NOTE ON MOTOR ANALYSIS OF INFANT SOUND

Jeannette M. van der Stelt and
Florina J. Koopmans-van Beinum

INTRODUCTION

The human communication system, speech, makes use of movements. In respiration we move our chest, in phonation the vocal cords vibrate and in articulation oral articulators move. Together these movements result in sounds. In communication one's own and someone else's movements are related to meaning. These movements are to be systematized and coordinated in the central nervous system. Without a highly sophisticated coordination system communication by means of speech movements would be very difficult.
A player of mimic can segmentate certain movements to accentuate aspects of the movements. Likewise, in the study of articulation some aspects of movements are stressed: some movements are frozen, in others the change is exaggerated. Since we know the speech movements of our mothertongue we expect sequences of movements as we expect gestures and actions in a social context.

Bullowa (1972) suggested "that it is appropriate to define the onset of speech in terms of recognition by adults of the beginning of language use." The recognition may be related to expectations about the development of babies and these expectations can vary greatly in different cultures. However a change in the child's behaviour, perceived by the parents, does not need to be a break in the child's development. Classification of infant behaviour often reflects the adult viewpoint. In the past sounds of young children used to be analysed by means of systems that describe more or less precisely adult speech sounds. A very elaborated example is the system given by Bush et al. (1973). The young child utters all kinds of sounds and some of them are recognized as sounds of the mothertongue. Movements of the speech mechanism, resulting in sounds for which adults have not been conditioned, are

often neglected or leave the researcher at a loss: "Why these elements might appear frequently in child babbling but not in meaningful child speech is not at all clear to us at this time", p. 9 (Oller et al., 1976). When studying speech development in the first year of a child's life, one should keep in mind that there is a difference between the development of the speech mechanism, which can be described by means of physiological terms and the development of speech, described in linguïstic terms. The early behaviour of the child is called "preverbal" or "prelinguïstic" (why not "preadult"), but communication is definitely present: the child expresses its needs and adapts to reactions from the environment. In the very first months the baby expresses only a few messages for which it needs almost all its energy. Adults react in a limited way, since they think only a few reactions to be adequate. On the other hand, all kinds of stimuli from the environment bring about only a few, stereotype, reactions from the baby. The interaction between baby and environment however becomes rapidly more complex as to visual, auditory, kinesthetic, and tactile components. Early communication involves the whole body of the baby and in communication the mother's role is a highly interpretative one.

In the development from early communication to speech the baby produces all kinds of sounds as the result of movements of the speech mechanism. Adults conditioned to sounds related to meaning, select in a shaping way the sounds of their children. In the interaction between mother and child the child becomes conditioned to the sounds of his mother's tongue. The sounds may be interpreted by the mother as purely emotional as well as linguïstical or in a behavioural complex (sounds uttered when dancing, climbing, f.e.). The movement-sound complex of the baby probably displays indices which make the mother react in the way she does.

When playing with little children the behaviour of adults is often exaggerated: games are repeated, sentences, mostly questions are repeated, and intonation patterns are emphasized.

We tried to analyse the physiological component in early speech development in order to link early communication movements to adult speech.

METHODS

In 1974 a project on speech development was started in our Institute. A review of the available literature revealed that a phonological approach was very common. We thought however the discrepancy between the sounds of children and adults too big to use an adult transcription system. We decided to listen to sounds not as linguistic elements but to relate them to what is happening physiologically in the speech apparatus, which is actually the approach of many speech therapists.

Transcription systems are made to describe products of the vocal tract in a more or less narrow way. However, we tried to listen not to the "notes" (the products) but to recognize the "musical instruments" that produced them: a global approach since communication in young children is a rather global process as well.

For a physiological approach of infant sound production, knowledge of the anatomy and physiology of the infant speech mechanism is necessary. The mechanism is still more or less directed towards vital functions. The motor activities are not quite comparable to the adult speech motor coordination, although Meltzoff and Moore (1977) indicated that imitation of movements is present at a very early age. Hendrickx et al. (1976) have stated that in the first year of life many different functional movements develop in the regio of the mouth. The development of certain motor structures will influence positively the neuro-motor function and vice versa. This reciprocity is an essential factor in the normal development of (speech) movements.

Movements are basic for sound production, be it babbling or speech or even clapping hands. The description of movements is not without problems. Criteria are needed. In ultra high speed motion pictures the criterion can be defined in relation to a visual image. In sound analysis the problem is quite different. Speech sounds are the result of movements in the vocal tract but not all moving parts are directly observable. Furthermore a change in sound has not necessarily a one-to-one relation to a movement in the vocal tract. The starting point of a movement might precede considerably the moment the sound changes.

From the above it will be clear that a narrow transcription of speech movements is not possible when listening to taperecordings. The speech movement system, working so reliable, has to be a rather global one.
Oller et al. (1972?) have given an overview of pro's and contra's, possibilities an impossibilities of transcription, which is worth reading. The broader the transcription the more valid it becomes. When trying to hear what the infant did we have been confronted with the problem of transcription validity. Since we just indicated the moving parts not describing all the fine movements, our system is rather broad. A certain guarantee for validity however, demands knowledge of the anatomy and physiology of the speech mechanism, for sound production is limited by the possibilities and restrictions of the mechanism that will produce the sounds. In the analysis of infant sounds we must keep in mind that the mechanism is constantly changing. Even vital functions are not yet stabilized after birth. A longitudinal analysis of infant sounds can indicate the development of the speech mechanism and the factors that influence that development.

We have limited our research to non-crying sounds, not denying that there might be a relation between the production of crying and non-crying sounds. But crying does not seem to be necessary to develop the speech mechanism.
Our anatomical and physiological notes are mainly based on Fletcher (1973) and Wind (1970). In embryo the speech mechanism proves to have just one source: the embryonal pharynx which develops in an apparently heterogenious apparatus.
Respiration:
In our analysis respiration is basic. In the neonate respiration is controlled by the respiration centre in the brain stem. For the production of speech sounds it is necessary that the airflow can be regulated and the infant only gradually does that. Since speech has natural limits set by the initiation of inspiration and expiration, we have segmented the infant's sound stream by those natural limits.

Phonation:

According to Wind (1970) the larynx is "old" in an evolutionary point of view, having a very important vital function. In the neonate the position of the larynx is closer to the skull than in the adult. The larynx entrance is T-shaped as a result of the relative retardation in growth of the arytenoid masses. It is probable that respiratory and laryngeal muscles have been activated before birth. However, in premature children paradoxal respiration is frequent: protection is the vital function of the larynx, not sound production. As Wind (1970) states: "Most sounds produced in the airway of the newborn infant result in communication with its surroundings, and may therefore be considered as constituting the voice, according to our definitions (Chapter 4,8). But they clearly bear an involuntary and instinctive, or possibly even a reflex character for about the first 3 months." (p. 107).

As to the closing mechanism of the glottis, both glottal stops and aspiration, frequent in infant sounds, can be indicated as dis-coordinations. This closing mechanism is probably prevalent over the tension mechanism, since many early sounds lack a change in pitch. Respiration and activities of the vocal folds will have to be coordinated in a complex way in order to produce the pitch and loudness patterns of the mothertongue.

Articulation:

Neonates explore the environment mainly via the mouth, pharynx and larynx, as Bosma (1967) states, which manifests itself in the child's need to put everything in its mouth. Movements in the mouth are coordinated in the brain stem. According to Hendrickx et al. (1976) the child has to learn to reorganize elements of motion into new movements that are adapted to speech. In the development after birth the oral cavity changes functionally and in shape as well, mainly due to muscular forces. Pharynx activity can be peristaltic in relation to swallowing or a rather abrupt sphincter movement. These activities might be connected to stimulation of the laryngeal and tracheal lining causing the protective mechanism to come into action. These reactions gradually extinguish. Directing the airstream by means of the velum is

limited since the Musculus levator veli palatini is still more or less a tensor while the action of the Musculus tensor veli palatini is lowering the velum. This influences the quality of the sounds uttered by the child. In the neonate the tongue is relatively massive, filling the mouth and is thus limited in motion, pressing on the upper and lower jaw and the palatal bones. When the intrinsic tongue muscles become mature the tongue gradually develops into an organ capable of many variable movements. Lip function becomes more complex as is indicated by the smile and other communicational gestures of the mouth. Only later the child can curl the corners of the mouth.

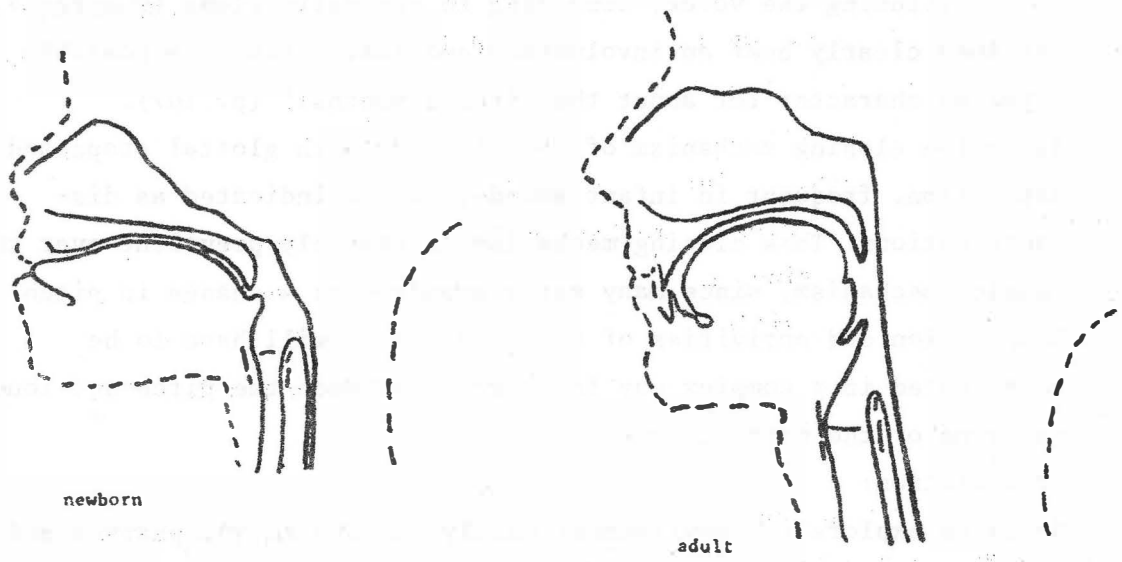


fig. 1

Notice the anatomical differences in form and structure of the oral cavity between the newborn infant and the adult.

TRANSCRIPTION

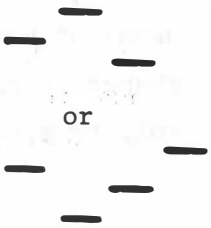
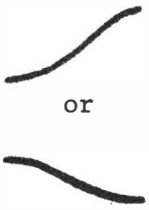
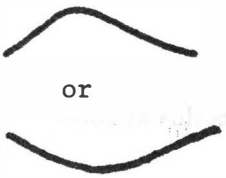
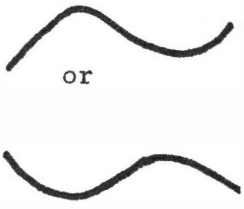
The basic unit of the analysis is the expiration. Since in the respiration cycle most sounds are produced in expiration we do not indicate the direction of the airstream. The expiration time will gradually increase in the development. The absolute value of the expiration time however is disregarded in our analysis.

Phonation per expiration is described with regard to pitch, breath pressure and loudness changes, vocal fold closure, and vocal fold tension.
Analysing infant articulation we indicated which part of the vocal tract is moving. The vocal tract can be transformed by various activities: by the pharynx, the velum (closing or not and a velum trill), the tongue (back, middle or front part and tongue trill), the lips (pouting, rounding or spreading and lip trill) and the lower jaw (opening or closing of the mouth).
Per expiration articulation is analysed and transcribed by means of movement indices which indicate what part of the speech mechanism is moving thus influencing the sound product.

A schematic representation of the analysis is given by means of the signs and patterns on the following pages.

PHONATION

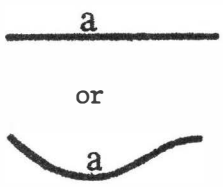
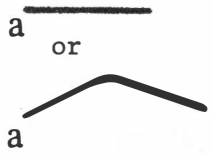
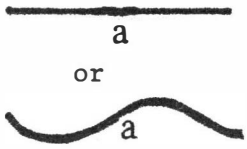
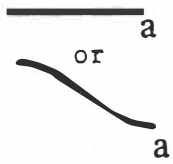
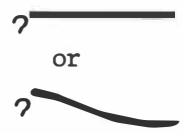
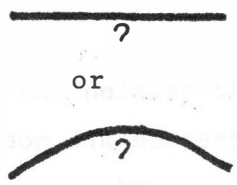
PITCH

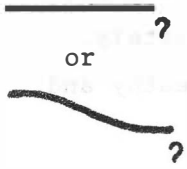
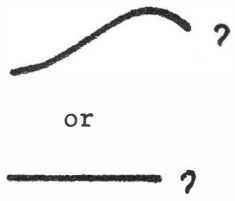
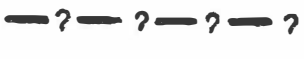
Notation	Description	Explanation
	flat sound	constant balance between breath pressure and vocal fold tension.
	series of flat sounds	the vocal folds are repeatedly closed for a short while during one expiration; no glottal stops.
	series of flat sounds with pitch change	either breath pressure or vocal fold tension or both change during one expiration.
	pitch glide	breath pressure and/or vocal fold tension vary gradually during one expiration, resulting in a rising or falling pitch.
	combination of pitch glides	rise-fall or fall-rise pitch pattern.
	combination of pitch glides	rise-fall-rise pitch pattern or a fall-rise-fall pattern.

BREATH PRESSURE AND LOUDNESS CHANGES

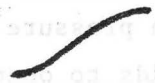
Notation	Description	Explanation
	sound becomes louder	increase of breath pressure.
	sound becomes weaker	decrease of breath pressure.
	pitch rises sound becomes louder	the loudness of a sound can be varied by means of breath pressure and change in pitch due to vocal fold tension.
	pitch rises sound becomes weaker	
	pitch falls sound becomes louder	
	pitch falls sound becomes weaker	
	combinations of pitch and loudness patterns	amplitude modulations
 or 		amplitude and frequency modulations

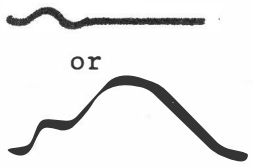
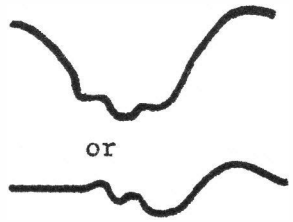
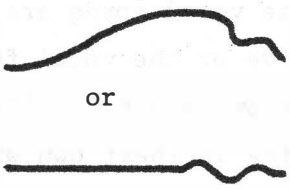
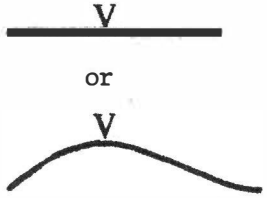
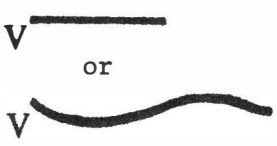
VOCAL FOLD CLOSURE

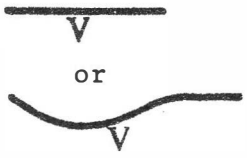
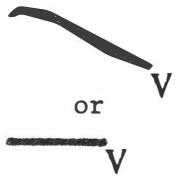
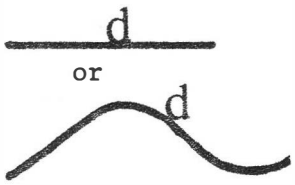
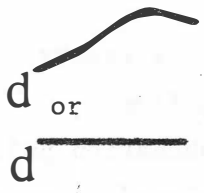
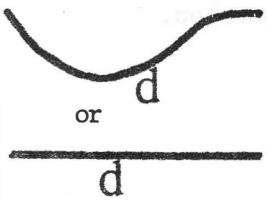
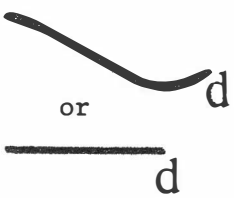
Notation	Description	Explanation
	sound is constantly aspirated, no interruption of voicing; pitch may vary	vocal folds are not closed completely, sound is breathy and hypotone.
	the beginning of a sound is aspirated	
	the middle of a sound is aspirated	
	the end of a sound is aspirated	
	glottal stop	the vocal folds are tightly closed, breath pressure forces the folds to open whereafter they close abruptly.
	sound starts with a glottal stop	
	the glottal stop is in the middle of the sound	

Notation	Description	Explanation
	the sound is ending with a glottal stop	
	the glottal stop comes after the sound	no inspiration meanwhile.
	series of glottal stops	

VOCAL FOLD TENSION

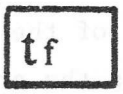
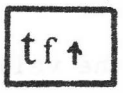
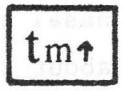
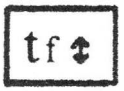
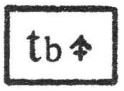
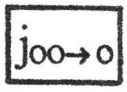
Notation	Description	Explanation
	true phonation	breath pressure and vocal fold tension are balanced.
		
		
	trembling phonation	vocal fold tension and breath pressure are not exactly balanced.

Notation	Description	Explanation
	the beginning of a sound is trembling	
	the middle of a sound is trembling	
	the end of a sound is trembling	
V	vocal fry	the voice is creaky resulting from a missing phonation pulse or from a too low vocal fold tension.
	the whole sound is made with vocal fry	
	the beginning of a sound is made with vocal fry	

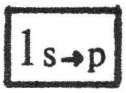
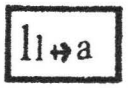
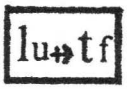
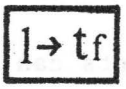
Notation	Description	Explanation
	the middle of a sound is made with vocal fry	
	the end of a sound is made with vocal fry	
d	diplophone sound	two tones can be noticed in the phonation, the false vocal cords are active or the vocal folds form two separate glottises moving in their own way.
	the whole sound is diplophone	
	the beginning of a sound is diplophone	
	the middle of a sound is diplophone	
	the end of a sound is diplophone	

ARTICULATION

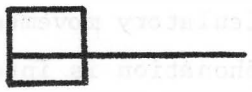
Notation	Description	Explanation
p	pharynx	constriction of the pharynx makes the sound sound squeezing.
v	velum	by means of the velum the way to the nose can be opened or closed. When the sound is not nasal nothing is described about the velum.
Vo	velum is not raised the way to the nose is open	
Vo→c	velum is raised the way to the nose is closed from open to closed	
Vc→o	the velum is lowered the way to the nose is opened from closed to open	
v↕	velum (uvula) is trilling	
t	tongue	the tongue can change the oral cavity in various ways. Three main moving parts are indicated.
tb	back of the tongue	
tm	middle of the tongue	

Notation	Description	Explanation
	front of the tongue	
	front part of the tongue rises	these indications of tongue movements may be used for all parts of the tongue indicated. When the tongue is raised a noise sound may result, when the tongue touches the palate an explosive sound may result.
	middle part of the tongue is raised	
	tongue trill	
	back part of the tongue touches the palate	
	jaw	the opening of the mouth and movement of the lower jaw are closely related. Movements of the jaw result in opening or closing of the mouth. Tight closure of the mouth requests action of the lips as well.
	the mouth is wide open (oo)	
	the mouth is closed (cc)	
	movement of the jaw from wide open to open	these indicated movements can be combined in several ways.

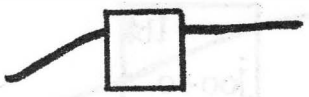
Notation	Description	Explanation
j o→c	movement of the jaw from open to nearly closed	
jc→cc	movement of the jaw from nearly closed to closed	
joo→c, c→o	movement of the jaw from wide open to nearly closed to open again.	
l	lips	lip movements can change the opening of the mouth in an important way. Furthermore, lip and tongue tip together can make various articulations.
l r	lips are rounded	
l p	lips are pouted	
l s	lips are spread	
l ◊	lip trill	
l r→ s	lips move from rounded to spread	

Notation	Description	Explanation
	lips move from spread to pouted	
	lower lip touches the alveolus	
	upper lip touches the tongue (front part)	
	tongue (front part) is between lips	
	lips and jaw are tightly closed, lips and jaw move from closed to nearly closed	

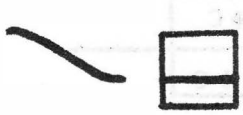
As said above we based ourselves on three main description categories: respiration
phonation
articulation.
By means of this transcription system we described the sound production of two children recorded weekly from birth till about eight months of age (Koopmans-van Beinum; van der Stelt, 1979). The sound stream is segmentated by means of the boundaries set by respiration. Each segment is thus described by one transcription string. After description of phonation all attention can be focussed on articulation. Each articulatory event is indicated by a rectangle. In case of just one event the moment of the movement in the sound can vary. Some examples are given below.

1) 

movement at the beginning of a sound, phonation is continuous, pitch is flat.

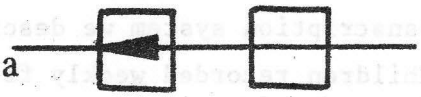
2) 

movement in the middle of a sound, phonation is interrupted during the articulatory movement, pitch rises to become flat.

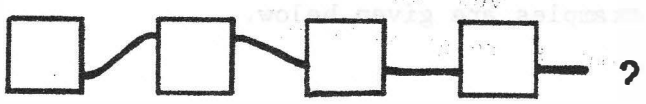
3) 

movement at the end of a sound, phonation is interrupted before the articulatory movement, pitch falls to become flat.

Two or more events are described together with phonation patterns in the following examples.

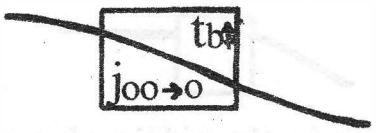
4) 

flat sound starting with aspirated phonation, two articulatory events (not transcribed) somewhere in the sound, phonation is not interrupted but sound becomes louder during the first articulatory movement.

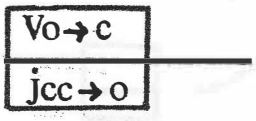
5) 

series of articulatory movements (not transcribed) during which phonation is interrupted; pitch rises, falls and becomes flat; glottal stop comes after the sound.

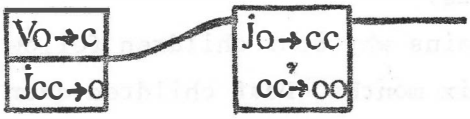
The following step in the analysis is the description of each of the movements together with phonation. Some examples are given below.

6) 

sound with continuous phonation, pitch falls and there is one articulatory movement: the back of the tongue touches the palate and the jaw moves from wide open to open.

7) 

sound starting with an articulatory movement, continuous phonation and pitch is flat; the way to the nose is closed and the jaw moves from closed to open.

8) 

sound with two articulatory movements, phonation is interrupted during the second articulatory movement; pitch rises between the articulatory movements then becomes flat. See for the first articulatory movement example 7); in the second one the jaw moves from open to closed and to wide open again.

One has to keep in mind that transcription of sounds never can fully represent the sound itself. Transcription has certain consequences due to the method used.Our transcription system enables us to show that the development of the speech mechanism is a systematic one till about the age of nine months. The child gradually masters a liberty to vary reflex methods of respiration and reflex movements of the larynx muscles. Tension and position of the vocal folds gradually can be varied, where at first the child tends to act in a reflex manner resulting in glottal stops and aspiration. When the child is about six months old it can vary voluntarily upon the primary reflex function of the larynx much the same as adults do when speaking. The development of articulatory movements can be regarded as a maturational process based on primary succing and swallowing movements, and the process is comparable to other maturational processes: from central to the perifery, and gross movements before the finer ones. Pharyngeal constriction was very tight at first, later on breath could pass more easily so that prolonged noise sounds are produced in the pharynx. Pharyngeal constriction, quickly followed by velar and jaw movements (resulting in opening or closing of the mouth) come before movements of the lips or the tongue tip. The child plays with movements of the speech apparatus controlloing them tactilly and kinesthetically. In our opinion the first six months of speech development should be regarded as a period of physiological development.

Independent from specific languages all children are "mapping" their speech apparatus.
This also explains why deaf children follow the same development untill about six months. Deaf children over six months do not play with sounds as hearing children start to do in the interaction with their parents or caregivers.
In literature, auditory, visual, kinesthetic, and tactile factors are said to influence the motor development, which is only partly determined by genetics. Whether these factors play an important role as early as the first six months of life is still a field in need of research.
We intend to analyse sound production of deaf and blind children in the first six months of their lifes in order to evaluate the role of the factors mentioned above.

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