode contact < 60% of duration of closure





The palatograms and mean ANR values for the velar closures, /k/ and /g/, are reproduced above. The palatograms for these closures show a more posterior pattern of contact in the experimental group subjects. While a more posterior contact pattern is normally associated with a higher ANR value, this may not be true for velar closures if linguo-palatal contact occurs behind the posterior border of the EPG plate. In this case, some linguo-palatal contact at the posterior limit of the closure may not be registered, resulting in an deceptively low ANR value.

Although the differences in mean ANR values between the two groups were small and failed to reach significance, the value for the experimental group was higher for the /g/ closure and lower for the /k/ closure. The reason for these contradictory ANR values is not clear, but other factors, such as the pattern of lateral contact, the balance between anterior and posterior contact, and the effect of different percentages of contact do influence the mean ANR value. As discussed above, the palatogram may be more useful than the numerical ANR value.

Examination of the palatographic and numerical data for the closures and words for the experimental group before and after therapy showed no clear pattern. Approximately equal numbers of mean values moved away from, and towards the control group values, although differences were all small. Furthermore, the palatographic and numerical ANR often gave conflicting impressions about what changes had taken place. For example, the palatograms and mean ANR values in Figure 12 on page 137 show that for 'chain' and 'clock', the mean ANR value indicates that after therapy, the experimental group children were more like the controls than before. On the other hand, the palatogram suggests the opposite. For the word 'dredger', the palatogram suggests that the experimental group children more closely resembled the controls after therapy, but the mean ANR value indicates otherwise. It should be noted that a higher ANR value may indicate more posterior contact, less anterior contact, or both as can be seen from the control and pre-therapy palatograms for 'clock' in Figure 12. Where more than one closure occurs within a word, and these are affected differently, the mean ANR may be of limited value.

For both dry and liquid swallows, differences were also small, and failed to reach statistical significance. However, evidence from the palatograms and the numerical ANR data both indicate a trend towards a more anterior pattern of palatal contact after therapy. This implies that swallowing function in the experimental group subjects resembled the control group more closely after than before the course of therapy. Examination of the palatograms in Figure 16 also suggests a more consistent and definite pattern of contact for both water and saliva swallows after the course of therapy, also more closely resembling the control group, which suggests that for swallowing, the therapy was at least partly successful in its aim of correcting the errant swallowing behaviour.

Palatograms of the swallows in Figure 16 show relatively sparse patterns of contact in the experimental group children compared with the control subjects, in whom a stronger pattern of peripheral contact, and a well defined posterior palatal bolus cavity were found. It is feasible that the sporadic contact pattern seen in the experimental subjects before therapy may be caused by reduced linguo-palatal pressure. Although some workers have found increased tongue pressure during swallowing in AOB patients (Kydd *et al.*, 1963), others have shown that some tongue thrusters exhibit little or no pressure, whereas others use very heavy pressure during swallowing (Proffit *et al.*, 1969). The post-therapy palatograms show that the pattern of contact after therapy had become more like that of the controls than before. It appears that after therapy the experimental group subjects had improved their pattern of contact, and it may be that they also increased the force with which they held the tongue against the palate during swallowing.

There was also some evidence of less consistent production of closures by the experimental group subjects. Although the reason for this is not clear, it is possible that it results from reduced linguo-palatal pressure during function.

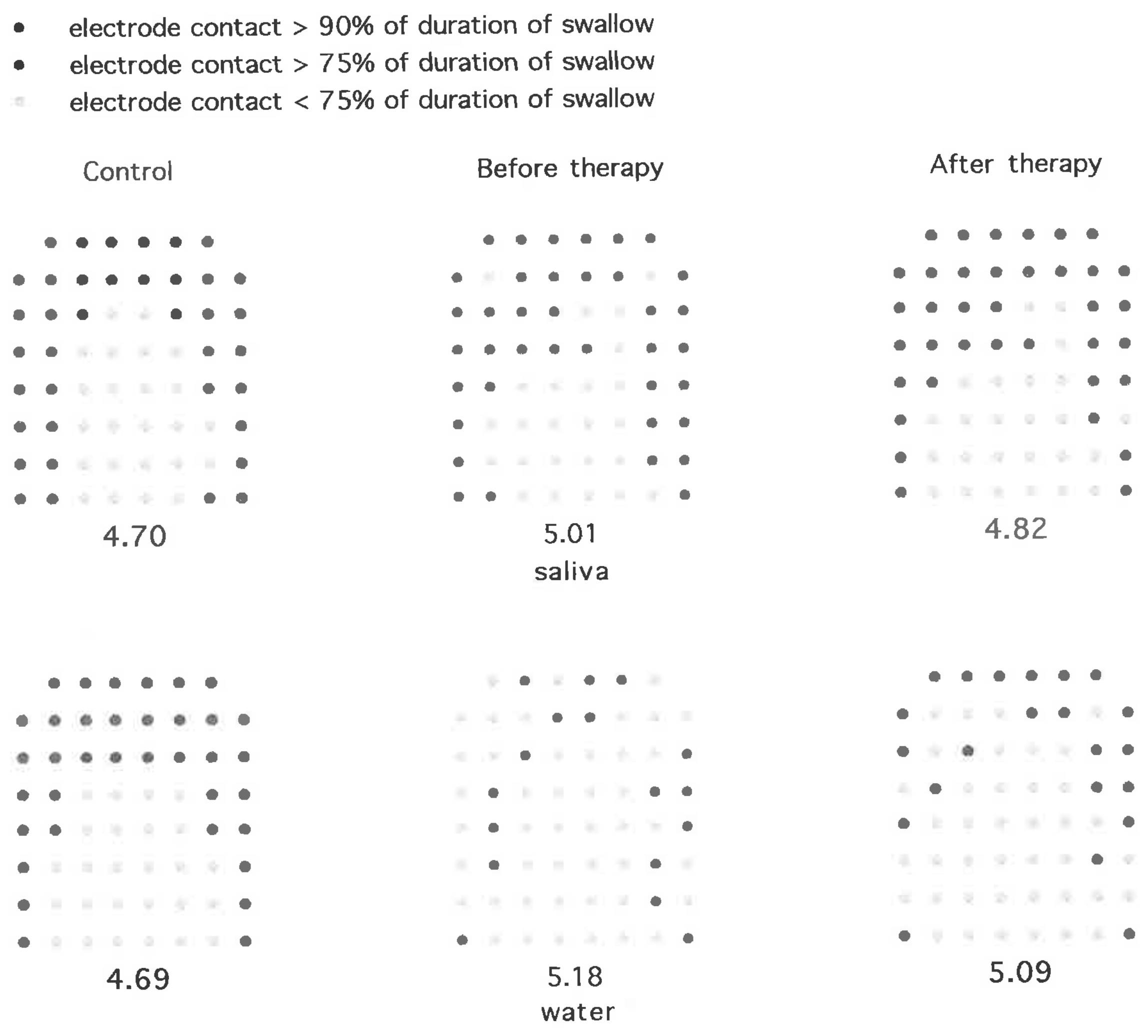


Figure 16 Palatograms & mean ANR values for saliva & water swallows for control group & experimental group before & after therapy

Previous work has established that dry and liquid swallows are different in nature, with greater tongue to palate contact occurring in the dry swallow (Hamlet, 1989). The results of the present study, and particularly the palatographic representations of the saliva and water swallows are in accordance with the findings of Hamlet.

There is some evidence that sensory feedback of bolus size modifies pharyngeal and oral function during swallowing (Hamlet, 1989), although the effect on linguo-palatal contact patterns may be small (Chi-Fishman & Stone, 1996). The mean bolus size used in thin liquid swallowing has been found to be 21ml, and it has been suggested that the bolus size for investigation of swallowing in men should be 25ml, and 20ml in women (Adnerhill, 1989). Unfortunately, no recommendation was made for the ideal bolus size for use with pre-adolescent boys.

In the present study, no attempt was made to standardise the size of the liquid bolus swallowed, and this might have been expected to exaggerate the variability found in the water swallows. Table 34 summarises the mean ANR values for both water and saliva swallows for the control group and for the experimental group before and after therapy. As can be seen from the table, values for the standard error were low for all groups for the saliva swallows, and even lower for the water swallows. It is also notable that variability was consistent across the 3 groups for each swallow type. Although Hamlet found that bolus size has some effect on the variability of liquid swallows (Hamlet, 1989), the low variability of the results of the present study may indicate that standardisation of the bolus size is not necessary. This may be either because the children drew reproducible volumes of water into their mouths unaided, which seems unlikely, or because the variability of ANR values is not greatly influenced by bolus size. Nevertheless, bolus size standardisation would have eliminated this source of potential error from the data. Hamlet's subjects were not selected for anterior open bite, and it would appear that the present study is the first to have compared the swallowing function of AOB children with a non-open bite control group.

Table 34 Mean ANR for all swallows for all groups (standard errors in parentheses)

	Mean ANR (standard error)		
Swallow	Control	Before therapy	After therapy
saliva	4.70 (0.15)	5.01 (0.15)	4.82 (0.15)
water	4.69 (0.11)	5.18 (0.12)	5.09 (0.12)

One aim of the present study was to produce a core of experimental data, and this was achieved. Great potential remains for further analysis of both the cephalometric and EPG data, and several possible directions for future work have become apparent during the course of the investigation.

As discussed earlier, a vast amount of data was collected in the present study, and data reduction was therefore necessary despite the information loss that this causes (Hamlet *et al.*, 1986; Fontdevila *et al.*, 1994; Byrd *et al.*, 1995). Analysis of the data for each individual would allow appraisal of individual responses to treatment. The experimental subjects showed a variety of responses to the therapy, and analysis of the subjects according to the outcome of therapy might reveal cephalometric and EPG differences between children who responded to therapy and those who did not.

The observation period in the present study was necessarily short, and precluded longer term follow up of the children involved. Cephalometric analysis of new lateral head radiographs of the experimental group subjects would show any dento-facial changes that may have occurred in the year since the end of therapy, although without an open bite control group, interpretation of the results would be difficult. Follow up EPG recordings would also be useful, but as the boys in the sample group are both growing and exfoliating deciduous teeth, it is unlikely that their EPG plates would fit after a year. Remaking the EPG plates would be expensive, and would introduce a potential source of error between the new data and data from the pre- and post-therapy recordings.

Earlier work has used EPG to investigate the production of the /s/ sound, although not in open bite subjects (Lundqvist *et al.*, 1995). Although the /s/ sound was not examined in detail in the present study, the pre-therapy experimental subjects were found to have a wider central groove in words containing the /s/ phoneme. Further analysis of the data might clarify differences in the production of the /s/ sound by open bite and non-open bite subjects.

Large differences in closure frequency were found between the control and pre-therapy experimental subjects, and for four of these closures the differences reached statistical significance. Different patterns of EPG contact for the /ʧ/ and /ʤ/ closures were also found in the two groups. Further investigation of these, and a variety of other phonemes would increase our understanding of the differences between open bite and non-open bite subjects.

9. Principal Findings

1. From a review of the published literature it was found that:

    - the ætiology of anterior open bite (AOB) remains uncertain, but resting tongue posture is thought to be an important ætiological factor. AOB can be caused by non-nutritive digit sucking.
    - treatment of AOB is notoriously difficult, but spontaneous closure is common. Myofunctional therapy (MFT), orthodontics and surgery have been used to treat AOB; if anterior tongue posture persists after open bite correction, relapse is likely.
    - tongue thrust swallow is commonly found with AOB, facilitating an anterior oral seal; tongue behaviour in these cases is probably adaptive.
    - tongue thrust has been treated by AOB closure, and with MFT.
    - MFT has not been subjected to systematic evaluation.
    - electropalatography (EPG) enables speech pathologists to measure dynamic tongue function for diagnosis, treatment and research purposes, but it has not been used widely in orthodontics.

2. Lateral head radiographs and EPG recordings of speech and swallowing were made for an experimental group of 8 AOB children, and a group of 8 non-open bite controls.

    a) Comparisons of the cephalometric data indicated:

    - that the groups were similar for all cephalometric variables measured except AOB, for which the difference between mean values was statistically significant ($p < 0.05$).
    - a trend towards longer face morphology and upper incisor proclination in the experimental group subjects.

    b) Comparisons of the EPG data indicated:

    - a trend for more consistent production of closures in the control group, with high variability in the occurrence of closures in both groups.

    c) A subset of 8 closures were selected for more detailed analysis, which indicated:

    - a trend in the ANR and palatographic data towards more anterior linguo-palatal contact in the control subjects.

- a different pattern of anterior contact for the palato-alveolar closures, /ʧ/ and /ʤ/, in the two groups.

- a trend for shorter /l/ and /n/ closures in the experimental group subjects.

- similar variability in duration, ANR and closure index values for both groups.

d) Analysis of the EPG data for whole words and swallows indicated that:

- the control group subjects showed a more anterior pattern of palatal contact.

- for /s/ phonemes, some evidence for a wider central lingual groove was found in the experimental group subjects.

- during swallows, the experimental children displayed relatively sparse patterns of EPG contact compared with the control subjects, in whom stronger peripheral contact, and a well defined posterior palatal bolus cavity were found. For water swallows, the difference in mean ANR values between the groups reached statistical significance ($p < 0.01$).

3. The children in the experimental group received a course of therapy designed to correct tongue thrust swallowing behaviour.

a) Comparison of the cephalometric data from before and after therapy indicated:

- very little change during the observation period, but some evidence for a trend towards reduction of the AOB, and further eruption of the upper and lower incisors.

b) Comparison of the EPG data from before and after therapy indicated:

- high variability but no clear pattern in differences in the frequency of occurrence of closures over the observation period.

c) A subset of 8 closures were selected for more detailed analysis, which indicated:

- that although the /l/ and /n/ closures increased in length between the recordings, and the /t/, /d/, /ʧ/ and /ʤ/ closures were shorter at the post-therapy recording, none of the differences in duration of the selected closures reached statistical significance.

- that mean closure index values for 2 closures, /l/eg and le/g/, increased between the two recordings, while for the remaining 6 closures the mean closure index fell. Only for /ʧ/ain did the difference reach statistical significance ($p < 0.01$).

- similar variability in the duration and ANR of the closures before and after therapy.

d) Analysis of the pre- and post-therapy EPG data for words and swallows indicated:

- conflicting numerical and palatographic evidence, with no clear pattern of change for the 32 words studied. Variability was high before and after therapy.

- a trend towards a more anterior pattern of palatal contact, and a more consistent and definite pattern of contact after therapy for the water and saliva swallows, but differences between recordings failed to reach statistical significance.

4. Potential remains for further analysis of the data collected, including individual rather than group analysis of data, and assessment of sounds not examined in the present study.

10. Appendices

10.1 Appendix 1. Word list used for EPG recording sessions

The following list of words, compiled by Professor Andrew Butcher, contains a variety of different sounds occurring in various contexts. Each phrase begins with 'it's a...', which contains a closure. This can be used as a reference point in data analysis. The 49 subject words are repeated 3 times throughout the course of the list, except the first word, 'thong', which occurs 4 times. Each word is placed in a different group each time it occurs.

1. It's a thong
   It's a kitkat
   It's a castle
   It's a shore
2. It's a squashkit
   It's a fishing rod
   It's a box
   It's a joke
3. It's a skate
   It's a slipper
   It's a tickler
   It's a leg
4. It's a mathsbook
   It's a clock
   It's a ladder
   It's a feather
5. It's a thickshake
   It's a cat's tail
   It's a zip
   It's a deckchair
6. It's a thread
   It's a suitcase
   It's a start
   It's a tractor
7. It's a seesaw
   It's a chain
   It's a dredger
   It's a star
8. It's a shack
   It's a team
   It's a tooth
   It's a desk
9. It's a door
   It's a flash
   It's a bookshop
   It's a cocktail
10. It's a sword
    It's a measure
    It's a sheep
    It's a razor
11. It's a tune
    It's a biscuit
    It's a nose
    It's a saddle
12. It's a trotter
    It's witchcraft
    It's a tack
    It's a catch
13. It's a stretcher
    It's witchcraft
    It's a desk
    It's a tune
14. It's a stretcher
    It's a shack
    It's a chain
    It's a thread
15. It's a shore
    It's a trotter
    It's a leg
    It's a bookshop
16. It's a suitcase
    It's a star
    It's a seesaw
    It's a team
17. It's a sword
    It's a skate
    It's a ladder
    It's a thickshake
18. It's a dredger
    It's a mathsbook
    It's a squashkit
    It's a box

19. It's a cat's tail
It's a flash
It's a tooth
It's a saddle

20. It's a sheep
It's a deckchair
It's a clock
It's a thong

21. It's a fishing rod
It's a biscuit
It's a joke
It's a slipper

22. It's a tack
It's a kitkat
It's a cocktail
It's a tickler

23. It's a nose
It's a tractor
It's a measure
It's a start

24. It's a catch
It's a zip
It's a feather
It's a castle

25. It's a door
It's a razor
It's a kitkat
It's a squashkit

26. It's a razor
It's a mathsbook
It's a fishing rod
It's a cat's tail

27. It's a clock
It's a skate
It's a shore
It's a deckchair

28. It's a bookshop
It's a zip
It's a shack
It's a joke

29. It's a star
It's a slipper
It's a tooth
It's witchcraft

30. It's a trotter
It's a saddle
It's a box
It's a desk

31. It's a sword
It's a sheep
It's a feather
It's a start

32. It's a door
It's a tractor
It's a thong
It's a thread

33. It's a suitcase
It's a chain
It's a flash
It's a tickler

34. It's a catch
It's a dredger
It's a cocktail
It's a thickshake

35. It's a measure
It's a stretcher
It's a nose
It's a tack

36. It's a leg
It's a seesaw
It's a castle
It's a biscuit

37. It's a team
It's a ladder
It's a tune
It's a thong

10.2 Appendix 2. Phonetic notations

Table 35 Phonemes & IPA symbols used for notation of closures

Word	Phoneme	IPA symbol	Notation
box	k	k	bo/k/s
box	s	s	bok/s/
castle	c	k	/k/astle
catch	ch	ʧ	ca/ʧ/
chain	ch	ʧ	/ʧ/ain
chain	n	n	chai/n/
clock	c	k	/k/lock
clock	l	l	c/l/ock
cocktail	ck	k	co/k/tail
cocktail	t	t	cock/t/ail
cocktail	l	l	cocktai/l/
deckchair	ck	k	de/k/chair
deckchair	ch	ʧ	deck/ʧ/air
desk	d	d	/d/esk
desk	k	k	des/k/
door	d	d	/d/oor
dredger	d	d	/d/redger
dredger	dg	ʤ	dre/ʤ /er
joke	j	ʤ	/ʤ /oke
kitkat	k	k	/k/itkat
kitkat	t	t	kitka/t/
ladder	dd	d	la/d/er
leg	l	l	/l/eg
leg	g	g	le/g/
mathsbook	k	k	mathsboo/k/
nose	n	n	/n/ose
slipper	l	l	s/l/ipper
squashkit	t	t	squashki/t/
start	t	t	star/t/
stretcher	t	t	s/t/retcher
stretcher	tch	ʧ	stre/ ʧ/er
suitcase	t	t	sui/t/case
suitcase	c	k	suit/k/ase
sword	d	d	swor/d/
tack	t	t	/t/ack
tack	ck	k	ta/k/
team	t	t	/t/eam
thong	ng	ŋ	tho/ŋ/
thread	d	d	threa/d/
trotter	tt	t	tro/t/er
witchcraft	tch	ʧ	wi/ʧ/craft
witchcraft	c	k	witch/k/raft

10.3 Appendix 3. Individual cephalometric values

The 3 tables on the following pages list the cephalometric values recorded in the study. These have been included to allow examination of the values for each individual, which are masked by the use of descriptive statistics.

Table 36 contains the values for the children in the control group. Lateral head radiographs were not available for 2 children from the control group.

Table 37 contains the values for the cephalometric measurements for the children in the experimental group before therapy. Lateral head radiographs were available for all subjects.

Table 38 contains the values for the cephalometric measurements for the children in the experimental group after therapy. A post-therapy lateral head radiograph was not taken for child A.

Table 36 Individual cephalometric values for control group subjects

	Child							
Value (units)	I	J	K	L	M	N	O	P
SNA (°)	79.5	81.0	83.0	79.5	79.5	80.0	-	-
SNB (°)	78.0	74.5	78.5	75.5	78.0	78.5	-	-
ANB (°)	1.5	6.5	4.5	4.0	1.5	1.5	-	-
SN-MP (°)	28.0	38.0	28.0	32.0	30.5	26.0	-	-
SN-PP (°)	6.0	9.5	4.5	9.0	6.5	6.0	-	-
N-PP (mm)	49.5	52.5	46.0	50.5	47.5	48.0	-	-
PP-Me (mm)	61.0	62.5	56.5	64.0	54.0	60.5	-	-
AFH (mm)	110.5	115.0	102.5	114.5	101.5	108.5	-	-
Is-PP (mm)	26.0	28.0	25.0	29.0	24.5	28.5	-	-
Ii-MP (mm)	36.0	38.0	36.0	39.0	31.5	33.0	-	-
AOB (mm)	1.5	1.0	1.5	0.0	0.0	0.0	-	-
U1-PP (°)	117.0	111.0	107.5	111.0	111.0	106.5	-	-
U1-SN (°)	111.0	101.5	103.0	102.0	104.5	100.5	-	-
IMPA (°)	93.0	96.5	95.5	101.0	94.5	100.0	-	-
IIA (°)	128.5	123.5	134.0	125.0	131.0	133.0	-	-
ILG (mm)	0.0	5.0	0.0	0.0	0.5	0.0	-	-
NLA (°)	121.0	122.0	105.0	118.5	111.0	109.0	-	-

Table 37 Individual cephalometric values for experimental group subjects before therapy

	Child							
Value (units)	A	B	C	D	E	F	G	H
SNA (°)	80.0	78.0	87.0	79.5	80.5	76.5	86.5	87.0
SNB (°)	74.0	77.0	82.0	72.5	76.0	74.0	80.5	79.0
ANB (°)	6.0	1.0	5.0	7.0	4.5	2.5	6.0	8.0
SN-MP (°)	38.0	37.0	34.0	40.0	31.5	36.5	30.0	39.5
SN-PP (°)	4.0	4.5	7.0	6.5	8.5	10.0	1.5	1.5
N-PP (mm)	50.0	47.0	49.5	50.0	52.5	51.5	49.0	49.5
PP-Me (mm)	63.5	62.0	63.0	69.5	62.0	59.0	63.5	71.0
AFH (mm)	113.5	109.0	112.5	119.5	114.5	110.5	112.5	120.5
Is-PP (mm)	28.5	27.5	25.0	33.0	26.5	23.0	28.5	33.0
Ii-MP (mm)	38.0	35.0	37.5	36.0	39.5	30.5	37.5	43.0
AOB (mm)	4.5	4.0	2.5	4.5	2.0	6.5	4.0	4.5
U1-PP (°)	112.0	110.5	117.0	106.0	121.5	119.0	121.0	113.0
U1-SN (°)	108.0	106.0	110.0	99.5	113.0	109.0	119.5	111.5
IMPA (°)	98.5	90.0	99.0	98.0	99.5	81.0	105.0	92.0
IIA (°)	116.0	127.5	117.0	123.0	117.0	134.0	107.0	118.0
ILG (mm)	4.0	0.0	0.0	8.5	1.0	0.0	2.5	0.0
NLA (°)	110.0	115.0	110.0	107.0	101.5	107.0	102.0	119.0

Table 38 Individual cephalometric values for experimental group subjects after therapy

	Child							
Value (units)	A	B	C	D	E	F	G	H
SNA (°)	-	78.5	87.0	79.5	81.0	75.5	85.0	86.5
SNB (°)	-	75.5	85.0	72.5	76.0	74.0	80.5	79.5
ANB (°)	-	3.0	2.0	7.0	5.0	1.5	4.5	7.0
SN-MP (°)	-	37.5	31.0	41.5	34.0	36.0	32.0	41.0
SN-PP (°)	-	4.0	6.0	11.0	8.0	8.5	0.5	4.0
N-PP (mm)	-	48.5	50.5	52.5	52.5	52.0	49.5	51.0
PP-Me (mm)	-	62.0	64.5	71.0	62.0	60.0	63.0	71.0
AFH (mm)	-	110.5	115.0	123.5	114.5	112.0	112.5	122.0
Is-PP (mm)	-	28.0	26.5	32.0	26.5	24.0	28.5	33.5
Ii-MP (mm)	-	36.0	38.5	38.5	41.5	31.5	39.5	43.0
AOB (mm)	-	1.5	0.0	5.5	1.0	6.0	4.0	3.5
U1-PP (°)	-	108.0	120.0	106.0	121.5	124.5	115.0	110.5
U1-SN (°)	-	104.0	114.0	95.0	113.5	116.0	114.5	106.5
IMPA (°)	-	95.0	101.0	97.0	101.0	83.0	105.0	94.0
IIA (°)	-	123.5	114.5	124.5	112.5	125.0	109.5	119.0
ILG (mm)	-	0.0	7.0	2.5	3.5	1.0	5.5	9.0
NLA (°)	-	122.0	113.0	108.0	90.0	112.0	99.0	104.0

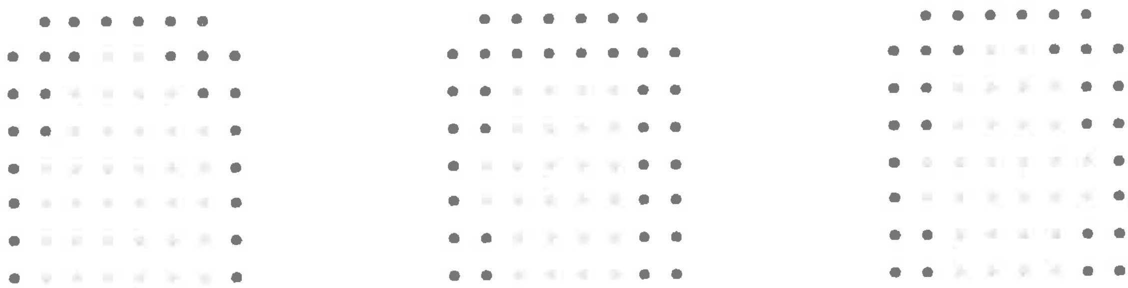
10.4 Appendix 4. Palatograms summarising EPG data

The following palatograms show mean EPG contacts for all repetitions by all children for the 8 closures, 32 words, and 2 swallows discussed in the text. Each coloured dot represents an electrode; its colour depicts the mean percentage of time the electrode was contacted during the recordings. The threshold levels used in each subsection were chosen to illustrate differences between the 3 groups. The palatograms are arranged in rows, which are labelled below. The left column refers to the control group, the middle and right columns refer to the experimental group before and after therapy respectively.

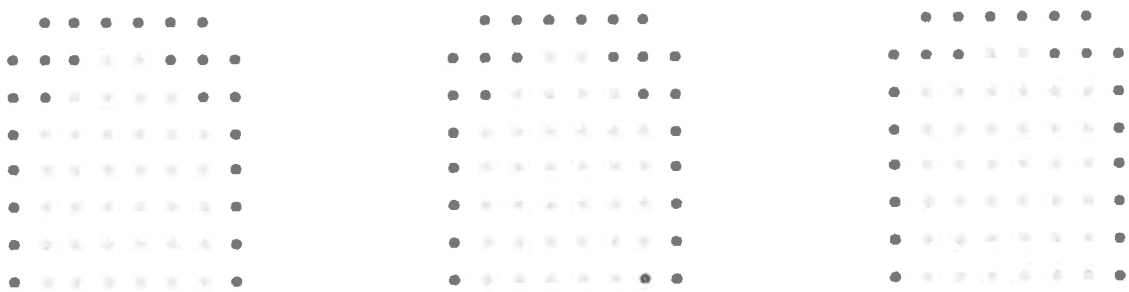
10.4.1 Closure data

- electrode contact > 80% of duration of closure
- electrode contact > 60% of duration of closure
- electrode contact < 60% of duration of closure

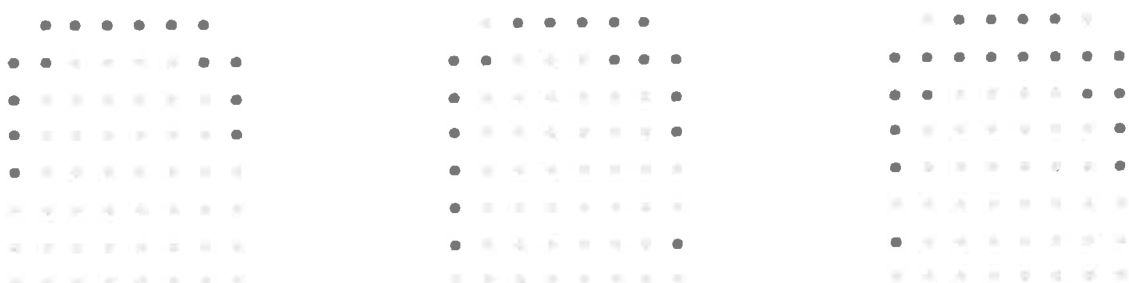
Control | Before therapy | After therapy



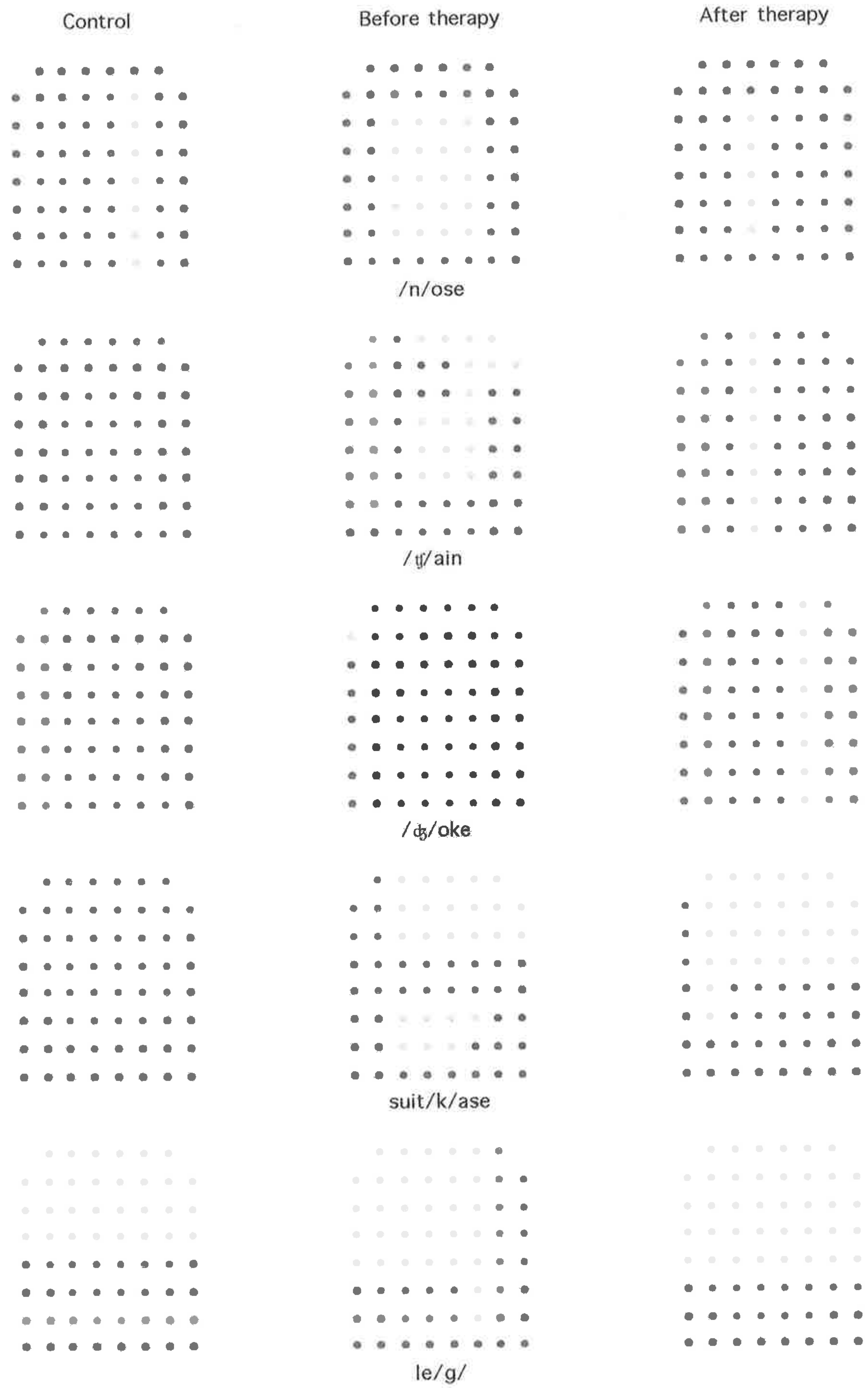
/t/eam



/d/oor



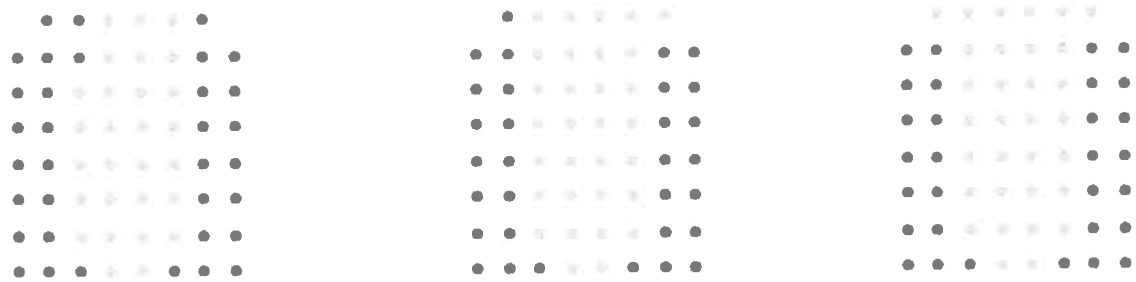
/l/eg


Control
Before therapy
After therapy
/n/ose
/ʧ/ain
/ʤ/oke
suit/k/ase
le/g/

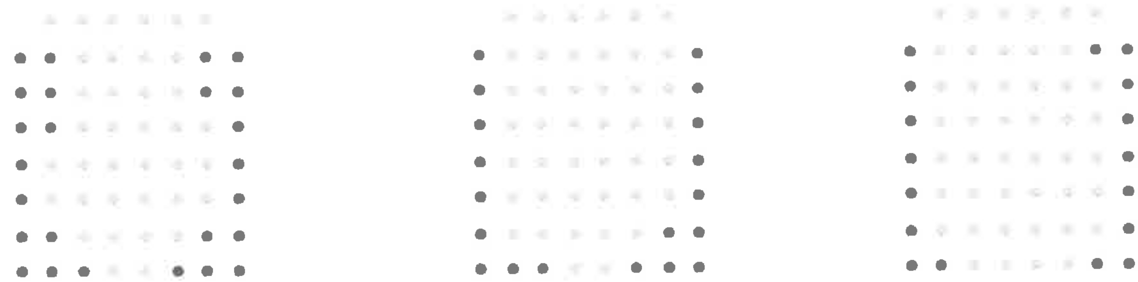
10.4.2 Word data

- electrode contact > 25% of duration of word
- electrode contact > 15% of duration of word
- electrode contact < 15% of duration of word

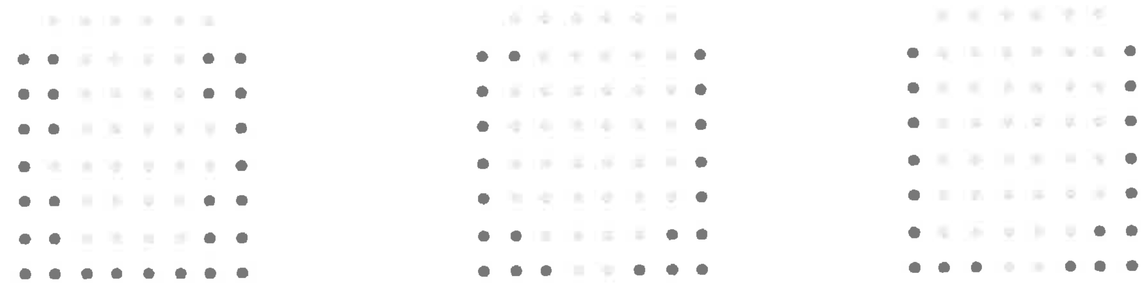
Control | Before therapy | After therapy



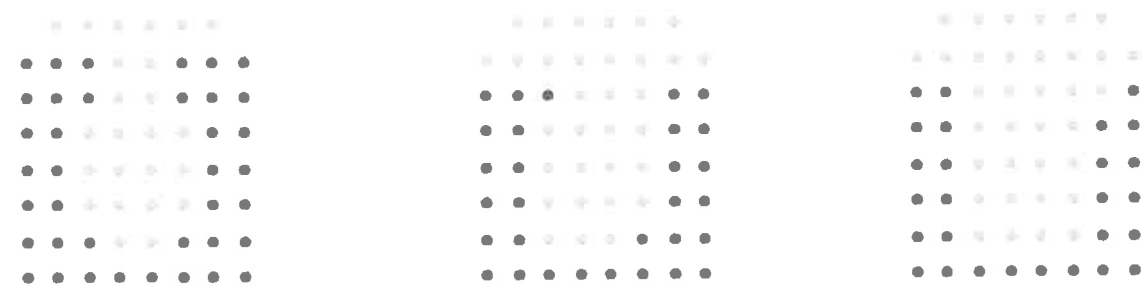
biscuit



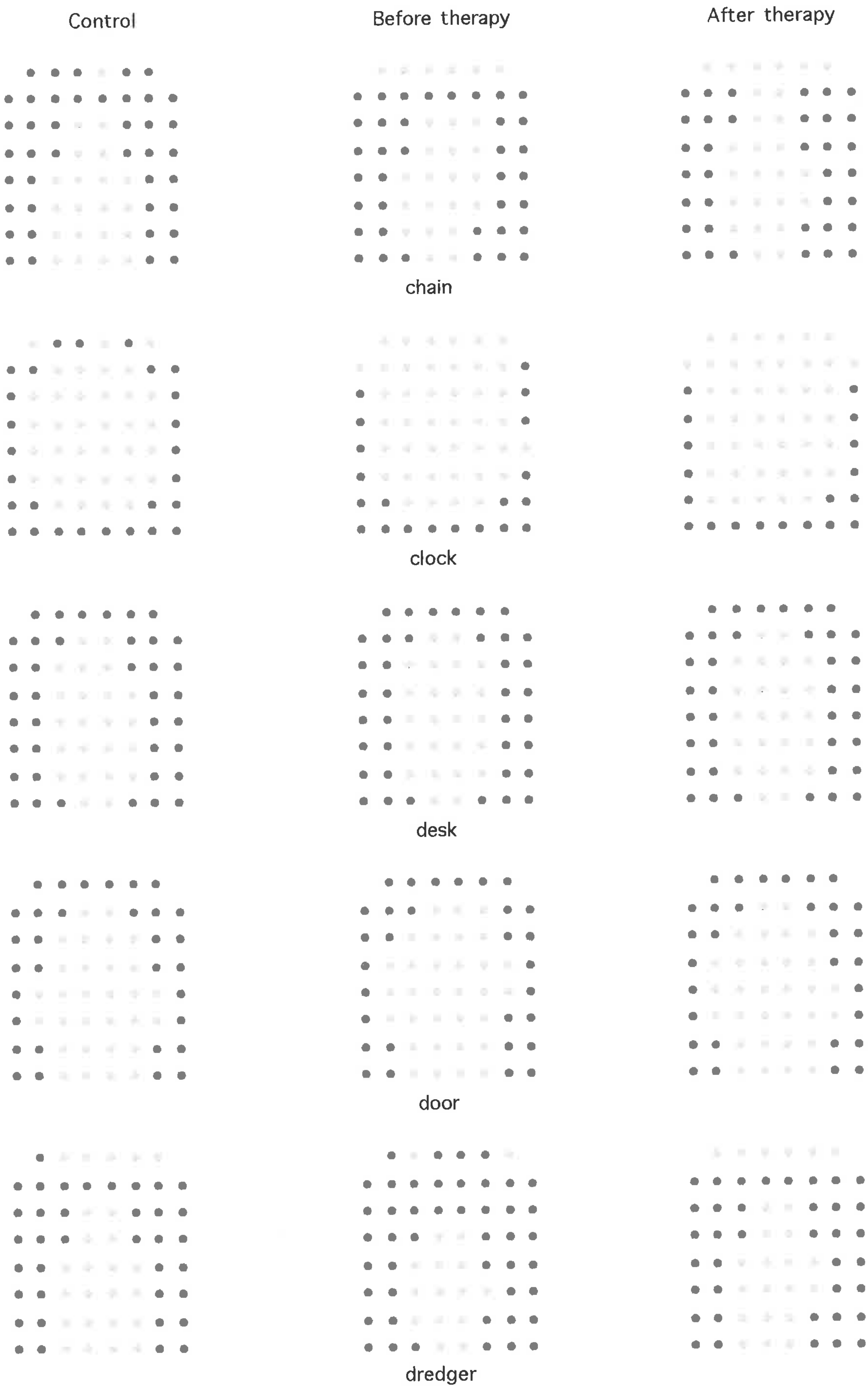
box



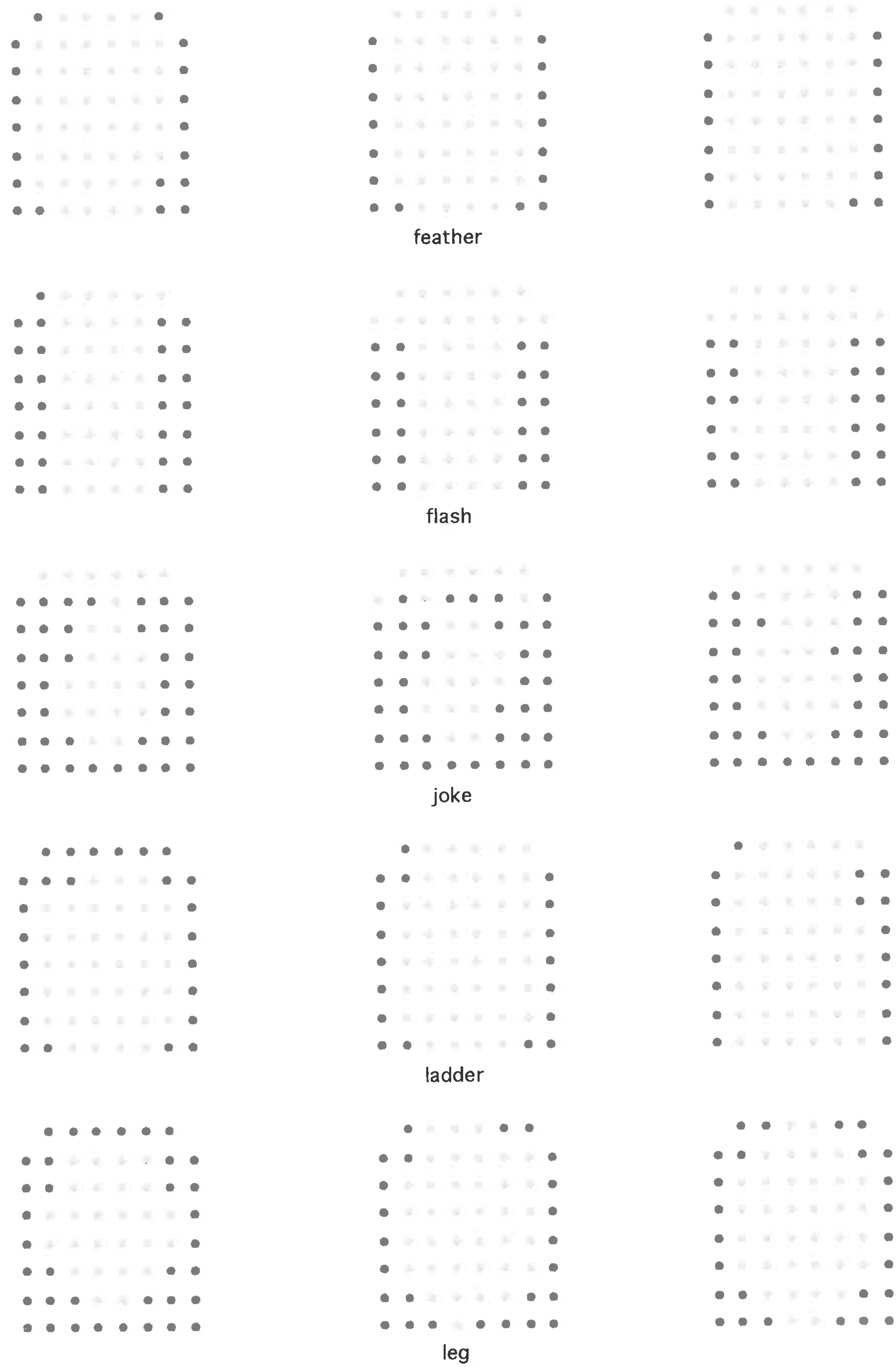
castle

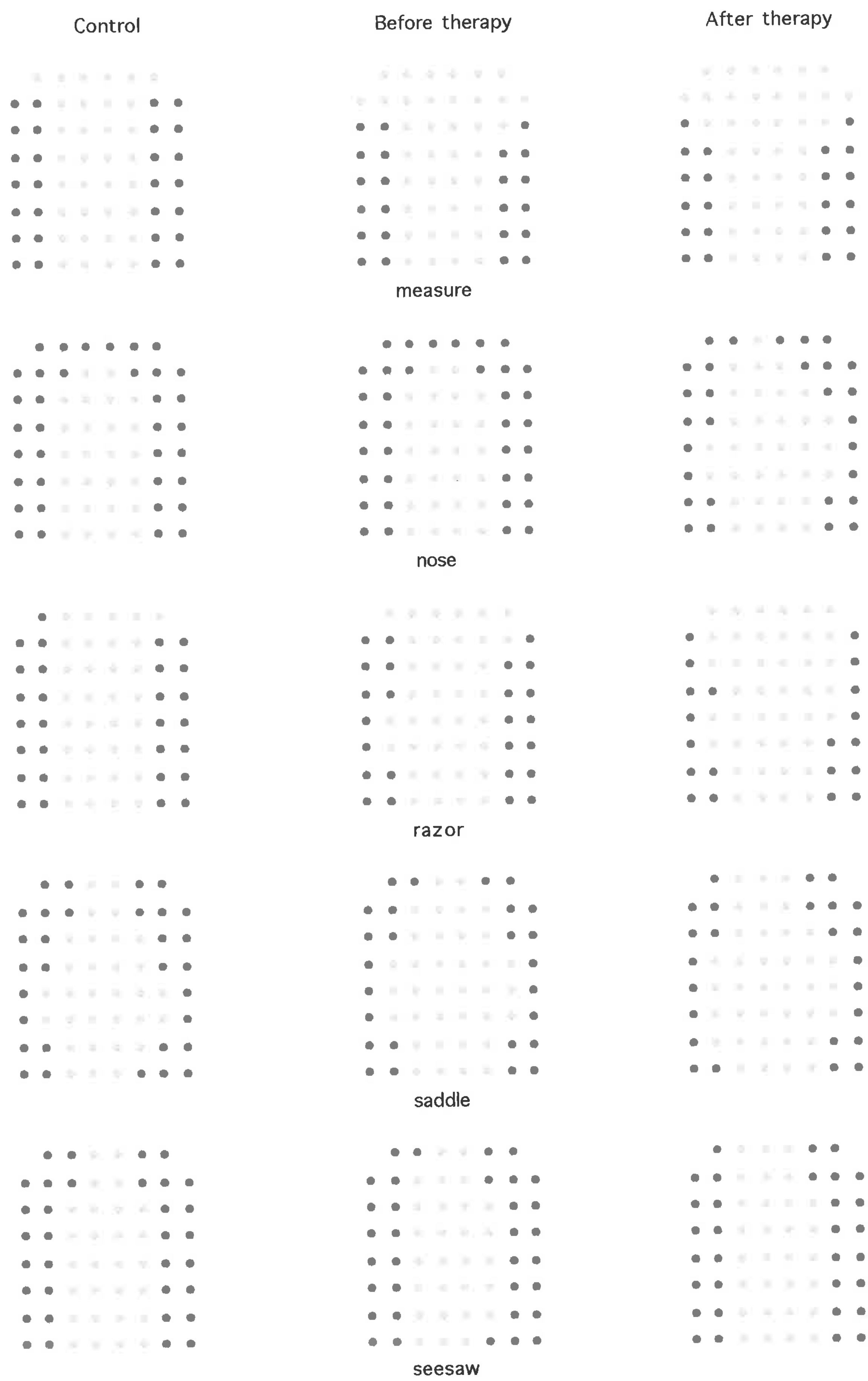


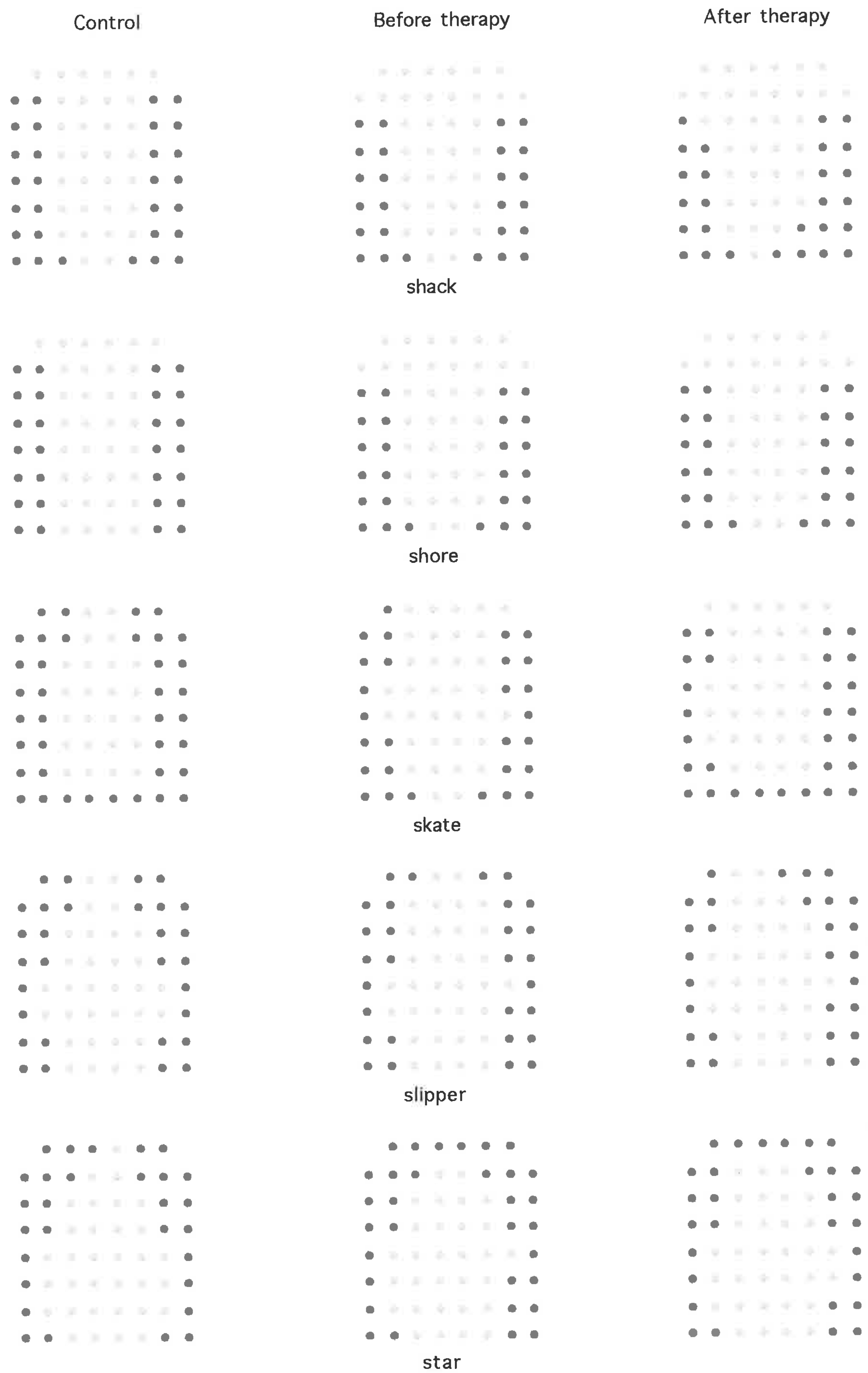
catch

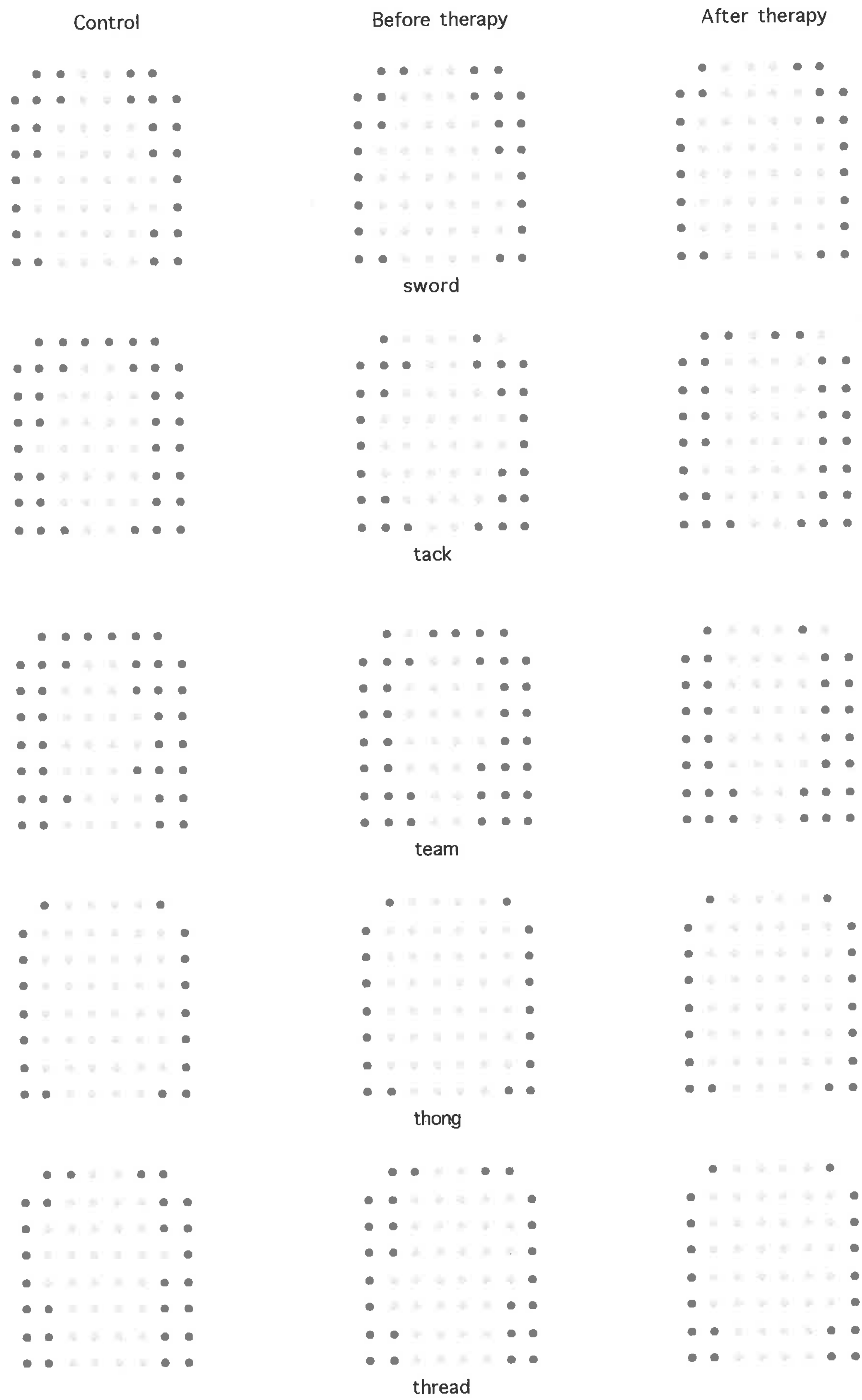

Control
Before therapy
After therapy
chain
clock
desk
door
dredger

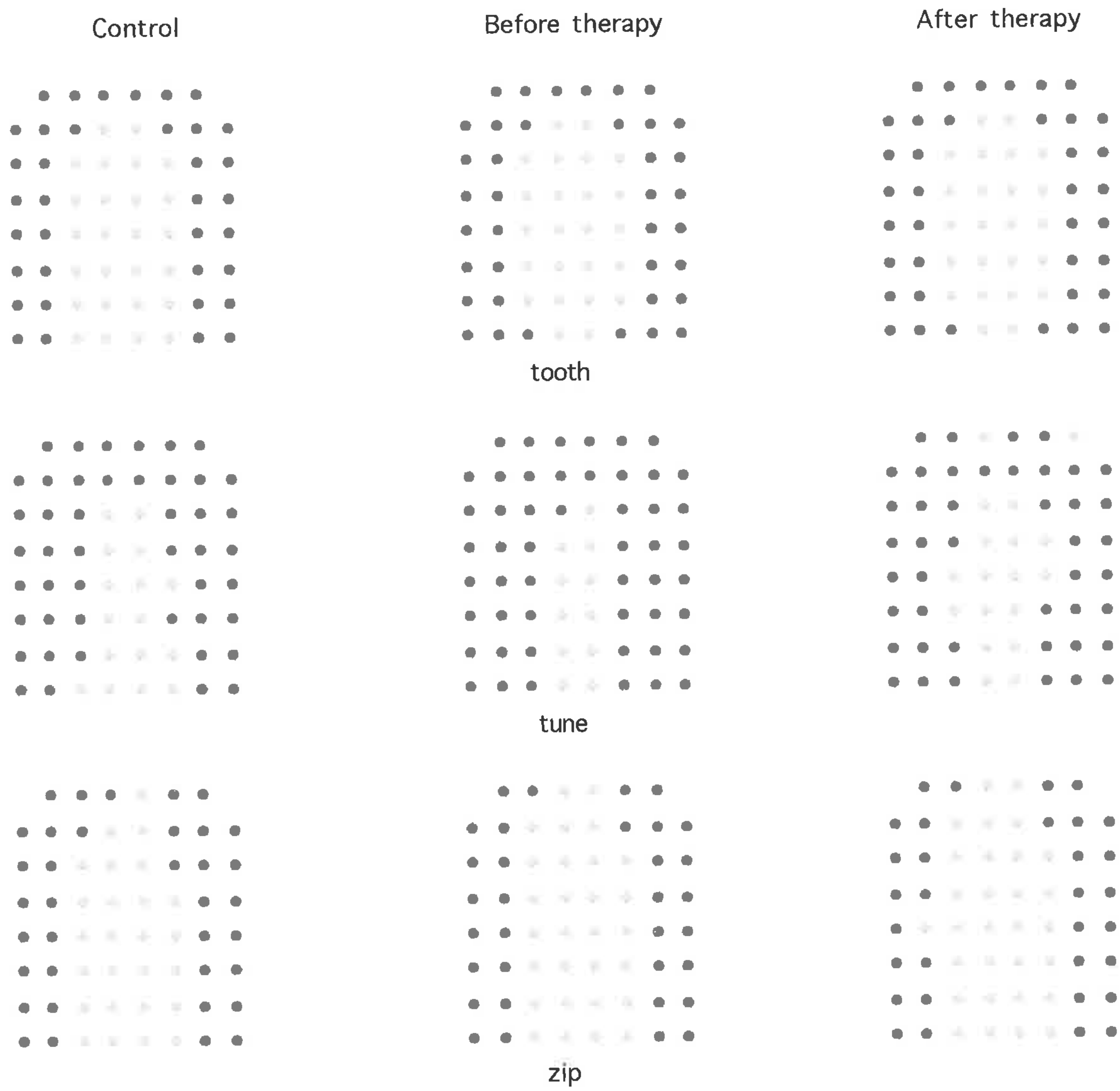
Control | Before therapy | After therapy




Control
Before therapy
After therapy
measure
nose
razor
saddle
seesaw

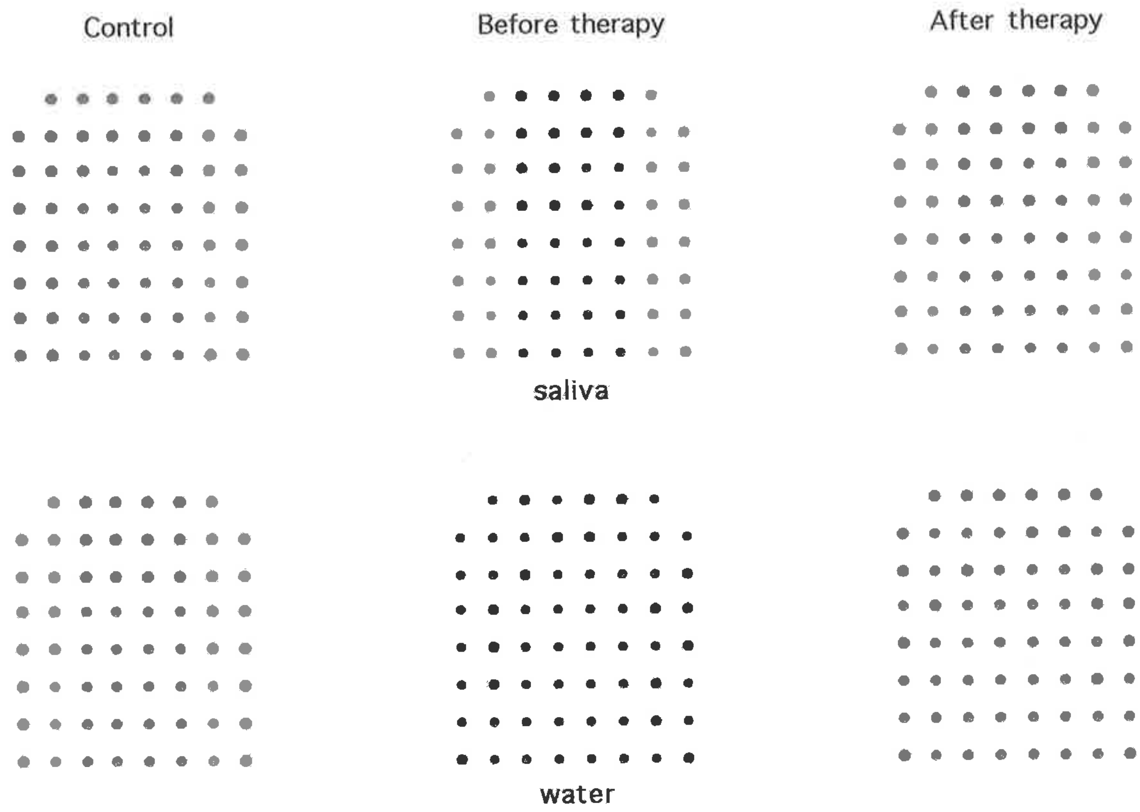

Control
Before therapy
After therapy
shack
shore
skate
slipper
star


Control
Before therapy
After therapy
sword
tack
team
thong
thread


Control
Before therapy
After therapy
tooth
tune
zip

10.4.3 Swallow data

- electrode contact > 90% of duration of word
- electrode contact > 75% of duration of word
- electrode contact < 75% of duration of word



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