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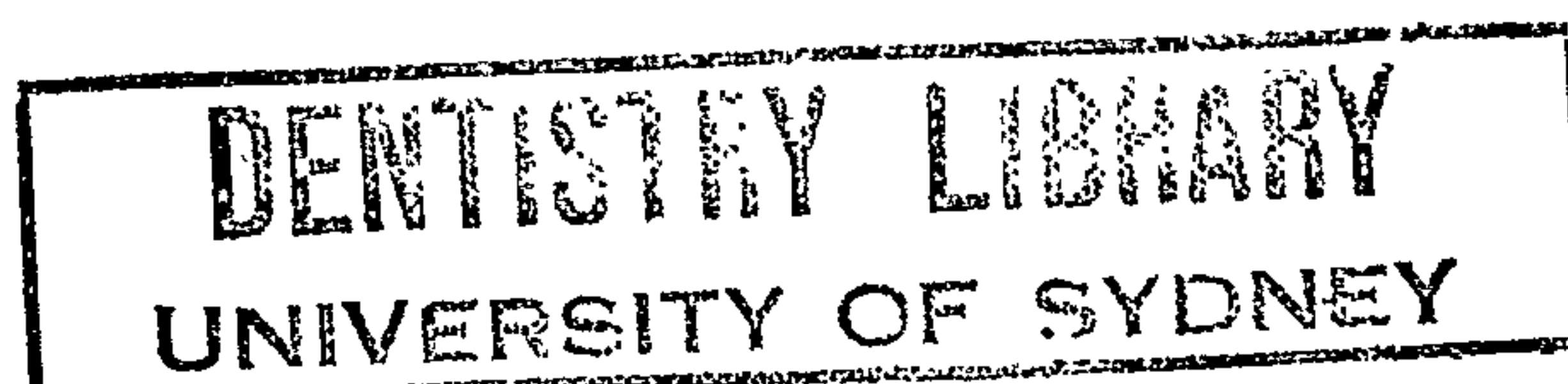
AN INVESTIGATION OF THE
CHARACTERISTICS OF TEMPOROMANDIBULAR JOINT CLICKING

by

R. GEOFFREY W. COOK BDS (HONS) (Syd)

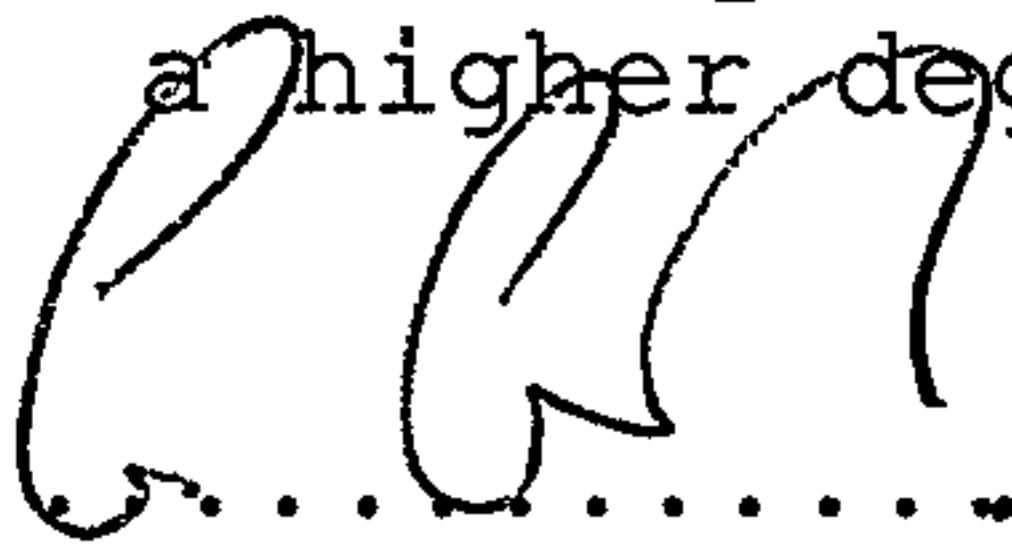
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CANDIDATE'S CERTIFICATE

This is to certify that the work
presented in this thesis was carried
out by the candidate in the Department
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a higher degree.

A handwritten signature in dark ink, appearing to be 'E. G. W.', is written over a horizontal dotted line.

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CHAPTER 1

INTRODUCTION

1. INTRODUCTION

Clicking of the temporomandibular joint (TMJ) is regarded as one of the signs and symptoms of TMJ dysfunction (Helkimo 1979, Hansson 1986, Solberg 1981). Studies have shown that up to 44% of a population can have clicks (Hansson and Nilner 1975) whilst Solberg (1986) believes that between 25% and 30% of the general population show some degree of TMJ clicking. Clicking has been found in the newborn baby (Berry 1968), and has been found to occur most frequently on the preferred chewing side (De Boever 1979).

The mechanism of joint clicking has been a source of controversy, various theories having been postulated. The most popular and accepted mechanism at present is some form of disc-condyle derangement, first proposed by Ashley Cooper in 1823, who felt that the click occurred as the condyle crossed the anterior band of the "inarticular cartilage" (Moloney 1984). Rees (1954), Bertoft (1972), Shore (1976), Olsen (1969) and Watt (1980) all agreed that this was a cause of clicking. Others (Pringle 1918, Ireland 1951, Sicher 1955, Farrar and McCarthy 1978, 1979) proposed that a click occurred as the condyle traversed the posterior thick band of the disc. This has been demonstrated in autopsy studies by Isberg-Holm (1982) and arthrographically by Farrar and McCarthy (1979), Dolwick et al (1979), Bronstein et al (1981), Oster et al (1984), Westesson (1982) and at the time of surgery by Leopard (1984), Moloney (1985) and Juniper (1984).

Other mechanisms for joint clicking have been proposed. Campbell (1963) discussed clicking as a result of the collapse of vapour filled vesicles that formed in the joint during movement. Yavelow and Arnold (1971) proposed that if the normal movement of synovial fluid was obstructed, a sudden release of the obstruction would result in a click as the fluid changed position. Nanthaviroj (1976) was of the opinion that at least some

clicking was due to irregularities in the normally smooth joint surface. Toller (1974) felt that if the disc hesitated in its forward translation whilst the condyle kept moving forward during opening a click would result as the disc overcame its hesitation and suddenly flicked forward against the back of the condyle. Another type of click has been proposed in which the condyle and disc translate over the articular eminence (Klineberg 1986). Watt (1980) stated that soft clicking arose from sudden movements of ligaments by the separation of articular surfaces and by sucking of loose tissue behind the condyle as it moves forward.

The significance of the presence of a click has also been a controversial subject. Ireland (1951), Farrar and McCarty (1979), Wilkes (1978), Dolwick (1983) and Westesson (1984) have suggested that reciprocal clicking in some joints may further progress to locking, that is, the anterior disc displacement does not reduce during mandibular opening. The condyle then articulates against the bilaminar zone of the disc. Prevention of reciprocal click progression to locking has been used as a justification for treatment. A study of seventy patients displaying reciprocal clicking by Lundh et al (1987) found that after three years only six subjects had developed locking. In another long term study of two hundred and five subjects displaying clicking, Greene and Laskin (1988) found only three subjects who described their symptoms as worse after five years. In light of these findings, Greene and Laskin (1988) stated that TMJ clicking is a benign condition that usually does not progress to more serious clinical dysfunction or disease.

Studies of the acoustic characteristics of clicks have in the past been relatively uncommon, one of the first to investigate the wave patterns of clicks being Ekensten (1952). Over the last ten years, however, as interest in joint dysfunction and treatment has grown there has been a

corresponding increase in the amount of research involving an investigation of the sound qualities of clicks. The aim of research into the characteristics of clicks, that is the waveforms, amplitudes, durations and frequency components, has been to discover whether these characteristics can be used as an aid to diagnosis. More recent studies have concentrated on spectral analyses of clicks (Gay and Bertolami 1987, Blaustein and Hefez 1985, Hefez and Blaustein 1986, Ciancaglini et al 1987). Spectral analyses show the relative magnitudes of the fundamental frequencies forming a click. The aim of research into the frequency spectra of clicks has been to determine whether clicks caused by specific joint conditions display specific frequency spectra which are different from the frequency spectra of clicks caused by other joint mechanisms. As yet, no specific characteristics have been discovered which differentiate one form of click from another.

This study aims to investigate the sound characteristics of TMJ clicking caused by different joint conditions. This will involve an analysis of click wave patterns, amplitudes, durations, spectral analyses, three dimensional mandibular movement at the time of clicking and a study of the effect upon click characteristics of clenching prior to mandibular movement.

CHAPTER 2

TEMPOROMANDIBULAR JOINT APPARATUS

- 2.1 Embryology of the TMJ
- 2.2 Anatomy of the TMJ
- 2.3 Epidemiology of TMJ clicking
- 2.4 Aetiology of Clicking of the TMJ
- 2.5 Classification of Clicking
- 2.6 Previous Studies of TMJ Clicking Characteristics

2.1 EMBRYOLOGY OF THE TEMPOROMANDIBULAR JOINT

The temporomandibular joint is anthropologically a relatively new joint and is therefore one of the last joints to develop. In contrast to most other joint surfaces which are covered by hyaline cartilage, the articulating surfaces of the temporomandibular joint are covered initially by fibrous cartilage which matures to a fibrous articular tissue by adulthood.

Condylar development begins in the eighth week of intra uterine life with a condensation of mesenchymal cells from the neural crest on the dorsal end of the developing mandible. During the next two weeks these cells proliferate and differentiate into the condylar cartilage. During the tenth week the condylar cartilage undergoes growth in size both in a posterior and lateral direction in order to keep pace with the widening cranial base.

At the same time, the temporal component of the temporomandibular joint forms as a separate condensation of mesenchymal cells posterior and lateral to the developing condyle. Between the two developing blastemata a third condensation of cells occurs which is associated with the lateral pterygoid muscle and which subsequently becomes the articular disc. The origin of the cells which form the disc is not precisely known. It is thought that the cells which form the disc are derived from the tendon of the lateral pterygoid muscle, or that they arise partly from the condylar and partly from the temporal blastemata, or that they are a separate mesenchymal condensation.

Growth of the condylar component causes the temporal and condylar blastemata to meet by the thirteenth week of intrauterine life. Cavitation then occurs by cell death and degeneration to form upper and lower joint spaces, the interposed disc forming the partition. Laterally and medially to the developing joint the capsule forms and is recognisable by the eleventh week. The muscles of

mastication are derived from the first branchial arch and differentiate as separate entities. These muscles continually reattach as the ramus and condyle change in size and shape.

Once the joint has formed, further growth and morphologic changes occur. The condyle is at this stage a "carrot shaped" cartilaginous cap consisting of four layers:-

1. An articular layer of flat undifferentiated cells.
2. An intermediate zone of proliferating cells.
3. An hypertrophic zone in which the cartilage cells enlarge and are haphazardly arranged with little matrix between them. A zone of pericellular mineralisation is present in the deeper layer.
4. An erosive zone in which the mineralised cartilage is removed by chondroclasts and below which bone formation occurs by a type of intramembranous process without the existence of a primary spongiosa. During later life the bone front moves superiorly reducing the size of the cartilage layers and completely replacing the condylar growth centre.

At term all joint components are vascularised and active bone formation is occurring in the condyle and glenoid fossa regions. Growth and maturation continue however during its maturation the condyle on its anterior articulating surface is covered by a thick layer of cartilage, the hypertrophic zone being the thickest layer. Loose mesenchymal columns consisting of vascular connective tissue extend into the bony condyle. During the first six months postnatally there is a reduction in the hypertrophic zone and thus of cartilage thickness. There is also a reduction in vascularity.

By age seven the cartilage is a thin layer. Growth continues during eruption of the permanent dentition, with the subarticular plate of bone forming in the late teens. This separates the cartilage from the cancellous spaces. The mature condyle is covered by a surface articular layer

of collagen fibres running antero-posteriorly and interspersed with elastin fibres. The intermediate layer remains as well as a diminutive layer of cartilage. This layer retains the ability to respond to functional stimulus by either progressive or regressive remodelling.

At birth there is no articular eminence. This forms during the first years so that by age seven the mature shape is obtained. The eminence appears to maintain contact of the condyle with the skull base during excursive movements of the mandible in the presence of teeth. In edentulism, the eminence reduces. The articular surfaces of the eminence and fossa become less vascular with age. The proliferative layer remains until the late teens, and collagen and elastin form the surface layer which is thickest on the postero-inferior aspect of the eminence.

During postnatal life the disc changes shape as the articular eminence forms. The disc becomes more compact with a decrease in the number of cells and an increase in the amount of collagen. The mature disc is avascular and aneural in its central bearing part, which consists of a basket weave of collagen with some elastin fibres. A band of connective tissue connecting the posterior rim of the disc to the squamotympanic fissure region, is composed of vessels, nerves and a thick band of elastin fibres (Keith 1987).

2.2 ANATOMY OF THE TEMPOROMANDIBULAR JOINT

The temporomandibular joint is a complex ginglymoarthrodial articulation consisting of a cranial component, a condylar component and a fibro cartilaginous disc separating the osseous components. The condylar and cranial components are covered to a varying thickness by fibrous articular cartilage, not cartilaginous tissue as are weight bearing joints.

A capsule and lateral ligament surround the joint in such a way as to allow movement of the condyle and disc forward and back from the articular fossa onto the articular eminence of the temporal bone. Forwards and backwards movement of the condyle and disc occurs in the superior joint compartment and is called translatory movement. Within the inferior joint compartment the condylar head rotates against the inferior surface of the articular disc. This movement is called rotatory or hinge movement of the condyle. It is thought this movement division is designed to reduce the friction generated in the joint during function - by dividing the movement, each component has approximately only half of the movement to perform.

2.2.1 Mandibular Condyle

The adult mandibular condyle is an ellipsoid bony structure, which extends superiorly from the distal border of the mandibular ramus. It is orientated obliquely to the coronal plane and its dimensions are between 13-25mm. in length mediolaterally with an average of 20mm., whilst its breadth anteroposteriorly varies from 5.5 to 16mm. with an average of 10mm. When extended medially and posteriorly, the axes of the two condyles converge approximately at the anterior margin of foramen magnum (Oberg and Carlsson 1979). Condylar form varies from one individual to another. Whilst Rees (1954) found the condyle most often "gable shaped", Solberg et al (1985) found that in the frontal plane the condyle is most frequently slightly rounded, then flat and least

frequently gable shaped. In the sagittal plane the condyle was found to be most often convex, then locally concave and least frequently wedge shaped. Horizontally it was found to be most often elliptical followed by cylindrical and then irregular.

At the posterior aspect of the condyle, below the line demarcating the articular surface, is a triangular region for attachment of the capsule and articular disc. The auriculotemporal nerve is closely related to this area as it passes laterally and superiorly innervating the posterior joint region (Hawthorn 1969). In contact with this triangular area, separated from the bone by the capsular attachment, is the glenoid lobe of the parotid gland which passes inwards to a variable depth between the condyle and the tympanic plate. This region is also occupied by loose vascular connective tissue.

Anteriorly below the articular head on the neck of the condyle lies a triangular depression for insertion of the fibres of the lateral pterygoid muscle, the pterygoid fovea. The two condylar poles usually lie at about the same horizontal level. By seven years of age the distance between the medial pole of one condyle and that of the other side has almost reached adult dimensions, but after this age each condyle continues to grow in an outwards direction in association with growth of the glenoid fossa. The trabeculae of cancellous bone of the condyle are orientated at right angles to the cortical bone, and in the intratrabecular spaces there is haemopoietic tissue.

2.2.2 Temporal Component of the Temporomandibular Joint

The temporal component of the joint consists of two parts - a concave posterior region, called the glenoid or mandibular fossa, and a convex anterior part, the articular eminence. Average dimensions of the temporal component are 20mm. in anteroposterior length and 25mm. in mediolateral width (Oberg and Carlsson 1979).

The articular fossa is concave in the sagittal and coronal planes, usually accompanied with a steep medial wall and an anterior wall of variable steepness. The anterior wall merges into the convexity of the articular eminence. The articular eminence is concave transversely and convex sagittally, with the medial half continuous anteriorly with the infra-temporal surface of the skull. The depth of the fossa and steepness of the eminence is very variable - shallow in some people and almost vertical in others. The presence of the eminence assists in maintaining the balance of the mandible against the base of the skull in lateral excursions, the disc integral to this action. Posteriorly the temporal component is bound by the squamotympanic fissure and its medial extension, the petrotympanic fissure. The postero-lateral lip of the fossa forms the post-glenoid tubercle which has a variable height in different individuals.

The roof of the articular fossa is a thin plate of cortical bone separating the glenoid fossa from the middle cranial fossa and the temporal lobe of the brain.

2.2.3 Articular Tissue

The soft tissue lining covering the condyle and temporal components is fibro-cartilage. This is in contrast with other weight bearing joints, the articular surfaces of which are covered by hyaline cartilage. This suggests an adaptive mechanism of a joint subject to friction under load. This tissue consists of four layers (Blackwood 1969, Hansson and Nordstrom 1977) :-

1. An articular zone;
2. A proliferative zone;
3. A cartilaginous zone;
4. Bone.

Oberg and Carlsson (1979) state there is an intermediate layer that lies between the proliferative zone and the cartilage.

The fibrous tissue covering the articulating surfaces consists of dense collagenous connective tissue orientated with respect to the curvature of the underlying surface. Elastic fibres are also present (Blackwood 1969). The proliferative zone consists of undifferentiated mesenchyme and this, together with the cartilage layers, forms a growth zone which is most active in the condyle. In areas where there is slow growth there is a differentiation of the undifferentiated cells into pre-osteoblasts and osteoblasts which form bone tissue, whereas in areas of rapid growth undifferentiated cells are transformed into pre-chondrocytes and hypertrophic chondrocytes. The growth zone plays an important part in development of the joint.

In adults the composition and thickness of these layers vary according to remodelling processes within them. Such processes, which are related to age and functional loads, constitute an essential part of the basis for changes in the form of joint components (Hansson & Nordstrom 1977, Hansson et al 1977, Hansson et al 1979). Superiorly and anteriorly on the condyle and posteroinferiorly on the articular eminence a cartilage layer, developed from undifferentiated mesenchyme due to functional load, remains throughout life. Sometimes the proliferating layer is utilized to such an extent that it disappears as a continuous layer in these areas.

According to Scott and Dixon (1972) the soft tissue layer is not designed to bear heavy mechanical stress. At the twenty to twenty-five year stage of development it is completely replaced by bone except for isolated islands of cartilage tissue - the perichondrium, becoming a layer of periosteum.

Hansson et al (1977) found that the soft tissue layer was thickest in the anterosuperior region of the condyle and on the posteroinferior slope of the articular eminence, in both of which it was found to be up to 0.5mm. The thinnest areas were on the posterior face of the condylar articular surface and in the floor of the fossa at 0.1-0.2mm. They concluded that the thickness of the soft tissue layers varies as to functional requirements, thicker areas having greater functional demands.

2.2.4 The Articular Disc

The disc is a dense sheet of fibrous tissue and lies between the condyle and the articular eminence. Its inferior surface is concave generally and is determined by the oval shape of the condyle. Superiorly the disc is convex posteriorly but anteriorly "saddle shaped", being convex from side to side, and concave from anterior to posterior.

When viewed from above the disc is "wedge shaped" with its apex anteromedially (Hawthorn 1969). According to Rees (1954) there are four distinct ellipsoidal zones:-

1. An anterior band;
2. An intermediate band;
3. A posterior band;
4. A bilaminar zone.

The anterior band is moderately thick medially due to the insertion of tendons from the lateral pterygoid muscle, but narrow anteromedially. It consists of densely packed collagen and elastin fibres orientated antero-posteriorly. Griffin et al (1975) state that the anterior band was seen to have arterioles, capillaries and neural elements. The Intermediate band is thin, thicker medially than laterally, and also consists of collagen and elastin

fibres orientated anteroposteriorly. Some cartilage matrix is present, but there are no vascular or neural elements. This area normally serves as the articulating cushion between the condyle and articular eminence. The posterior band is the thickest of the three bands and is widest anteroposteriorly. It also consists of dense bundles of collagen and elastin fibres which, unlike the anterior and intermediate band, are not orientated, rather they are swirled and contain no neural or vascular elements.

The bilaminar zone of the temporomandibular joint consists of an upper stratum which is attached to the posterior wall of the glenoid fossa and the lateral aspect of the squamo-tympanic fissure, and a lower stratum which is attached to the posterior surface of the mandibular condyle.

The upper layer of the bilaminar zone is composed of loose fibro-elastic tissue (Rees 1954, Scapino 1983). Loose neurovascular tissue with veins in this area constitute a cavernous sinus (Griffin et al 1975). According to Rees (1954) the upper stratum of the bilaminar zone represents the disco-malleolar band of foetal life. This can be seen in histologic sections of twenty week fetuses (Hawthorn 1969). The lower stratum of the bilaminar zone is composed chiefly of white fibrous tissue and contains relatively few elastic fibres. The superior stratum is attached with the capsule to the posterior slope of the mandibular fossa, the bony auditory meatus and the fascia of the temporal bone. The inferior stratum of the bilaminar zone is a compact inelastic sheet of collagen fibres that attaches to the posterior surface of the neck of the condyle below its articular covering. Anteriorly both strata are continuous. At the posterior band of the disc fibres of the lower stratum spread out and become interlaced with transverse fibres of the posterior band and the anteroposterior orientated fibres from the central part of the disc.

Medial and Lateral Attachment

Medially and laterally the disc is not attached to the articular capsule but to the neck of the condyle a few millimetres inferior to the poles. The lateral extremity of the condyle may be fused to the lateral ligament. Solberg et al (1985) found that in joints with multiple deviations in form, the medial capsular attachment was more inferior than the lateral capsular attachment giving a greater play in movement of the disc.

Anterior Attachment

Anteriorly the disc is attached to the anterior margin of the articular eminence and to the front of the articular margin of the condyle. The disc is also attached anteromedially to the superior head of the lateral pterygoid muscle. Sicher (1955) wrote that this attachment of the lateral pterygoid to the disc stabilises the disc during closing rather than giving it movement. The inferior head of the lateral pterygoid attaches to the pterygoid fovea.

Rees (1954) found that the disc is also attached to the masseter and temporal muscles via fibrous bands at right angles to the direction of the muscle fibres which are continued from the epimysium and perimysium into the anterolateral portion of the disc.

Attachment of the Disc to the Lateral Pterygoid Muscle

Prior to the work of Wilkinson and Marynuik (1983) there was agreement that the two heads of the lateral pterygoid muscle had distinct insertions and that the lower head was attached to the condyle and the upper head was attached to and was confluent with the disc. (Ireland 1951, Rees 1954, Sicher 1955, Hawthorn 1969, Griffin et al 1975, Oberg and Carlsson 1979). Troiano (1967) identified three heads but agreed that fibres from the lateral pterygoid

muscle fused to and were confluent with the disc. Wilkinson and Marynuik (1983) and Chan and Wilkinson (1986) found, however, that there was no direct attachment of fibres from the upper head of the lateral pterygoid muscle to the disc. In their opinion the anterior margin of the disc adheres to the top of the muscle. Meyenberg et al (1986) found from dissection studies only 60% of discs with direct muscle attachment, and that the majority of fibres, even in this 60%, insert directly into the condyle. These authors also found that it was not possible to gain independent movement of the disc by pulling on the muscle attachments.

The current understanding is that the anterior part of the disc is attached to the upper part of the lateral pterygoid muscle, with few, if any, muscle fibres actually inserting into the disc.

Posterior Attachment

Posteriorly the disc is attached by the bilaminar zone to the postglenoid process, the bony auditory meatus, the fascia of the temporal bone, medially to the squamo-tympanic fissure and the condyle.

2.2.5 Joint Capsule

The joint capsule surrounds and encases the entire joint. Posteriorly the capsule is formed by extensions from the bilaminar zone (Rees 1954, Griffin et al 1975). The posterior superior stratum attaches the capsule to the posterior slope of the mandibular fossa, the bony auditory meatus and the fascia of the temporal bone. The postero-inferior stratum attaches the capsule to the condyle. Medially the capsule is loose and weak, and is separated from the disc by a deep synovial extension of the upper compartment. Anteriorly the capsule becomes confluent with the anterior reflection of the disc as it unites with the tendinous insertion of the Lateral pterygoid.

The lateral wall of the capsule is loose and thin posteriorly. Anteriorly it is strongly reinforced by the

lateral ligament, a flat sheet of dense collagenous tissue without elastic fibres. This ligament is so inseparably blended with the capsule as to be regarded as a thickened part of it. The lateral ligament is at one end attached to the zygomatic tubercle and at the other to the neck of the condyle. The lateral ligament has two parts: a horizontal band and an oblique band (Rees 1954, Solberg 1986).

The oblique portion arises from the outer surface of the articular tubercle and inserts into the outer surface of the condylar neck. The horizontal band arises from the same area and inserts into the condyle and the posterior part of the articular disc. The oblique band limits the amount that the condyle can be distracted inferiorly in the closed joint position as well as during the translatory cycle. The horizontal band limits how far the disc-condyle complex may be displaced posteriorly. The ligament as a whole suspends the mandible from the cranio-facial skeleton and resists downward and posterior displacement.

The capsule and lateral ligament are innervated presumably for proprioceptive monitoring of movement and joint position (Thilander 1961). They also contain nociceptive innervation, and the capsule is well vascularised.

Synovial lining is present on the inner walls of the capsule and the elastic retrodiscal lamina. The membrane is deeply folded in the retrodiscal lamina area to permit freedom of forward translation of the disc-condyle complex without injury to the membrane. The passive volume (Toller, 1974) of synovial fluid in the upper joint compartment is 1.2 mls., and in the lower compartment is 0.9 mls.

The vascular supply for the capsule arises from the superficial temporal artery and the anterior tympanic artery supplies the retrodiscal tissue.

Afferent nerve fibres for proprioception and nociception are branches of the masseteric, auriculotemporal and posterior deep temporal nerves (Thilander 1961). Fibres of the auriculotemporal nerve innervate the posterior capsule and retrodiscal tissue, those of the masseteric and temporal nerves innervate the anterior and possibly medial part of the capsule and ligament. These nerves terminate in the periphery of the articular disc. Free nerve endings, thought to mediate pain, are abundant throughout the capsule. Ruffini corpuscles, Golgi tendon organs and Pacinian corpuscles are found in the capsular ligament, and are thought to have a role in monitoring condylar position and movement. Visceral fibres supply the blood vessels of the capsule. Griffin et al (1975) identified mechanoreceptors in the fascia of the lateral and medial ligaments of the articular disc.

2.2.6 Condyle Disc Relationships

Rees (1954) states that in the retrusive position the posterior thick band of the disc lies just in front of the transverse condylar ridge. Scapino (1983) is of the view that when the jaw is closed, the posterior band of the disc overlies the superior aspect of the condyle, the central part of the disc lying between the anterosuperior surface of the condyle and the posteroinferior aspect of the articular eminence. The anterior band of the disc lies just anterior to the condyle.

Dolwick (1983) found that in the closed position of the mandible the posterior thick band of the meniscus envelops the most superior portion of the condyle. There appears to be general agreement amongst researchers that the thick posterior band should be directly above the most superior point of the condyle (Hansson et al 1979, Solberg 1986, Isberg 1982, Farrar and McArty 1978, 1979, Griffin et al

1975, Oberg and Carlsson 1979). Any position anterior to this suggests that the disc is anteriorly displaced. In a post mortem study of 115 cadavers Hellsing and Holmlund (1985) found that in one third of the specimens the posterior band of the disc was anterior to the condyle. In all these cases the condyle could pass beneath the posterior thick band during protrusion. As a result and because of the high incidence of anterior disc placement, Hellsing and Holmlund (1985) concluded that disc placement anterior to the condyle is a variant of normal and not an abnormal or pathologic condition. Bell (1986) is in agreement with this, and states that disc position in regard to the condyle and the temporal fossa is determined by the shape of the disc. Bell (1986) considers that a healthy disc, due to its morphology being thin between two thickened bands, is passively held in place by apposition of the two bony parts. The contour of the disc allows an automatic self-centring mechanism and a rotatory movement of the disc to bring a thinner portion between the bones. The thick posterior margin prevents displacement of the disc anteriorly and the thick anterior margin prevents displacement of the disc posteriorly. When disc contour changes this self-centring capability may be lost.

2.2.7 Disc and Condyle Movements

The temporomandibular joint is a joint in which two types of movement are possible. Firstly, hinge or rotatory movement may occur between the condyle and disc in the lower joint compartment. The second is translatory movement occurring between the disc and the temporal bone in the upper joint compartment.

During opening and closing movements both translation and rotation occur. The initial movement during opening is a small vertical distraction or drop of the mandible controlled by the mylohyoid muscle and the inferior head of the lateral pterygoid muscle. This is followed by movement of the disc - condyle complex downward and

forward about the articular eminence in a combination translatory and rotatory movement. As this downward and forward movement occurs, the articular disc rotates posteriorly about the condyle due to tension in the posterior disc attachment. The majority of the rotatory movement occurs in the latter half of the opening movement, after the condyles have traversed to the articular eminence. Rotation occurs about the fossa and eminence by the disc condyle complex in the upper compartment and between the disc and condyle in the lower compartment.

Centring of the disc relative to the condyle so that the thin part of the disc is interposed between the condyle and the temporal component is brought about by stretching of the posterior disc attachment and the self centring effect caused by disc shape. During opening, the upper head of the lateral pterygoid is inactive, thus disc movement is entirely passive.

Maximum jaw opening causes a varying degree of anterior condylar displacement. Obwegeser et al (1987) state that the condyle can move far beyond the articular eminence without fixation. At full opening, gliding of the disc is terminated by the limitation of muscle stretch, resistance in the capsule, and by the lack of available articular surface. When the mouth is fully opened the soft tissue is sucked in from the postero-lateral aspect of the joint.

Jaw closing is a continuation of retrusion, elevation and rotation with the translatory movement occurring early in the movement. Stretch of the elastic posterior attachment causing recoil of the disc is relatively unimportant during closing. Activity in the superior part of the lateral pterygoid muscle during closing provides an anterior component of tension on the disc and condyle ensuring full contact between the joint components.

Protrusive and retrusive movements of the mandible are mainly translatory. During protrusion the condyles are pulled forward together with the articular discs and movement occurs symmetrically in the two upper joint compartments.

In lateral movements the disc-condyle complex on the contra lateral side is pulled forward, downward and medially along the articular eminence while the ipsilateral condyle exhibits limited movement of rotation and lateral displacement. This lateral displacement of the ipsilateral condyle, or Bennet movement, is variable, the amount being related to age, parafunctional habits, the tightness of the ligamentous attachments of the disc and to the health of the disc.

When the mouth is closed during chewing, the jaw receives maximum stress. Depending on where on the occlusal table a food bolus lies, distracting or loading forces may be produced at the condyle. The activity of the upper head of the lateral pterygoid during closing causes the condyle to compress against the eminence to ensure full contact between the joint components during maximum function. The integrity of the posterior band prevents anterior displacement of the disc during normal function (Solberg 1986).

2.3 EPIDEMIOLOGICAL STUDIES OF THE INCIDENCE OF CLICKING OF THE TEMPOROMANDIBULAR JOINT

There have been many studies of the incidence of temporomandibular joint dysfunction which have included clicking as one of the symptoms.

Agerberg and Carlsson (1972) studied 1106 people by questionnaire and found that 39% reported clicking of the temporomandibular joint. Clicking occurred in 44% of females and 34% of males. In a further report on the results of their questionnaire involving 1106 people, Agerberg & Carlsson (1975) found that whilst 39% of the general population exhibited clicking, in a group of 82 patients with temporomandibular joint dysfunction, 79% displayed clicking.

Hansson and Nilner (1975) studied 1069 male shipbuilders by questionnaire and physical examination. 28% reported clicking sounds from the temporomandibular joint, whilst 44.3% exhibited clicking or crepitation on physical examination.

Solberg et al (1979) studied 739 students and at examination 28.3% had clicking of their temporomandibular joints, 21.7% of males and 35% of females. Ingervall et al (1980) studied 387 Swedish men with a mean age of 32 years and found clicking in 16.1% of men, only 0.8% showing crepitation.

Molin et al (1976) studied 253 Swedish men with an average age of 19, and reported that 14% were aware of clicking. On examination they found that 8% had clicks, and individuals with clinical symptoms of dysfunction had a higher frequency of clicking. 35% of those with clinical signs of dysfunction had clicking, whilst 11% of those without signs of dysfunction had clicking.

Nilner and Lassing (1981) studied the prevalence of functional disturbances and diseases of the stomatognathic

system in 440 7-14 year olds and found that 13% reported clicking. On examination they found that 8% displayed clicking, whilst only 3 children had crepitation. Nilner further reported (1981) on the prevalence of functional disturbances and diseases of the stomatognathic system in 309 15-18 year olds in which it was found that 17% had noticed clicking and 74% reported parafunction. On clinical examination 14% had clicking.

Kampe et al (1986) and Kampe et al (1987), in a study of mandibular dysfunction related to dental filling therapy, found that in a population of 15 to 19 year olds with no occlusal amalgams 10.3% had clicks, whereas in 15 to 19 year olds with occlusal amalgams 16.3% had clicks.

Wanman and Agerberg (1986 a, b, c, d.) in a study of adolescents found 13% of 285 17 year olds reported clicking, whilst physical examination showed that 22% had clicking. In a two year longitudinal study of the signs and symptoms of mandibular dysfunction in the same subjects, they found that in girls the report of clicking increased significantly from 14% to 23%, whilst in boys the report of clicking remained constant at about 10% from 17-19. Wanman and Agerberg also found that at the age of 17 there was a significant relationship between clicking of the temporomandibular joint and tenderness to palpation of the lateral pterygoid muscle.

In summary, epidemiological reports of clicking vary from a low of 13% to a high of 44%. It also appears that with increasing age there is increasing incidence of clicking, and that females report a higher incidence of clicking than males.

2.4 AETIOLOGY OF CLICKING OF THE TEMPOROMANDIBULAR JOINT

Considerable attention has been given to the cause of clicking of the temporomandibular joint. In the course of this research there has been conjecture and many theories. At the present time much of the controversy surrounding the mechanism of clicking has been resolved.

There is no single cause of clicking - different conditions of the temporomandibular joint cause different types of click - hard clicks; soft clicks, early, medium and late clicks; and hypermobility clicks. Theories of the causes of clicks reported by researchers may be divided into five main categories:-

1. Deviations in form of the components of the temporomandibular joint.
2. Derangements of the disc-condyle complex.
3. Eminence Click.
4. Hypermobility Clicks.
5. Others.

2.4.1 Deviations in form of the components of the Temporomandibular Joint

In the adult the soft tissue lining of the articular surfaces of the temporomandibular joint retains a layer of undifferentiated mesenchyme. Changing occlusal patterns and altered condylar patterns leads to functional loading of the joint. This functional loading constitutes biomechanical stress and may stimulate undifferentiated mesenchyme cells to proliferate and differentiate to form a thickened cartilaginous layer (Hansson and Nordstrom, 1977). These soft tissue changes are later followed by radiographically visible changes in bony contour (Solberg 1986). These changes in the hard and soft tissues are termed remodelling, and offer protection against injury by unfavourable loading of joint components. Grossly visible evidence of remodelling is termed deviation in form. Secondary to changes in the condyle and temporal components, the disc passively deforms by physical

compression. If the capacity for remodelling is exceeded, degenerative changes occur.

Nanthaviroj et al (1976) suggested that locking/clicking of the temporomandibular joint could be due to deviations in form of the articular components in the form of local bulges of fibrous cartilage. The free movement of joint components is obstructed by these bulges, the click occurring as movement is regained with a release of mechanical energy. This view was supported by the autopsy studies of Hansson and Oberg (1977) and Hansson et al (1979). Hellsing et al (1986) also stated that hard clicks may be due to specific defects of the joint surface.

Isberg-Holm and Westesson (1982), in another study using autopsy specimens, found that in one joint that demonstrated clicking, the click was due to a condylar deviation in form striking against the disc.

According to Klineberg (1986) the characteristics of clicking due to deviations in form are:

1. The click is soft.
2. The click occurs in the same position in the open/close cycle.
3. The deviation in form responsible for the click may be seen on an appropriate radiograph.

2.4.2 Clicking due to Derangement of the Disc Condyle Complex

It has long been recognised that clicking could be due to a mechanical fault which interferes with the smooth action of the joint. Cooper in 1823 is reported by Moloney (1984) to have concluded that the snapping sensation was brought about by the condyle slipping forward over the interarticular cartilage. The various theories regarding

clicks due to disc condyle derangement may be divided into three categories:

1. Clicking due to the condyle traversing the anterior thick band of the disc.
2. Hesitation in the forward translation of the disc.
3. Clicking due to the condyle traversing the posterior thick band of the disc.

Clicking due to the condyle traversing the anterior thick band of the disc

Rees (1954) reported that while during opening of the mandible the condyle and disc both move anteriorly, the condyle moves forward more than the disc, so that whereas in the intercuspal position the condyle rests against the posterior thick band of the disc, in extreme opening the condyle is against the anterior thick band. In some people the condyle slips forward of the anterior thick band, producing a click. Bertoft (1972) also considered that clicking was due to the condyle crossing the anterior thick band; in his opinion hypotrophy of the upper head of the lateral pterygoid led to disco-ordination of the translation of the articular disc. This hypotrophy, according to Bertoft, was due to man's modern soft diet. In contrast to this Olsen (1969) found that clicking was due to hyperactivity and loss of timing of the lateral pterygoid causing the condyle to contact the edge of the disc at the terminal position of the mandible. Shore (1976) believed that wide opening clicks were due to anterior condylar displacement, as did Watt (1980) who regarded hypertonicity of the lateral pterygoid causing inco-ordination of the condyle and disc to be the cause. It is now recognised that posterior disc displacement is a very rare condition (Solberg 1986) although a few cases have been reported in the literature (Blankestijn and Boering 1985).

Hesitation in the forward translation of the disc

Toller (1974) after studying clicking temporomandibular joints arthrographically, stated that at no stage did he

see the condyle cross any thickened part of the disc. His assumption was that during opening a forward hesitation of the disc while the condyle kept moving forward was followed by a sudden release of the disc. This released mechanical energy caused a click. The hesitation of the forward movement of the disc was due to unco-ordinated contraction of the upper and lower heads of the lateral pterygoid muscle. Helsing et al (1986) have also written that muscle inco-ordination may be a cause of soft clicks.

Clicking due to the condyle traversing the posterior thick band of the disc

It is now generally accepted that clicks that occur reciprocally are caused by the condyle passing over the posterior thick band of the disc during opening and closing. Pringle (1918) described this as the cause of clicks and also described a method of manipulating the condyle onto the disc when anterior disc displacement was not self reducing. Ireland (1951) further defined clicking as due to the condyle being mechanically displaced in a posterior and upwards direction over the posterior thick band on closing. On opening the condyle again clicks over the posterior thick band. Ireland (1951) also described a progression from early clicking to late clicking and thence to locking. Sicher (1955) stated that the reason for this was spastic contraction of the sphenomeniscal head of the lateral pterygoid muscle, which eventually causes disc displacement either by the disc moving anteriorly in relation to the condyle, the condyle moving posteriorly in relation to the disc, or more likely a combination of the two. Schwartz (1959) agreed with this, but also believed that clicking could occur because of posterior disc displacement.

Farrar and McCarthy (1978, 1979) rekindled interest in Ireland's premise that clicking progresses to locking. They defined internal derangement of the temporomandibular joint as anterior or antero-medial displacement of the

disc when the teeth are closed into the intercuspal position, and stated that clicking, which they described as reciprocal, is caused by the disc snapping in and out of place during opening and closing. According to these authors clicking is pathologic and ultimately leads to osteoarthritis, and that clicking is early, intermediate or late - the later the click the more anteriorly displaced the disc.

Conclusive proof that reciprocal clicking is due to anterior disc displacement was provided by Isberg-Holm and Westesson (1982 a & b). Using cineradiography and autopsy specimens of clicking temporomandibular joints they found the clicking to occur when the condyle hit the temporal component after having rapidly slipped over the posterior ridge of the disc. Isberg-Holm and Ivarsson (1980) also showed that mouth opening prior to clicking was observed to be steadily increasing following repeated movements. This increasing opening prior to clicking was attributed to a temporary change in elastic resistance of the posterior attachment tissue against forward disc movement (Wilkes 1978, Wilkinson and Marynuick 1983, Moloney 1985, Meyenberg et al 1986). Progressive disc displacement anteriorly may also occur during exercises which limit mandibular opening to before a click occurs.

Anterior disc displacement has been shown in autopsy studies (Hansson et al 1979, Hansson et al 1983), by arthrography (Farrar and McCarty 1979, Dolwick et al 1979, Bronstein et al 1981, Oster et al 1984, Westesson 1982, Erikson and Westesson 1984), and at surgery (McCarty and Farrar 1979, Leopard 1984, Moloney 1985, Juniper 1984). Thus it is now generally accepted that reciprocal clicking is due to reduction and subluxation of an anteriorly displaced disc.

Ireland's (1951) original premise that clicking can progress to locking in some cases has also been confirmed

surgically and radiographically (Wilkes 1978; Farrar and McArty 1979; Bronstein 1981; Westesson 1982, Westesson and Rohlin 1984; Eriksson and Westesson 1983, Dolwick et al 1979; Oster et al 1984). In locking of the temporomandibular joint, the condyle can no longer traverse the posterior ridge of the disc and thus the disc becomes a physical barrier to translation of the condyle. Locking has become known as anterior disc displacement without reduction, whilst clicking is now known as anterior disc displacement with reduction. Oster et al (1984) have reported reciprocal clicking in joints showing anterior disc displacement without reduction. Rohlin et al (1985), Westesson (1985), Westesson et al (1985), have shown that joints demonstrating anterior disc displacement have greater deviations in form, and this may be assumed to be responsible for any clicks that are present.

2.4.3 Eminence Clicks

Klineberg (1986) asserts that excessive steepness of the articular eminence results in velocity changes in the disc condyle complex as it translates down the eminence. This velocity change between the disc and the condyle may cause a partial anteromedial disc displacement, with a resultant click. The characteristics of an eminence click are (Klineberg 1986):

1. A hard click
2. The click occurs in the same position in the open close cycle
3. The steepness of the articular eminence may be observed on a suitable radiograph.

2.4.4 Hypermobility Click

Hypermobility clicks are associated with excessive condylar translation during mandibular movements. Hypermobility is involved with laxity of joint structures (Solberg 1986), which may be perpetuated and reinforced by movement habits. Hypermobility associated with joint laxity is more common in women and in edentulism and may be associated with general joint hypermobility. In hypermobility the condyle translates beyond the articular

eminence to an excessive degree and may be displaced from the anterior thick band of the disc. It is assumed that the movement of the condyle/disc beyond the eminence causes the clicking noise.

2.4.5 Other theories of click mechanisms

Campbell (1963) discussed temporomandibular joint clicking as a result of vapour filled vesicles forming due to the creation of a vacuum. Collapse of these vesicles results in a cracking noise. Campbell (1963) found it difficult to fit his theory to the temporomandibular joint. Yavelow and Arnold (1971) postulated that an abnormal relationship between temporomandibular joint components might lead to an obstruction of the normal movement of synovial fluid during function. As a result the fluid could be confined under pressure, which on release due to normalisation of the components causes clicking sounds. Watt (1980) believed that soft clicking arose from sudden movements of ligaments by the separation of articular surfaces; and sucking of loose tissue behind the condyle as it moves forward.

2.5 CLASSIFICATION OF CLICKING

Temporomandibular joint clicking is classified as:

- . The side of clicking: left or right, or both. Bilateral clicking is the most resistant to therapy (Solberg 1986).
- . During opening or closing, or both.
- . The degree of mouth opening at which clicking occurs. Farrar (1979) classified clicks as early, middle or late, and found that the later the click, the more resistant to treatment. Solberg (1986) states that clicks that occur at more than 20mm. of mouth opening do not respond as well to treatment. Watt (1980) felt that classifying clicks as "near", "middle" or "wide" was less confusing, and in contrast to Solberg (1986) and Farrar (1979) found wide clicks the most amenable to treatment.
- . Hard or soft. Hard clicks indicate either an eminence click, an hypermobility click or an anteriorly displaced disc with reduction, whilst soft clicks usually indicate deviations in form.
- . reciprocal or non-reciprocal clicks. Reciprocal clicks usually do not occur in the same position in the open close cycle and indicate anterior disc displacement with reduction, whilst non-reciprocal clicks do occur in the same position in the open close cycle and indicate deviations in form, hypermobility or eminence clicks.
- . The duration of the click - clicks that have been present for more than one year are most difficult to treat (Moloney and Howard 1986).

2.6 PREVIOUS STUDIES OF TEMPOROMANDIBULAR JOINT CLICKING

Ekensten (1952) was among the first to report a study of the sound characteristics of TMJ clicking. Employing a constant amplitude microphone held by the subject over the joint area, joint sounds were recorded photographically after amplification and oscilloscope display. He examined 30 patients and concluded that normal joints were silent. However, he was not able to draw any conclusions about joints that produced sounds because he did not record mandibular movements simultaneously.

In 1960 Findlay and Kilpatrick carried out an analysis of sounds produced by movement of the temporomandibular joint. In this study recordings were made by a constant velocity transducer microphone, contoured to fit the mastoid bone. Sounds produced were amplified and then displayed on an oscilloscope. Simultaneous recording of joint movements was recorded with a headgear attachment, connected to an oscilloscope through an amplifier. Permanent records of the amplified joint noise and degree of mouth opening were obtained by photographing the oscilloscope display. They found that all normal joints showed some noise during opening and closing and defined two main types of joint noise: (1) a "click" which was a single diphasic sound and, (2) a "clicking, cracking and grinding" sound which was multiple, diphasic and polyphasic. Sounds observed during opening were greater than those during closing. However, they found that there were no significant differences between records of temporomandibular joints with clicking and those without clicking, and concluded that crepitus alone cannot be taken as a sign of temporomandibular arthrosis.

Watt (1966,1980), reported a study of sounds produced by the masticatory mechanism which he termed "gnathosonics". In this study sounds were recorded with a tape recorder through a microphone placed on the skin overlying the masseter muscle. The tape data was displayed on a paper

recorder as a permanent record. Watt correlated where joint noises occurred in the opening and closing cycles by noting where tooth contact was made. He described (a) hard, cracking clicks, (b) soft (popping) clicks, and (c) hard and soft crepitus. He suggested that hard sounds indicated joint pathology, but that soft sounds could occur in normal joints. Watt (1980) categorised sounds into two main categories - clicks and crepitus, classified both as hard and soft, and identified their position in the opening/closing cycle relative to the position of occlusion, as near, middle or wide.

Watt stated soft clicks may be caused by sudden movements of ligaments and separation of articular surfaces, or by the sucking of loose tissue behind the condyle as it moves forward. They appear as short, low frequency sounds with low amplitude peaks on the gnathosonic record. Soft crepitus is defined by Watt (1980) as a surface effect, and appears as a prolonged low frequency, low amplitude noise on the gnathosonic record. Hard clicks may indicate joint pathology, in that specific defects of joint surface are responsible for generating these sounds. The gnathosonic records show peaks against a confused pattern of background noise which suggests roughness of joint surfaces. Hard crepitus is described as diagnostic of arthritic changes in the joint - perforation of the meniscus and consequent proliferation of the articular surface producing a surface irregularity.

Ouellette (1974) reported on a study of temporomandibular joint sound by electronic auscultation and sonographic audio-spectral analysis of the temporomandibular joint to determine whether joint sounds are diagnostically significant. Bilateral crystal microphones were placed over the temporal or zygomatic bone and amplification and recording was accomplished by the use of a stereophonic cassette tape recorder. Tape recordings were made of joint sounds with jaw opening and closing, as well as the

sounds of centric contact. These recordings were then played into a sonagraph, which provided a spectral analysis of the signal by breaking it down into each frequency component and by recording the amplitude and level in decibels of each component as a function of time. Using this method, a comparison was made of patients with and without symptoms of dysfunction and it was found that symptomatic patients tended to have higher recorded signals on the sonagrams. It was concluded that sonagrams were reproducible from one recording session to another.

Oster et al, in 1984, explored the possibility that characteristic alterations in tissue morphology and function of the temporomandibular joint might produce distinguishable acoustic patterns during joint function. They also correlated arthrographic diagnosis with patterns of joint sounds. In this study a standard condenser microphone element, mounted in a lead housing coupled to an infant's stethoscope, was placed over the condyle. The output of the microphone was fed into a videotape recorder. The videotape recorder was also connected to a standard radiographic table for simultaneous recording of fluoroscopic images obtained arthrographically. Contrast material (0.5cc) was injected into the lower joint space and then auscultatory and videotape fluoroscopic images of the temporomandibular joint were recorded simultaneously while the patient opened and closed. This procedure was carried out on 210 patients. The recordings were then fed into a strip chart recorder, and the joint sound analyses were grouped according to the arthrographic diagnosis. Joint sound analyses were carried out on 67 recordings, and the sound tracings studied for major differences in duration, timing and amplitude characteristics.

The arthrographic diagnosis of the joints were as follows:-

1. meniscus displacement with reduction
2. meniscus displacement without reduction
3. degenerative joint disease.

In meniscal displacement with reduction, the meniscus was anteriorly displaced in relation to the condylar head, but with a reduction in displacement during opening there was an audible "snap" or "click". In most cases as the jaw closed a faintly audible reciprocal click sound was noted. The sound characteristics showed that the opening click contained higher frequency components than the closing click.

Meniscal displacement without reduction occurs when the meniscus is displaced anterior to the condyle head and shows no reduction during opening. Oster et al (1984) examined patients who presented with this condition and who also had clicking. They found there was a sharp click during opening and a softer closing reciprocal sound. The sound characteristics were a sharp peak amplitude in the opening phase with multiple additional peaks of low amplitude and high frequency. During closing the characteristics were disorganised and showed high and low amplitude high frequency oscillations.

In patients who had distinct opening and closing clicks but were shown arthrographically to have normal menisco-condyle function, the sound characteristics were simple low amplitude deviations on the tracing. They described this as an "eminence click".

It was concluded from this study that a detailed analysis of temporomandibular joint sounds might offer valuable information for diagnosis and initiation of treatment, and that characterisation of joint sounds may offer important insights into the pathophysiology and progression of internal derangements using a non-invasive method.

Erikson et al (1985) reported on a correlation of joint sound with arthrographic and surgical observations in patients with disc displacement. In this study, 27

patients who were indicated for temporomandibular joint surgery had arthrograms and joint sounds recorded with a stethoscope prior to surgery. Six of the patients had bilateral operations, resulting in a study of 35 joints. Joint sounds were recorded as silence, reciprocal clicking, single clicking or crepitation.

Arthrographic studies classified disc dysfunction with or without reduction. Of the 35 joints, 12 showed reciprocal clicking, 3 single clicks, 12 were silent, and 8 had crepitation. Joints with reciprocal clicking consistently showed disc displacement either anteriorly or antero-medially with reduction on opening. Silent joints and most of those with crepitus on movement showed disc displacement without reduction. Joints with reciprocal clicking and most of the silent joints had non-arthrotic articular surfaces at surgery, whereas crepitation was recorded in both arthrotic and non-arthrotic joints. They also found that the degree of deformation and the amount of displacement could not be diagnosed by sound analysis, and that the cause of single clicking could not be disclosed during surgery. From these results it was concluded that crepitation is an unreliable sign of arthrosis, that reciprocal clicking can be considered as an accurate sign of reduction of anteriorly displaced discs and that silence in a joint does not always mean that the joint is normal.

Muhl et al (1986), reported on an examination of joint sounds in 102 patients undergoing orthodontic treatment and found that opening sounds tended to be later in the opening cycle and that closing sounds were more towards the middle. 75% of the sounds were of medium amplitude.

Blaustein and Heffez (1985) and Heffez and Blaustein (1987) examined joint sounds for wave pattern frequency and power spectrum. To provide this information they used a digitised stethoscope interfaced with a computer. A

computer programme specifically written was used to view the patient's sound pattern in both "real time" and slowed to allow detailed examination. The programme also provided a power spectral analysis of the recorded sounds. 100 patients were included in the study. The data showed that comparisons of wave patterns were possible and the authors claimed that assumptions based on sound patterns and power spectral analysis were applicable as diagnostic tools. Patients with arthrographic evidence of internal derangements had sound patterns which were predictive of similar internal derangements in other patients. Four wave patterns were identified: 1) crescendo-decrescendo; 2) crescendo; 3) coarse continuous; and 4) fine continuous. The frequencies of sound produced in subjects with anterior disc displacement were in the middle to high range. No firm conclusions, however, could be drawn regarding wave pattern or frequency and joint condition.

Rohlin et al (1985) studied 55 fresh autopsy temporomandibular joints and correlated joint sounds with macroscopic examination of joint morphology. Joint sounds were recorded as vibrations in the temporal bone using a vibration transducer attached to the squama temporalis with a clamp. These signals were then fed into an amplifier, band pass filtered by a second amplifier and visualised on a digital storage oscilloscope. The memory was connected to an XY plotter which produced a graphic representation of sound. The joint noises were classified into: 1) silence, 2) demonstrating clicking - rapid changes in amplitude were followed by changes of lessening magnitude. Reciprocal clicking implied two clicks, one during opening and another during closing, and 3) crepitation - repeated changes of amplitude of differing magnitudes. Of 55 joints studied, 58% were silent. One third of these, however, displayed anteriorly displaced discs morphologically; 20% elicited clicking and showed anterior disc displacement; 22% elicited crepitation and exhibited mostly arthrosis of the articular surfaces and

perforation of the discs. From these results, the authors concluded that clicking usually indicates arthrosis. Absence of sound, however, does not indicate a normal joint.

During 1984 and 1987 Gay and Bertolami reported on the technique of arthrophonometry of the temporomandibular joint and the spectral properties of temporomandibular joint sounds. These authors measured the frictional losses of joint movements as revealed by their acoustical characteristics. They then stated that because the various diseases of the temporomandibular joint are characterised by different physical conditions the associated joint sounds correspond categorically and uniquely to specific disease state. The procedure involved the placement of vibration transducers over the joints and a light-weight magnet on the lower central incisors to record the bone conducted joint sounds and jaw movement. The sensors produced voltages which were displayed on a chart recorder or a computer terminal. Using these methods they reported "dramatic and categorical differences in the acoustic characteristics of normal (and MPD), arthritic and internally deranged joints".

Joints of normal and MPD patients were essentially silent. Anteriorly displaced joints were characterised by short duration transients during jaw opening and closing. They concluded that arthrophonometry had significant potential as a method for diagnosing temporomandibular joint disorders. In a later paper on the interim results of their study they "confirmed their original findings".

In 1987 these authors reported on spectral analyses performed on sounds recorded from temporomandibular joints classified into different intracapsular categories. This was done in an attempt to determine whether the inherent properties of these sounds were unique for each different

disorder. A total of 55 joints were studied, 32 of which showed displacement with reduction, 10 displacement without reduction and 13 degenerative joint disease. The spectral analysis for each recorded joint sound was performed using a Fast-Fourier transform routine, the results of which were plotted as a frequency vs. amplitude envelope. Analyses of the different joints showed that while there were some cross group differences, they usually shared significant common spectral properties. On these findings it was concluded that comparison of the spectral envelopes of joint propagated sounds would have only limited application in the differential diagnosis in intra-capsular temporomandibular joint disorders. Although it has been known for a considerable time that different intra-capsular joint conditions produce different noises, comparatively few analyses of joint sounds have been carried out. The majority of studies so far have, however, drawn the same conclusion, that the analysis of joint sounds is of limited value, a stethoscope giving as much diagnostic information on joint noises as is required.

CHAPTER 3

MATERIALS AND METHODS

3.1 Aims of Present Investigations

3.2 Subjects

3.3 Methods

3.4 Analysis of Data

3. MATERIALS AND METHODS

3.1 AIMS OF PRESENT INVESTIGATION

The aim of this research is threefold.

1. to record clicks of the TMJ and to study the waveform, duration and power spectrum of each click to determine whether clinically similar joint conditions give rise to similar click features.
2. To study simultaneous recordings of mandibular movement and clicking to determine jaw deviation and velocity at the time of the click.
3. To study the effect of clenching prior to opening on the features of the click.

3.2 SUBJECTS

Sixteen subjects displaying unilateral or bilateral TMJ clicking were selected from the staff, patient and student groups of Westmead Hospital Dental Clinical School. The ages of the subjects ranged from 17 to 67; the average age being 38.2 years. Of the sixteen subjects, nine were male and seven female, and eight subjects had bilateral clicking, resulting in a total of twenty-four joints for examination.

3.3 METHODS

History and Clinical Examinations

A detailed history and examination was carried out for each subject; the Orofacial Pain Dysfunction form employed for routine assessment of orofacial pain in the Orofacial Pain Clinic at Westmead Hospital Dental Clinical School was used.

Clinical examination included external inspection, palpation and auscultation of the TMJ's using a stethoscope and inspection and palpation of the orofacial musculature. Also, a measurement of maximal opening and maximum lateral excursions and assessment of deviation of the mandible during opening and closing movement was made. Intraoral examination noted premature contacts in retruded jaw

The Parramatta Hospitals



Westmead Hospital
Dental Clinical School

Title		Family Name		D.R.N.	
Given Names				D.O.	
Address		Street		Age	Sex
Suburb		Postcode		Adm Date	

CLINICAL EXAMINATION

1.

Date										
T.M. JOINTS	R	L	R	L	R	L	R	L	R	L
Pain — lateral										
Pain — posterior										
Clicking										
Creptitation										
Limited movement										
Subluxation										
Inflammation										
Score										

2. JAW MUSCLE PALPATION	R	L	R	L	R	L	R	L	R	L
Temporal ant										
Temporal post										
Temporal tendon										
Masseter origin										
Masseter body										
Masseter insertion										
Masseter deep										
Pterygoid med										
Pterygoid lat										
Digastric ant										
Digastric post										
Sternomastoid origin										
Sternomastoid body										
Sternomastoid insertion										
Trapezius origin										
Trapezius insertion										
Tongue										
Submandibular gp										
Score										
Total Score										

3. MANDIBULAR MOVEMENTS	mm	Pain localisation and degree	Clicking point mm Hard/Soft	Provocation test Pain/fatigue at bruxofacet location	Deviation open — close	Deviation open — close
Opening Max incisor dist 2 1 3 1					R	L
Vertical overbite						
Horizontal overbite						
Max laterotrusion R					5	0 mm
Max laterotrusion L					5	0 mm
Max protrusion					5	0 mm
Score pain						
Date						
MANDIBULAR MOVEMENTS REASSESSMENT	mm	Pain	Click mm	mm	Pain	Click mm
Opening						
Max incisor dist						
Max laterotrusion R						
Max laterotrusion L						
Max protrusion						
Score pain						

Binding Margin — No Writing

ORO — FACIAL PAIN AND DYSFUNCTION

DR-10
Fig. 3.1(a) - Orofacial pain dysfunction form clinical examination

4. OCCLUSAL ANALYSIS																																																															
Type of jaw relationship. ant. post . . . vertical . . . transverse 																																																															
MOP—					RP—																																																										
1 8 7 6 5 4 3 2 1 4		2 1 2 3 4 5 6 7 8 3		1 8 7 6 5 4 3 2 1 4		2 1 2 3 4 5 6 7 8 3		Slide: RP-IP distance ant-post. mm vertical mm lateral displacement . . . mm to R/L																																																							
Laterotrusion R—				Laterotrusion L—				<table border="0" style="width: 100%;"> <tr> <td style="width: 30%;">Partial denture</td> <td style="width: 30%;">Complete denture</td> <td colspan="2" style="width: 20%;">Initial lateral guidance</td> <td style="width: 10%;"></td> <td style="width: 10%;"></td> </tr> <tr> <td>☐ satisfactory</td> <td>☐</td> <td colspan="2">Max. tooth</td> <td>☐ R</td> <td>☐ L</td> </tr> <tr> <td>☐ not satisfactory</td> <td>☐</td> <td colspan="2">incline mesial</td> <td>☐ R</td> <td>☐ L</td> </tr> <tr> <td></td> <td></td> <td colspan="2">distal</td> <td>☐ R</td> <td>☐ L</td> </tr> <tr> <td colspan="2" style="padding: 5px;">Degree of attrition</td> <td colspan="2">inc can prem mol open bite</td> <td colspan="2"></td> </tr> <tr> <td colspan="2" style="padding: 5px;">Soft tissue trauma.</td> <td colspan="2"></td> <td colspan="2"></td> </tr> <tr> <td colspan="2" style="padding: 5px;">Tongue/cheek biting</td> <td colspan="2">☐</td> <td colspan="2">Mucosal ridging ☐</td> </tr> <tr> <td colspan="2" style="padding: 5px;">Deviant swallow</td> <td colspan="2">☐</td> <td colspan="2">Tongue ridging ☐</td> </tr> <tr> <td colspan="2" style="padding: 5px;">Vertical dimension*</td> <td colspan="2">optimal ☐ reduced ☐ severely reduced ☐</td> <td colspan="2"></td> </tr> </table>		Partial denture	Complete denture	Initial lateral guidance				☐ satisfactory	☐	Max. tooth		☐ R	☐ L	☐ not satisfactory	☐	incline mesial		☐ R	☐ L			distal		☐ R	☐ L	Degree of attrition		inc can prem mol open bite				Soft tissue trauma.						Tongue/cheek biting		☐		Mucosal ridging ☐		Deviant swallow		☐		Tongue ridging ☐		Vertical dimension*		optimal ☐ reduced ☐ severely reduced ☐			
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Vertical dimension*		optimal ☐ reduced ☐ severely reduced ☐																																																													
1 8 7 6 5 4 3 2 1 4		2 1 2 3 4 5 6 7 8 3		1 8 7 6 5 4 3 2 1 4		2 1 2 3 4 5 6 7 8 3																																																									
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Score. MOP: _____ RP: _____ Lat R: _____ Lat L: _____ Pro: _____ Brux: _____ Attrition: _____																																																															
DATA CODE: T.M. Joint lateral palpation: 1 - mild discomfort; 2 - moderate discomfort/pain (palpebral reflex); 3 - severe pain, 4 - very severe Muscle palpation: 1 - mild discomfort; 2 - moderate discomfort/pain; 3 - severe pain; 4 - very severe Mandibular movement pain. 1 - mild discomfort; 2 - moderate discomfort/pain; 3 - severe pain, 4 - very severe Code "IP", "RP" etc. Circle tooth with black for contact, red for interference. Attrition. 0 - nil; 1 - only enamel; 2 - dentine; 3 - dentine extensively; 4 - dentine and secondary dentine involved																																																															
5. RADIOGRAPHIC SURVEY AND SPECIAL TESTS (Summary of radiographic analysis and other special tests)																																																															
6. ASSESSMENT																																																															
SUMMARY OF SUBJECTIVE AND OBJECTIVE FINDINGS																																																															
1 Joints _____																																																															
2 Muscles: _____																																																															
3 Jaw Movements _____																																																															
4 Occlusal Features: _____																																																															
5 Parafunction _____																																																															
6 Psychological Profile. _____																																																															
DIAGNOSIS _____																																																															
TREATMENT PLAN _____																																																															

Fig. 3.1(b) - Orofacial pain dysfunction form. Clinical occlusal analysis, radiographic survey, assessment, diagnosis and treatment plan.

position and during medio-trusive and latero-trusive excursions.

TMJ clicking was classified by:

1. the distance in millimetres from occlusal contact at which the click occurred during opening and closing jaw movement;
2. the movement during which the click occurred - as a single click during opening, as a single click during closing or during both opening and closing;
3. the nature of the sound - that is a hard or soft click or crepitation.

If clicking was present bilaterally the examination procedure was carried out for each click.

Recording of TMJ sounds

To record the sounds produced by the TMJ during movement, subminiature vibration transducers (Knowles Electronics Inc. Illinois, USA, Model No: BU-1771) were selected. These are accelerometers, which are ideal for recording vibration. The transducer was mounted on the skin lateral to the TMJ, with the final position of the transducer being determined by that position which afforded the greatest response. Double sided adhesive tape (Neomedica Systems) was used to fix the transducer to the skin. The transducer was further secured to the subject by two strips of adhesive tape at right angles to one another across the transducer. Five centimetres away the cables from the transducer were taped to the subject's skin to reduce bending. This was done to minimise tension and compression forces that could have created noises due to capacitance effects.

Signals received by the transducer were fed to an isolation amplifier with fixed amplification and then to a Grass EEG amplifier (model 7PS115-Grass Instrument Co. Quincy, Mass. USA). Due to the variability in the amount

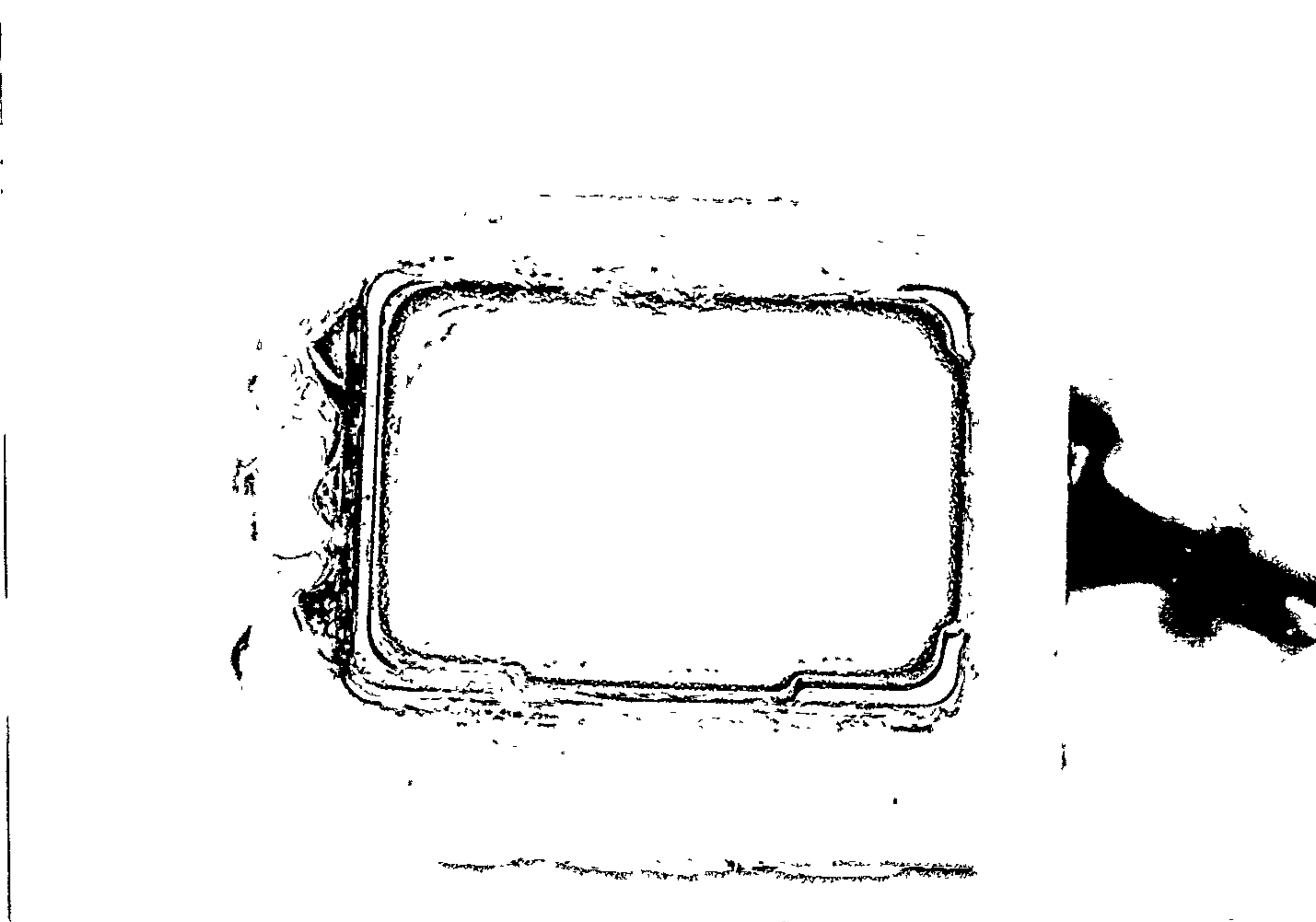


Fig. 3.2 - Subminiature vibration transducer.

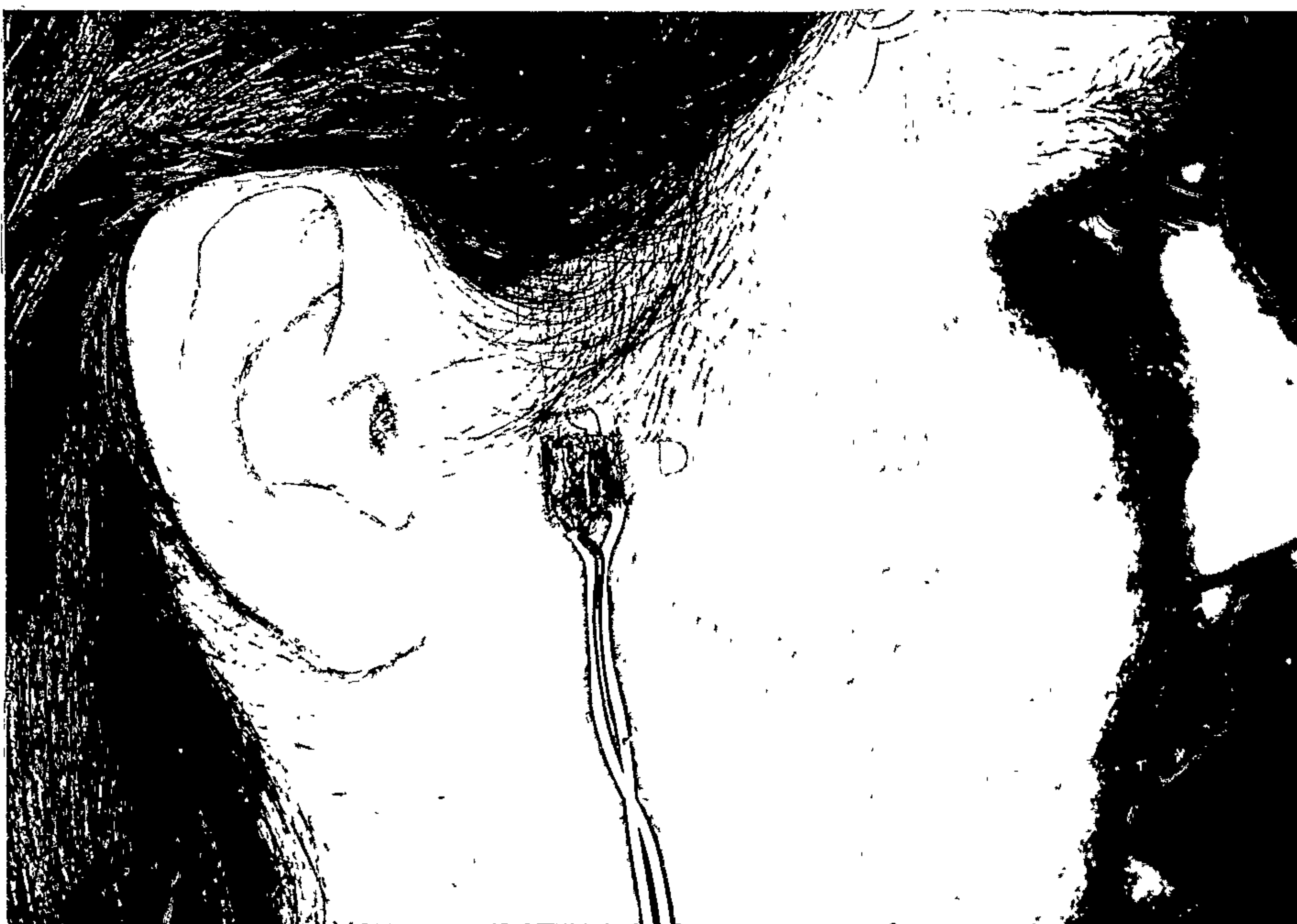


Fig. 3.3 - Subminiature vibration transducer in place on subject.

of vibration produced by clicking joints from one subject to another, it was necessary to vary the amount of amplification of the click accordingly. After amplification the signal was recorded by an eight track Hewlett-Packard Instrumentation Tape Recorder (Model 3968A; frequency response DC to 5000 hertz). Visual display of the signal was possible with a Grass 7D Polygraph.

Recording of Mandibular Movement

Recording of three dimensional jaw movement was carried out using a Sirognathograph tracking system (Siemens AG., W. Germany). This system is based on the Hall effect, whereby the displacement of a bar magnet, attached temporarily with adhesive cement to the lower central incisor teeth, is monitored by eight sensors in a head frame. This allows the trajectories of jaw movement during command open-close movements to be studied. Information gained by the Sirognathograph was conveyed by cables to a Grass EEG amplifier (model 7PS11J) and then to an eight track Hewlett Packard Instrumentation tape recorder (model 3968A) for storage. Simultaneously information from the Sirognathograph was displayed visually by a Grass 7D polygraph to give a preliminary hard copy.

Procedure

Recording of joint noises during normal open/close movements

The subject was seated in a firm chair with an upright back and a solid head support. The transducer was positioned so that its long axis was at a right angle to the Frankfort plane, and with the negative pole of the transducer facing inferiorly. The subject was then instructed to open/close his/her mouth to enable initial assessment of the magnitude of the click so that the appropriate amplification could be determined. Once the amplification factor had been ascertained the patient was

instructed to close his/her mouth to reach light tooth contact. The tape recorder monitored sounds when the subject opened his/her jaw. No instructions were given concerning the manner or speed of jaw opening, nor the degree of opening. Once the subject's opening movement was complete, the position was held for five seconds and then the subject was instructed to close until tooth contact. Again, no instructions regarding the manner or speed of closing were given. To differentiate between opening and closing clicks a foot switch activated electric signal was simultaneously recorded during the opening movement. Tape speed during clicking recording was 38.1 cm/sec. The subject was requested to open/close his/her mouth for a total of ten cycles.

Recording of joint noises during open/close cycles following clenching

The procedure for recording clicks following clenching was the same as described above, with the added instruction to the subject to clench his/her teeth together as tightly as possible without causing pain for three seconds before each open/close cycle.

Simultaneous recording of joint noise and mandibular movement

Recordings of joint noise took place as described. To record movement, a bar magnet was temporarily cemented to the labial surface of the lower central incisors with zinc phosphate cement, ensuring that the magnet was free from interference from the maxillary incisor teeth during functional and clenching movements. The head frame and sensors of the Sirognathograph were then set such that the magnetometers lay parallel to the mid sagittal plane when viewed from the front. The sensors on each side were then adjusted to be parallel to the Frankfort plane using an alignment jig.

3.4 ANALYSIS OF DATA

Data analysis was carried out using a PDP11 computer (General Robotics, Sydney). This computer is based on a DEC LS1-11/23CPU, and has a memory of 512 Kilobytes with a 128 Megabyte hard disc. Data digitisation was via a 116A/D converter (Grant Technology Systems Co., 11 Summer Street, Chelmsford, MA 01824 USA). Data analysis was more time consuming than its acquisition and was carried out at a separate time. A Retrographics ADMS terminal was used to programme the computer and visually display the data.

Digitisation and analysis of clicks

Data Acquisition and Graphical Package (Laboratory Software Associates, Melbourne), an application programmable software, was used to display the pattern of the click and to carry out a Fast-Fourier transform analysis. The pattern of the click was displayed as amplitude versus time, whilst the spectral analysis was displayed as hertz versus relative magnitude. For analysis each click was individually played through the computer. This was done by locating the click on the tape recording, setting the time window over which the click analysis was to be carried out (25 milliseconds, 50 milliseconds, 75 milliseconds, 100 milliseconds, determined by the duration of the click), setting a trigger level in millivolts above the background noise of the recording, activating the tape recorder and then activating the computer. The sampling rate during analysis was 10,000 per second, and the programme was able to sample frequency responses up to 5,000 Hz. A hard copy of the analysis was produced by a Hewlett Packard 7550A Graphic Plotter and consisted of a graphic representation of the recorded click as an amplitude versus time diagram and a power spectrum of the click as a frequency versus relative magnitude diagram. The scale of the waveform diagram was 1000 millivolts/centimetre on the Y axis and either 2.5, 5, 7.5 or 10 milliseconds/centimetre on the X axis. The scale of the power spectrum was 100

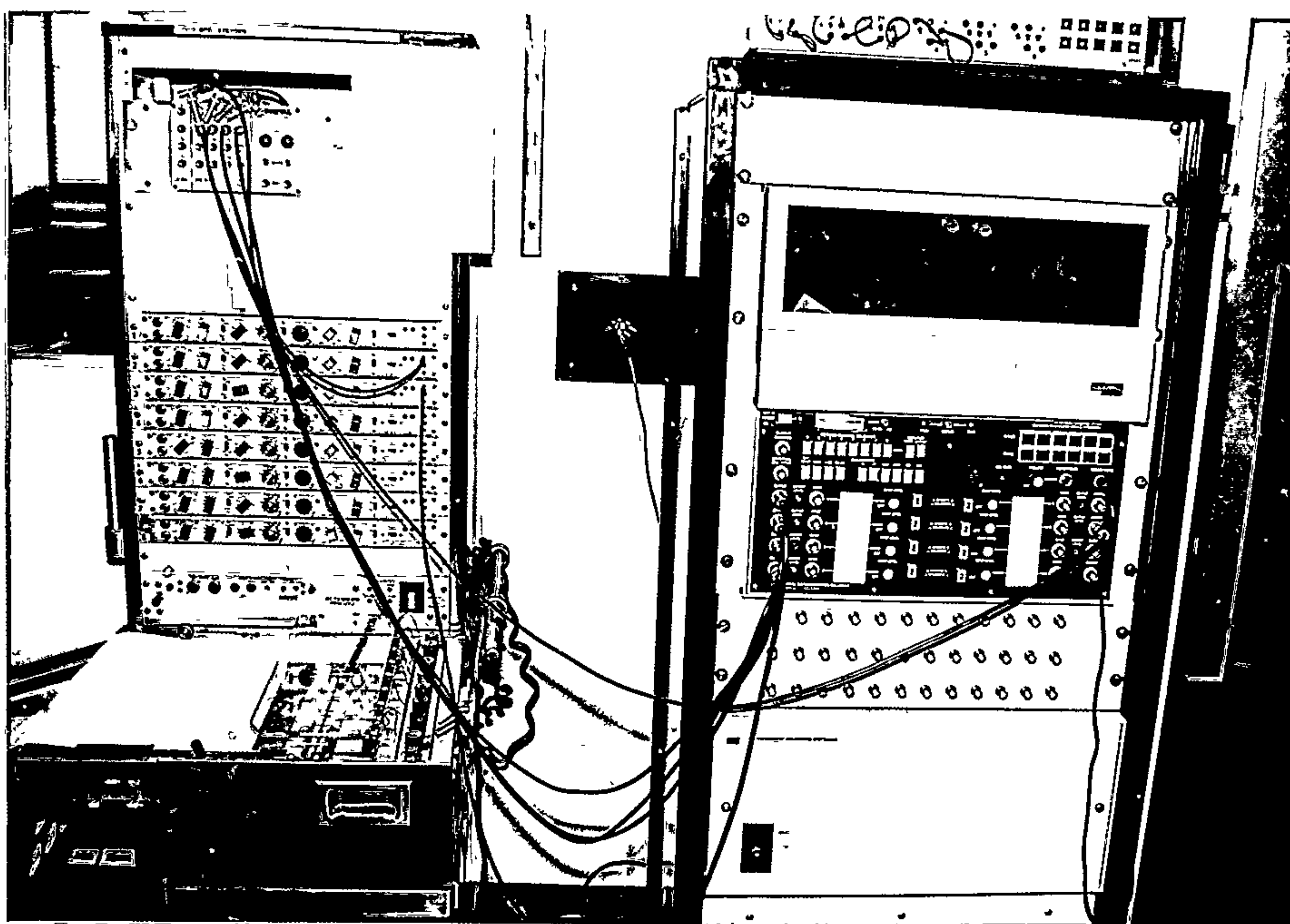


Fig. 3.5 - Click and mandibular movement recording and display apparatus.

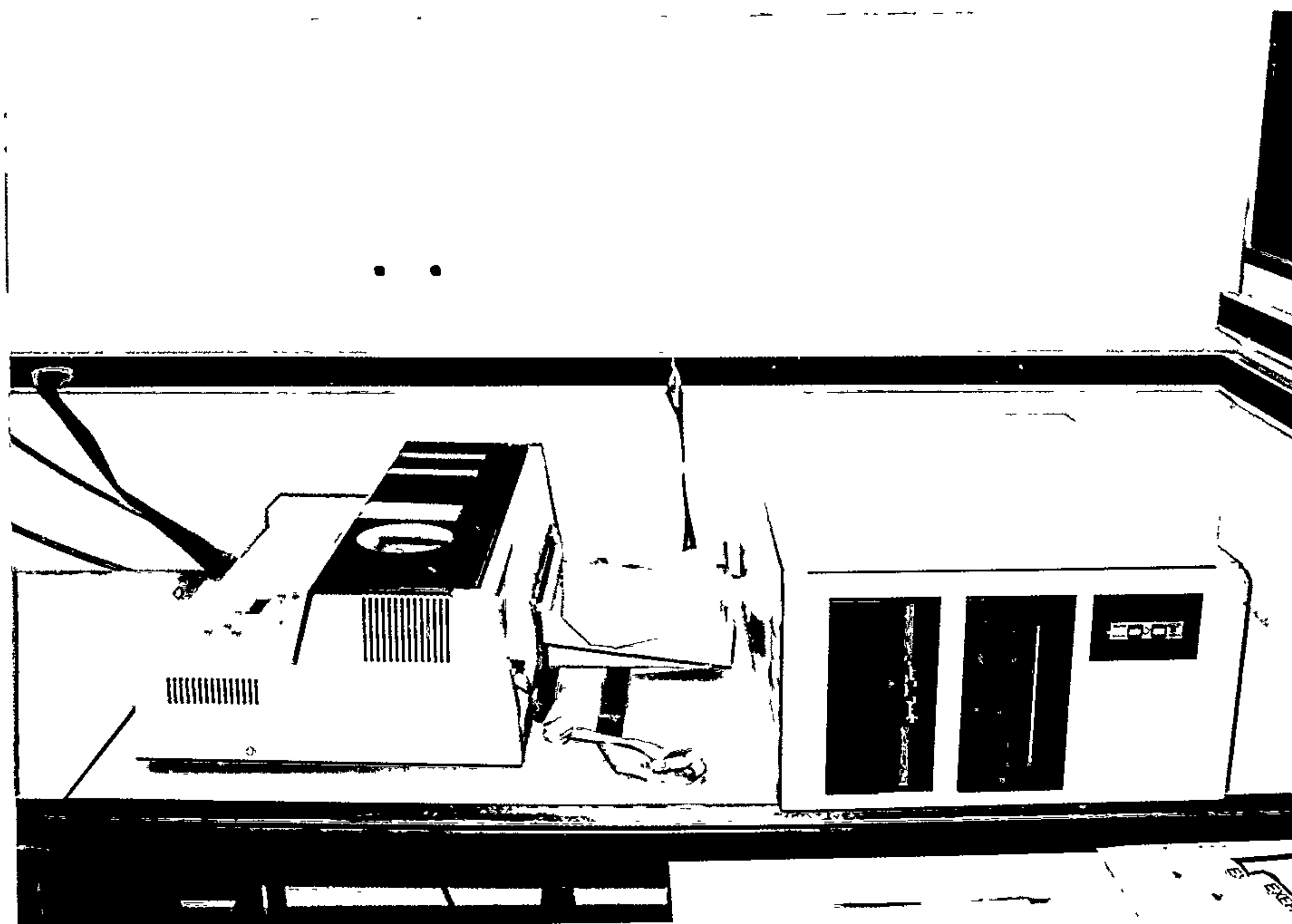


Fig. 3.6 - Computer and printer for production of hard copies.

hertz/centimetre. Measurements of the amplitude, duration and frequency peaks were done manually with a ruler.

Simultaneous recording of click and mandibular movement analysis

Data analysis and display was carried out using the Data Acquisition and Graphics Package (Laboratory Software Associates, Melbourne). The recorded information was played through the computer which analysed the data and displayed the information in the form of a hard copy via a Hewlett Packard 7550A Graphic Plotter. The hard copy consisted of a representation of the relative movement in the open-close, left right and anterior posterior planes of reference, the vibrations recorded from the transducer and a time frame. If a click was present then a line was drawn across the plot to indicate at which stage in the movement cycle the click occurred. The relative velocity of mandibular movement in each reference plane was determined by an examination of the velocity tracing that was simultaneously displayed with mandibular movement. The velocity at the time of the click was described as occurring either at a maximum, at zero, or as either increasing or decreasing. The absolute value of the velocity at any one time was not identifiable. Each plot represented 32 seconds of recorded movement, scale of the tracings was 1mm. of movement represented by 1mm. of plot. All measurements were done manually using a ruler.

SUBJECT	TYPE OF CLICK	RIGHT OR LEFT	DURATION MONTHS OR YEARS	CLICK SOUND	EARLY, MIDDLE, LATE
1	Reciprocal	Right	15 years	Soft	Early opening
2	Reciprocal	Left	4 months	Soft	Middle opening
3	Reciprocal	Left	10 years	Soft	Early opening
3	Reciprocal	Right	10 years	Soft	Early opening
4	Reciprocal	Left	40 years	Hard	Late opening
5	Reciprocal	Left	20 years	Soft	Late opening
5	Single opening	Right	20 years	Soft	Late opening
6	Single opening	Left	7 years	Hard	Early opening
6	Single opening	Right	10 years	Hard	Early opening
7	Closing	Left	20 years	Soft	Early closing
8	Crepitus opening click closing	Left	40 years	Soft click crepitus	Late opening
8	Single opening	Right	40 years	Soft	Late opening
9	Single opening	Left	10 years	Hard	Late opening
10	Reciprocal	Right	20 years	Hard	Late opening
11	Reciprocal	Left	More than 10 years	Soft	Middle opening
12	Reciprocal	Left	5 years	Soft	Early opening
12	Single opening	Right	5 years	Soft	Early opening
13	Reciprocal	Left	10 years	Soft	Late opening
13	Reciprocal	Right	10 years	Soft	Late opening
14	Single Opening	Right	5 years	Hard	Middle to late opening
15	Reciprocal	Left	15 years	Soft	Early opening
15	Reciprocal	Right	15 years	Soft	Early opening
16	Reciprocal	Left	5 years	Soft	Early opening
16	Reciprocal	Right	5 years	Soft	Early opening

5
00

Table 3.1 - Clicking subjects: clicking characteristics.

CHAPTER 4

RESULTS

- 4.1 Features of clicks
- 4.2 Simultaneous recording of click and movement
- 4.3 Effect of clenching prior to opening upon the features of clicks

4. RESULTS

The results from the different experiments will be reported under the following headings:

1. Features of the click, that is,
 amplitude
 duration
 power spectrum;
2. Simultaneous recording of click and movement; and
3. Clenching and its effect upon the features of clicking.

4.1 FEATURES OF CLICKS

The results will be reported by subject, with a summary in the form of a table at the end of this section.

Subject 1

This subject displayed a right sided reciprocal click which had never caused pain and had been present for at least fifteen years.

The opening click for this subject displayed a consistent pattern of four peaks. Between the second and third peaks there was a consistent rapid change in polarity of the tracing, often resulting in a supplementary peak. The average duration of the ten clicks was 20.6 ms, SD 1.22 ms, whilst the average maximum amplitude for the tracings was 2622 mv, SD 1094 mv. The spectral analysis of this subject's clicks had an average maximum peak of 95.4 Hz, SD 65.7 Hz. The spectral analysis did not show great consistency with other peaks occurring at 30, 260 and 400 Hz.

The closing clicks of this subject displayed simple three peak tracings, average duration being 10.6 ms, SD 0.5 ms. The tracings were remarkably consistent in outline, only varying in amplitude. The mean amplitude of these clicks was 3961 mv, SD 1288 mv. The spectral analysis of these

Subject code: 1
L or R: RIGHT
O or C: OPEN
Gain factor: 2800

2-Feb-89

Peak to peak (mV): 2763
Maximum at (Hz): 97

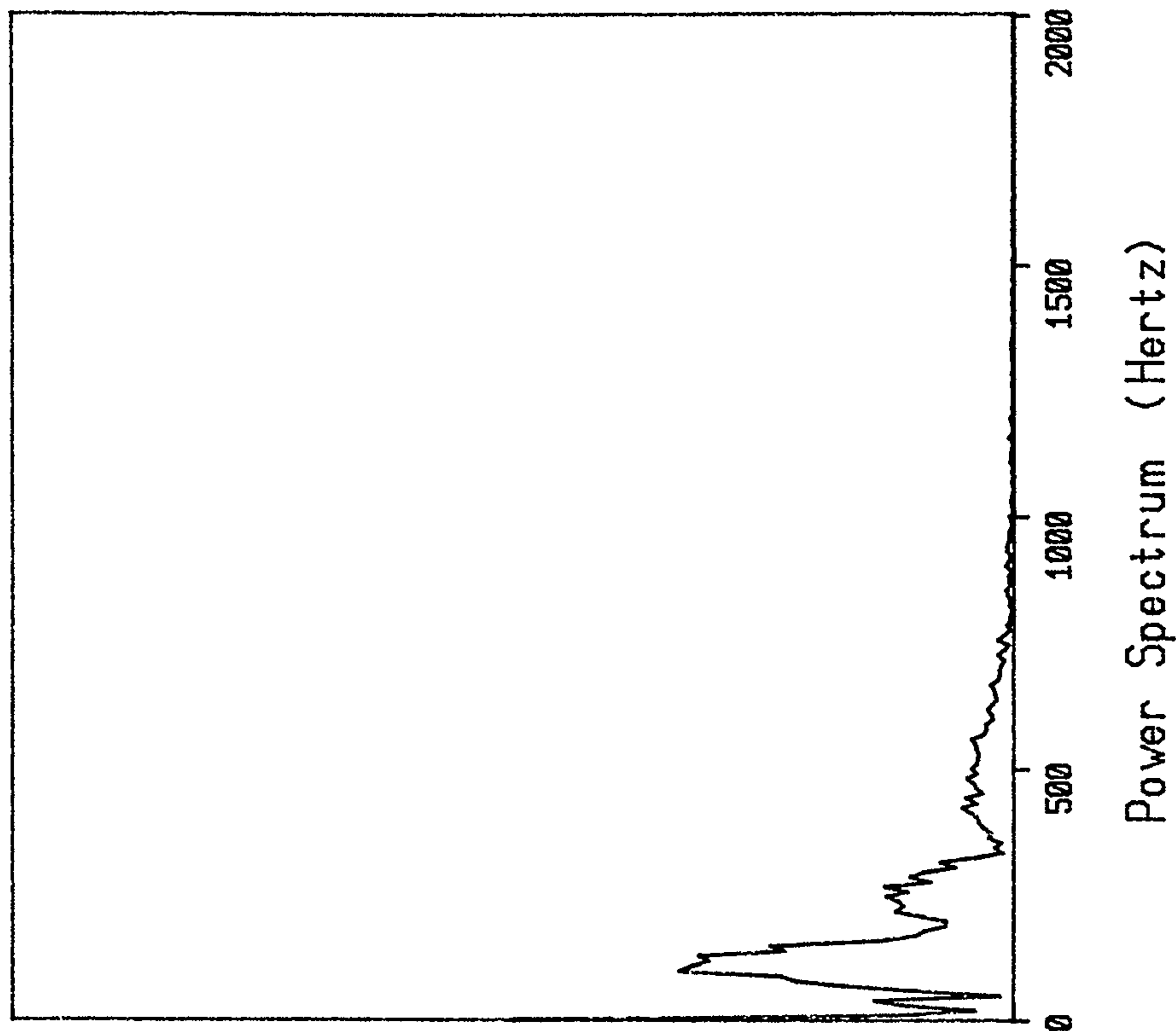
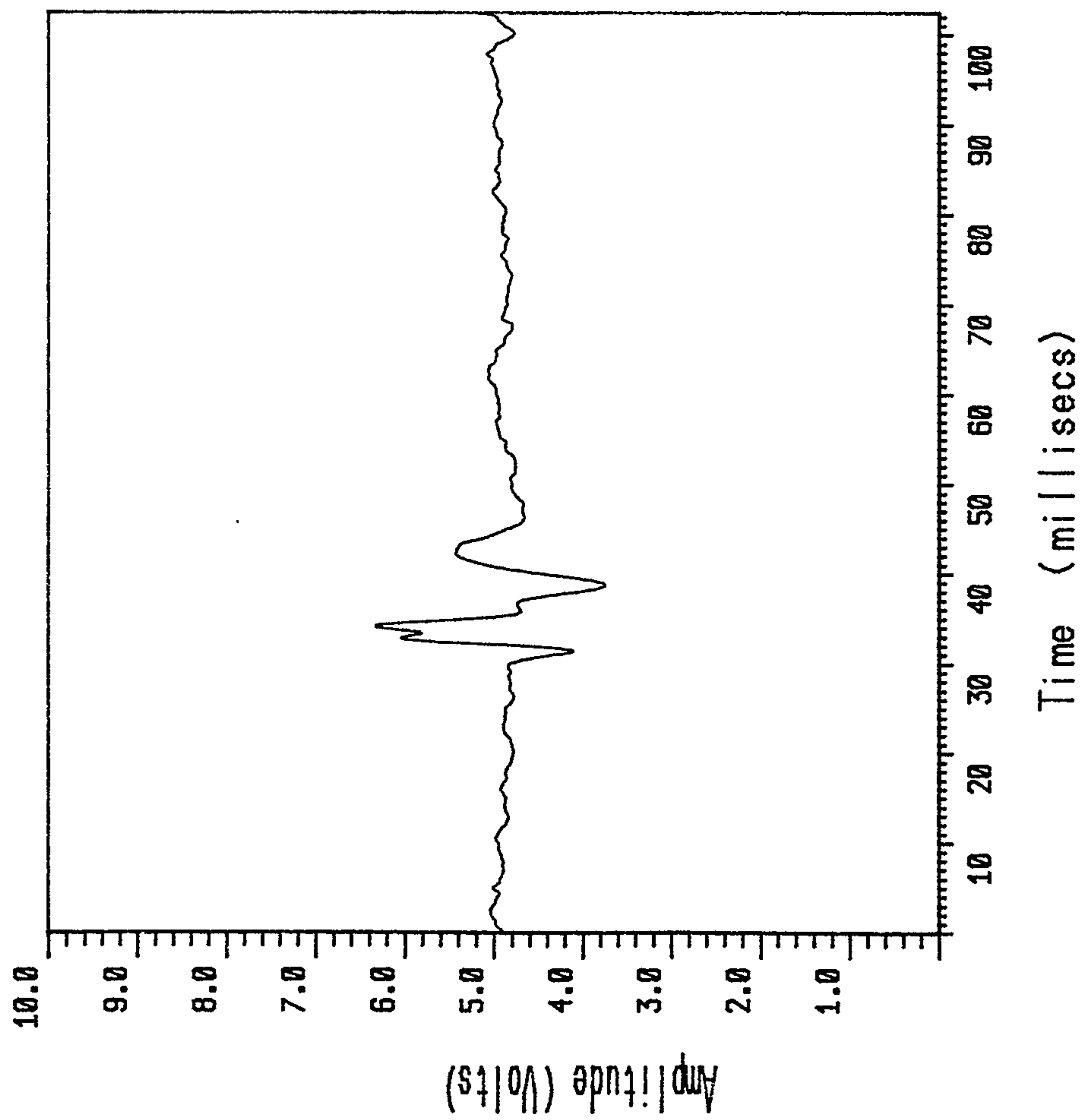


Fig. 4.1.1 - Subject 1 opening click, wave pattern and power spectrum.

2-Feb-89

Subject code: 1

L or R: RIGHT

O or C: CLOSE

Gain factor: 2800

Peak to peak (mV): 4208

Maximum at (Hz): 146

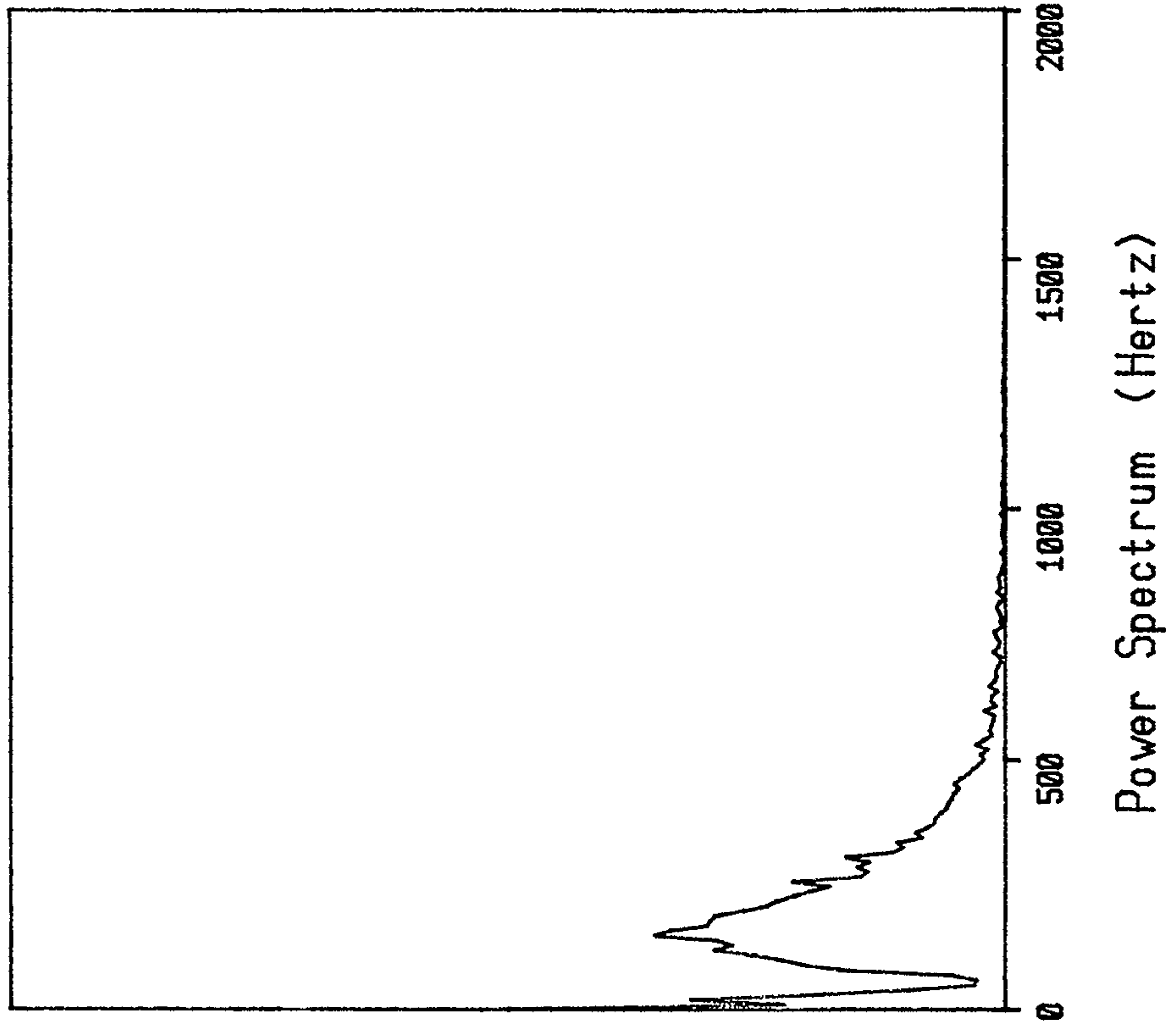
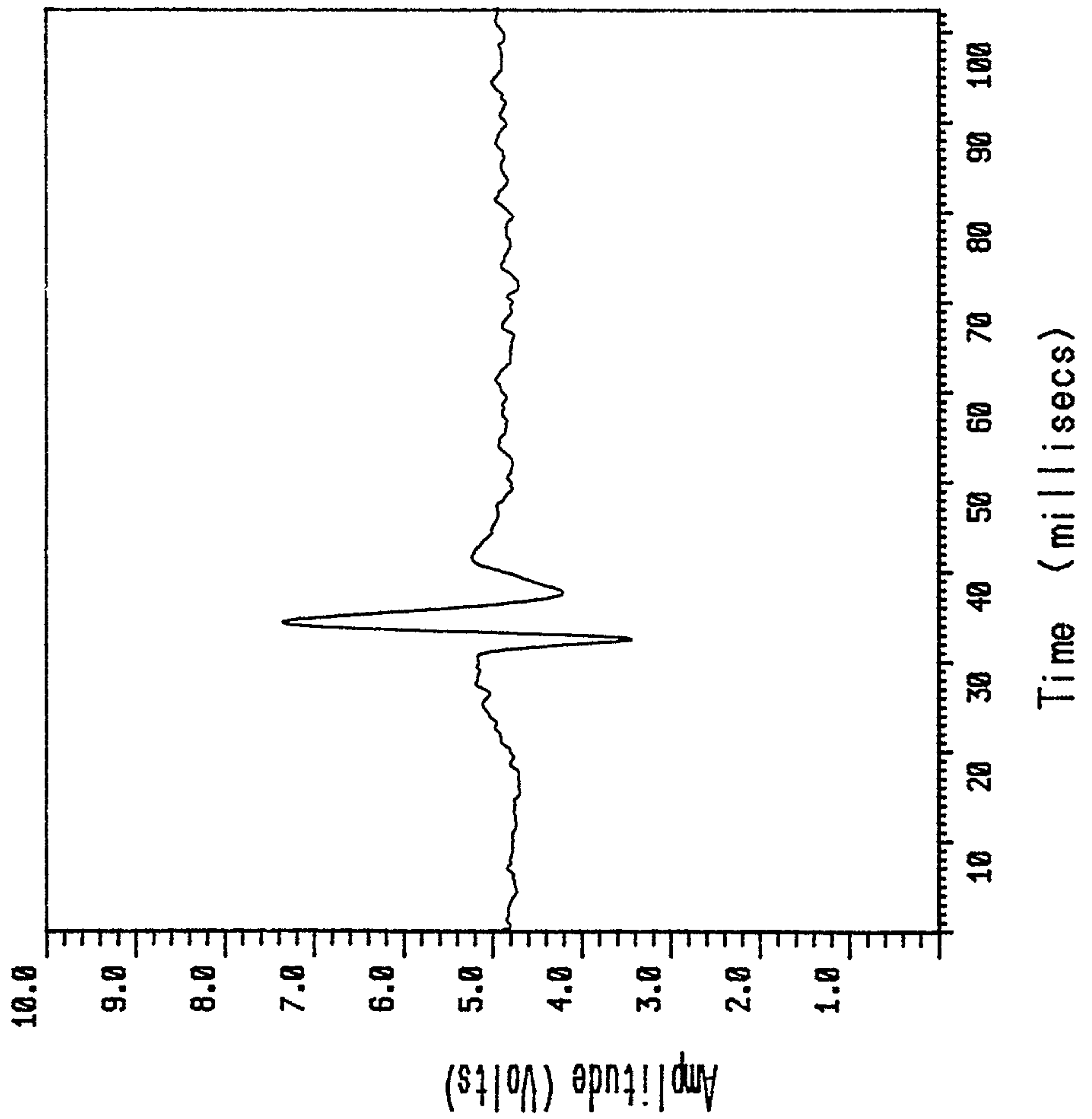


Fig. 4.1.2 - Subject 1 closing click, wave pattern and power spectrum.

clicks was also very consistent, with peaks at 30 and 140 Hz, the average maximum being 140.5 Hz, SD 41.9 Hz.

Subject 2

This subject had a left sided opening click which caused no pain. The click had been present for four months, following amalgam restorations in the lower left quadrant. Although a very slight closing click could be palpated, no click could be recorded.

The tracings of this subject's clicks displayed three peaks. Between the first and second peaks there was a sudden change in polarity which occasionally resulted in a supplementary peak. The average duration of the tracings was 34.6 ms, SD 0.7 ms. Average amplitude was 3447 mv, SD 1209 mv. The spectral analyses consistently displayed two peaks in the 30 and 100 Hz regions, the average maximum being 97.8 Hz, SD 12.0 Hz.

Subject 3

Clicking in this subject had been present bilaterally for over ten years, pain being present in the left joint for six months. Both left and right sides displayed reciprocal clicks, no closing clicks were able to be recorded.

On the right side the tracing of the click displayed five peaks, with a rapid change in polarity between the 1st and 2nd peaks causing a supplementary peak in this position. The average duration of the click on this side was 34 ms, SD 2.6 ms. The average maximum amplitude was 2111 mv, SD 643 mv. The spectral analyses displayed numerous peaks in the 30, 80 and 150 Hz regions, with the average peak frequency being 81 Hz, SD 3.8 Hz.

The clicks from the left side of this subject displayed four peaks on the tracing, with no sudden changes in polarity. Average duration was 28 ms, SD 6.2 ms. A great deal of variability was shown in the amplitude of the clicks, with the average peak amplitude being 3144 mv, SD

Subject code: 4
L or R: LEFT
O or C: OPEN
Gain factor: 1400

9-May-89
Peak to peak (mV): 1452
Maximum at (Hz): 107

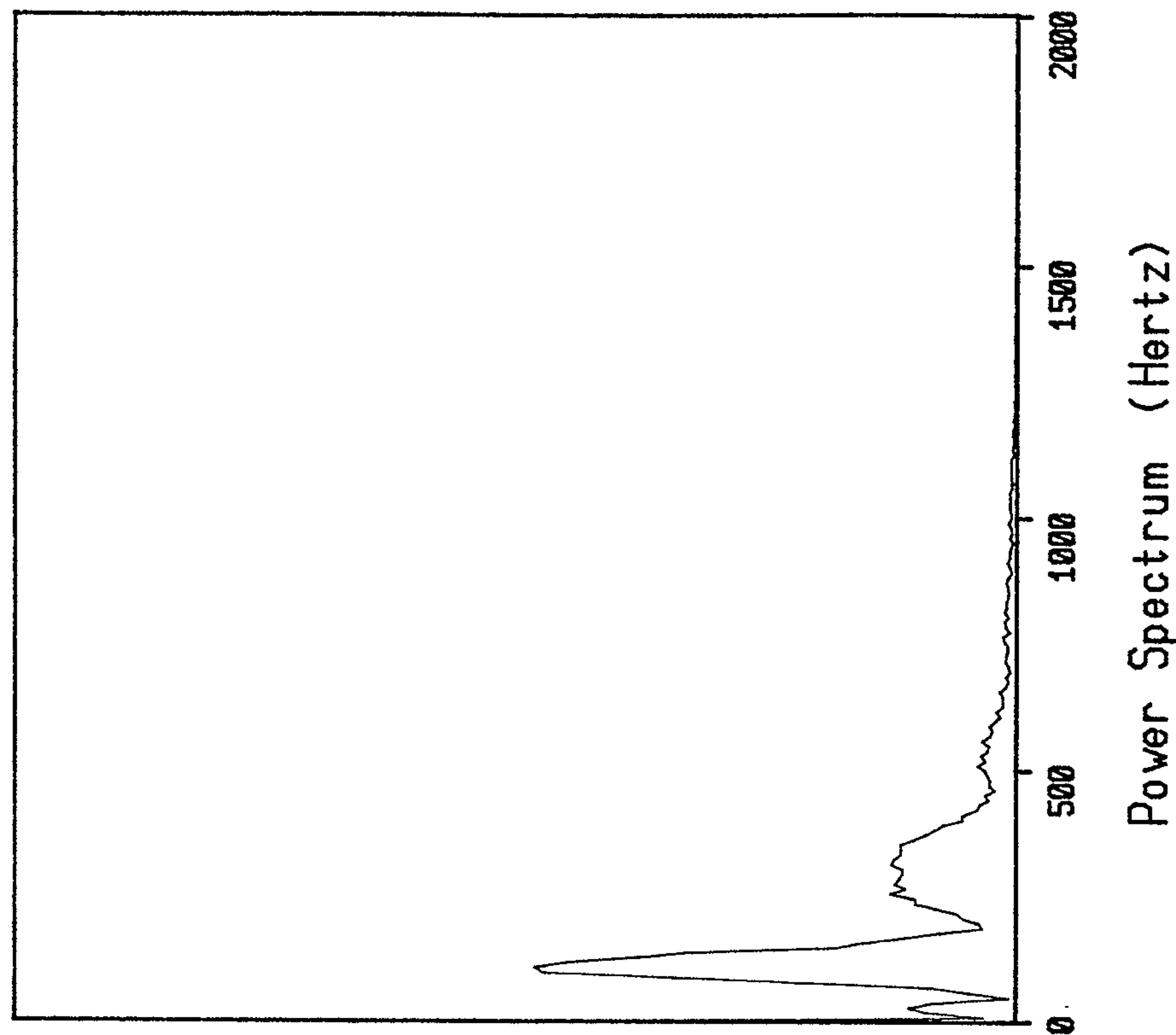
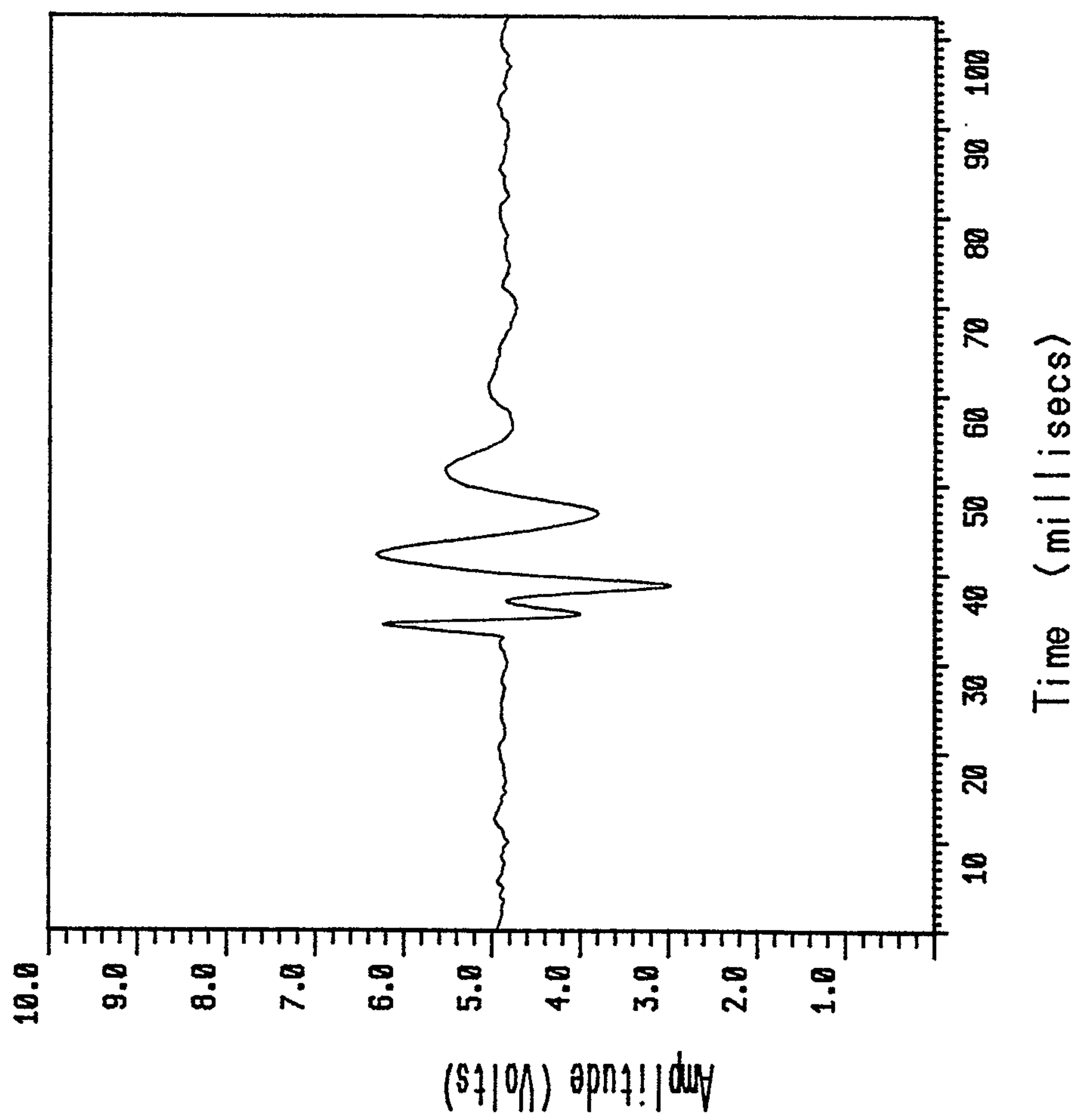


Fig. 4.1.3 - Subject 4 opening click, wave pattern and power spectrum.

2057 mv. The spectral analyses also had great variability, with numerous peaks most frequently occurring in the 30 and 90 Hz regions. The average peak frequency was 99 Hz, SD 24 Hz.

Subject 4

This subject had had a reciprocal click on the left side for over forty years. The opening click was hard, and occurred late in the opening cycle. Although a closing click could be palpated, it could not be recorded.

The tracing from this subject was remarkably consistent, always showing five peaks with a sudden change in polarity between the first and second peaks causing a supplementary peak. Average duration for these clicks was 35 ms, SD 1.6 ms, whilst the average maximum amplitude was 2927 mv, SD 323 mv. The spectral analyses also displayed great consistency with peaks occurring in the 30, 120, 260 and 350 Hz regions. The average peak frequency was 114 Hz, SD 5.2 Hz.

Subject 5

This subject, who displayed bilateral opening clicks, had been aware of the clicking for over twenty years. The left temporomandibular joint had been painful for the previous two months. The left joint also had a closing click which could be palpated but not recorded.

The tracing of the left joint displayed three peaks with a sudden change in polarity between the first and second peaks giving rise to a supplementary peak. The average duration for this click was 30 ms, SD 9.2 ms, whilst the average maximum amplitude was 5219 mv, SD 1247 mv. The spectral analyses did not show great consistency with peaks most frequently in the 90, 240 and 420 Hz regions. The average peak frequency was 84 Hz, SD 32 Hz.

The right side click displayed four peaks, with no sudden changes in polarity anywhere in its course. The tracing

showed remarkable consistency both in form and amplitude. The average duration for the clicks was 25 ms, SD 1.1 ms, whilst the average amplitude was 7388 mv, SD 908 mv. The spectral analysis for this click also showed good consistency, with a single major peak, the average of which was 100 Hz, SD 0 Hz.

Subject 6

This subject displayed bilateral clicking upon opening. No clicks could be discerned on either side during closure. The click on the right side had been present for over ten years. Orthodontic treatment had been carried out to remedy this click seven years previously. Unfortunately this not only failed to remove the right side click but following this treatment a click developed on the left hand side. Both left and right clicks were hard and occurred early in the opening cycle.

The tracings of the clicks on the right side showed an exceedingly complex pattern, representing two clicks which usually followed one another but on occasions overlapped. On one occasion only one click was displayed. The number of peaks displayed varied from five to eleven. Some tracings showed rapid changes in polarity, whilst others did not. The average duration for these clicks was 51 ms, SD 8.6 ms, whilst the average peak amplitude was 6198 mv, SD 837 mv. The spectral analyses for these clicks displayed numerous peaks, with the most common occurring at 30, 80, 160, 350 and 540 Hz. The average peak frequency was 116 Hz, SD 60 Hz.

The tracings of the left side click were less complex than those of the right side. These tracings also revealed a double click, with a varying degree of time between the two clicks. The second, or major click displayed great consistency in both form, with five peaks, and amplitude. The first click, however, showed a great variety of amplitudes, ranging from barely being discernible to being

Subject code: 7
 L or R: LEFT
 O or C: CLOSE
 Gain factor: 2800

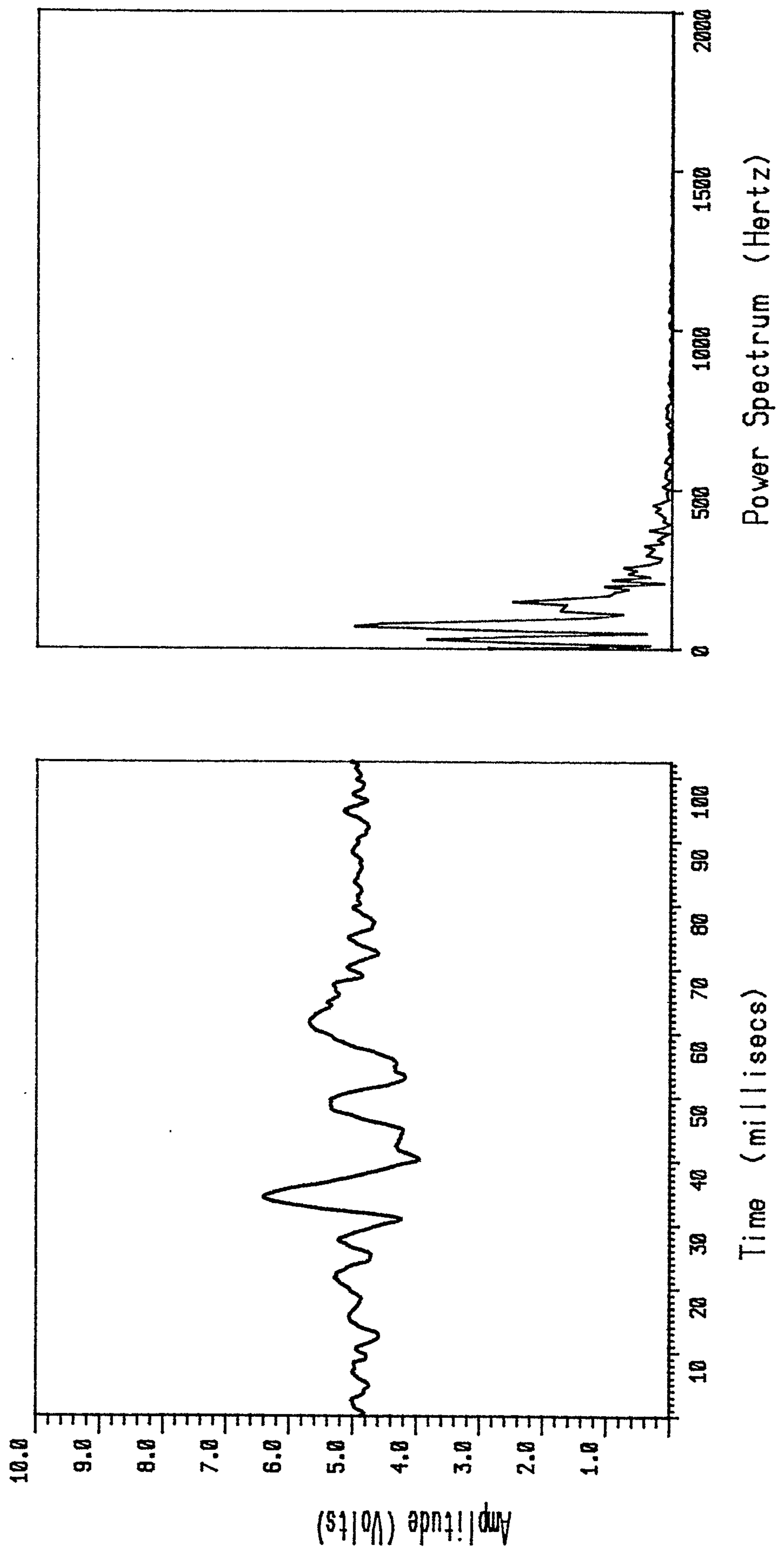


Fig. 4.1.4 - Subject 7 closing click, wave pattern and power spectrum.

equal to that of the second click. The form of this click was consistent, it having two major peaks. Neither click showed any rapid changes in polarity. The spectral analyses showed two major peaks in the 30 Hz and the 100-130 Hz range. The average peak frequency was 122 Hz, SD 16 Hz. The average maximum amplitude for the clicks was 7332 mv, SD 853 mv, whilst the average duration for the clicks was 9 ms for the first click, 11 ms for the gap between the first and second clicks, and 39 ms for the second click.

Subject 7

This subject displayed a left side closing click very early in the closing cycle. The click was soft, and had been present for as long as the subject could remember. At no time had the click caused pain or discomfort.

The tracing of the click showed a complex form with five major peaks. The third peak on three occasions showed a rapid change in polarity resulting in double peaking. The form of the click was not consistent. The average duration for the click was 49 ms, SD 4.1 ms, the average maximum amplitude being 3027 mv, SD 643 mv. The spectral analyses of the clicks showed frequency peaks most often at 30, 70 and 150 Hz. The average peak frequency was 73 Hz, SD 4.8 Hz.

Subject 8

This subject displayed clicking and crepitus on opening and clicking on closing on the left side, and on the right clicking on opening. Both sides had displayed joint noise for over forty years. Neither joint caused the subject any concern.

The left side tracings of opening displayed very rapid changes in polarity followed by a prolonged period of gradual changes in polarity. The rapid changes in polarity consisted of four sharp peaks, followed by up to

Subject code: 8

L or R: LEFT

Peak to peak (mV): 2428

O or C: OPEN

Maximum at (Hz): 78

Gain factor: 2800

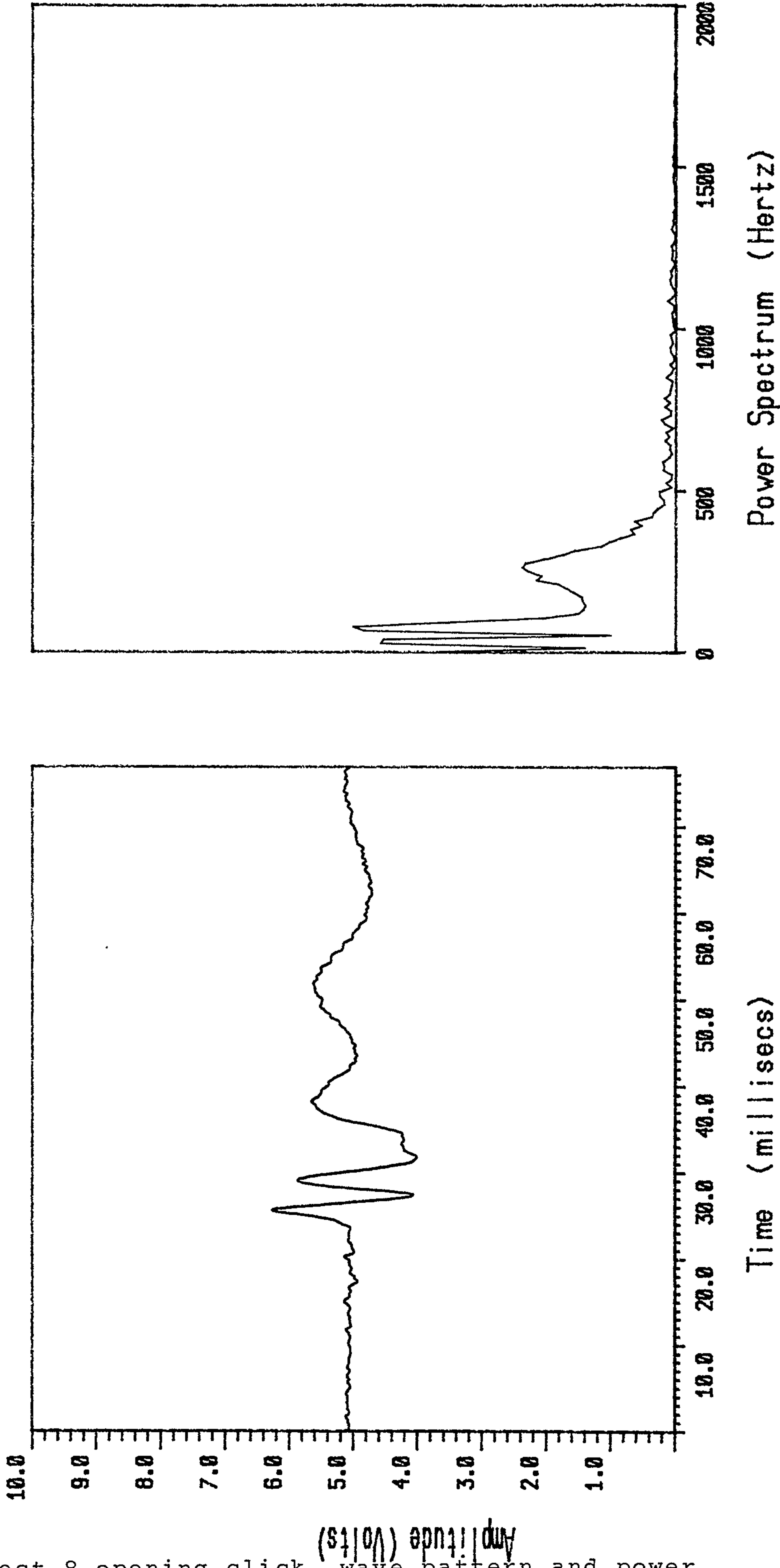


Fig. 4.1.5 - Subject 8 opening click, wave pattern and power spectrum.

three more rounded peaks. The average duration of these tracings was 62 ms, SD 7.5 ms. The average maximum amplitude was 2045 mv, SD 1226 mv. The form of the tracings for these clicks was variable, whilst the spectral analyses showed a degree of consistency, the most common frequency peaks being 30, 70 and 260 Hz. The average peak frequency for this side was 54 Hz, SD 24 Hz.

The tracings of the left side closing clicks for this subject generally consisted of a simple form with three peaks and no rapid changes in polarity, but there was great variability. One click displayed five peaks, with a rapid polarity change on the fourth peak causing a double peak. The average duration of the click was 22 ms, SD 8.2 ms, the average amplitude being 2683 mv, SD 1576 mv. The spectral analyses also showed variability, the most common frequency peaks being at 40, 90, 240 and 330 Hz. The average peak frequency was 117 Hz, SD 50 Hz.

The tracings of this subject's right side click showed greater uniformity than those of the left side. In each tracing, six major peaks were displayed, and in four of the ten a change in polarity between the second and third peaks was visible to a varying degree. The average duration for these clicks was 42.3 ms, SD 3.4 ms, whilst the average maximum amplitude being 4663 mv, SD 839 mv. The spectral analyses displayed peaks most frequently at 30, 90 and 300 Hz, whilst the average peak frequency was 30 Hz, SD 0.

Subject 9

This subject's left side click had been present for over ten years and had never been painful. The click was extremely loud and hard and occurred late in the opening cycle. There was no click detectable by any means on closing. The tracing of the click displayed great consistency with four major peaks, the first two being by far the most pronounced followed by a gradual return to

the baseline. The average duration of the clicks was 33 ms, SD 4.3 ms, the average maximum amplitude being 5865 mv, SD 670 mv. The spectral analyses also showed good consistency, with a short sharp peak at 30 hertz, a large peak in the 150-180 Hz range that covered a large area and tapered off in the 750 Hz region and a third minor peak that varied from 900 to 1200 Hz. The average peak frequency was 174 Hz, SD 9.7 Hz.

Subject 10

A reciprocal click had been present in this subject's right temporomandibular joint for over twenty years. The opening click was very loud, being audible some distance from the patient, and occurred late in the opening cycle. Although a closing click could be palpated, it could not be recorded. The tracings of the clicks recorded showed general consistency in form, displaying wave patterns with seven peaks, the first five of which occurred very rapidly. Two tracings showed sudden reversals in polarity over the course of the wave pattern, but these two did not coincide. The amplitude of the tracing varied, the average being 6734 mv, SD 1502 mv whilst the duration was more consistent with an average of 41 ms, SD 3.1 ms. The spectral analyses of the clicks varied consistently with the variety in the amplitude, the trend being for an initial large peak in the 170 Hz region that tapered to a minimum in the 500 to 600 Hz region, followed by three minor peaks up to 2000 Hz. The average peak frequency was 118 Hz, SD 63 Hz.

Subject 11

This subject had bilateral reciprocal clicking which had been present for as long as the subject could remember. The subject had experienced pain in both joints over the previous six months, and had sought treatment. Unfortunately the subject felt unwell during the course of the recording, so only clicking of the left temporomandibular joint was captured.

Subject code: 11
L or R: LEFT
O or C: OPEN
Gain factor: 28

Peak to peak (mV): 4054
Maximum at (Hz): 136

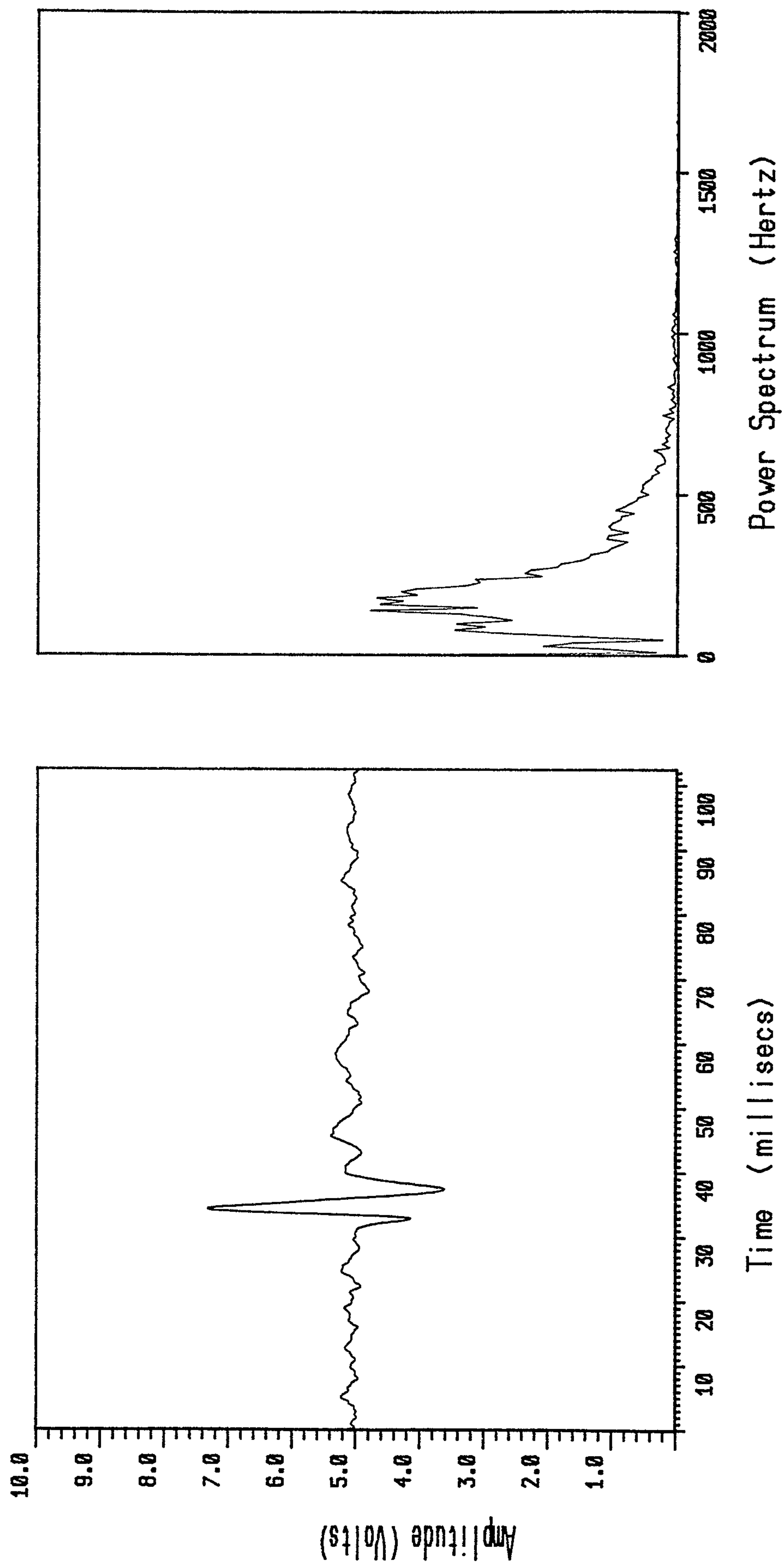


Fig. 4.1.6 - Subject 11 opening click, wave pattern and power spectrum.

Subject code: 11
L or R: LEFT
O or C: CLOSE
Gain factor: 28

Peak to peak (mV): 1108
Maximum at (Hz): 68

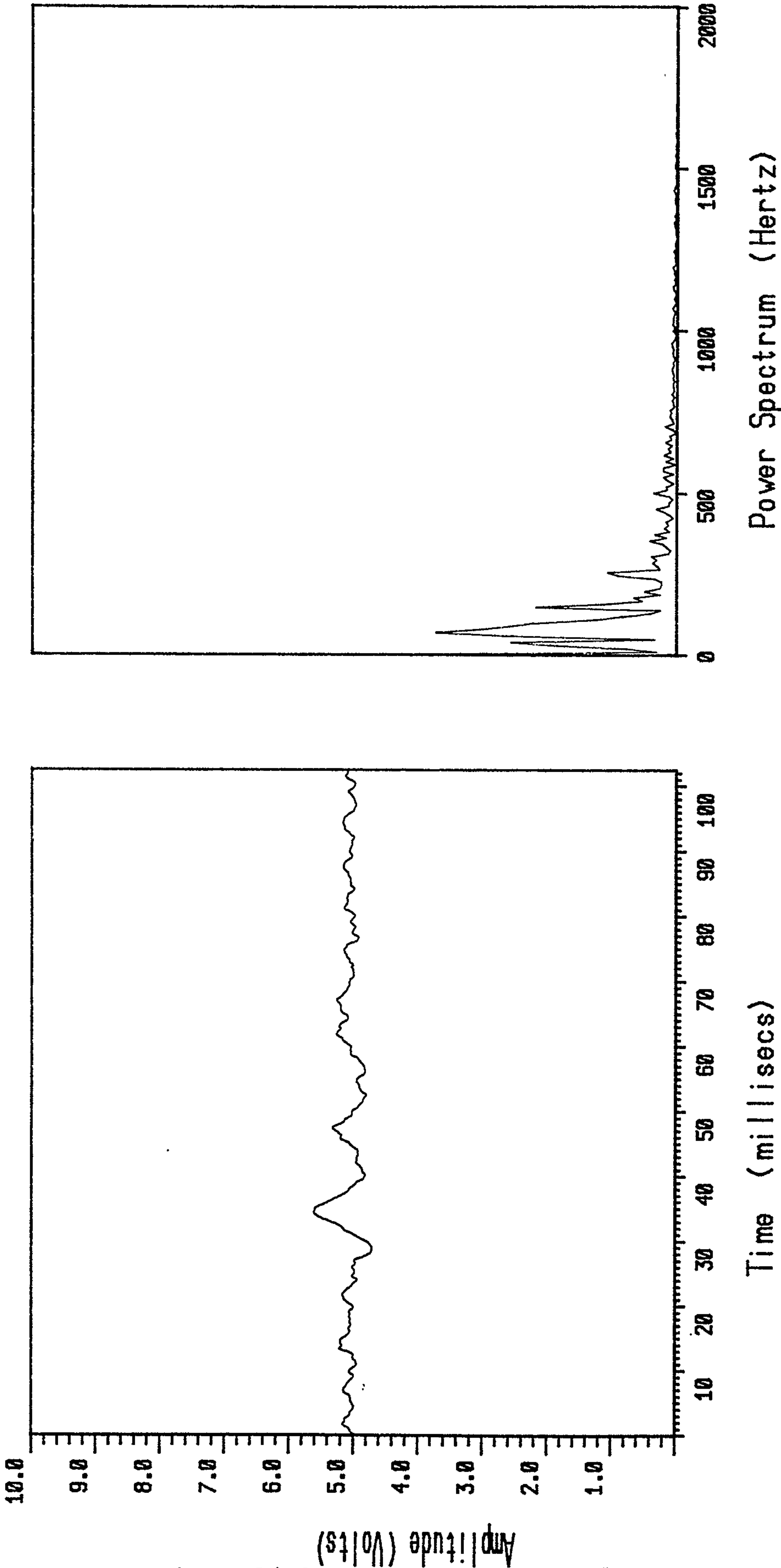


Fig. 4.1.7 - Subject 11 closing click, wave pattern and power spectrum.

The tracing of the opening click revealed a simple three peaked pattern of relatively short duration. The pattern of the click was consistent, however the amplitude was very variable, and ranged from a maximum of 7200 mv to a minimum of 2350 mv. The average maximum amplitude was 4121 mv, SD 1853 mv. The duration of the click was more consistent, the average being 10 ms, SD 1.0 ms. The spectral analysis showed consistent peaking generally at 150 Hz and reaching the baseline in the 700 to 1000 Hz region. The average peak amplitude was 156 Hz, SD 16.9 Hz.

The closing click displayed a click of longer duration than the opening click, with five wave peaks, As for the opening click, the amplitude was variable, the average maximum being 1098 mv, SD 320mv. The average duration was 26 ms, SD 3.3 ms. The spectral analysis showed multiple peaking from 30 to 250 Hz, the average peak frequency being 67 Hz, SD 12.9 Hz.

Subject 12

This subject, a twenty three year old male dental student, displayed a left sided reciprocal click and on the right side a single opening click. The tracing of the right click displayed a multi peaked pattern, the number of peaks varying from 8 to 11. The click was of long duration, the average being 66 ms, SD 13.3 ms. Between the second and third peaks there was at least an indication of a rapid change in polarity on each tracing. The overall trend of the tracings was consistent, however, there was some variability in the rapidity of the initial four peaks of the wave pattern. The average amplitude of the clicks was 4536 mv, SD 1544 mv. The spectral analyses varied with the rapidity of the wave pattern, some clicks showing no frequency components above 250 Hz, whilst others showed frequency components up to 1500 Hz. The general trend was for frequency peaks in the 40, 80, 200 and 360 Hz regions. The average peak frequency was 91 Hz, SD 38.5 Hz.

The tracings of the left side showed the opening click to be a double click with a variable amount of time between the first and second clicks, this time ranging from 0 to 35 ms. The average duration of the clicks when combined was 46.9 ms, SD 8 ms. The wave pattern of the first click consisted of five peaks, and in five of the ten tracings between the second and third peak there was an indication of a change in polarity. The second click was always of less magnitude than the first and displayed a simpler wave form with three major peaks and no change in polarity between major peaks. The average maximum amplitude for these clicks was 2720 mv, SD 1070 mv. The spectral analyses for these clicks displayed generally four major peaks in the 40, 100, 220 and 400 Hz regions. No tracing showed any frequency component above 600 hertz. The average peak frequency was 105 Hz, SD 10.6 Hz.

The left side closing click tracings showed a consistent simple wave form of four peaks, the average duration being 33.5 ms, SD 3.6 ms. The average maximum amplitude for these clicks was 2073 mv, SD 608 mv. The spectral analysis showed great consistency with two major peaks in the 30 and 80 Hz regions, with very little frequency component above 200 Hz. The average peak frequency was 81 Hz, SD 7.8 Hz.

Subject 13

This subject, a twenty three year old male dental student, had been aware of bilateral clicking for over ten years. Two years previously jaw exercises had been prescribed which had decreased the loudness of the click. Six months following treatment, however, the clicking returned to pre-treatment levels. At no time had the clicking of either temporomandibular joint caused pain or discomfort, although the subject did report that it was more noticeable during times of stress, particularly examinations.

The tracings of the left opening click revealed a simple pattern of two major peaks of low amplitude and short duration. In four of the ten opening cycles, no click was recorded. The average peak amplitude for these clicks was 958 mv, SD 430 mv, the duration average being 13 ms, SD 0.4 ms. The spectral analyses proved to be irregular, the most frequent peaks occurring at 100 and 160 Hz. Very low irregular peaks continued on all tracings until 1500 Hz. The average peak frequency was 123 Hz, SD 29.4 Hz.

The left closing click proved to produce a far greater amount of vibration than did the opening. The click was present on each closing cycle. The wave form of the tracings proved to be remarkably consistent, each tracing having three major peaks. The maximum amplitude was also consistent. No tracing showed any sign of rapid polarity reversal. The average maximum amplitude for these clicks was 6082 mv, SD 348 mv, whilst the average duration was 10.1 ms, SD 0.3 ms. The spectral analysis also proved to be uniform in outline, consisting of a single major peak in the 160 Hz region that tapered towards the baseline at 500 Hz. The average maximum frequency for these clicks was 159.5 Hz, SD 23.5 Hz.

The right side opening click tracings were similar to those of the left side, displaying simple low amplitude short duration wave patterns with two major peaks. The click was not always present for each opening cycle. The average maximum amplitude was 1118 mv, SD 293 mv, whilst the average duration was 14.3 ms, SD 1.6 ms. The spectral analyses revealed a major peak in the 80 Hz region with lesser peaks in the 160, 260 and 350 Hz areas. Each recording revealed some frequency components up to 1500 Hz, though only on a very minor scale. The average peak frequency was 91 Hz, SD 10.69 Hz.

The right closing click was, as for the left side, a far more pronounced click than the opening. The wave pattern

Subject code: 14
L or R: RIGHT
O or C: OPEN
Gain factor: 28

9-May-89

Peak to peak (mV): 7242
Maximum at (Hz): 126

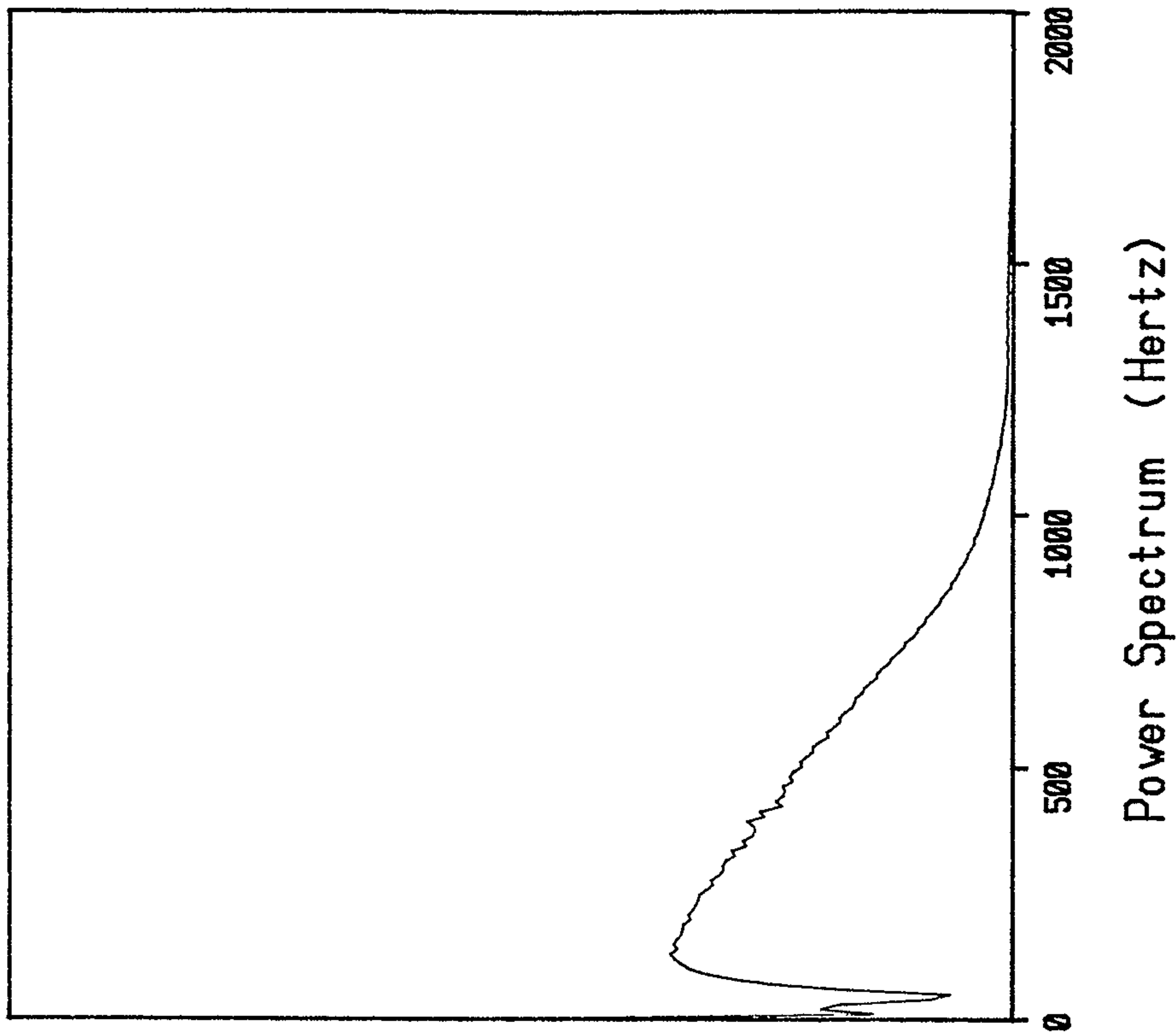
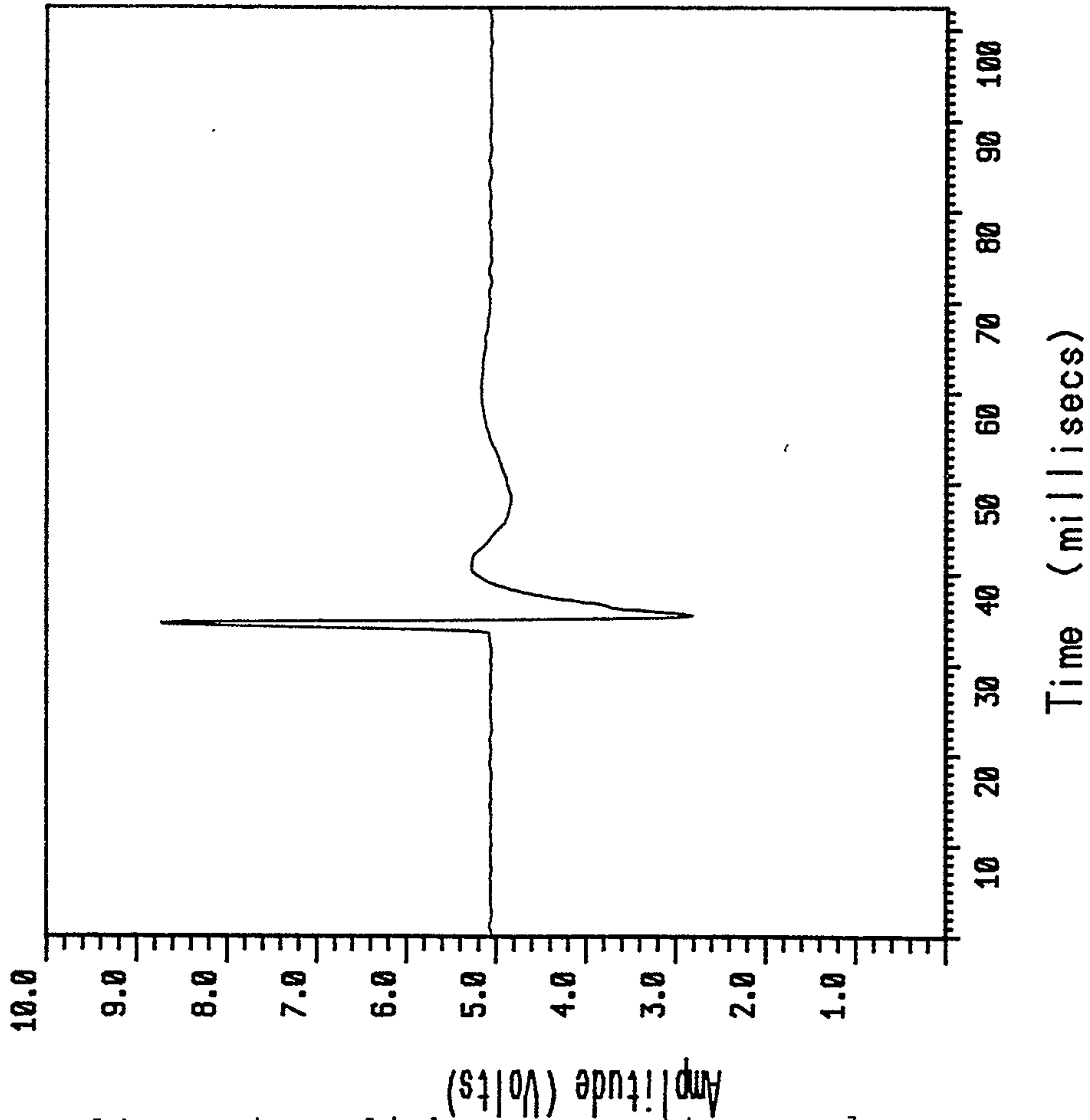


Fig. 4.1.8 - Subject 14 opening click, wave pattern and power spectrum.

of this click was more complicated than that of the left side, however, showing four major peaks and a sudden polarity reversal between the second and third peaks resulting in a supplementary peak. The pattern of the wave form was consistent, the amplitude, however, was not. The average maximum amplitude was 2639 mv, SD 801 mv. The average duration was 16.6 ms, SD 0.9 ms. The spectral analyses of the clicks always revealed two major peaks, the first and largest in the 120 Hz region, and the second, smaller and more variable in its position, in the 250 to 350 Hz region, falling to a minimum in the 500 Hz range. The average peak frequency was 118 Hz, SD 6.7 Hz.

Subject 14

This subject was a seventeen year old dental nurse seeking treatment for a disturbingly loud right side opening click. The click was hard and could be provoked by the manner in which the subject opened her mouth. The click itself caused no pain, but its loudness was causing the patient some concern.

The tracings of the recorded clicks showed an extremely short, sharp wave pattern with two major peaks. The amplitude was extremely variable, on some occasions barely being recorded and on others saturating the recording equipment. The wave pattern and duration, however, were consistent. The average maximum amplitude was 3554 mv, SD 2493 mv, whilst the duration mean was 4.6 ms, SD 1.0 ms. The spectral analyses of these clicks displayed a single peaked tracing that originated in the 50 Hz area, peaked in the 140 to 320 Hz range and then gradually tapered off to a minimum in the 1600 Hz range. The average maximum frequency was 204 Hz, SD 93.1 Hz.

Subject 15

This subject, a thirty-two year old public servant, had had bilateral opening clicks for over fifteen years. The clicks were painless, but over the previous twelve months

head and neck pain had developed causing the subject to seek treatment. The clicks were hard in nature, and occurred early in the opening cycle. No closing clicks could be recorded, although the subject reported that he could feel a right side closing click.

The left side opening click was simple in pattern but varied in number of peaks, amplitude and duration. Most commonly there were four peaks in the wave pattern, but three peaks and six peaks were recorded. No pattern showed any sudden polarity reversal. The mean maximum amplitude was 2301 mv, SD 1045 mv, the duration mean being 16.9 ms, SD 3.3 ms. The spectral analyses of these clicks revealed a single irregular major peak in the 160 Hz region, the peak beginning at 50 Hz and reaching a minimum again at 500 Hz. A very small peak was also always present at 30 Hz. The average peak frequency was 166 Hz, SD 12.7 Hz.

The tracings of the right side opening click revealed a more complex click than that of the left side. The wave form was also more consistent, consisting of three major peaks with a sudden change in polarity between the first and second peaks causing a supplementary peak. The amplitude, however, was not consistent, the click on occasions barely being recordable. The mean amplitude was 1133 mv, SD 526 mv. The average duration for the clicks was 17.9 ms, SD 2.5 ms. The spectral analyses of the right side clicks was also more complex than that of the left side, with multiple peaks ranging from 30 to 260 Hz. The most commonly occurring peaks were at 30, 100, 170, 200 and 250 Hz. The average peak frequency for the click was 101 Hz, SD 4.3 Hz.

Subject 16

This subject, a forty-two year old unemployed male, had bilateral early opening and bilateral late closing clicks. The clicks had been present for over five years and had

been progressively worsening. In centric occlusion contact was only made on the anterior teeth. The subject reported these were wearing and as the wearing progressed so the click worsened. The clicking was extremely loud and occurred with a gross deviation of the mandible first to the right and then to the left early in the opening cycle. In spite of the loudness of the clicking, it was found very difficult to record the clicks without increasing the gain on the amplifying equipment until the background noise on the tracings was unacceptable.

The tracings of the left opening click revealed a double opening click, the time between the clicks being 500 ms. The second click was the shorter of the two with a simple two peaked wave pattern, whilst the first was more prolonged and had a three peaked wave pattern. Both clicks were extremely variable in their wave pattern. The average duration for the first click was 53.9 ms, SD 5.7 ms, whilst the average maximum amplitude was 3155 mv, SD 762 mv. The second click mean amplitude was 2933 mv, SD 693 mv, whilst the average duration was 22 ms, SD 8.7 ms. The spectral analyses for the first click revealed a multi peaked pattern from 30 to 300 Hz, the most common peaks being at 30, 70, 160 and 250 Hz. The average peak frequency was 29 Hz, SD 2.1 Hz. The second clicks' spectral analyses showed peaks also occurring from 30 to 300 Hz, the most frequent being at 30, 90, 150, 200 and 250 Hz. The mean peak frequency was 41 Hz, SD 8.7 Hz.

The left side closing clicks revealed a more uniform tracing than did the opening clicks. The wave form had a four peaked pattern with a polarity reversal between the first and second peaks on each tracing. The mean duration for these clicks was 40 ms, SD 5.0 ms, and the mean maximum amplitude 4875 mv, SD 435 mv. The spectral analyses revealed a multi peaked response from 30 to 300 Hz, the peaks most commonly occurring at 40, 80, 150 and

OPENING CLICK CHARACTERISTICS

SUBJECT	GAIN	PEAKS POLARITY REVERSAL	DURATION MILLISECONDS	SD MILLISECONDS	AMPLITUDE MILLIVOLTS	SD MILLIVOLTS	PEAK FREQUENCY Hz	SD Hz
1R	2800	4 yes	20.6	1.22	2622	1094	95.4	65.7
2L	2800	3 yes	34.6	0.7	3447	1209	97.8	12.0
3R	2800	5 yes	34.0	2.6	2111	643	81.0	3.8
3L	2800	4 no	28.0	6.2	3144	2057	99.0	24.0
4L	1400	5 yes	35.0	1.6	2927	323	114.0	5.2
5L	5000	3 yes	30.0	9.2	5219	1247	84.0	32.0
5R	5000	4 no	25.0	1.1	7388	908	100.0	0
6R	1400	5-11 yes	51.0	8.6	6198	837	116.0	60.0
6L	28	5 no	39.0	2.2	7332	853	122.0	16.0
8L	5000	7 no	62.0	7.5	2045	1226	54.0	24.0
8R	5000	6 yes	42.3	3.4	4663	839	30.0	0
9L	20	4 no	33.0	4.3	5865	670	174.0	9.7
10R	1400	7 yes	41.0	3.1	6734	1502	118.0	63.0
11L	2800	3 no	10.0	1.0	4121	1853	156.0	16.9
11R	2800	8-11 yes	66.0	13.3	4536	1544	91.0	38.5
12L	2800	8 yes	46.9	8.0	2720	1070	105.0	10.6
13L	2800	2 no	13.0	0.4	958	430	123.0	29.4
13R	2800	2 no	14.3	1.6	1118	293	91.0	10.69
14R	28	2 no	4.6	1.0	3554	2493	204.0	93.1
15L		3-6 no	16.9	3.3	2301	1045	166.0	12.9
15R		3 yes	17.9	2.5	1133	526	101.0	4.3
16L	8000	3 yes	53.9	5.7	3155	762	29.0	2.1
16R	8000	3 yes	55.4	5.2	3328	1767	34.4	5.26

Table 4.1 - Summary of opening click characteristics.

CLOSING CLICK CHARACTERISTICS.

SUBJECT	GAIN	PEAKS POLARITY REVERSAL	DURATION MILLISECONDS	SD MILLISECONDS	AMPLITUDE MILLIVOLTS	SD MILLIVOLTS	PEAK FREQUENCY Hz	SD Hz
1R	2800	3 no	10.6	0.5	3961	1288	140.5	41.9
7L	2800	5 yes	49	4.1	3027	643	73.0	4.8
8L	5000	3 no	22	8.2	2683	1576	117.0	50.0
11L	2800	5 no	26	3.3	1098	320	67.0	12.9
12L	2800	4 no	33.5	3.6	2073	608	81.0	7.8
13L	2800	3 no	10.1	0.3	6082	348	159.5	23.5
13R	2800	4 yes	16.6	0.9	2639	801	118.0	6.7
16L	8000	4 yes	40	5.0	4875	435	76.0	19.6

Table 4.2 - Summary of closing click characteristics.

250 Hz. The peaks at 30 and 80 Hz were present for each click. The mean peak frequency was 76 Hz, SD 19.55 Hz.

Tracings of the right side opening click had the same features as the first opening click on the left side, that is, a prolonged three peaked wave form with polarity reversal between the first and second peak. The pattern of the click was variable, however. On three occasions there were two additional peaks. The average duration for these clicks was 55.4 ms, SD 5.2 ms, whilst the mean maximum amplitude was 3328 mv, SD 1767 mv. The spectral analyses consisted of a multiple peaked response between 30 and 300 Hz, the most commonly occurring peaks at 30, 60, 100, 150 and 250 Hz. The mean peak frequency was 34.4 Hz, SD 5.26 Hz.

Unfortunately, due to the need for a great amplification and therefore a high background noise, no useful information could be gleaned from the right side closing click recordings.

4.2 SIMULTANEOUS RECORDING OF CLICK AND MANDIBULAR MOVEMENT

Subject 1

This subject displayed a classic description of a reciprocal click, that is a click on opening and on closing, the two clicks occurring at differing distances from centric occlusion.

The opening click occurred 7mm. into the opening cycle. There was no increase in this distance from the first opening cycle to the tenth. As the opening click occurred there was no sudden shift in the direction of mandibular movement. The click coincided with maximum velocity of the mandibular movement in the open-close and anterior-posterior reference planes.

Subject code: 1
L or R: RIGHT

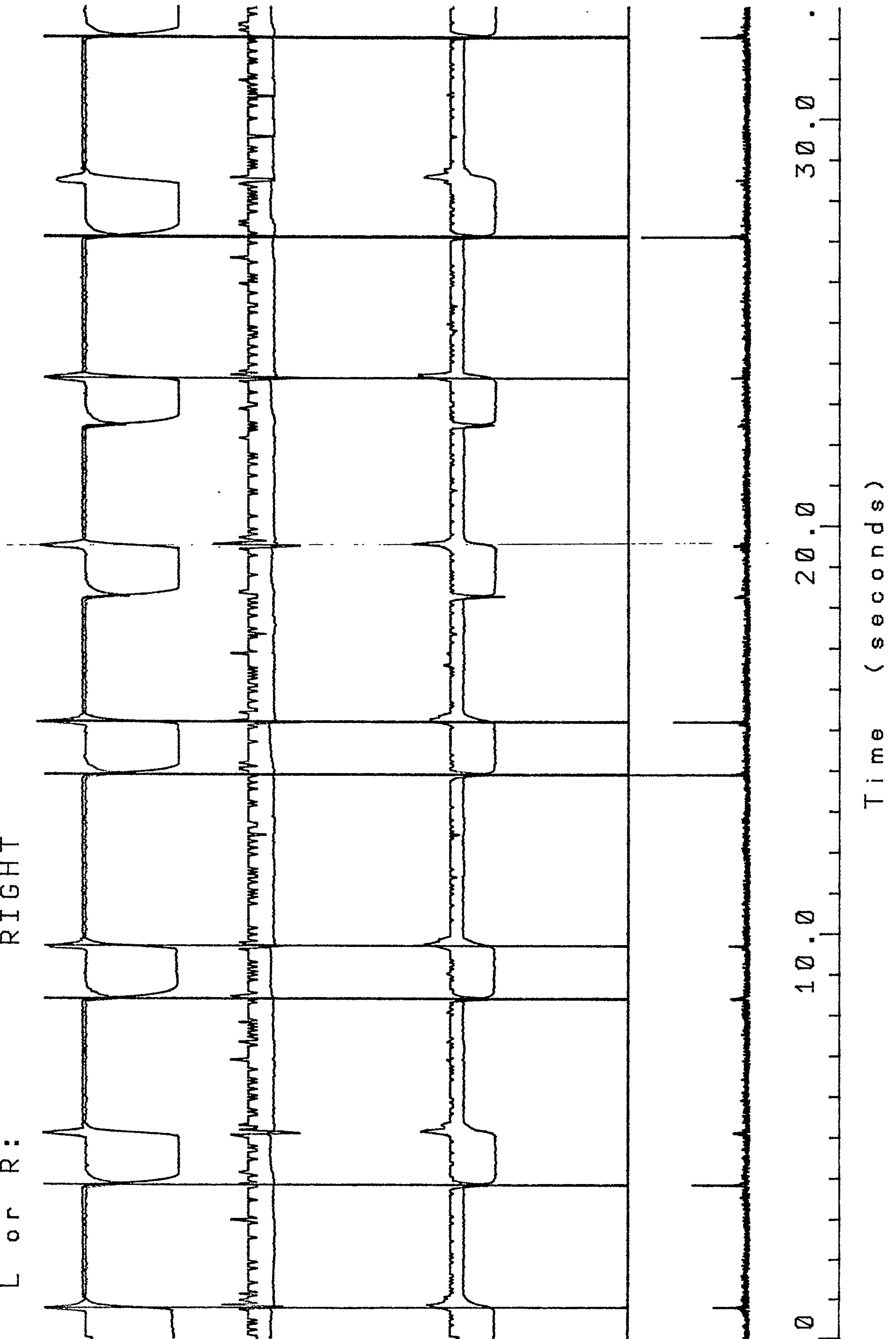


Fig. 4.2.1 - Subject 1, click and mandibular movement.

The closing click occurred 12mm. before occlusal contact and this did not change over the course of the recording. There were no sudden shifts visible in the anterior-posterior or open-close planes. In the left-right plane, however, there was a sudden 1mm. mandibular shift to the right immediately before the click. Immediately after the click there was a sharp 2mm. shift to the left followed by a more gradual 1mm. shift to the right again. Whilst the click coincided with the maximum velocity of mandibular movement in the open-close and left-right planes, it occurred before the maximum velocity in an antero-posterior direction.

Subject 2

This subject displayed a single opening click that occurred in the middle of the opening cycle. It was also apparent that the click was not present with each opening. When the click did occur it did so 12mm. into the opening movement. The click did not occur with any sudden shift in either the open-close or anterior-posterior planes. In the left-right planes, however, the click was immediately followed by a 3mm. shift to the right. This shift occurred whether a click was recorded or not. In no reference plane did the click coincide with maximum mandibular velocity.

The other noticeable feature of this subject's open-close cycle is the relative slowness of movement.

Subject 3

On the left side this subject displayed a single opening click. The click occurred 5 to 8 mm. into the opening cycle and was not present each time the subject opened. The click was not associated with the maximum velocity of jaw movement in any of the three planes, but was associated with a 2mm. deviation to the right. There was no sudden deviation after the click. If, during opening, the subject moved the mandible to the left 1mm., there was no click. As the open-close cycle recording progressed

there was no progressive increase in the amount of opening before the click occurred.

On the right side the click occurred 12 to 4mm. into the opening cycle. As the recording progressed, the distance from tooth contact to click decreased. As for the left side the click was associated with a deviation to the right as the subject opened. After the click there was a slight forward shift in jaw position. The click was not associated with maximum jaw velocity in any plane.

Subject 4

This subject had a single left opening click that occurred late in the opening cycle. The click occurred 18mm. from tooth contact and did not vary in its position throughout the recording. Prior to the click there was a 3mm. shift to the right. Immediately after the click there was a 1mm. mandibular shift to the left. This deviation to the right was maintained until the subject closed. In the open-close and antero-posterior plane there was no sudden shift in mandibular direction. The click was associated with a velocity peak in the antero-posterior plane. In the left-right plane the velocity tracing underwent a sudden polarity reversal as the click occurred so that the velocity at the time of the click was 0.

Subject 5

On the right side this subject displayed a simple opening click. The click did not vary in its position in the opening cycle, occurring 18mm. from occlusal contact, after 8mm. deviation to the right and after 7mm. posterior movement of the mandible. Immediately after the click there was either a decrease in the velocity with which the mandible moved to the right, or a slight mandibular shift to the left. At the time of the click the left-right velocity of the mandible was 0. During closing there was no sudden shift in movement in any plane and no corresponding click.

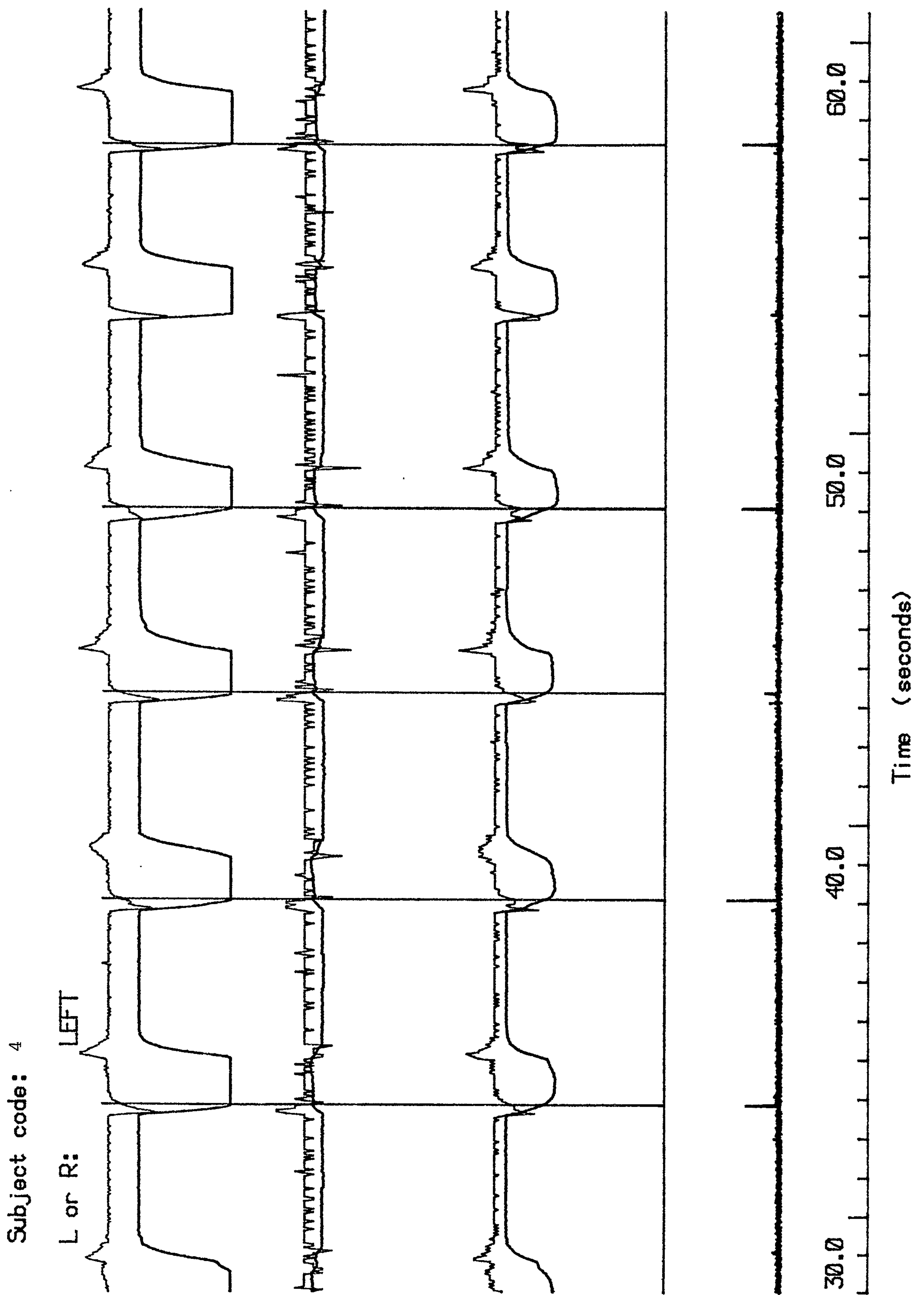


Fig. 4.2.2 - Subject 4, click and mandibular movement.

On the left side the opening click occurred in the same place as did the right, that is, 18mm. from tooth contact, after an 8mm. deviation to the left and after 7mm. of posterior movement of the mandible. As for the right side the click occurred with a sudden decrease in movement to the left and in some cases a very slight shift to the right. At the time of click, the left-right velocity approached 0. On one of the open-close cycles a closing click was recorded. This occurred near the end of the closing movement 7mm. from tooth contact, that is at a different mandibular position from the opening click and as such is indicative of a reciprocal click (Klineberg 1986). When the closing click occurred there was no sudden change in direction or velocity in any plane of mandibular movement.

Subject 6

The right side click of this subject occurred after 10mm. of opening, 8mm. deviation to the right and 6mm. posterior movement of the mandible. The click was not associated with a sudden shift in any direction of the mandible. The click occurred concurrently with maximum mandibular velocity in all three planes. There was no closing click recorded and no sudden deviations in mandibular movement.

On the left side the click occurred after 10mm. opening and after 2mm. of deviation to the right, and corresponded with a decrease in the rate of movement to the right. Overall movement to the right was 4mm., whereas overall movement to the right when recording the click on the right side was 10mm., the click occurring after 8mm. of right movement. Antero-posteriorly the left click occurred after 2mm. of posterior jaw movement, the mandible moving a total of 7mm. When the right side click was recorded the mandible moved 9mm. posteriorly. At the time of clicking on the left side, whilst the velocity in the open-close and antero-posterior direction were at a

maximum, the left-right movement velocity decreased and then rose again after the click.

Subject 7

This subject's click occurred on the right side during closing. During opening the mandible deviated 14mm. to the right and the posterior movement of the mandible at the incisors was 13mm. During opening no click was recorded. The closing click occurred as soon as closing began at an opening of 18mm. Immediately before the click on closing, there was a very slight mandibular shift to the right and posteriorly. Immediately after the click, there was a mandibular shift to the left and anteriorly. The maximum velocity of movement occurred not at the same time as the click, but immediately afterwards.

Subject 8

On the right side this subject displayed a click on opening 18mm. into the movement with a 4mm. shift to the right and a 5mm. posterior displacement of the mandible. The click was not associated with any sudden hesitation or change in direction of the mandible. The velocity at the time of the click was at a maximum. On two occasions a closing click was recorded. This occurred 2mm. prior to tooth contact and was, as for the opening click, not associated with any hesitation or change in direction of the mandible. Whilst the velocity of movement was not at a maximum in any of the three planes, it did not suddenly reverse and reach zero at the time of the click.

The left side click on opening occurred at an opening of 12mm. with a 3mm. deviation to the right and a 3mm. posterior movement at the mandibular incisors. The click was not associated with any sudden shifts or hesitations in mandibular movement and was always associated with maximum mandibular velocity in all three planes of reference. The left side closing click occurred 2mm. from occlusal contact and followed movement of the mandible at

the incisors to the left and anteriorly. The click was not associated with a zero velocity but occurred after the velocity had reached its peak.

Subject 9

This subject displayed a very loud opening click on the left side. The click occurred late in the opening cycle at a distance of more than 18mm. from occlusal contact. There was no sign of a closing click. On opening the subject deviated 3mm. to the right, the mandible at the incisors moving 7mm. posteriorly. At the time of the click the mandible had moved to its maximum extent in both the open-close and anterior-posterior planes. Immediately following the click the mandible rapidly shifted 1mm. to the left but maintained its position in the antero-posterior plane. At the time of the click the velocity in all three planes was at zero. Immediately after the click, whilst the velocity in the open-close and antero-posterior planes remained at zero, there was a sharp rise in the velocity in the left-right plane. As the recording progressed, there was no shift in the position of the click.

Subject 10

This subject displayed a very loud click on the right side after 13mm. of opening. Throughout the recording the position of the click did not alter. The click occurred after 8mm. of deviation to the right. Following the click there was a further 2mm. right deviation followed by a rapid 3mm. deviation to the left. At the time of the click the velocity in the left-right plane was at a maximum. This was not the case in the open-close plane, the velocity here being just past its peak. Whilst there was no closing click, during closing the mandible initially deviated rapidly 3mm. to the right and then progressively left towards the midline until occlusal contact.

Subject 11

This subject unfortunately became ill during the experiment so that data for mandibular movement and clicking could not be recorded.

Subject 12

On the right hand side, this subject's click occurred after 3mm. of opening. There was no deviation of the mandible to either left or right before the click. Immediately after the click, however, there was an immediate 1mm. shift to the left, then a 1mm. shift to the right, a 1mm. shift to the left again and finally, as opening progressed, a 4mm. right deviation. The antero-posterior plane revealed 1mm. of rapid posterior movement before the click. Following the click for 200 milliseconds there was no further posterior movement. After this delay there was continuous posterior movement until a maximum of 7mm. had been reached. The maximum right deviation of the mandible was 4mm. During opening, the velocity of movement in the open-close and antero-posterior planes was at or near a maximum, whilst in the left-right plane the velocity was 0.

No closing clicks on the right side were recorded.

On the left side both opening and closing clicks were recorded. The opening click occurred after 2mm. of opening. On two occasions the click occurred after 5mm. of opening. The click did not change further in the opening cycle with subsequent recordings. Prior to the click, there was no deviation of the mandible to either left or right. Immediately following the click there was a rapid 1mm. shift to the left, followed by a 1mm. shift to the right, followed by 200 ms of no left-right movement, followed by a progressive deviation to the right until a maximum of 4mm. displacement had been reached. In the antero-posterior plane there was no movement either before or immediately after the click. At 200 ms

following the click, the mandible began to move posteriorly until a maximum displacement of 5mm. had been reached. At the time of the click, the velocity in the antero-posterior and left-right planes was at 0. In the open-close plane, the velocity at the time of the click showed a sharp reduction from maximum.

The left side closing click occurred 6mm. before occlusal contact. Prior to the click the mandible was moving to the left. Immediately following the click the mandible moved to the right. In the antero-posterior plane prior to the click movement had been anteriorly. Following the click the mandible moved posteriorly. In one case the opposite of this occurred, that is the mandible was moving anteriorly, deviated posteriorly 2mm., the click occurred and then the mandible moved anteriorly until occlusal contact. In other recordings there was only a hesitation in the anterior movement of the mandible at the incisors at the time of the click. At the time of the click the velocity in the open-close plane showed a decrease from maximum, whilst in the left-right and antero-posterior planes the velocity was zero. Throughout the recording the closing clicks maintained the same relative position.

Subject 13

On the right side this subject had a very soft click on opening and a much harder and more pronounced click on closing. Only two opening clicks were recorded during the ten open-close cycles. Both of these clicks occurred at openings of 18mm. Immediately after the click the rate at which the mandible moved posteriorly and to the left increased. The click occurred after 7mm. deviation to the right and 4mm. posterior movement. The mandible reached a position 9mm. to the right and 7mm. posterior to their relative positions at tooth contact. The velocity of movement in all three planes was at a maximum at the time of the click.

The right side closing click occurred 15mm. from tooth contact. This click also was not present on each closing cycle. At the time of the click, the mandible was moving anteriorly and to the left. The click had no effect on the direction or timing of the movement. The velocity of mandibular movement for all three planes of reference was at a maximum when the click occurred. The click occurred at the same position in the closing movement for each recording.

On the left side only the closing click was able to be recorded. This click occurred 15mm. before occlusal contact, the mandible being 5mm. to the right and 4mm. posterior to the occlusal contact position. After the click there was a reduction in the rate of movement in all three planes of reference. At the time of the click the velocity of movement in all three planes was at a maximum and decreased sharply after the click. Throughout the recording the position of the click did not alter.

Subject 14

This subject had an extremely loud, hard click on the right side during opening. The click varied in its position during opening, the minimum distance from tooth contact being 12mm., the maximum 22mm. The most frequent distance was 14mm. Two features were most notable about this subject. Firstly the extreme variability of movement in all three planes. Secondly, the click only occurred if the subject protruded the mandible during opening. If the more normal retrusion occurred during opening then no click ensued. During opening the subject mandible deviated to the left. This deviation appeared to have no bearing on the occurrence of a click. On those tracings displaying a smooth, sharp posterior opening movement with a slow deviation to the left, no click was recorded. At the time of the click the velocity in all three planes of reference was at a maximum.

Subject code: 14

L or R: RIGHT

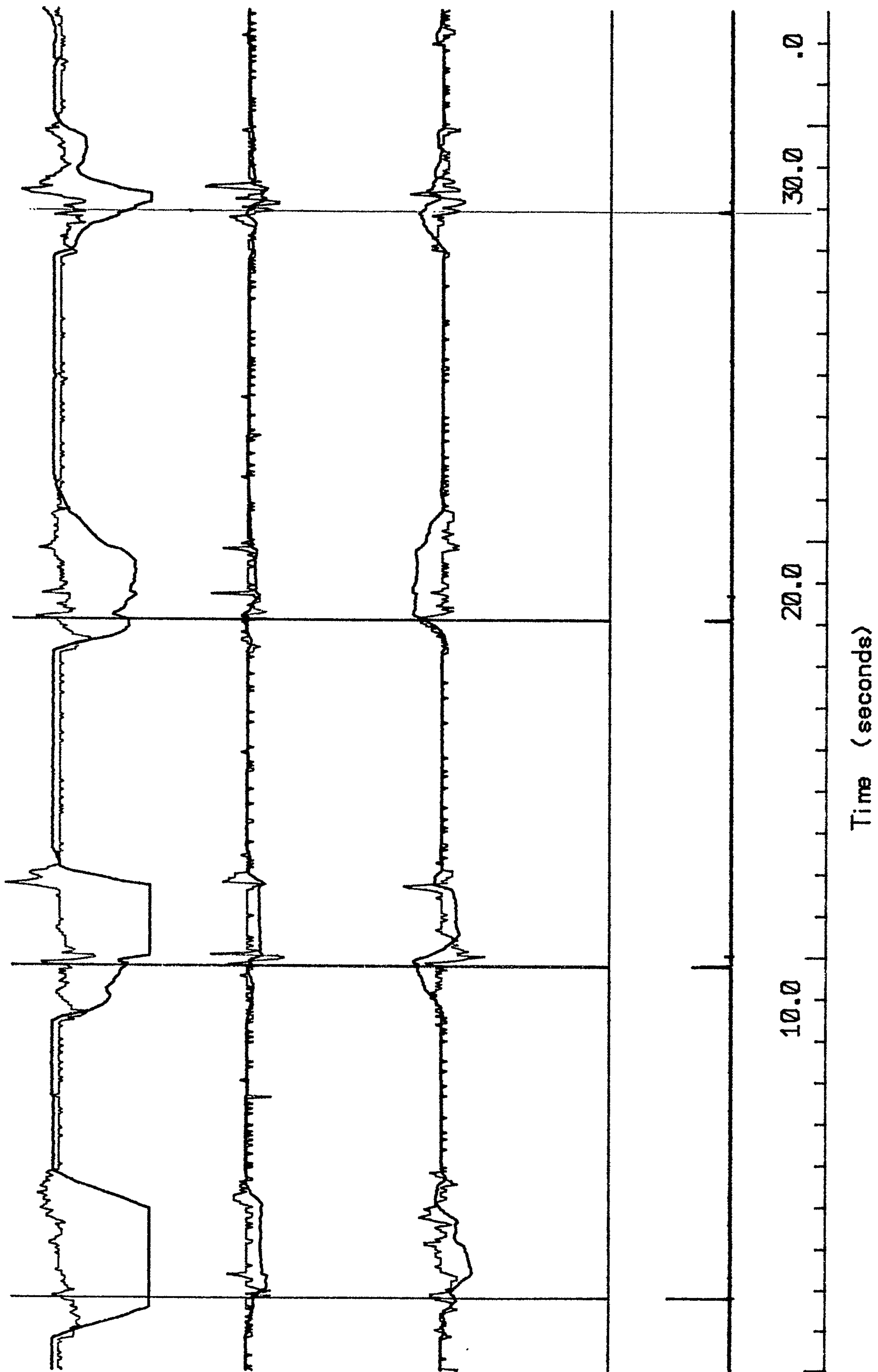


Fig. 4.2.3 - Subject 14, click and mandibular movement.

Subject code: 14

L or R: RIGHT

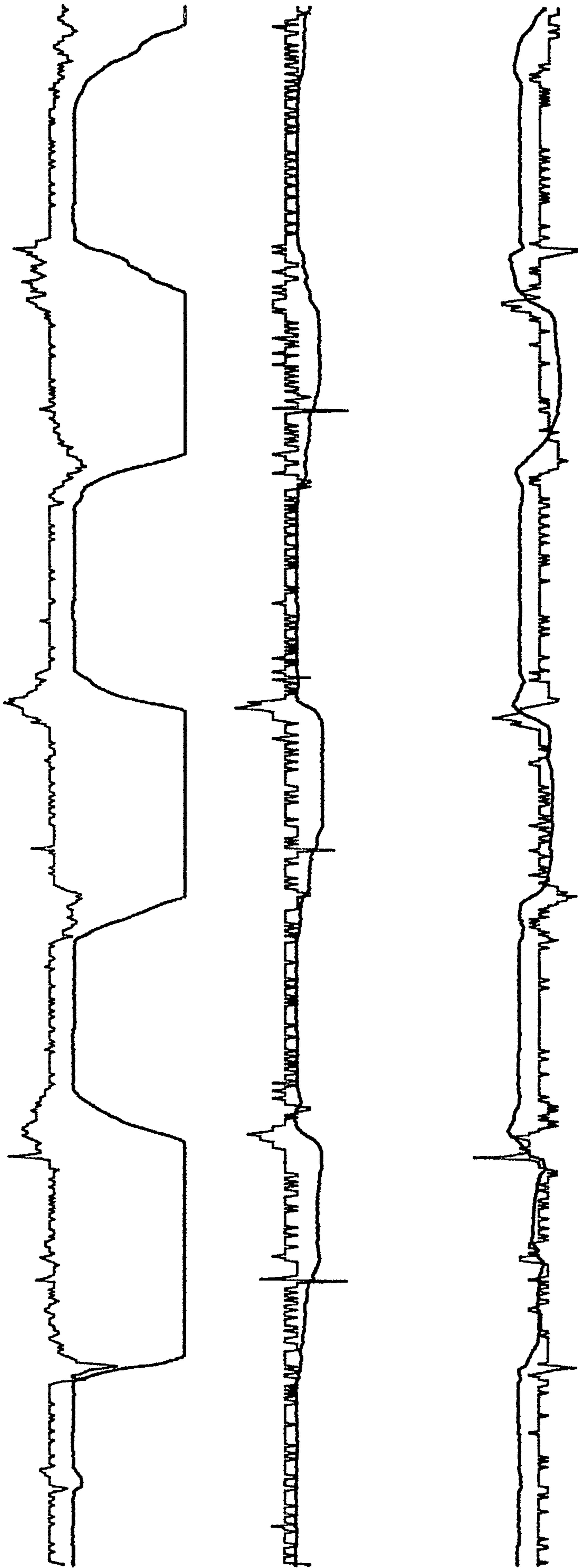


Fig. 4.2.4 - Subject 14, mandibular movement when no click occurred.

Subject 15

This subject displayed an opening click on both the right and left sides. On the left side the click occurred after 2mm. of opening. This did not vary throughout the recording. There was no deviation to left or right before the click. Immediately following the click, the mandible at the central incisors deviated 2mm. to the left. In the antero-posterior plane, posterior movement occurred both before and after the click, with no hesitation in movement during the click. The left-right velocity at the time of the click was zero, whilst the velocity in the antero-posterior and open-close planes was increasing to a maximum, which occurred just after the click. The deviation to the left of these recordings ranged from 0 to 2mm.

The tracings of the right side click revealed a click that occurred after 2mm. of opening. In contrast to the recording of the click on the right side in which the mandible moved a maximum of 2mm. to the left, the mandible during recording of the right side click always moved 6mm. to the left. The same degree of posterior movement occurred during recordings of both sides. The click occurred after the beginning of movement to the left, unlike the right side which clicked just before movement to the left. At the time of the click the velocity in all three reference planes was at a maximum. This also differs from the right side recording. Throughout the recording the position of the click did not become progressively later in the opening cycle.

Subject 16

This subject had bilateral opening and closing clicks. On the left side the opening click occurred 9mm. into the opening movement. On the open-close plane at the time of the click there was a hesitation in the movement. On the left-right plane, the initial movement was a rapid 3mm. displacement to the right followed by a rapid 8mm.

Subject code: 15

L or R: LEFT

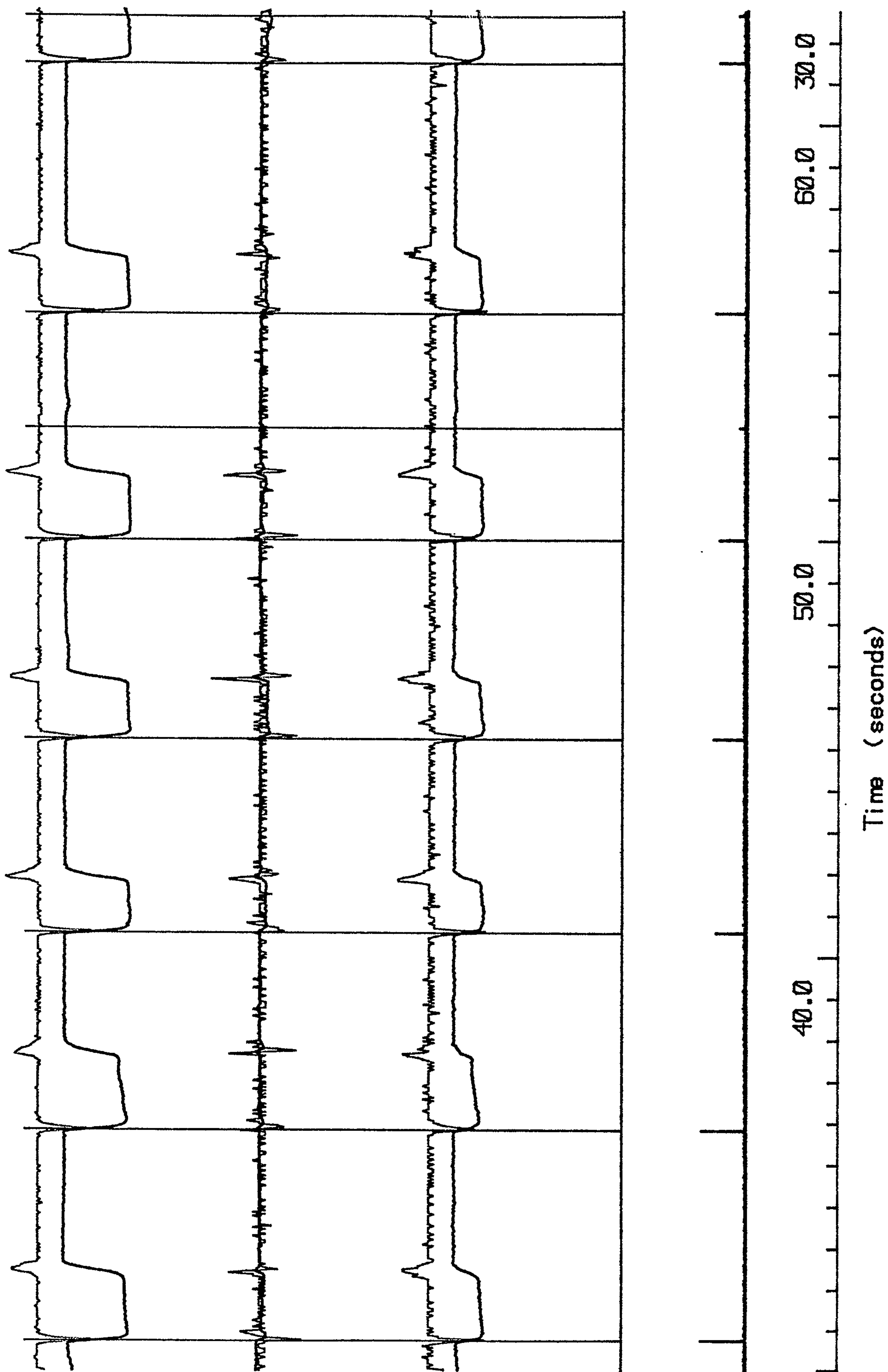


Fig. 4.2.5 - Subject 15, click and mandibular movement, left side.

Subject code: 15
L or R: RIGHT

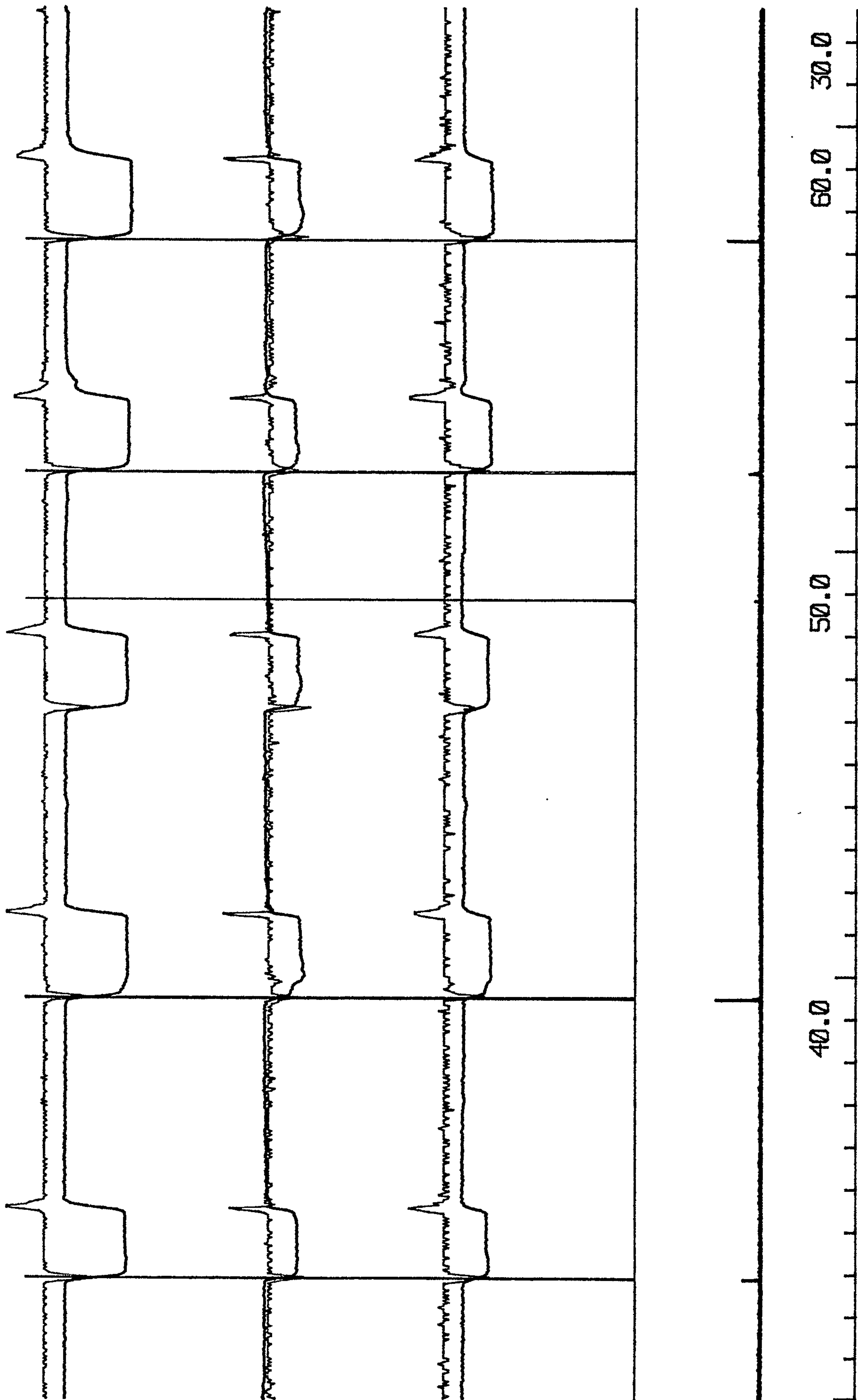


Fig. 4.2.6 - Subject 15, click and mandibular movement, right side.

displacement to the left. At the point where the mandible crossed the midline to the left, the click occurred. After the 8mm. of left movement, the mandible rapidly moved 3mm. towards the right again. On the antero-posterior plane immediately following the click there was an increase in the rate of posterior movement. The click occurred after 2mm. of posterior movement, the mandible reaching a maximum of 5mm. posterior movement at the central incisors relative to the position of tooth contact. The velocity of movement in the open-close plane rapidly fell at the time of the click, whilst in the antero-posterior and left-right planes the velocity was at a maximum at the time of the click.

The left side closing click occurred 7mm. before occlusal contact. There was no hesitation or deviation seen in the open-close tracing. In the left-right tracing there was a plateau in the movement of the mandible to the right, indicating a hesitation in displacement. On the antero-posterior tracing, as closing began, there was an initial posterior movement of the mandible of 2mm. The click occurred at the peak of this posterior movement and was followed by a rapid anterior movement. The velocity of movement in the open-close plane at the time of the click was at a maximum, while in the antero-posterior and left-right planes the velocity was zero.

The right side also displayed an opening and a closing click. The opening click occurred 9mm. from occlusal contact, the tracing on the open-close plane having a plateau indicating a hesitation on opening. The tracing of left-right movement showed an initial 3mm. deviation followed by a sudden 6mm. deviation to the left. The click occurred 3mm. into this left movement. Following the click there was a further 3mm. deviation to the left, followed by a rapid 3mm. movement back to the right side. There was no overall deviation of the mandible once the initial right-left-right movement had been overcome. On

CLICK AND MANDIBULAR MOVEMENT

SUBJECT	CLICK	OVERALL OPENING DEVIATION	CLICK DISTANCE FROM OCCLUSAL CONTACT	IMMEDIATE SHIFT ASSOCIATED WITH CLICK BEFORE	CLICK AFTER
1 Right	Open	0	7 mm		
	Close	0	12 mm	1mm right	2mm left
2 Left	Open	3mm right	12 mm		3mm right
3 Left	Open	2mm right	5- 8mm		2mm right
3 Right	Open	2mm right	4-12mm		2mm right
4 Left	Open	2mm right	18 mm	3mm right	1mm
5 Right	Open	8mm right	18 mm	8mm right	
5 Left	Open	8mm right	18 mm	8mm right	
6 Right	Open	11mm right	10 mm		11mm right
6 Left	Open	4mm right	10 mm		4mm right
7 Right	Close	14mm right	18 mm	1mm right	14mm left
8 Right	Open	4mm right	18 mm		4mm right
8 Left	Open	3mm right	12 mm		3mm right
8 Left	Close	3mm right	2 mm		3mm left
9 Left	Open	2mm right	18 mm	3mm right	1mm left
10 Right	Open	10mm right	13 mm		After 8mm right
	Open	4mm right	3 mm		1mm left
12 Left	Open	4mm right	2- 5mm		1mm left
12 Left	Close	4mm right	6 mm		
13 Right	Open	9mm right	20 mm		2mm left
	Close	9mm right	15 mm		After 7mm right
13 Left	Close	9mm right	15 mm		9mm left
14 Right	Open	3mm left	12-22mm		9mm left
15 Left	Open	2mm left	2 mm		Protrusion
15 Right	Open	6mm left	2 mm		2mm left
16 Right	Open	0	9 mm		6mm left
16 Left	Open	0	9 mm		8mm left
16 Left	Close	0	7 mm		6mm left
16 Right	Close		6 mm		3mm left
					2mm left

Table 4.3 - Click and mandibular movement.

the antero-posterior tracing the initial movement was 2mm. anteriorly, where the click occurred. Immediately following the click there was a 4mm. posterior movement of the mandible and then a 2mm. anterior movement. The overall result was that the mandible was in the same antero-posterior position when opened as when closed. The velocity in the open-close plane at the time of the click decreased rapidly from a maximum, whilst in the antero-posterior and left-right planes, the velocity was at a maximum.

Only one right side closing click was recorded during the ten open-close cycles. This click occurred 6mm. before tooth contact. On the left-right tracing the click occurred at the end of a 2mm. mandibular shift to the left. On the antero-posterior tracing the click followed a 2mm. posterior movement of the mandible and was immediately followed by a 2mm. anterior movement. The velocity for the antero-posterior and left-right tracings was at zero, whilst the velocity for the open-close movement at the time of the click was at a maximum.

4.3 THE EFFECT OF CLENCHING ON THE FEATURES OF CLICKS

Subject 1

Clenching had a marked effect on the opening click of this subject. During unstrained opening the wave pattern of the click displayed four major peaks, the mean maximum amplitude was 2622 mv, SD 1094 mv, the mean duration was 20.6 ms, SD 1.22 ms, and the mean peak frequency was 83.3 Hz, SD 34.2 Hz. Clicks produced following clenching displayed an altered wave pattern with a minimum of six peaks, the mean maximum amplitude was 6489 mv, SD 1144 mv, the mean duration was 51.4 ms, SD 9.5 ms and the mean peak frequency was 38.2 Hz, SD 37.9 Hz. The mean maximum amplitude, mean duration and mean peak frequency of the clicks was significantly different at $p = .05$ level of confidence, from the respective means without clenching.

The effect of clenching on the closing click of this subject was less marked. No effect on the wave pattern was observed. The maximum amplitude of the clicks during unstrained closing was 3961 mv, SD 1288 mv, whilst the mean duration was 10.6 ms, SD 0.5 ms and the mean peak frequency was 140.5 Hz, SD 41.9 Hz. Following clenching these figures were 1957.5 mv, SD 719.5 mv, 12.0 ms, SD 1.8 ms, and 95.4 Hz, SD 65.7 Hz. These means were significantly different ($p = .05$).

Subject 2

No click was recorded from this subject during opening following clenching.

Subject 3

During normal opening the maximum amplitude of the right click for this subject was 2111 mv, SD 643 mv. The mean duration was 34 ms, SD 1.7 ms, whilst the mean peak frequency was 81 Hz, SD 3.8 Hz. During opening following clenching these means were 1545 mv, SD 469 mv; 33.4 ms, SD 2.6 ms, and 78 Hz SD 3.5 Hz. The mean maximum amplitude of clicks during opening following clenching was significantly less than clicks during normal opening at $p = .05$. The other values were not statistically different. The wave patterns of the clicks were also unchanged by clenching.

Left side clicking had no statistically different features following clenching. The wave pattern of clicks after clenching was similar to that of clicks during routine opening.

Subject 4

Clenching before opening had no significant effect on the characteristics of this subject's left side opening click.

2-Feb-89

Subject code: 1

L or R: RIGHT

Peak to peak (mV): 8194

O or C: OPCL

Maximum at (Hz): 19

Gain factor: 2800

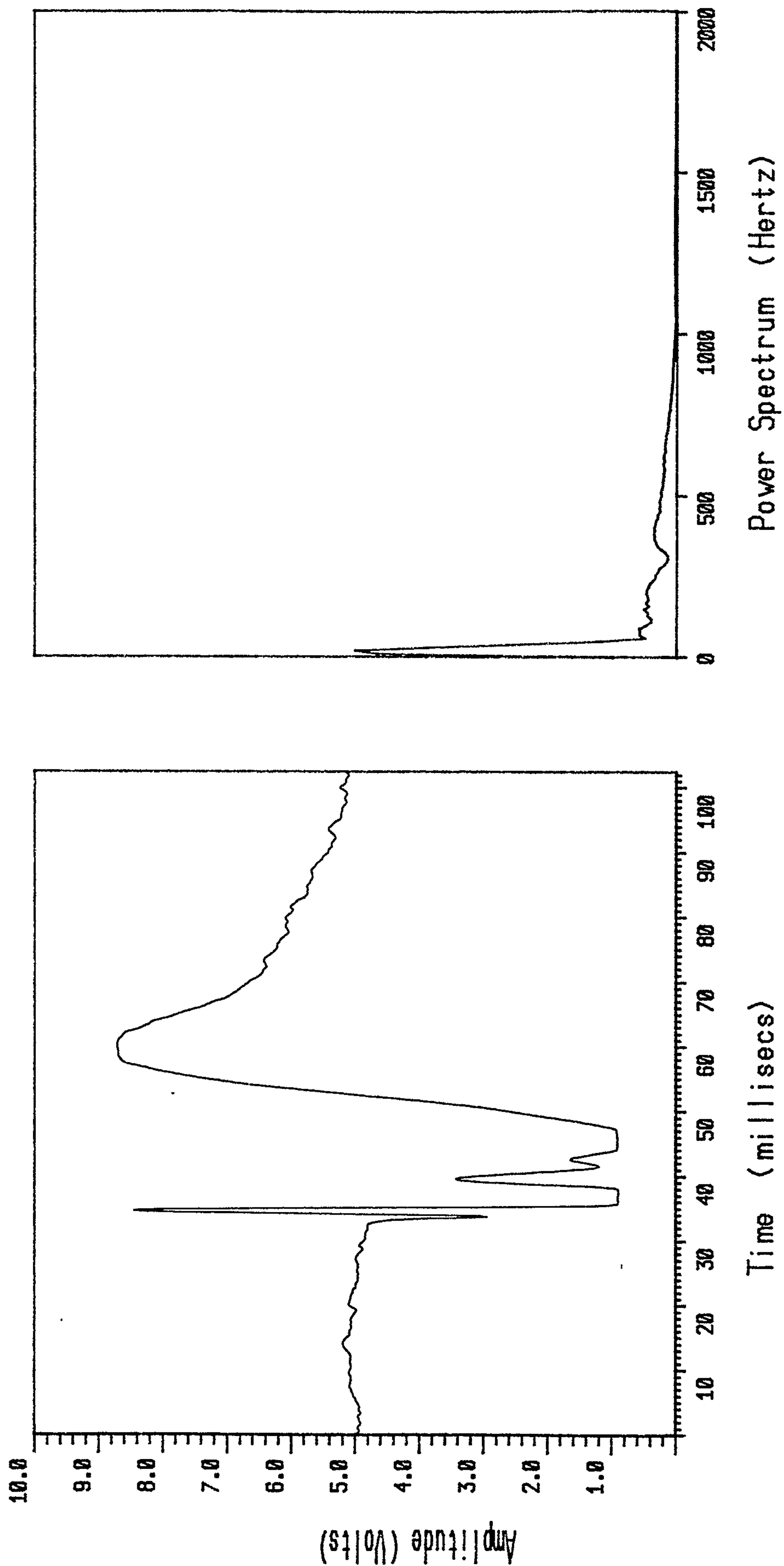


Fig. 4.3.1 - Subject 1, opening click following clenching, wave pattern and power spectrum.

Subject code: 4

9-May-89

L or R: LEFT

Peak to peak (mV): 2995

O or C: OPEN/CLENCHING

Maximum at (Hz): 107

Gain factor: 1400

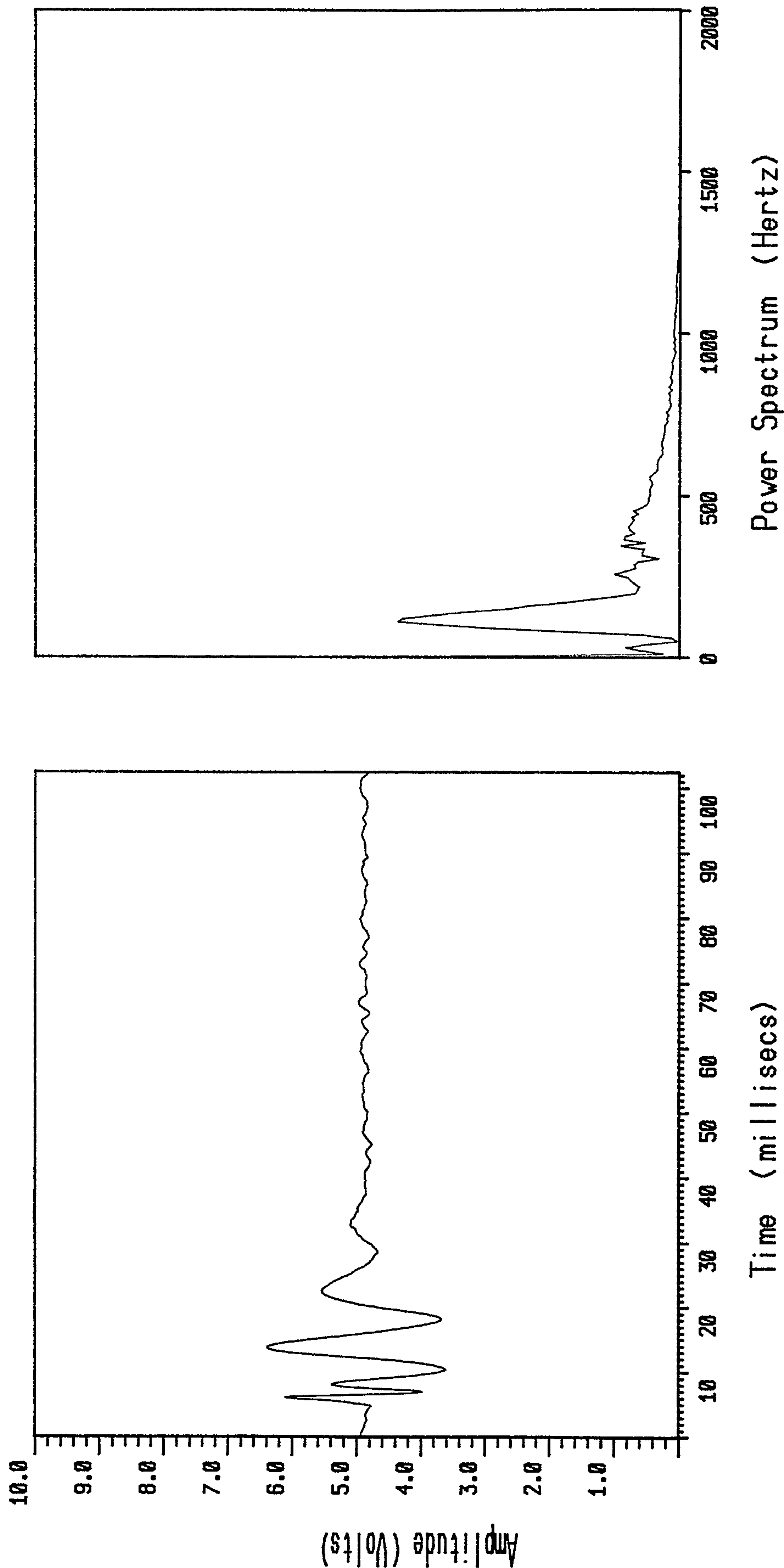


Fig. 4.3.2 - Subject 4, opening click following clenching, wave pattern and power spectrum.

Subject 5

On the right side, clenching before opening had no effect on the characteristics of the click. On the left side the maximum amplitude, duration and peak frequency were all significantly different following clenching. During routine opening the values were 549 mv, SD 1247 mv, 30 ms, SD 9.2 ms, and 84 Hz, SD 32 Hz respectively. Clicking following clenching resulted in the following values being recorded: 7071 mv, SD 407 mv, 44 ms, SD 1.3 ms, and 111 Hz, SD 28.8 Hz. The wave form of the click, however, did not differ between opening with or without clenching.

Subject 6

There were no significantly different characteristics of the click following clenching on the left side.

On the right side, the mean maximum amplitude, duration and peak frequency were all significantly different for opening clicks following clenching. During normal opening these mean values were 1328 mv, SD 278 mv, 51 ms, SD 8.6 ms, and 116 Hz, SD 60 Hz. Following clenching the values were 7625 mv, SD 40 mv, 65 ms, SD 3.3 ms, and 34 Hz, SD 13.8 Hz. The wave pattern following clenching was also markedly different but was totally irregular in outline.

Subject 7

During normal opening no click was detected in this subject on the left side. Opening following clenching, however, did produce a click with a simple 3 peaked wave form. The mean maximum amplitude for this click was 2027 mv, SD 985 mv, mean duration 13 ms, SD 2 ms and mean peak frequency 172 Hz, SD 35 Hz.

Clenching had no significant effect on the characteristics of the left side closing click.

Subject code: 7
L or R: LEFT
O or C: OPCL
Gain factor: 2800

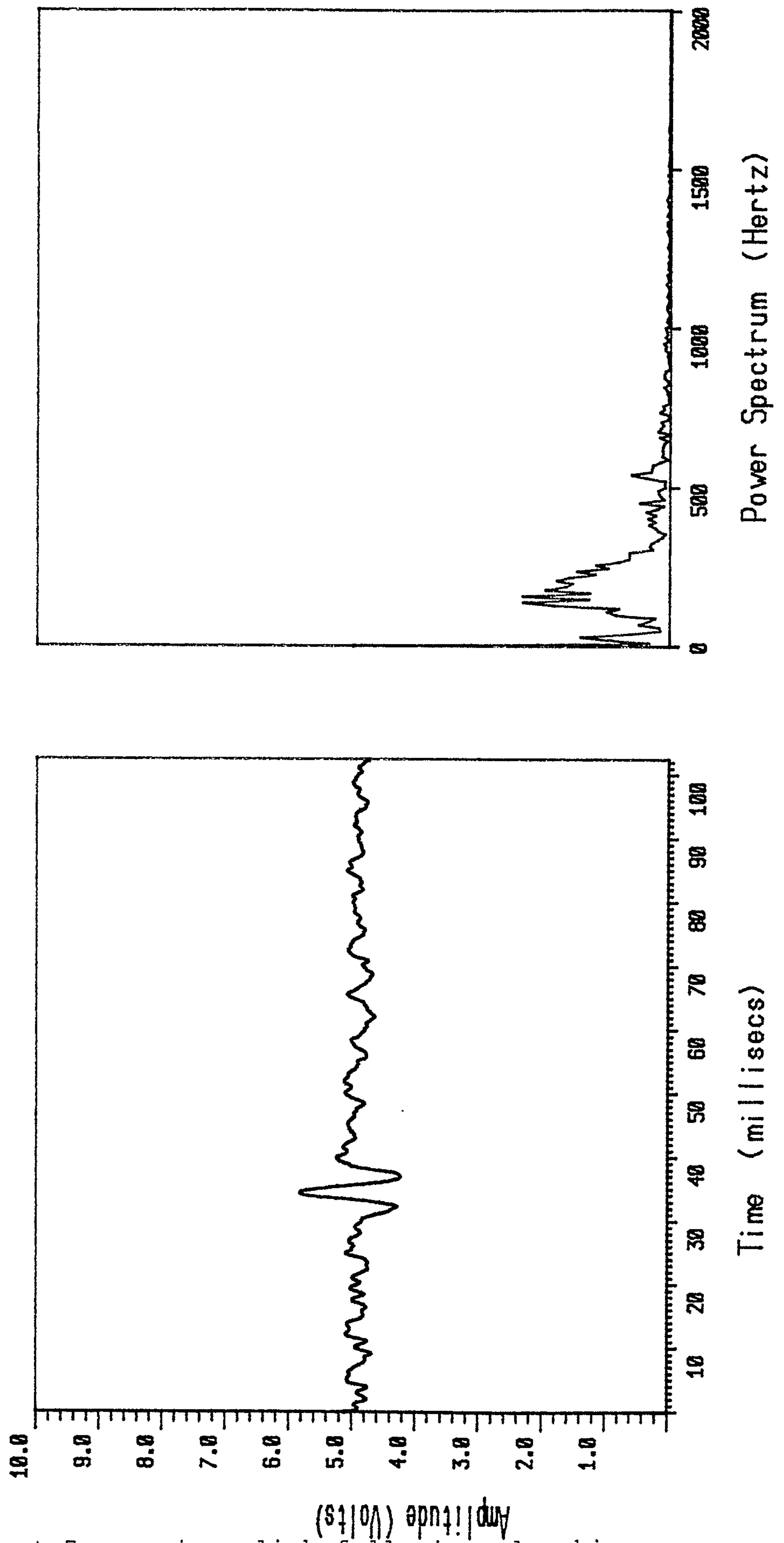


Fig. 4.3.3 - Subject 7, opening click following clenching, wave pattern and power spectrum.

Subject 8

There was no significant effect of clenching upon the opening click of this subject. Clenching did, however, significantly effect the left side closing click. The wave form of the normal closing click was a single three peaked pattern. Following clenching the wave form was more complex with seven major peaks. The maximum amplitude and mean duration were unaffected. The mean peak frequency, however, of normal closing clicks was 117 Hz, SD 50 Hz. Following clenching, this figure was 252 Hz, SD 106 Hz.

The right side closing click was unchanged in mean duration and mean peak frequency by clenching. The wave form also remained unchanged. The mean maximum amplitude, however, did significantly differ. During normal opening the mean amplitude of the click was 4663 mv, SD 838.5 mv. Following clenching this figure fell to 3038 mv, SD 702.8 mv.

Subject 9

There were no significant differences in the features of the clicks between clenching and non-clenching for this subject.

Subject 10

There were no significant differences in the features of the clicks between clenching and non-clenching for this subject.

Subject 11

There were no significant differences in the features of opening or closing clicks between clicks during normal open-close movements and those following clenching.

Subject 12

Left side opening and closing clicks were not significantly effected by clenching. Following clenching,

right side opening clicks were significantly greater in maximum amplitude. During normal opening the mean maximum amplitude of the opening clicks was 4536 mv, SD 1544 mv. Following clenching the mean maximum amplitude of the clicks became 6658 mv, SD 982 mv.

Subject 13

Clenching had no significant effect upon the characteristics of the left opening or closing or right opening or closing clicks.

Subject 14

Clenching had a marked effect upon the wave form of this subject's opening click. During normal opening the click displayed a simple two peaked outline. Following clenching the click became a double click, the two clicks superimposed upon one another, there being four peaks. The mean maximum was unchanged after clenching, as was the mean duration. Whilst the mean peak frequency was not significantly different after clenching, the shape of the power spectrum was markedly different following clenching. Clicking during normal opening produced a frequency response with a single peak in the 160 Hz region that gradually tapered to a minimum in the 1500 Hz region. Clicking following clenching, however, while showing a maximum frequency peak in the 160 hertz region had at least two other major peaks in the 750 and 1400 Hz regions.

Subject 15

Clenching prior to opening had no significant effect upon the characteristics of the left side opening click of this subject.

Clenching prior to opening increased the mean maximum amplitude and mean duration of the right side opening click. During normal opening the mean maximum amplitude of the click was 1133 mv, SD 526 mv, and the mean duration

was 17.9 ms, SD 2.5 ms. Following clenching these values became 3488 mv, SD 567 mv, and 31.2 ms, SD 1.2 ms. The mean peak frequency was unaffected by clenching.

Subject 16

In this subject neither the left, opening or closing, or right, opening or closing, clicks were effected by clenching.

CHAPTER 5

DISCUSSION

- 5.1 Features of clicks
- 5.2 Simultaneous registration of click and movement
- 5.3 Effect of clenching prior to opening upon the features of clicks

5. DISCUSSION

5.1 FEATURES OF CLICKS

The rational with previous studies examining the characteristics of TMJ clicking, and with this study, has been an attempt to provide a "non invasive, non radiographic, painless, inexpensive, permanent record which allows both diagnosis of the cause of the click and an assessment of treatment" (Gay and Bertolami, 1984). Recent studies examining TMJ clicking have concentrated on an examination of their spectral properties, that is, an examination using a Fast-Fourier transform analysis of the relative magnitudes of the frequencies contained in a click. This study differs from the majority of previous examinations of click characteristics by carrying out analyses at a rate twenty times slower than the rate at which the click was recorded. Heffez and Blaustein (1986) analysed clicks at a rate ten times slower than the recorded rate, but used a digital stethoscope to auscultate and record TMJ sounds. This study used a vibration transducer (a form of accelerometer) ideal for recording vibration transmissions, and which is less liable to record extraneous "noise" such as may be derived from skin movement during mandibular opening and closing. This was to ensure that only useful information emanating from the click was recorded.

It was found that the level of vibration or noise emitted by TMJ clicking varied greatly from subject to subject. In order for a detailed analysis of each click to be carried out, it was necessary to vary click amplification amongst subjects. The amplification required for each subject is indicated in Tables 2 & 3 (see under the columns headed "Gain").

This study involved sixteen subjects only. As a result, where a clinical diagnosis was made concerning the cause of the click, confirmation of the clinical data could not be made absolutely. However certain trends were observed

from the results and these will be discussed under the appropriate headings as listed below.

5.1.1 Waveform and Duration

Blaustein and Heffez (1986) and Heffez and Blaustein (1986) studied the characteristics of clicks of the TMJ and examined the waveforms of clicks in real time. Their computer analysis of waveforms, at a rate ten times slower than the recorded rate, allowed these authors to report the wave patterns of clicks recorded as (1) crescendo-decrescendo; (2) crescendo; (3) coarse continuous; or (4) fine continuous. They also reported that the sound patterns were indicative of similar internal derangements in other subjects.

The present study of TMJ clicking, recorded joint noise at twenty times the speed at which the noise was subsequently analysed, and this allowed a detailed analysis of the sound pattern of recorded clicking to be carried out. Previous studies by Ekensten (1952), Findlay and Kilpatrick (1960), Watt (1966, 1980), Ouellette (1974), Oster et al (1984), Erikson et al (1985) and Rohlin et al (1985), in which the joint noise was recorded and analysed at the same speed, were only able to report the relative amplitude and duration of the click. In this study, an examination of the waveform and duration of the recorded clicks allowed the clicks to be categorised into four broad categories. Unlike Heffez and Blaustein (1986), who classified click waveform in relation to its shape, classification into groups 1, 2, 3 and 4 is based on the complexity of the waveform displayed by the vibrational pattern of the click.

Group 1

This was the largest group and consisted of the clicks produced by Subject 1 right opening, Subject 2 left opening, Subject 3 right opening, Subject 4 left opening, Subject 5 left opening, Subject 6 right opening, Subject 7

left closing, Subject 8 right opening, Subject 10 right opening, Subject 12 left and right opening, Subject 13 right closing, Subject 15 right opening and subject 16 right and left opening and left closing. Whilst the average duration of these clicks was variable, ranging from 16.6 to 66 ms, and the number of peaks varied from three to nine, the common characteristic amongst them was a sudden polarity reversal of the waveform along its course. None of the clicks in this group were of high amplitude, all displaying a medium to low amplitude response.

Group 2

Clicks in this group, whilst showing a similar though generally simpler waveform to those in Group 1, differed by having no sudden polarity changes along their course. The duration of the clicks from this group ranged from 10 to 33 ms, whilst the waveform, which displayed three or four major peaks, was of medium to low amplitude. Subjects displaying this form of clicking were 1 right close, 3 left open, 5 left open, 8 left close, 11 left open and close, 12 left close, 13 right and left open and 15 left open.

Group 3

This group displayed very high amplitude short duration waveforms with two major peaks, the durations of which ranged from 4.6 to 25 ms. The subjects displaying these waveforms were 5 right open, 9 left open and 14 right open. All of these clicks had been clinically diagnosed as eminence clicks, that is single sharp opening clicks with no corresponding closing click.

Group 4

The waveform from one subject was included in this group, and was the opening click of Subject 8's left TMJ. This had been diagnosed clinically as crepitation following joint degeneration and was of an average duration of 62

milliseconds. The waveform consisted of three short wavelength, medium amplitude peaks of 10 milliseconds duration, followed by a varying number of lower amplitude prolonged wavelength peaks over a duration of approximately 40 ms. Other researchers (Creagh et al 1989) found a similar pattern of irregular medium to low amplitude peaks extending for a period from 65 ms. The relatively short duration waveform displayed by crepitation in this subject, may in part be explained by the extreme rapidity with which he opened his jaw, the total time for opening ranging from 150 to 200 ms.

Whilst differences were apparent between these four groups based on the complexity of the waveform, no statistically significant differences could be obtained in the average durations between groups, because of the wide range of intergroup durations. There did appear to be a trend, however, for clicks with simpler waveform to be of shorter duration than those with complex waveforms. Thus Group 3 clicks were those with the shortest duration followed by clicks from Group 2, then Group 1 with the click from Group 4 being the longest. The amplitude of the click also showed cross group similarities, with only those from Group 3, which had been clinically diagnosed as "eminence clicks", showing significantly greater amplitude than the other groups.

It is not possible to determine with certainty the relationship between click wave form and joint pathology, in the absence of a definitive diagnostic test. The mechanism of the click may be identified by procedures such as arthrography, arthroscopy or magnetic resonance imaging. It is reasonable to assume, however, that the more complicated the waveform, the more complex the joint pathology. Studies by Isberg-Holm and Westesson (1982) suggested that joint clicking was produced by the condyle and disc striking the temporal bone after the condyle had traversed the posterior thick band of the disc. In one of

the joints studied, Isberg-Holm and Westesson (1982) found that no movement of the condyle across the posterior thick band occurred, and it was assumed that the click resulted by the condyle and disc striking the temporal component, after crossing a deviation in form on the articular eminence. Thus the noise of reciprocal clicking was regarded as a single event caused only by the condyle and disc striking the temporal bone. It is likely, however, that some vibration could be produced as the condyle strikes and crosses the posterior thick band of the disc. If this was the case, then clicks caused by the reduction of an anteriorly displaced disc would show at least two events in the wave pattern, one as the condyle crossed the disc and one as the disc and condyle struck the articular eminence. These two events would occur almost simultaneously and is a likely cause of the wave patterns displayed by the joints in Group 1. This is supported by the fact that of the fifteen clicks included in Group 1, twelve had been clinically diagnosed as reciprocal clicks due to disc displacement. Whilst a closing click could not be recorded in each of these subjects, one could be palpated in all subjects except Subjects 6, 8 right and 12 right. Lack of a palpable or recordable closing click does not necessarily mean, however, that disc displacement has not occurred.

In contrast with the understanding that the waveforms of clicks associated with a reduction of disc displacement contain a polarity reversal, it should be noted that Subjects 3 left, 11 left and 13 left displayed opening and closing clicks but the waveforms of the clicks did not show a sudden polarity reversal. As well these three subjects displayed bilateral clicking. The clicks on the contralateral side in Subjects 3 and 13 did display sudden polarity reversal, whilst no recording of Subject 11's right side click was made due to the subject's illness. As a result it was felt that the more simple clicks displayed by these subjects were secondary effects of the

clicks occurring on the contralateral side. The relationship of click waveform to click mechanism will be discussed further in considering the effect of clenching before opening on the click characteristics.

5.1.2 Spectral Properties of Clicks

Recent research on the characteristics of TMJ clicking has attempted to differentiate mechanisms that produce clicks, by an examination of the frequency spectra of the click (Blaustein and Heffez 1986, Heffez and Blaustein 1986, Gay and Bertolami 1987, Oster et al 1984). This study, in common with the results of Blaustein and Heffez (1986), Heffez and Blaustein (1987), Gay and Bertolami (1987) and Oster et al (1984), found that it was not possible to classify TMJ clicks by analysing peak frequencies of clicking. It may seem logical that clicks emanating from the TMJ due to different mechanisms should have different frequencies, and it is acknowledged that the same components (condyle, disc and temporal bone) are involved in all joint conditions. However there is a limit to the variation in relationships and timing of these components that is possible in creating variation in joint sounds. In this study no click was found to have an average frequency peak above 250 Hz. Whilst it was found that hard clicks diagnosed clinically as being "eminence clicks" tended to have an higher average peak frequency, no statistically significant difference between frequency peaks could be found. The finding that no frequency peak was above 250 Hz. was in general agreement with a recent study by Creagh et al (1989), but contrasted with Gay and Bertolami (1987) who found peak frequencies in all joint conditions at 1,000 Hz., and Ouellette (1974) who found frequency components of up to 4,500 Hz.

To be able to classify joint conditions by spectral properties, it is necessary that the spectral range for a diagnosed joint condition be consistent. This has not been found in this study. Not only has there been

variability amongst subjects displaying a similar joint condition, but as well, intrasubject variability was apparent where the peak frequencies of successive clicks recorded from one subject were often markedly different.

Between subjects peak spectral variability may be explained by the fact that, whilst the same components, condyle, disc and temporal bone are involved in click production, other factors are important. These factors include the tautness/laxity of the disc, the density and thickness of the bone of the condyle and temporal component, the thickness of the soft tissue lining of the condyle and temporal component, the thickness of the disc, the speed of the condyle during its downward, forward and rotational movement, hormonal effects on ligament tissues and attachments and the thickness of the soft tissue between the joint and the recording apparatus on the overlying skin. The lack of consistency shown by peak spectra, even though they all occurred in a relatively small low frequency range, leads to the conclusion that analysis of the frequency peak exhibited by a click is of limited value in differentiating joint conditions.

Whilst no significance could be found in the peak frequency of a click, the shape of the spectral distribution curve may hold more information. It has already been seen that by using the wave patterns of clicks as a basis, clicks from different subjects had similar characteristics, and that by using these similar characteristics as a guide, four broad groupings could be made. Similarities in the shape of spectral distribution curves amongst clicks from these four groups were also evident.

Group 1 clicks, in which a polarity reversal was present somewhere along the course of the waveform, displayed an average peak frequency which varied from 71 Hz. to 118 Hz. The feature which differentiated the spectral distribution

of this group from others was the presence of at least one other broad based peak at a higher frequency, the peak of which ranged from 150 to 500 Hz. The presence of this second peak indicates that in click production from this group of joints, more than one mechanism is involved.

The common characteristic of Group 2 clicks was a simple waveform of medium to low amplitude and medium wavelength peaks. Using the spectral patterns of these clicks it was possible to further subdivide these clicks into two separate groups. The first, from Subject 3 left open, 11 left close, 13 right and left open and 12 left close, showed a narrow based peak at 30 or 40 Hz. followed by a second more significant peak ranging from 67 to 123 Hz. which fell to baseline at or below 300 Hz. The second group, from Subjects 1 right close, 11 left open and 8 left close, 13 left close and 15 left open displayed a single major peak, with a peak frequency from 117 Hz. to 159 Hz. which decayed to baseline at or above 500 Hz.

Group 3 clicks contained a sound pattern which displayed two peaks of very high amplitude and short duration waveform, and as well displayed a spectral pattern with a single major peak of large area, with maximum frequencies ranging from 122 Hz. to 204 Hz. which decayed to baseline at or above 600 Hz.

Group 4 displayed a similar spectral distribution to those of Group 1, the distinguishing feature being that the major peak occurred at a much lower frequency than generally occurring for Group 1.

Intergroup differences, identified by the form of the spectral analysis, were not as marked as those in which the sound pattern was assessed. It is significant to note, however, from an analysis of the spectral distributions, that clicks from Groups 1 and 4 displayed a more complex pattern of multiple peaks than did the other

groups. Thus the spectra of Groups 2 and 3 may display a single event producing a click, whilst Groups 1 and 4 displayed multiple peaks and exhibited clicks that involved more than one event in their production. If the assertion of Isberg-Holm and Westesson (1982) is correct i.e. that reciprocal clicking occurred only as a result of the condyle and disc striking the temporal bone, then it would be expected that spectral analyses would give only one major peak. This was not found in joints diagnosed as having "reciprocal" clicking, which suggests that not only does the condyle and disc strike the articular eminence, but that the condyle probably strikes some portion of the disc as well.

Opening versus closing clicks

It is generally accepted that in reciprocal clicking the opening click is more distinct than the closing click. Whilst this was found to be the case for the majority of clicks in this report, two of the joints examined, Subject 7 and Subject 13 left, both displayed closing clicks of significantly higher magnitude than the opening click. It is also noteworthy that the characteristics of these closing clicks were similar to those of the opening clicks in Group 1. Both of the closing clicks occurred early in the closing cycle, whilst the opening clicks occurred late in the opening cycle. Because of the similarities between the closing clicks of these subjects and the opening clicks of other subjects, and because of the similarities of the opening clicks of these subjects and the closing clicks of subjects who showed reciprocal clicking, it is possible that the mechanism causing the clicks may be the same.

Arthrographic, surgical and autopsy studies (Isberg-Holm & Westesson, 1982) have shown that reciprocal clicking occurs as the result of the condyle and disc striking the temporal component after the condyle has traversed the posterior thick band of the disc. The opening click is

louder than the closing click because the central bearing surface or articulating section of the disc is thinner than either the bilaminar zone or foot of the disc and results in less cushioning of the condyle as it strikes the temporal component with the disc interposed. Two mechanisms are suggested as explanations for the characteristics of the clicks in Subjects 7 and 13:

Firstly, the clicks comprise a hypermobility click (Klineberg 1986) where the condyle and disc translate beyond the articular eminence to an excessive degree and the condyle becomes displaced over the anterior thick band of the disc. During closing the condyle returns to a central position on the disc. The closing click is of greater magnitude than the opening click because the foot of the disc is thicker than the articulating zone and cushions the condyle to a greater degree. Translation of the condyle past the anterior thick band of the disc constitutes a posteriorly displaced disc. Whilst this mechanism is in agreement with the views of Rees (1954), Bertoft (1972), Shore (1976) and Watt (1980), Blankestijn and Boering (1985) and Solberg (1986) state that posterior disc displacement is a very rare condition.

Secondly, the characteristics of the clicks in Subjects 7 and 13 may be explained by the views of Solberg (1986) and Blankestijn and Boering (1985). This explanation is that when the teeth are in contact, the disc is totally anteromedially displaced with the condyle articulating against the bilaminar zone, which has responded to the constant presence of the condyle by adaptation, becoming thinner and forming a "pseudodisc" (Greene and Laskin 1988). Only during wide opening does the condyle approach a more anterior

position on the disc and during closing returns almost immediately to its now established position on the retrodiscal tissues. The reason for the louder closing click than opening click lies in the thickness of tissue between the condyle and temporal component in these subjects, the "pseudodisc" being thinner than the articulating region of the disc due to adaptation.

Without employing more sophisticated imaging procedures it is not possible to prove which of these mechanisms explains the characteristics of clicking observed in Subjects 7 and 13. However, neither possibility disagrees with the proposition that the passage of the condyle across a band of the disc onto its more normal articulating zone gives rise to a complicated sound pattern with a characteristic polarity reversal.

Simultaneous Registration of Movement and Click

Three notable features were revealed by the results of the simultaneous recording of mandibular movement and clicking.

1. Overall Deviation of the Mandible

It has been claimed by Farrar and McCarty (1979) and shown by Isberg-Holm (1980) that during opening, the mandible deviates towards the side where reciprocal clicking occurs. This deviation is reportedly due to an anteriorly displaced disc acting as an obstruction to forward translation of the condyle. Of the seven subjects displaying unilateral clicking in this report, one showed no appreciable deviation to either side during opening, one deviated to the same side as that on which the click occurred, and five deviated to the contralateral side to the click. There appears to be no association between the side of the click and the side to which deviation occurs, and rather than the disc forming an obstruction to

condylar movement, muscle function appears to play a greater role in the determination of deviation.

2. Deviation at the time of the click

The generally accepted mechanism of click production for a reciprocal click is that the condyle, after overcoming the posterior thick band of the disc, rapidly moves forward and strikes against the temporal component of the joint (Farrar and McCarty 1979, Isberg-Holm and Westesson 1982). The expected opening movement, therefore, would be one in which firstly there was a midline deviation to the effected side, due to the disc of the effected side acting as a barrier to condylar translation whilst the uneffected condyle moves normally. Once the obstruction of the disc is overcome the condyle moves rapidly forward and down the disc and strikes against the eminence causing a click. This sudden condylar movement would cause the midline deviation, which initially occurred towards the effected side, to then suddenly move in the opposite direction away from the effected side. The click should occur either along the course of, or at the end of this sudden deviation. Of the thirty clicks examined in this study two (7%) displayed no association with a midline deviation at the time of the click, six (20%) displayed a sharp deviation immediately after the click, three (10%) displayed a click at the end of a sudden deviation and eighteen (63%) displayed a click which, whilst associated with a general deviation during opening, displayed no sudden alteration in the direction of deviation before, during or after the click. This lack of association between clicking and any particular immediate deviation, indicates that during the reduction of an anteriorly displaced disc, not only does the condyle move forward but the disc rapidly moves backwards, the overall effect being no rapid midline shift of the mandible. Lack of association between clicking and a consistent sudden midline deviation also indicates that joint mechanics

appear to be less important than muscle function in determining mandibular midline deviations during opening.

Position of the Click

In no subject was it found that the opening distance progressively increased before clicking occurred, as was reported by Isberg-Holm and Ivarsson (1980). A progressively increased opening distance before clicking has been attributed to a temporary change in the elastic resistance of the posterior attachment tissue against forward disc movement (Wilkes 1978, Wilkinson and Marynuik 1983, Moloney 1985, Meyenberg et al 1986). The finding that opening did not progressively increase before clicking was in agreement with the work of Widmalm and Larsson (1982).

Differences in movement patterns between recordings of right and left clicks

Of the nine subjects displaying bilateral clicks, seven showed no significantly different opening patterns when comparing recordings of right and left sides. However, whilst subjects 6 and 15 showed no significant differences during opening in the sagittal and horizontal reference planes, there was significantly different left-right movement recorded in the frontal plane.

With recordings for subject 6, clicks of the left TMJ deviated an average of 4mm. to the right; whilst recording clicks from the right TMJ the average deviation to the right was 12mm. With subject 15 during recording of right TMJ clicks an average deviation of 6mm. occurred to the left and only 2mm. deviation to the left occurred during recordings of left TMJ clicks. There are two possible mechanisms to explain this occurrence.

Firstly, the headframe of the tracking equipment altered in its position on the subject between recordings of left and right clicks. Once the recording equipment had been attached, however, it was not

deliberately altered or repositioned. The only alteration to the recording setup was the relocation of the transducer from one side to the other.

Secondly, in an unsolicited attempt to be helpful and increase the magnitude of the clicks, the subjects may have opened in such a manner as to make the clicks more distinct. If this was so, it would indicate that muscle function is important in click propagation. It has been found that isometric exercises (Au 1988, Berman and Klineberg 1982) and splint therapy (Creagh et al 1989) can reduce the incidence and magnitude of TMJ clicks. Both of these procedures influence the masticatory musculature and confirms the importance of muscle activity in clicking.

Effect upon clicking of clenching prior to mandibular movement

It can be seen from the results that clenching before jaw opening had a statistically significant effect on the opening click characteristics of subjects 1 right, subject 2 left, subject 3 left, subject 5 left, subject 6 right, subject 7 left, subject 12 right and subject 15 right. Subjects 2 and 3 displayed a significant decrease in the magnitude of the click. In the case of subject 2, the click decreased to such an extent that it was no longer recordable. All other clicks that were significantly effected showed an increase in amplitude of the click after clenching. Of the six joints that demonstrated an increased amplitude following clenching, five (83%) also demonstrated a significant increase in the duration and four (67%) demonstrated a significantly altered average peak frequency.

There are a number of possible explanations for the finding that jaw clenching before opening is likely to effect click characteristics:

- (a) It appears that clenching potentiates the jaw musculature, with the result that the condyle is held more intimately and forcefully against the temporal bone, with the disc more closely adapted between. Any obstruction to condylar movement would be exaggerated due to this increased muscular tension, giving rise to a greater click as the obstruction was overcome. With this explanation it would be expected that all opening clicks would show greater amplitude including the crepitus displayed by the left TMJ of Subject 8. However, this was not found to be the case. Of the twenty-four opening clicks recorded only six (25%) showed an increase in magnitude following clenching. The other 75% showed either no significant difference or a decrease in click magnitude.
- (b) Until recently, it was considered that the upper head of the lateral pterygoid muscle inserted directly into the interarticular disc (Rees 1954, Hawthorn 1969, Griffin et al 1975, Sicher 1955, Shore 1976, Zarb and Carlsson 1979), and that this muscle could independently pull the disc forwards and medially without effecting condylar position. It has been shown by EMG recordings in primates (McNamara 1972), and man (Juniper 1984) that the upper head of the lateral pterygoid is most active during clenching. If disc movement could occur independently of the condyle due to the action of the upper head of the lateral pterygoid it could explain an increase in click magnitude following clenching. If more of the disc was drawn forwards independently from the condyle as a result of lateral pterygoid upper head activity, more of the posterior thick band would be located anterior to the condyle and this would result in a significant

obstruction to the condyle during its forward translation. This increased obstruction would necessitate greater condyle movement, and greater velocity to overcome the increased obstruction. As a result of the higher velocity, a click of greater magnitude would result as the condyle and disc contact the temporal bone. It has been shown more recently that the upper head of the lateral pterygoid muscle does not routinely insert directly into the disc, and when this occurs the proportion of muscle fibres is small (Wilkinson and Marynuick 1983, Meyenberg et al 1985). In these studies independent movement of the disc by pulling the muscle did not occur (Meyenberg et al 1985, Chan and Wilkinson 1986). Meyenberg et al (1985) found in their study of twenty-five human TMJ's that in 60% of specimens some fibres of the upper head of the lateral pterygoid inserted into the medial half of the disc, whilst in the remaining 40% there was no muscle insertion. The amount of fibres was small, and independent pull of the fibres did not alter disc position. This is thus an unlikely explanation of the increase in click magnitude following clenching.

- (c) The most likely explanation for the results observed in this study is that clenching has a mechanical effect upon the disc-condyle relationship in some joints. Clenching of the teeth involves increased activity in the masseter, medial pterygoid, temporalis and upper head of the lateral pterygoid muscle bilaterally. During clenching, the temporalis, medial pterygoid and masseter muscles act in a manner which tends to seat the head of the condyle further into the articular fossa. This action is thwarted if teeth are present and thus only a slight degree of condylar seating allowed by physiologic tooth intrusion is possible. The upper head of the lateral pterygoid, however, acts in a different direction to the other closing muscles. The action of this muscle is in an

antero-medial direction. It is possible that contraction of the upper head of the lateral pterygoid muscle during clenching causes a slight anterior movement of the condyle so that the head of the condyle moves towards the articular eminence. If the disc is normally centred this condylar loading against the eminence will have no effect. If, however, the disc is anteriorly displaced with the articular surface of the condyle resting upon the posterior slope of the posterior thick band, then increased condylar loading will further displace the disc anteriorly (this action resembles the effect of an orange seed being squeezed between finger and thumb). Because of increased anterior disc displacement, the condyle has more of the posterior thick band to negotiate, gaining a greater velocity in doing so and thus creating a larger click as it strikes against the articular eminence. If the condyle rests against the anterior slope of the posterior thick band, clenching will centre the disc by posterior disc movement. Partial disc displacement will not be affected by clenching, because whilst some of the posterior slope of the posterior thick band may be anterior to the condyle, some of the anterior slope lies posterior to the condyle. When clenched, the nett effect is cancellation of any movement and flattening of that part of the disc which lies between the condyle and temporal component. If the disc is totally anteriorly displaced, so that the condyle lies posterior to the posterior thick band on the bilaminar zone, clenching will again have no effect on disc position and thus no effect upon click magnitude.

In the context of the above biomechanical considerations, the results obtained during this study may be explained as follows:

The three subjects who displayed hard clicks that were diagnosed as eminence clicks, where the disc is centred with the teeth in centric occlusion, demonstrated no significant effect of clenching on the magnitude or characteristics of the click. Subject 1 right, subject 5 left TMJ, subject 6 right TMJ, subject 7 left TMJ, subject 12 right TMJ and subject 15 right TMJ all displayed increased click magnitude following clenching. Of these six subjects four displayed clicks that occurred early in the opening cycle and two that occurred late. The increase in click magnitude in these subjects following clenching is likely to occur as a result of an increase in the obstruction that it is necessary for the condyle to pass across before reduction occurs.

Subject 2 displayed no recordable click following clenching. This may be explained by either the disc being displaced anteriorly into such a position that it was held anteriorly without reduction throughout the opening movement, or that by clenching, the condyle centred the disc so that there was no disc displacement before opening.

Subject 3's left TMJ displayed a significantly reduced click amplitude following clenching. This may be explained by clenching decreasing the amount of disc displacement before opening.

The remainder of the opening clicks from the subjects of this study displayed no significant effects of clenching on clicking. This is explained by either the disc being totally or partially displaced or that some other mechanism is involved in click production for these subjects.

A notable feature of the results of the effect of clenching upon the features of clicking is gained by an examination of the waveforms. Of the eight joints which

displayed a significant effect of clenching, whether it was an increased or decreased amplitude, seven displayed a waveform that included a sudden polarity reversal along its course. The eighth, subject 7, while not displaying this pattern for the opening click, did so for the closing click. This subject displayed no recordable click at all during normal unstrained opening. If the assumption that the alteration in click characteristics observed in these subjects is due to disc displacement being increased or decreased by the action of the condyle compressing against either slope of the posterior thick band is true, then it lends weight to the view that a waveform that contains a sudden polarity reversal is indicative of disc displacement. It will also be noted that of the six joints showing an increase in click amplitude following clenching, five displayed a significantly increased click duration. If the clicks emanating from these joints were only the result of the condyle and disc striking against the eminence, the durations should not change. The longer durations observed in these clicks suggests that clicking is not only a product of the condyle and disc striking the eminence, but also a result of the condyle striking or traversing the disc.

It has been reported by Au (1988) that many of the twenty-two dental students involved in his study noted an increase in the magnitude of their clicks during times of stress when they were aware of increased parafunctional clenching/bruxing. The finding in this study that clenching can in some cases cause an increase in click magnitude, while not suggesting that clenching is involved in the initial mechanism causing a click, does indicate that clenching may play a part in the worsening and perpetuation of a click. Continual tooth clenching or grinding that causes a slight increase in the forward displacement of the disc by mechanical means, may lead eventually to permanent stretching of the posterior disc attachment. The disc in this way becomes totally

anteriorly displaced, and the retrodiscal tissues are no longer able to exert any retraction force upon the disc.

CHAPTER 6

CONCLUSIONS

6.0 CONCLUSIONS

1. Examination of peak frequencies obtained from clicking TMJ appears to have little value in the diagnosis of the click mechanism. This is due to the overall similarity displayed by the peak frequencies of clicks that have been clinically diagnosed as being due to different joint conditions and the variability of peak frequencies displayed by clicks that have been clinically diagnosed as being caused by similar joint conditions.
2. More value may be obtained from an examination of the click waveform and the shape of the frequency distribution displayed by various clicks. Without a firm diagnosis of the click mechanism obtained by arthrographic, arthroscopic, magnetic resonance imaging or surgical means however, no firm conclusion regarding click waveform, frequency distribution, shape and click mechanism may be made.
3. Deviation of the mandibular midline at the time of the click appears to bear little connection to the events occurring in the joint to produce a click.
4. Deviation of the mandible during opening is not always towards the joint in which the click occurs in those subjects displaying unilateral reciprocal clicking.
5. The finding that some clicks are significantly effected by clenching before opening whilst others are not, suggests a simple non-invasive method that may be used to give some indication of the degree of disc displacement.

CHAPTER 7

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