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Abstract

PILE (Programme International pour le Langage de l'Enfant[1]), the International Program for Child Language aims to describe the processes leading to the emergence of speech in infants thanks to statistic techniques. A qualitative data base was established on the basis of one minute video sequences (the statistical units) of babies aged from 3 to 9 months interacting with their mothers. The phenomenon under study is the process of speech construction. The 110 infants are belonging to seven cohorts: infants without disorders, hospitalized infants, premature infants, infants of visually deficient mothers, infants of blind mothers, infants with neurological disorders. We present a statistical study of this data base through inferential techniques (non parametric comparison tests) and factorial analyses. Some of our findings confirm or bring additional precision to clinical hypotheses concerning the impact of certain factors, such as age cohort, calendar age, infant's sex. The statistical results describing the infant's behavior while interacting with its mother indicate that the development of the baby's perceptive system is central in the construction of language precursors.

Keywords: infant, comodalization, rhythmic envelope, perceptive system, Principal Component Analysis, nonparametric statistics

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1 Introduction

The aim of this study is to identify the precursors of language organizing the pre-verbal communication of babies and opening the way for the emergence of speech. The study is based on videos of babies interacting with their mothers, filmed in the framework of the International Program for Child Language (PILE Programme International pour le Langage de l'Enfant). The study is longitudinal, and monitors babies from the age of 3 months to 9 months. The set was designed so as to be able to measure the dynamics of exchange and the baby's evolution. Our aim being to understand how the psychical processes preceding the emergence of speech are gradually put in place, we analyzed the baby's movements organizing and building exchanges with its mother: movements of the hands and feet, vocalizing, and eye movements. Rather than a study of single movements, the research focuses on the synchronization of all the baby's movements in terms of interactions. The cohorts were put together thanks to the generosity of parents who volunteered to participate in the research. The therapeutic effect of the exchanges with the clinical psychologists during the filming was more or less significant. During this period, when the babies were between 3 and 9 months old, the families did not pass any tests and we did not use the anamnesis[2]. The aim of the statistical analysis was to grasp the baby's change of behavior as it begins to construct what will later become language.

After a preliminary study on the reliability of the results of the judges who score the videos (see Chauveau *et al.* [4]), we selected among the base data fields three blocks of qualitative data for which the judges' responses were in agreement. On the basis of these fields, we created three quantitative criteria, the first corresponding to the baby's behavior regarding its body, and the two others to the relationship between baby and mother, according to different relationship parameters. In order to study these three parameters according to cohort, we began with a principal component analysis. This enabled us to visualize the links, if any, among the different criteria and the differences in these links between the cohorts of babies. We then used other types of representations and statistical tools such as *boxplots*, or sample comparison tests. The ideas governing the computations in this study are based on clinical experience with children who do not have access to language (autistic and psychotic children) and on the observation of babies. During this research, the interaction of these thoughts with statistical analysis led to the emergence of concepts which designate the baby's perceptive system as the driving force of the emergence of language. In Section 2, we present the concepts of the model for the establishment of the perceptive system as determined during the research. We then present the objectives of the study. These objectives are limited by the very nature of the studied phenomena, which can only be analyzed during the baby's development seen as a global whole. Section 2 also provides the data base for the scoring performed by clinical psychologists of the video sequences of babies aged from 3 to 9 months. We then explain the significance of the three quantitative criteria retained.

In Section 3, depending on the cohort, the study shows through descriptive statistics how the interacting mother and child use the perceptive system to communicate. Thanks to the large number of babies in most cohorts, it is possible to analyze development in relation to calendar age. This dimension was necessary to the research, since language precursors can only be identified from the point of view of development. Not only do we focus on the three quantitative criteria, but also on the links between them.

During this research, we found we could measure the influence of vocalization on the

[2] the information given by the mother on her baby's history.

basis of the babies other means of communication. This study is described in detail in Section 4.

One of the original characteristics of this data base is the scoring of rhythmic behavior in the relationship between mother and baby. Section 5 provides a precise statistical analysis of this relationship for the different cohorts. The fact of whether the baby was giving or receiving this rhythm was taken into account in the analysis of the criteria. The criteria describe how the baby receives or gives rhythm with its hands, feet or through vocalization. Last, the rhythmic coordination is described according to perceptive modes.

Section 6 regroups the conclusions for each cohort from a clinical point of view, based on the interpretation of the results of the statistical study. We also give the conclusions concerning the role of rhythm in mother-baby communication. In the appendix (Section 9), we provide information on the protocols, the fields used in the data base and several statistical tools.

PILE members. The co-directors of the PILE project are Professor Bernard Golse and Mrs. Valérie Desjardins. The video unit was created in the Child Psychiatry Department (Pr. B. Golse) of the Necker-Enfants Malades Hospital in Paris. The clinical base used in this research was set up by Valerie Desjardins with Christelle Benony. The base fields usable for this study (see Chauveau et al. [4]) were developed by Valérie Desjardins. Filming was done by the clinical psychologists Valérie Desjardins, Christelle Gosme, Marluce Leitgel-Gille and Julia Wenke Motta de Castilho, and by Drs. Lisa Ouss and Roberta Simas. Technical support was ensured by Alain Casanova, Xavier Jeudon, Gwenaël Mulsant and Nicolas Perinetti. The scoring of the cohorts was performed by Valérie Desjardins, Christelle Gosme, Florence Lafine, Marluce Leitgel-Gille, Julia Wenke Motta de Castilho and by Dr. Roberta Simas. Mme. Edith Thoueille, director of the Institut de Puériculture in Paris, was responsible for recruiting most of the babies who participated in this research.

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2 Presentation of the Study

2.1 Model of the Formation of Language Precursors through the Perceptive System

The perceptive system is involved every time a person speaks. Not only does it fulfill a function during the duration of speech, but also, from the very start of life, it plays a fundamental role in the constitution of the phenomena which make the emergence of speech possible. A detailed analysis of how the perceptive system develops helps us to understand language precursors. Our five perceptive modes (Touch, Smell, Taste, Hearing and Sight) are solicited at the same time, but according to certain patterns determined early on in life. The infant perceives movements and not fixed objects. Depending on each perceptive mode, it perceives a movement. This perception is a rhythmic movement. For example, the baby perceives a voice through audition or a hand movement through sight. The rhythmic character of the perceptive movements leads to their intrication, a phenomenon called comodalization (Meltzer 2004 [11]).

Thanks to the repetition of events perceived according to several modes, the baby perfects the rhythm of its perceptive modes while at the same time comodalizing them like musical instruments rehearsing together. For example, the infant perceives at the same time a voice and a moving hand. There is an intrinsic link between comodalization and rhythm.

In research, it is easier to measure rhythm than comodality. Comodality and rhythm (Gepner B. 2006 [7]) exist both on a partial and on a global level. Each perceptive mode can be thought of as comodalizing with the others and the patterns governed by the comodality of perceptive modes represent a whole which builds the perceptive system. Rhythm can be considered for each perceptive mode and there is also a global notion of rhythm, called rhythmic envelope. The word "envelope" must not be understood as a representation but as a function, since the entire body is stimulated by rhythm. We distinguish proximal perception from distal perception because the perceptive modes are not experienced on the same level. When what is perceived is near, they are proximal, and they are distal when what is perceived is at a distance.

Feeding time was chosen as the best time to understand how the perceptive modes organize their links to one another. During feeding time, three perceptive modes are involved at the mouth level: Touch, Smell, and Taste (TST): these are proximal modes. When the baby is feeding, it creates rhythm on the TST level and produces a sound which is sufficiently audible to stimulate Audition. The sucking rhythm is constructed already in utero, it is the result of the rhythmic sounds of the mother's body received by the baby's organs and perceived by its ears. These sounds are comodalized at least on the level of Touch and Audition (Streri 1996 [15]), and this creates the pleasant texture of sucking. Life in the womb links audition to touch forever, through comodalization. After birth, the baby continues to harmonize the rhythm of sucking to the rhythm of the mother's voice perceived in comodality through audition and touching of the skin. This rhythm is determined by universal rhythms such as those of breathing and heartbeat, together with the rhythm of the mother tongue, rhythms which are distinguished from one another by their perception originating internally or externally.

The sucking act is fundamental in that through sucking the baby becomes an actor in his mother tongue. More precisely, sucking is the first moment when the perceptive system pervades the tongue. Feeding constructs a proximal comodality with four perceptive modes: Touch, Smell, Taste and Audition (TSTA). During sucking motions, the rhythm is simpler and ensures solid comodality; proximal comodality is thus more surely attained. The rhythm of the mother's body holding the baby keeps the sound around the baby and acts as a sounding board, thus improving the reception of the mother's voice by the baby's body. Proximal comodality has an impact on the entire rhythmic envelope of the baby. It is important to note that audition becomes proximal here thanks to its comodality with touch, which covers the entire body. Thanks to life in utero, proximal audition is thus very closely linked to global body rhythms.

Sight is also important on a proximal level, in a specific way. When people look at each other, they do not create an eye image but a feeling of touch. This is due to the fact that Sight is comodalized with the TSTA of feeding experience. In the early stages of life, the baby looks at the shiny spots in a face, while sucking and feeling the liquid in its mouth. Sight thus becomes proximal. Then, when the experience of TSTA + Sight (TSTAS) is solid, the baby, by looking at its mother, can call up this psychic experience without feeding. (TSTA)S. Contact through sight is forever linked to proximal perception, and its rhythm is later also organized by the eyelashes. Audition comodalized with touch, already in the womb, is linked to the global rhythmic envelope.

In the womb, and in the early stages of life, the baby constructs its proximal perception through the five modes. After birth, it is important to understand that audition and sight are experienced through comodality on a proximal level in the communication between mother and baby. This specificity creates for the baby a feeling of proximity with its mother, close to what was felt in the womb, even though mother and baby are now separate. This proximity concerns the entire body through the constitution of the rhythmic envelope called the proximal envelope. It is characterized mainly by micro-movements (Devouche E. and Gratier M. 2001/2 [3]) constructed in utero. At birth, one can observe these micro-movements in the hands, feet and face. The mother's voice also goes along with broader movements, macro-movements which the baby receives on a proximal level through touch and audition and which nurture the proximal envelope. Due to its uterine origin, the proximal envelope is necessarily global and unifies the body.

Right before feeding, right after or during feeding, the baby perceives through Sight and Audition the mother's "voice-face" system. This comodality, which is distal, is organized through the harmonized movements of the mother's voice and facial expressiveness. Throughout these experiences, these intertwined maternal movements are the perceptive background for comodalization of the Audition and Sight by the baby. The mother tongue (or the language of the care-givers) triggers the comodal development of the perceptive system of distal audition and sight. These movements are essentially macro-movements. They are more easily perceptible by the baby than micro-movements. The baby perceives these movements, organized by language and gives meaning to this experience by building a system of codes.

Proximal and distal perception are organized by language. Two easily observable behaviors show that the baby has entered the realm of language. Sucking during feeding is a founding movement of the proximal envelope while the production of rhythms with hands, feet, vocalizing and the face mark the production of the distal envelope. In both cases, the baby is an actor in the production of rhythms (Ciccone A1. 2007 [2]). The baby communicates with the adult by involving its entire body in language. The baby produces these movements when it perceives the rhythms in its mother's voice and sees her body and especially her facial expressions. Both comodal transmissions of rhythms, one proximal and the other distal are founding elements in the child's access to speech.

Later, when the mother holds the baby less, she begins to communicate in a face-to-face relationship and the proximal perceptive system evolves accordingly. This distance means the baby has a good proximal envelope thanks to a good level of audition and touch comodality, which means it no longer needs to be held by the mother's body rhythms. This distance also corresponds to the fact that the infant is now able to solicit the comodal experience of audition/touch when it hears a sound, and that it can trigger the (TSTA)S experience of making eye contact without TSTA stimulation in the mouth. At this distance of communication, both protagonists touch T each other essentially with their hands and are in audition contact A, comodalized with touch T on the entire body. The use of the auditive mode A in proximal mode is easily observable with a baby, in the sense that both protagonists seem to be touched by sound; it is an instantaneous contact. Little by little, the proximal system ceases to be the main function and communication becomes more distal, while maintaining proximal communication through eye contact and voice. Harmonization, in reference with Stern's emotional harmonization [14] involves the harmonization of rhythmic envelopes, thanks mainly to the harmonization of proximal envelopes through eye contact and voice reception. The baby's evolution is positive between 3 and

9 months if audition A and sight S are formed in both proximal and distal modes, thus ensuring adequate communication skills.

Our model is based on the following postulate: Before the emergence of speech, a real event perceived by the baby according to at least two perceptive modes is registered as an "external" psychic event that is experienced, felt and indexed as being exterior to the baby. The psychic event is experienced with disappearing elements. At the same time as the event is classified as being external, it takes on meaning in the psychic organization. For example, when the baby breastfeeds, it comodalizes touch, smell, taste, audition and sight TSTAS upon contact with the mother's body, which then disappears; this psychic experience is then registered as an external event. The psychic experience is registered with a "meaning" whose reference organizing system is the mother's body in the baby's history. The development of the perceptive system involves the organization of processes defining the relationship between external and internal, depending on time.

This boundary between inside and outside also develops through the baby's processes of appropriation and body integration. The baby can only integrate its own body if it does not perceive its different body parts as external, thus, according to the unimodal postulate. For example, the baby unimodally perceives its body by touching it with its hand. In the case of sight, the visual perception of the hand is linked to proprioceptive sensation when the baby moves its hand. The auditive mode A acts unimodally for the appropriation of voice linked to vibrations in the throat. The postulate structuring the perceptive model studied here is based on the fact that the ego is rooted in the body and on the existence of a distinction between the ego and non-ego when the baby will have access to representation (Freud, 1923 [6]).

This study aims to develop a perceptive model bringing together statistical analyses and clinical experience. The model aims to shed new light on the understanding of the construction of speech in infants and to resolve the following problems:

- Clinical experience with children who have severe language disorders has generated several concepts on the construction of speech. These concepts have the advantage of having been developed taking into account the global evolution of the child. On the other hand, phenomena experienced during therapy are not measurable, and occur with only a few specific children.

- One can observe behaviors by watching babies interacting with their mothers, but this form of observation has two major drawbacks: it takes place at a given instant and does not take development into account. It concerns a partial movement which is not linked up with the baby's global performance.

- The study of speech precursors must not focus on individual specificities, but grasp universal phenomena.

If our findings are meaningful on the global level of the baby's interaction with its mother as it develops, they can lead the way for new ideas to better care for children suffering from severe language disorders.

2.2 Presentation of the Database

The base fields are defined by attempting to reduce the influence of the constraints mentioned above. For this purpose, it is necessary to score a large number of infants; one must also choose movements that are simple and easily identifiable on film. The chosen body movements correspond to the perceptive models described in 2.1. These movements are rhythmic and are part of the baby's construction and communication. The data is gathered from the films on the babies of the protocols presented in appendix 9.1. During the study, it appeared that this base can serve to identify the role of the different perceptive modes (Touch, Audition and Sight) depending on whether they are experiences on a proximal or distal level by the baby in its relationship with the mother.

Three groups of specific fields were selected in the database for this study (see appendix 9.2 for the description of the fields):

- the group covering the baby's coordination with its own body (22 fields in the base), denoted by *cbb*.
- the group covering the baby's coordination with the parent (20 fields), which describes how the baby and the parent touch each other through voice or gesture, denoted *cbp*.
- the group covering the rhythmic coordination of baby and parent (38 fields), describing communication through rhythm, denoted *cry*.

Answers for the coordination fields are noted in binary mode (yes, no). Each field corresponds to a movement or an action performed by the baby, which will be described in greater detail in paragraph 2.3. We do not look at the number of times the baby has made the gesture but at the fact that the gesture took place during the video sequence, which lasts one minute. If the baby does not touch its body during that time, the answer is "no", if it touches it at least once, the answer is "yes". The same rule is applied when the mother touches the baby with her hand or voice, as well as when there is a transmission of rhythm. Specific attention is given to the analysis of rhythm transmission. In particular, the base tells us whether the baby or the mother are transmitters or receptors of the rhythm through their hands, feet or voice. The relevance of the fields also makes it possible to analyze the influence of the comodal dimension in the transmission of rhythm.

For the first two groups, we can determine for each field whether or not the baby has vocalized (see appendix 9.2). Let us note that the differentiation between "with" and "without" vocalizations is not exclusive, the baby can touch its foot while vocalizing and later make the same gesture, this time without vocalizing. The study covers 7 cohorts, selected according to the following criteria:

- the cohort of infants without disorders (*st*): 45 infants (954 sequences). They are without handicap or genetic illness, from any ethnic origin, and have been randomly selected. Their parents do not have handicap as well.
- the cohort of infants who were hospitalized in infancy (*hos*) : 7 babies (195 sequences).
- the cohort of infants subjected to feeding constraints due to pediatric, malformation or metabolic disorders. This cohort is called "eating disorders" (*tal*) : 15 babies (172 sequences).
- the cohort of premature infants (*prm*) : 15 babies (195 sequences). The premature babies were selected if they were born between 30 and 36 weeks of gestation.

- the cohort of infants having mothers with a visual deficiency (*dev*) : 6 babies (135 sequences). The mothers of these babies are visually impaired to a variable degree. At the time of the study, the babies themselves did not have any problems of sight. In addition, none of the fathers had impaired vision.
- the cohort of infants whose mothers are blind (*mav*) : 7 babies (106 sequences). The mothers of these babies are blind. At the time of the study, the babies did not have any sight problems. In addition, none of the fathers had impaired vision.
- the cohort of epileptic infants with West syndrome. This cohort is called "neurological disorders" (*neu*) : 16 babies (183 sequences).

The statistical unit is the sequence. It is based on an infant, its age, its cohort, a protocol (spontaneous, with an object ("giraffe"), a song ("ainsi font font"), see appendix 9.1). What we call sequence is the result of the scoring (response to a questionnaire representing the data base) of a one-minute video, performed by a judge. Table 2 provides the number of sequences for each cohort scored by 1 to 7 judges.

For the following study, the infants came at regular intervals, between ages 3 to 9 months; in some cases it was difficult to maintain the regularity of the intervals and in other cases the infants stayed for longer periods. It is interesting to observe at a later stage (fig.1) the distribution of the number of video shootings as compared to the age of the infants, for each cohort.

During the minute of observation, the judge analyses the gestures, defined in advance, made by the baby alone or interacting with someone else. On average we found two or three "yes" answers in each coordination group. For each sequence, we counted the number of positive answers for the three coordination categories. We thus obtain 3 quantitative variables *cbb*, *cbp* and *cry*, with values within respectively $\{0, 1, \ldots, 22\}$, $\{0, 1, \ldots, , 20\}$ and $\{0, 1, \ldots, 38\}$ for n observations (where $n = 1940$ is the number of scored sequences). In practice the maximum values of *cbb*, *cbp* and *cry* did not exceed 15, 12 and 14.

Figure 2 gives the histograms for the three criteria, for all the sequences. The abscissa gives the number of "yes" answers in one sequence for each *cbb*, *cbp* and *cry* group:

- the number of times the infant touched itself or looked at itself (*cbb*)
- the number of times mother or baby touched each other with a sound or their bodies (*cbp*)
- the number of times when the rhythm was transmitted by the infant or the mother (*cry*).

Very often there are no "yes" answers over a one-minute period. Some "mother-infant" couples can interact up to 15, 14 or 12 times in one sequence, but this remains rare. This distribution of histograms justifies our choice of applying the analysis to the sum of answers. One can observe a difference in the mode[3] of the empirical distribution, between *cbb* and the other two criteria; this difference means that observations are more frequent for the *cbb* criterion.

2.3 The Quantitative Criteria of Perceptive Communication

The three criteria *cbb*, *cbp* and *cry* are described on the basis of the hypotheses of the model of development of the perceptive system.

[3] the value of highest (empirical) probability

cbb: "Yes" is given for a cbb field when the baby touches part of its own body with a hand or foot or when it looks at part of its body. The perceptive modes involved and noted down in the base are touch T and sight S. We also observe whether the baby vocalizes while touching its body. The behavior of the baby observed in this paragraph belongs to the process of body appropriation and unification. According to the hypothesis made in the introduction, the visual mode is necessarily unimodal, so that the body parts (and particularly the hands) that are looked at are not considered external but as part of the baby's body. Used unimodally, the visual perceptive mode V switches to a proximal function, like touch T. Analysis based on vocalizing provides information on the auditory perceptive mode A which plays a double role. Sound is received comodally through audition and skin touch, and maybe through other more internal body parts. The listening baby can also recall other psychic experiences where audition was already comodalized with touch. When appropriating voice, audition A is used unimodally. The *cbb* criterion characterizes the proximal use on the baby's body of touch T and audition A (both unimodally and comodally) and of sight S unimodally. Thus, **the *cbb* criterion describes the development of processes of appropriation and unification (integration) of the body thanks to the proximal perceptive system**.

cbp: A field is determined when the baby touches its mother with its hand or foot or when the mother touches the baby with her hand. The perceptive mode for each of them is touch T. This mode of touching can be comodalized. We also note that when mother and baby touch each other through sound, this exchange is characterized by immediate response. This characteristic leads us to the conclusion that this form of contact, through the auditory perceptive mode, is experienced as proximal as it is comodalized with touch by sound on the skin or on other more internal parts of the body. The comodality of audition with touch can also be obtained by creating psychic experiences where audition and touch are already solicited. **The *cbp* criterion describes the processes at hand in exchanges between baby and mother in proximal mode through Touch and Audition**. In order to better interpret the results of the *cbp* group, it is necessary to find out whether one or the other of the two protagonists, mother or baby, influences more the relationship, in other words, if one of them is more active in initiating the relationship. The results of the *cbp* group are interpreted taking into account the fact that the parents are most often the initiators of the relationship.

Both *cbb* and *cbp* fields measure the proximal perceptive system processes mainly through touch T, audition A both unimodally and comodally and sight S unimodally.

cry: A field is determined if the baby moves its hands or feet rhythmically to the sound of its voice. A field is also determined if the baby perceives a rhythm in the mother which it then performs with its hands, feet or voice. A field is determined if the mother repeats a rhythm with her voice or hands, a rhythm perceived in the baby as well. In *cry*, the two modes used are audition A and sight S. These exchanges are made in distal mode, contrary to the proximal mode observed for *cbb* and *cbp*. **The *cry* criterion describes modes of transmission of rhythm in the relationship according to the distal perceptive system**. The study of distal rhythm provides information on the quality of distal comodality A and S. Let us note however that rhythms are not only transmitted through the distal mode, but also proximally through micro-rhythms.

3 Analysis of Mother-infant Communication through the Perceptive System

The analysis of the whole population has a limited interest since the cohort of infants without disorders (hereafter *st*) represents much more sequences than the other cohorts. We thus choose to study each cohort separately, trying to highlight differences between cohorts in terms of behaviors with respect to our quantitative criteria and qualitative factors. The calendar age of the infants has been recoded (grouped) into a qualitative factor with 3 levels: younger than 4 months (-4m), between 4 and 7 months (4-7m), and older than 7 months (+7m). This recoding has been chosen since it amounts to acceptable repartition in each cohort, and corresponds to clinical criteria.

In the following statistical analysis, the *statistical unit* (individual) is a video sequence scored by a judge for the three criteria. Since the same sequence may be scored by several judges, we have chosen to associate to each such sequence denoted s_i, a weight $1/j_i$, where j_i is the number of judges having scored s_i (see also Table 1).

To help visualization of the cohorts behavior in terms of the three criteria *cbb*, *cbp* et *cry*, we first use the very well-known descriptive statistic technique of *Principal Component Analysis* (PCA), see, e.g., Lebart *et al* [9]. Briefly, the principle of the PCA consists in finding a lower (typically 2) dimension projection of the multidimensional scatterplot of the data, optimal in term of keeping as much as possible of the original dispersion. Here, we have a very simple application of the PCA since the original scatterplot is only 3-dimensional, and we will only have to reduce its dimension to the 2 first principal components (axes). The computations and representations have been done using the R statisical software [12], together with the ade4 package [1]. For brevity, only the PCA results leading to clear interpretation have been displayed in Section 8.

We have also drawn the *boxplot* distribution of each criterion, per age factor levels, for each cohort. Briefly, in a boxplot (also called *box-and-whiskers*) the limits of the box represent the 25% (Q_1) and 75% (Q_3) quartiles; the horizontal line in the box is the median, and the whiskers show some sort of extreme values of the (empirical) distribution, the computation of which depends on the statistical software. In R, these are extreme values at a distance lesser than $1.5IQR$ from the box, where $IQR = Q_3 - Q_1$ is the interquartile range. Higher boxes thus mean more various or important movements of the corresponding sub-population of infants.

Note The cohort “eating disorders” (*tal*) has been removed from the analysis in this paper, since it concerns $n = 172$ sequences, but with only 15 sequences before 4 months, which precludes usage of meaningful statistical techniques (see Desjardins *et al.* [5]).

3.1 Cohort Without Disorders (*st*)

This cohort consists in $n = 954$ individuals (statistical units). Table 1 gives the number of scored sequences per age factor. Figure 3 displays the result of the PCA, with the main factorial plot (i.e. projection of the individuals with respect to the 2 first principal components) and *correlation circle*, which explains graphically the statistical relationships between the principal components and the original variables (the 3 criteria *cbb*, *cbp*, *cry*).

On the individuals plot (Figure 3, left), the two ellipses of inertia corresponding to the age factor levels older than 4 months are similar and include the ellipse for infants lesser than 4 months. For all the cohorts, clinical observation shows that infant younger than 4 months presents movements with very few coordination, that get more organized later. The statistical analysis is thus in accordance with this difference of behavior after 4 months. The correlation circle (Figure 3, right) shows that the first principal component (horizontal axis, PC1) is mostly correlated with *cbb* and *cbp*, whereas the second principal component (vertical axis, PC2) is correlated with *cry*. Since the differences between the ellipses are mostly along PC2, we can conclude that the *cry* criterion evolves more with age than the two others.

The analysis of the quality of distal rhythm, which is linked to the quality of distal comodality of Sight and Audition through the *cry* criteria is meaningful to study infant evolution.

Figure 6 provides the *boxplot* distribution of each criterion, per age factor levels. As stated before, higher boxes show more various or important movements of the corresponding infants.

Comparisons of distributions per age factor. We also have tried to investigate possible differences between the distributions of the criteria per age factor, with statistical tests of hypothesis. The most immediate and intuitive way of comparing distributions amongs to compare the empirical means of the criteria per factor levels. Table 4 gives these means for all the cohorts, together with their corresponding 95% confidence intervals (CI's) (based on the Central Limit Theorem which is valid for large enough sample sizes, like we have here). The most usual statistical method for testing the null hypothesis of equality of means between factor levels is the *analysis of variance*, which assumes that each sub-sample is gaussian-distributed with same (unknown) variance. Unfortunately, the normality assumption cannot be accepted here. Indeed, a statistical normality test like, e.g., the Shapiro-Wilk test (see [13]), rejects the null hypothesis of normality for each of the three criteria, with p-values $p < 2e - 16$, i.e. rejection is not questionable.

A standard answer to multiple comparison tests for non-normal data consists in using *nonparametric* techniques, such as the Kruskall-Wallis test (see, e.g., [8]). In short, nonparametric means that no (parametric) assumptions are stated upon the underlying distributions of the data, in particular these are not assumed to be normal. The null hypothesis H_0 of equal distributions is tested against alternate hypothesis such as a shift between distributions of sub-populations (that is, per factor levels).

Table 5 gives the results of the Kruskall-Wallis test for all the cohort. For instance for the *st* cohort, the first p-value $p = 0.03$ suggests that the null hypothesis of same distribution for *cbb* between age levels should be rejected (e.g. at the stantard type I error of 5%). When the global hypothesis of equal distribution is rejected, we can get more precised results by performing 2-by-2 similar tests, that are displayed for all the cohorts for which the global test has rejected homogeneity, in Table 6. Note that in case of a comparison between two distributions, the Kruskall-Wallis test reduces to a Mann-Whitney test (see, e.g., [10]).

- *cbb*: Between 3 and 9 months, the infant increases his gestures which participate to his body appropriation processes, as can be seen by looking at the increasing medians (fig.6); these observations are also validated by the statitical test for *cbb* (tab.4 and tab.6).

- *cbp*: This criterion does not change with age (fig.6). The movement quantity between mother and infant to touch themselves seems to be not influenced by the infant's age.

This is shown also by the means and the statisical test (tab.4 and tab.5, *st* cohort) This fact can be understood partially because (as already pointed out) the mother initiate more the movements than the infant, hence the measure for the infant is attenuated.

- *cry*: We observe in the evolution of the medians and the means a treshold between the first age level and the two other levels (fig.6, tab.4 and tab.6). The values of this criterion increase with age. This fact also matches clinical observation: the infant after 4 months shows a good ability for the transmission of distal rhythm.

3.2 Cohort Without Disorders (*st*) by Sex

It also seems interesting to study the eventual effect of the factor "sex of the baby", which is possible for this cohort since it represents a large population. The Shapiro-Wilk's test obviously rejects the null hypothesis of normality for the *cbb*, *cbp* and *cry* criteria (the p-value is always $p < 2e - 16$). Clearly, girls and boys have similar results for *cbb* and *cry*, but show differences for *cbp*. Discovery of the infant's body, and rhythm transmission evolve in a similar manner whatever the sex of the baby. The observed difference for *cbp* may be due to a difference in the mother's behavior between girls and boys.

3.3 Cohort of Hospitalized Infants (*hos*)

This cohort consists in $n = 195$ sequences (statistical units). We can see in fig.4 a difference in comparison with the *st* cohort (without disorders) on the principal projection (corresponding to the two first principal components). The ellipsoids for ages older than 4 months are not superimposed now, which tends to show a slower evolution for hospitalized infants. Like for the *st* cohort, *cry* is the criterion which evolves more. The correlation circle show similar relationships than for the *st* cohort.

- *cbb*: for the two first age levels, we observe a progression similar to that of the *st* cohort, however the test result is less decisive (and the *hos* cohort also represent a smaller number of individuals). At 4 months old, the baby reduces his backwardness. The evolution almost stops after 7 months, in contrary to that of the *st* cohort. Hence there is an overall backwardness, which is confirmed by the homogeneity test which does not reject the null hypothesis (tab.5, *hos* cohort).

- *cbp*: this criterion is even less discriminant (in term of evolution with age) than for the *st* cohort. Even though mothers here initiate at 92% the relationship, *cbp* values do not show an increase in the exchanges.

- *cry*: this criterion is smaller than for the *st* cohort for the two first age levels, and increases rapidly in the third level. *cry* is low before 4 months and high after 7 months.

3.4 Cohort of Premature Infants (*prm*)

This cohort consists in $n = 195$ scored sequences. Notice that for these infants, the age factor values are *corrected*, i.e. these are ages that each baby would have if born after a normal gestation duration.

The ellipsoids on the PCA projection show some evolution with age for the three criterion (the figure is not displayed for brevity). The empirical means and associated statistical tests show an evolution of the 3 criteria *cbb*, *cbp* and *cry*. The particularly high value for *cbp* implies a high movement quantity in the exchange at the proximal stage, even though the mother only initiate the exchange 77% of time, as for the infants without disorders (*st*). The values for *cbb* increase in parallel with the proximal exchange, which was not the case for the *st* cohort.

3.5 Cohort of Visually Deficient Mothers (*dev*)

This cohort consists in $n = 135$ scored sequences. We notice that:

- The way the video unit is settled implies that mothers are facing their baby. Mothers with visual deficiency do not use normally this type of interaction, which prevent them to compensate easily the proximal contact of sight, that stimulates the proximal envelope. They compensate using touch through hands and voice (and probably also smelling). This king of compensation is easier if they are closer to their baby.
- The baby is in a situation which does not allow him to construct himself along with his mother using usually learned modalities. It is interesting to notice on the video sequences, that as soon as a person without visual disability appears in the field of view of the infant, he immediately recovers an interaction with full usual capacities.
- In contrary with the other cohorts, results here do not describe the normal behavior of the infants, but a behavior induced by the constraint of the experiment.

We notice in fig.5 a clear evolution with age, mostly related to the first principal component (axis 1) corresponding as seen in the correlation circle to the evolution in the 3 criteria. The Shapiro-Wilk test clearly reject the null hypothesis of normality distribution for *cbb*, *cbp* and *cry* (p-values $p < 3e - 06$).

We observe an evolution of the criteria after 7 months for this particular interaction where mothers with visual deficiencies have to adapt themselves to the constraint of the video experiment (see section 9.1). These mothers less initiate the relationship, in comparison with mothers of the *st* cohort (69% vs. 78%, see tab.3). After 7 months, *cry* reaches a value equivalent to that of the *st* babies, whereas in the first age level, the *cry* value is noticeably small. After 7 months, *cbb* and *cbp* are noticeably high (see 6.2).

3.6 Cohort of Blind Mothers (*mav*)

This cohort consists in $n = 106$ sequences. The remarks we have stated for the mothers of the *dev* cohort (see section 3.5) also hold here. Moreover, because of the small number of scored sequences in comparison with the other cohorts (see tab.1 for this cohort), the statistical conclusions have to be taken with caution here (see, e.g., the “degenerated” boxplots in fig.11 for *cry*).

The ellipses in the PCA projection (the figure has been omitted for brevity) evolve with age levels on the horizontal axis, which corresponds here to *cbp* and *cbb* criterion. We may deduce that the communication stays at the proximal level, even when the infant grows in age. To compensate for their blindness, the mothers of this cohort over-invest touch mode using hands and voice, whatever the baby's age. Since *cry* level is close here to that of infants from the *st* cohort, we can conclude that these babies have good rhythm envelope and comodality. The high values for *cbb* (see e.g., fig.11) are connected to a highly developped proximal envelope. The proximal perception of the infant is not dependent to that of its mother, since *cbb* does not evolve, in contrary to *cbp*, as shown by the p-values from table 5 (*mav* cohort). The evolution of these two criteria is the inverse of those from the *prm* cohort.

3.7 Cohort with Neurological Disorders (*neu*)

This cohort consists in $n = 183$ sequences. It is important to notice that the age factor level definitions that have been chosen for the other cohorts are no longer meaningful for the babies from this cohort, since these are less developed than others at corresponding ages. They consequently have been filmed way after 9 months. The following age levels have been defined: age ≤ 8 months, age in $]8; 10]$ months, and age > 10 months. This selection has been motivated by the actual repartition of the babies from this cohort, which is different than from the others (see fig.1), and by clinical observations, that clearly show a backwardness or this cohort.

We do not display the PCA projection for this cohort, since the three ellipsoids corresponding to the age factor are completely superimposed, which shows a lack of evolution for our three criteria. This statistical measure is in accordance with the clinical observations which show a difference between this cohort and the others. The Shapiro-Wilk test reject normality for *cbb*, *cbp* and *cry* (with corresponding p-values $p = 7e - 4$, $p = 2.3e - 3$ and $p = 7.4e - 7$). The Kruskall-Wallis tests (Table 5 for this cohort) do not reject the null hypothesis of homogeneity, which confirms the clinical observation and the PCA plot.

- *cbb*: The results do not show a significative evolution. Babies with neurological disorders show a failure in their processes for body appropriation.
- *cbp*: We have already stated that, mothers of infants with neurological disorders initiate movements a lot (see table 3). These mothers do not change this behavior as the ages increase.
- *cry*: In comparison with the infants from the *st* cohort, a significative backwardness is visible. The rhythmic transmission is failing.

4 Influence of Vocalization

4.1 Behavior of the Infant whith Respect to his Body

The goal in this Section is to study the effect of the cohorts upon the infant's movements, while making a distinction between movement *with* and *without* vocalization. The fields of the database that are taking into account for this study are (see the description of these fields in Appendix 9.2):

- fields related to "coordination of the infant with vocalization", denoted *cbbav*
- fields related to "coordination of the infant without vocalization", denoted *cbbss*.

We have designed a statistical numerical character for each of the set of fields, that have been denoted also by *cbbav* and *cbbss*. Our methodology consists in analyzing the *two-way contingency tables* giving the cross-counts of the population of sequences per cohort and per *cbbav* or *cbbss* "factors". It is standard to summarize the result of such cross-classification table by the chi-square (χ^2) test of independence between the two involved factors. Briefly, the null hypothesis H_0 of this test if that the (unknown but estimated) distributions of both factors are independent. Technically, the computation of the test's statistic requires table cells (counts) with not "too small" values, for the asymptotic of the statistic — and hence the computation of the p-value and consequently the conclusion of the test — to be valid. The lack of enough data for some cohorts requires us to *recode* the integer-valued variables (*cbbav* and *cbbss*) into qualitative factors. Since the lack of data appears essentially in tails (high values for *cbbav* or *cbbss*), we have chosen to keep the first 3 values $\{0, 1, 2\}$ as modalities, and to recode as "3+" the observations from sequences for which $cbbav \geq 3$ or $cbbss \geq 3$. *cbbav* and *cbbss* are now qualitative factors with 4 ordered modalities.

In addition, since some video sequences are sometimes scored by more than one judge, we have to reweight some counts, which is the reason why we obtain contingency tables with non-integer counts. For instance, if 3 judges score the same sequence from the *st* cohort, for the *cbbav* factor, and one judge scores it by "1", and the 2 others judges score it by "2", the count 1/3 will be added to the cell $(st, 1)$, which crosses the modality *st* of the cohort factor, with modality "1" of the *cbbav* factor. Similarly, the count 2/3 will be added to the cell $(st, 2)$.

Table 7 gives the p-values associated to the chi-square test of independence beween the (nominal) factors *cbbav*, *cbbss*, ..., and the cohort factor.

We also display (e.g., as in fig.13) the conditional histograms (also called *profile histograms*, or *spineplots*) associated to the two-ways tables. This sort of representation conveys an information that is computed from the cells in the two-way table, but displays it a much more intuitive way: the principle is to graphically depict, in each "bar" of the frequency histogram associated to one factor (cohort here), the empirical distribution of the other factor (e.g., *cbbav*), conditionnally to the event represented by the bar of the histogram (coming from a particular cohort here). That kind of plot may vary a little, depending on the statistical software used. In R [12], the width of each bar is proportional to the frequency of the corresponding modality (cohort here), and the conditional distribution within each bar is depicted by the repartition in gray levels associated to the other factor's modalities (*cbbav* modalities here). For instance, we see from fig.13, left, that conditionnally to the fact of coming from the *st* cohort (without disorders), modalities 0 or 1 of the *cbbav* factor are much more frequent than modalities 2 or 3+. These histograms allow one to graphically "feel" if the two involved factors are independent (in the sense that their distributions are stochastically independent). In the case of independence, the distributions of the (vertical) factor in gray levels should be approximately similar for all the conditionning modalities of the other (horizontal) factor. The chi-square test of independence statistically precises this graphical and intuitive judgment.

Movements of the infant

- with vocalize (*cbbav*): the chi-square test clearly rejects the null hypothesis ($p = 0.0012$), which means that there is a connection between the cohort and *cbbav* factors. In other words, the movement quantity issued by the infant depends on the cohort he comes from.

- without vocalize (*cbbss*): here as well the test rejects H_0 ($p = 4e - 10$).

Moreover, the comparison of the two spineplots allows us to state that, for all the cohorts, the infant touch his body more, and with more different moves, when he is not vocalizing. The emmission of vocalization comes in concurrency with the gesture, as measured by the *cbb* criterion, where touch and sight come into play.

4.2 Proximal Mother-infant Communication

We have also searched for an eventual "cohort influence" on the movements of the infant and its mother in interaction, while making the distinction for vocalization, as in section 4.1. The fields considered here (cf. Appendix 9.2) are:

- fields related to "coodination infant-parent with vocalization" (*cbpav*)
- fields related to "coodination infant-parent without vocalization" (*cbpss*)

Like before, we have computed a statistical numerical variable for each group, that have been denoted *cbpav* and *cbpss*. The same recoding also applies here for the same reasons, and we have coded "3+" the observations greater than or equal to 3. Here as well, the chi-square tests clearly reject the null hypothesis, which indicates an influence of the cohort of origin. Moreover, the comparison of both spineplots (fig.14) shows that vocalization implies less interacting movements between the infant and its mother.

5 Analysis of Rhythm in Distal Communication

One of the originality of the database collected in PILE is its ability to organize an information based upon rhythm transmission, which constitutes the rhythmic envelope that is fundamental for langage installation. In this Section, we study distal rhythm transmission. The fields of the database that are used here are listed in Appendix 9.2. A field is scored "1" when the clinical psychologist notices that the left element in that list has induced a rhythm done by the right element. Each field is constituted by an action and a reaction. For instance, for the field labelled "vocalize baby - hands parent", the question for scoring is to know wether the baby emitted a vocalize followed by a movement of one of the parent's hand (or wether both actions were simultaneously performed). All these fields are doubled since we distinguish for each wether the infant has an object in his hand or not.

5.1 Comparison of Infant's Emission/reception Capacity in Rhythmic Communication

The baby emits, or receives a rhythm. He is emitting when he initiates the rhythmic movement, and receiver when his mother initiates it. We observe that the infant is receiving since he produces a rhythm. The infant is active in his production with hands, feet, and vocalize. Prior to produce a rhythm, he have to perceive it.

We have seen that transmission of distal rhythm is done with a distal perception with Audition A and sight S. To better understand this phenomenon, let us consider for instance sequences with the little song "*ainsi font font*", where the mother moves her hands in rhythm with her voice. The infant perceive in a comodal way AS his mother's hands and voice. This perception is easier when these movements are simpler. This perception is in distal and commodal modes in AS.

In this Section, we study the influence of the cohorts for emission and reception of distal rhythm. We also study influence of the age factor, but for the cohort of infants without disorders (*st*) only, since the sample sizes per age levels in the other cohorts are too small for this kind of analysis.

Influence of the cohorts. The fields of the database involved in this study of the rhythm are those where the infant is interacting with his parent. As before, we build statistical numerical characters *rec* for rhythm reception, and *emt* for rhythm emission, by adding the concerned field values. For the reasons already explained in Section 4, we have recoded as "k+" the observations from sequences for which $rec \geq k$ or $emt \geq k$, where k is the largest possible integer (for retaining as much information as possible) compatible with the data (i.e. allowing two-way tables with not too small values). We also give the corresponding spineplots.

The chi-square tests clearly reject the null hypothesis; hence there is a significant influence of the cohort on these variables. The comparison of the two spineplots (fig.15), allows us to say that, whatever the cohort, the infant receives more than he emits. In this age where the baby construct himself, this seems logical. We could also infer from the reception spineplot fig.15, left, that the rejection of H_0 was mostly due to the *tal*, *dev* and *neu* cohorts. However, a chi-square test based only on the other cohorts clearly reject H_0 as well ($p = 3.e - 4$).

Influence of the age factor for the *st* cohort. The p-value of $1e - 3$ from the spineplot (fig.16, left) indicates that the infant without disorder receives more while he gets older, which shows that he increases its relation with his parent. The p-value of 0.067 for emission is less significative, but the spineplot (fig.16, right) suggests a similar interpretation.

5.2 Influence of the Protocols on Rhythmic Communication

This study is based on the 38 fields of the database that describe rhythmic communication in the *cry* criterion (see Section 2.2). The comparison of the associated profiles conditionnaly to the cohorts for each protocol shows that rhythm is better received in the "song" protocol. In this case, comodal perception of Audition and Sight in distal mode is facilitated by the movements from hands and voice.

5.3 Rhythm Reception Through Hands, Feet and Voice

It is also interesting to know wether the baby receives rhythm with his hands, feet or vocalizes. The infant is thus considered as a receptor of the rhythm here. In addition, we detail in fig. 17 the influence of the age factor, for the *st* cohort only since the sample sizes per age levels in the other cohorts are too small to be meaningful, like in the preceding study.

Influence of cohorts. We construct here the 3 statistical variables: reception by hands *recm*; reception by feet *recp*; reception by voice *recv*. The parent himself emits through hands and voice. In the database, there are 4 possible modalities (see Appendix 9.2) for each criterion.

For reception by hands, the interesting fields are those where the infant, interacting with his parent, moves his hands in accordance with the parent's rhythm (i.e., fields 13 and 19 with and without objects, which results in 4 fields). We build a variable *recm* adding the responses of these 4 fields. Similarly, we define *recp* from fields 14 and 18, and *recv* from fields 15 and 17. Modalities represent: 0 (no) reception (black in spineplots figures); 1 reception (dark grey); 2 receptions (light grey). Here again, we recode by "1+" modalities 1 and 2 for the *recv* criterion. Table 8 shows that all the tests reject independence: there is a clear influence of the cohort upon reception by hands, feet or voice.

- *recm*: the cohort of infants with neurological disorders (*neu*) is the single one with noticeably smaller results than others, however, the chi-square test based on the other cohorts alone concludes for dependence with a p-value $p = 1e - 3$.
- *recp*: The same three cohorts *tal*, *dev* and *neu* which already showed a distinct behavior on fig.15 are different here. And here as well, a chi-square test without these cohorts reject independence (p-value of $8e - 5$).

5.4 Rhythm Generation Using Hands, Feet and Voice per Cohorts

This analysis is not provided here for brevity, and can be found in Desjardins *et al.* [5]. It appears that the baby emits more using his voice, secondary using his hands and finally using his feet, which is an expected conclusion.

6 Conclusions

We now wish to draw conclusions on understanding the communication between mother and baby when there is no disorder, and on babies according to cohort and with the help of the perceptive model. These conclusions are drawn from the statistical results without looking at the anamneses[4].

6.1 Infants without Disorders Interacting with their Mothers

Understanding the baby's behavior thanks to the perceptive model. The study concerns infants aged from 3 to 9 months interacting with their mothers. As the baby developed, we analyzed those movements which belong to body integration and those belonging to communication. We established two types of communication, proximal and distal. As it grows, the baby increases the quantity and diversity of its movements belonging to the appropriation and unification process (see table 4 for this cohort, *cbb* criterion, where we studied only touch and sight, both in proximal mode, among the range of perceptive modes involved in these processes). This leads us to conclude that as the baby develops, it becomes more and more active in the appropriation of its own body. In 80% of the cases (see tab. 3) the mother initiates communication where proximal audition and touch are involved in a face-to-face situation. The quantity of movements made by the mother and the infant to touch each other with hands or sound does not increase with the baby's age (see tab. 5, *st* cohort, high p-value for the *cbp* criterion). This result shows that the mother does not change her proximal communication with her baby

[4]informations given by the mother about her baby's history

between the ages of 3 to 9 months. Communication according to proximal perception does not develop during this period, when the baby gradually moves away from the adult; the proximal mode of relationship is replaced by a distal mode, where communication is governed by audition and sight. Also, the quantity of movements is larger with boys than with girls (tab. 4 and 5 for sex, *cbp* criterion).

We observed a deep breach in rhythmic transition around 4 months (tab. 4, 5 and 6 *st* cohort, *cry* criterion); indeed at that age the baby seems capable of good distal comodality of audition and sight, leading to a good transmission of distal rhythm. The *cry* criterion, which measures the distal transmission of rhythm, which is linked to the comodality of audition and touch, significantly evolves with age between 3 and 9 months. This criterion is relevant for the observation of the evolution of babies of those ages.

Between 3 and 9 months, the baby appropriates its own body more and more actively and in different ways. The quantity of movements exchanged between mother and baby in proximal mode is constant. The baby communicates more and more through exchange of seen and heard rhythms. This distal transmission clearly begins at four months. The proximal envelope develops during the very first months of life. At four months, this envelope is significantly improved with the input of distal rhythms.

The study of distal communication between infant and mother. This study describes the exchange of macro-rhythms perceived in distal mode. An infant 3 to 9 months old is more often likely to receive a distal rhythm than to initiate it (see profiles (spineplots) fig. 16 together with indicated p-values). During this period of construction, this result seems logical. As it develops, a baby without disorders receives more and in a greater variety of ways (fig.16), a sign that it is entering a relationship making it possible to integrate language. The complexity and diversity of a baby's movements are the sign that the baby is evolving satisfactorily from the angle of language precursors.

If we study the influence of the three protocols ("spontaneous", "with giraffe" and "with songs") on the transmission of distal rhythm, we observe that the transmission of distal rhythm is more satisfactory for the "song" protocol. Thus, if we facilitate the baby's distal comodal perception through audition and sight (song *ainsi font font*), we improve its rhythm production. This is true for all cohorts. This shows the direct link between distal and comodal audition and sight perception and the production of rhythm. This perceptive mode is the one used in the decoding of the "voice-face system", which participates in psychic organization. Thus, distal rhythm observed in an interacting baby beginning at four months is the sign that the perceptive system is developing well and will ensure good communication. A baby aged four to seven months interacting with its mother produces numerous rhythms with its feet, then slightly relinquishes this activity (fig. 17, profiles for *recp*).

During this central period, the infant produces less rhythm with its hands, but actively resumes this activity later on. It seems that the vocalizing evolves gradually towards growing activity, an evolution which corresponds to the central role of voice in communication. Contrary to foot activity, hand activity and vocalizations increase (fig. 17) in preparation for speaking together.

An interacting baby receives much more than it transmits. We observe that it produces most through voice, next through hands, and last through feet, which is an expected result.

Importance of hearing perception in the infant's construction and communication. The criteria *cbbav* and *cbbss* in fig. 13 indicate that the baby uses its perception and sight on its own body less when it vocalizes. One of the effects of the baby's vocalizing is that it reduces proximal exchanges through touch and sight between mother and baby (criteria *cbpav* and *cbpss* of tab. 7 and fig. 14).

On one hand, the baby perceives its body through sight or touch, its perceptions are unimodal and linked to a proprioceptive sensation. This experience is part of the body appropriation process. Sight and touch are also used through proximal comodality in the baby's relationship with its mother. On the other hand, the baby perceives its own vocalizing by using audition in two ways: the reception of the sound arouses a psychic experience of proximal perceptive elements, where audition is already comodalized with touch; the vocalizing is perceived through unimodal audition, linked to a throat sensation. The baby's vocalizing stimulates its proximal envelope and that of the mother. There is a common vibration of rhythmic envelopes. The results show that there is greater richness and complexity in the vocalizing process than in touch and sight perceptions. Another consequence is that the mother's initiatives are reduced and the baby becomes an actor in the interaction. This same trend is observable in all the cohorts.

6.2 Understanding the Infant's Behavior with the Perceptive Model, According to Cohort

Effect of early hospitalization on the development of the perceptive system. Infants who were hospitalized due to an acute illness show a delay in the process of appropriation of their body, though they do catch up slightly with time (compare *cbb* of tab. 4 between *st* and *hop* cohorts). We notice that mothers initiate proximal communication in 92% of the cases (tab. 3); however, the quality of these proximal contacts is lower than for babies with no disorders (compare *cbp* in tab. 4 between *st* and *hop* cohorts).

What is remarkable is that they are unable to change the situation, which suggests that mother and baby are not optimally tuned to each other, an idea which is supported by the fact that the basis for this "tuning" is the proximal envelope. This is probably the mark of the trauma caused by the sudden event of early hospitalization. This trauma reduces the mother's capacity for proximal tuning and delays the development of the baby's proximal envelope. We notice that the value of distal rhythmic transmission after 7 months is very good, higher than that of normal babies (compare the *cry* criterion in tab. 4 between *st* and *hop* cohorts). This result is all the more surprising that in the previous months these babies do not develop distal communication as much as normal babies do. This situation can be understood as follows:

Infants who were hospitalized were forced to develop distal communication with their caregivers before healthy babies. This type of communication becomes effective only at 7 months because it is probably dependent on the proximal envelope system. It seems that the baby can only use the decoding system through distal rhythms if the complex system of the proximal envelope has reached a certain level of development. It is only when the proximal envelope has reached maturity (after 7 months) that the quality of distal communication is higher for these babies than for healthy babies.

This result shows how a trauma, such as an acute illness with early hospitalization can hamper the development of the proximal envelope and tuning. However, despite this, the comodal distal perception of sight and audition can develop. But the use of the distal decoding system is possible only after the proximal envelope has reached a certain level of maturity.

The specific development of the perceptive system in premature babies. The particularity of the cohort of premature babies is the increase in the quantity of movements in proximal interaction (compare the *cbp* criterion in tables 4 between *st* and *prm* cohorts), which goes along with a significant increase in the baby's body appropriation processes and the transmission of distal rhythm (*cbb* and *cry* criteria, in the same tables). It is crucial to note that all the values increase simultaneously and exceed those of babies with no problems. This parallel development cannot be found among babies with no disorders. This shows the dependency of the rhythmic envelope of premature babies on the mother's rhythmic envelope, which leads to the increased values for these babies compared to those without disorders. This could mean that in order to pursue the comodality process, the premature baby's rhythmic envelope must enter into high resonance with its mother's. This reminds us of the intra-uterine situation where the baby is constantly rocked in the mother's rhythm. This situation could be due to the lack of intra-uterine comodality of audition and touch, which has been interrupted due to premature birth. The high values show the existence of very dense tuning aiming to repair what was disrupted by premature birth. The dependence of the baby on this rhythmic envelope may make the separation process more difficult.

It is interesting to note that the premature infant is able to draw its mother into a dense mutual tuning process (reminding one of the intra-uterine situation), enabling it to make up for lost time.

Compensation among babies whose mothers are visually impaired. The early interactions of visually impaired and blind mothers are filled with proximal perception through touch. Face and voice movements are not very expressive because they themselves are unable to perceive the fine movements of the baby. The necessary face-to-face situation is certainly at the origin of the low rate for the three criteria until 7 months (compare the three criteria in tables 4 between *st* and *dev* cohorts). The values of these three criteria after 7 months are higher than in babies without disorders. This means that after 7 months, the baby has constructed a decoding system in distal perception thanks to which it can be autonomous in the context of maternal difficulties. After 7 months, the distal and proximal perception systems function coherently.

It seems that when one imposes distance in interaction on a baby whose mother is visually impaired, the baby is capable of overcoming this unusual difficulty at 7 months. It is then capable of establishing good quality communication and probably thanks to a perceptive system which is more powerful than that of babies with no problems.

Proximal communication between babies and their blind mothers. We can imagine that for these babies the proximal envelope receives more support when it is still in the womb. For blind mothers, communication is maintained on a proximal level even when the baby grows up (see criterion *cbp* in tab. 4 between *st* and *mav* cohorts). In order to offset their disability, blind mothers favor touching with hands and voice regardless of the baby's age. The baby's proximal perception process (*cbb* criterion) does not increase with the increase in proximal interactions with the mother (*cbp* criterion), contrary to premature babies (compare *prm* and *mav* cohorts in table 4). In the interaction conditions of the filming setup we observe that although the distal rhythm improves, it remains close but does not catch up with the values observed for babies with no problems (*cry* criterion in table 4, *mav* cohort). We see that distal communication (*cry* criterion) suffers more disruption before 4 months in the cohort of infants whose mothers are visually impaired. This is explained by the fact that the baby produces distal rhythms independently of the blind mother's facial immobility, by compensating for the latter with the perception of other movements. On the other hand, babies with visually impaired mothers are stimulated by the "voice-face" system of the mother, which is inadequate under the filming conditions. *In face to face conditions, the babies of blind mothers are able to communicate even at the distal level thanks to a very good proximal perceptive system, even though they are not stimulated by the mother's "voice-face" system.*

Initiatives of babies with blind or visually impaired mothers. Babies with visually impaired or blind mothers initiate the relationship in respectively 31% or 33% of cases as opposed to 22% for babies without problems (table 3). It is remarkable to see that babies compensate for their mother's disability right from the very beginning of life. This performance is due to the fact that the proximal mode is very developed and results in a subtle understanding of communication.

Epileptic infants with West syndrome. For epileptic babies suffering from the West syndrome, the body appropriation and unification processes and the proximal and distal communication processes do not significantly change depending on age (see p-values in table 5, *neu* cohort). Even though the values for *cbb* and *cbp* criteria are the same or higher than those of babies without problems, clinical observation shows that the babies' movements are simple and repetitive. The lack of variety in the movements explains the absence of change. This corresponds to a closure in the baby. In addition, the level of distal communication is lower than that of other cohorts (see the *cry* criterion in tab. 4 between *st* and *neu* cohorts). Mothers often initiate the communications movements (90%), but this has no effect since the baby's rhythmic envelope cannot harmonize with the mother's. *For these West syndrome epileptic babies, we do not observe any evolution in the criteria for the development of the perceptive system.*

6.3 Conclusions of the Study

The statistical results in the framework of the perceptive system development model opens new avenues of research on the development of infants and their communication skills. Detailed research on rhythm highlights the baby's communication through hands, feet and vocalizing. The observation of rhythm in a baby aged 3 to 9 months can certainly serve as an indicator of its satisfactory development.

This research shows the relevance of conceptualizing the perceptive system and perceptive communication as two sub-systems, proximal and distal. The study has enabled us to develop new concepts, in particular:

- the role of proximal and distal perceptions and their interactions
- the organizing role of rhythm in distal communication
- the importance of harmonization on the proximal level of the two rhythmic envelopes of mother and baby to ensure distal communication.

The results of this study can be used effectively for prevention purposes for infants in the following situations: premature birth; early hospitalization due to an acute illness; feeding disorders; neurological disorders such as the West syndrome; communication between babies and visually impaired mothers.

These conclusions also make it possible, indirectly, to improve the understanding of grave speech disorders and to better adapt the care of troubled children by working on the level of the perceptive system.

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7 Tables

		age			sex	
		$-4m$	4-7m	$+7m$	Female	Male
st cohort	video seq	160	253	202	297	318
	scored seq	320	345	289	470	484
mav cohort	video seq	18	42	27		
	scored seq	24	48	34		

Table 1: Number of video and scored sequences per age levels in *months* (left), and per sex (right, *st* cohort only).

number of judges	1	2	3	4	5	6	7	video seq.	scored seq.
infant *st*	425	116	32	20	14	5	3	615	954
infant *hop*	105	24	9	0	3	0	0	141	195
infant *tal*	86	0	10	2	0	1	6	105	172
infant *prm*	187	4	0	0	0	0	0	191	195
infant *dev*	38	44	3	0	0	0	0	85	135
infant *mav*	77	1	9	0	0	0	0	87	106
infant *neu*	97	28	6	3	0	0	0	134	183

Table 2: Number of video sequences scored by several judges.

Cohort / Transmitter	Parent	Baby
No disorder (st)	78%	22%
Hospitalized infants (hos)	92%	8%
Eating disorders (tal)	74%	26%
Premature babies (prm)	77%	23%
Mother with visual deficiency (dev)	69%	31%
Blind mother (mav)	67%	33%
Neurological disorders (neu)	88%	12%

Table 3: Distribution of initiative between baby and parent.

cohort	variable / age levels	$-4m$	4-7m	$+7m$
without disorder (st)	cbb	2.67 ± 0.23	2.81 ± 0.24	3.31 ± 0.31
	cbp	1.80 ± 0.25	1.82 ± 0.22	1.64 ± 0.26
	cry	1.43 ± 0.23	2.24 ± 0.27	2.58 ± 0.31
hospitalized (hos)	cbb	1.90 ± 0.63	2.36 ± 0.37	2.35 ± 0.41
	cbp	1.40 ± 0.55	1.31 ± 0.36	1.48 ± 0.43
	cry	1.03 ± 0.52	1.70 ± 0.50	3.17 ± 0.55
premature (prm)	cbb	2.16 ± 0.62	2.91 ± 0.45	3.58 ± 0.37
	cbp	1.60 ± 0.45	2.11 ± 0.34	2.48 ± 0.36
	cry	1.51 ± 0.6	2.36 ± 0.38	2.97 ± 0.4
visual deficiency (dev)	cbb	2.24 ± 0.69	2.44 ± 0.48	4.00 ± 0.76
	cbp	1.69 ± 0.69	1.44 ± 0.57	3.31 ± 1.33
	cry	0.62 ± 0.38	1.94 ± 0.57	2.63 ± 0.69
blind mothers(mav)	cbb	3.54 ± 0.78	4.10 ± 0.67	4.09 ± 0.97
	cbp	2.98 ± 1.11	3.79 ± 0.88	5.41 ± 1.46
	cry	1.41 ± 0.38	1.99 ± 0.45	2.10 ± 0.33
neurological (neu)	cbb	2.77 ± 0.57	2.61 ± 0.53	2.74 ± 0.75
	cbp	2.46 ± 0.54	2.38 ± 0.52	2.44 ± 0.66
	cry	1.34 ± 0.48	0.88 ± 0.32	1.44 ± 0.47
without disorder (st) per sex	variable / sex	female	male	
	cbb	2.95 ± 0.21	3.11 ± 0.22	
	cbp	1.47 ± 0.18	2.02 ± 0.21	
	cry	2.12 ± 0.23	2.32 ± 0.24	

Table 4: Empirical means of each criterion per age factor levels, together with 95% confidence intervals, for each cohort, and per sex for the st cohort.

cohort	cbb	cbp	cry
without disorder (st) for age	0.03	0.15	1e-6
without disorder (st) for sex	0.33	5e-4	0.15
hospitalized (hos)	0.18	0.88	2e-6
premature (prm)	4e-4	6e-2	1e-3
visual deficiency (dev)	7e-4	0.07	6e-5
blind mothers(mav)	0.62	0.05	0.02
neurological (neu)	0.99	0.97	0.13

Table 5: p-values of the Kruskall-Wallis test for homogeneity between age levels, for each criterion and each cohort, and homogeneity in sex for the st cohort.

cohort	variable $/H_0$	$-4m = 4-7m$	$-4m = +7m$	$4-7m = +7m$
without disorder (*st*)	*cbb*	0.64	0.018	0.03
	cry	1e-3	2e-7	0.078
hospitalized (*hos*)	*cry*	0.19	8e-6	6e-5
premature (*prm*)	*cbb*	0.01	1.3e-4	0.06
	cbp	0.09	0.02	0.39
	cry	4e-3	6e-3	0.18
visual deficiency (*dev*)	*cbb*	0.55	1e-03	9e-4
	cbp	0.31	0.20	0.02
	cry	1e-03	2e-05	0.09
blind mothers(*mav*)	*cbp*	0.31	0.02	0.07
	cry	0.08	0.004	0.20

Table 6: p-values of the 2-by-2 Kruskall-Wallis test for homogeneity between age levels, for cohorts and criteria for which the global homogeneity has been rejected.

coordination factor	p-value
infant with vocalization (*cbbav*)	0.0012
infant without vocalization (*cbbss*)	$4e-10$
infant-parent with vocalization (*cbpav*)	$2e-10$
infant-parent without vocalization (*cbpss*)	$8.3e-12$

Table 7: p-values of the χ^2 tests for two-factor tables crossing the cohort factor with each coordination factor.

	recm			*recp*			*recv*	
cohort	0	1	2	0	1	2	0	1+
st	420.8	105.4	88.8	412.4	104.7	97.8	510.8	104.2
hos	98.8	13.0	29.2	90.1	16.5	34.3	116.6	24.4
tal	76.9	23.6	4.5	81.1	20.0	3.9	86.6	18.4
prm	141.0	32.0	18.0	116.5	33.5	41.0	145.5	45.5
dev	61.5	15.0	8.5	59.3	14.7	11.0	73.3	11.7
mav	56.8	22.5	7.7	55.0	27.7	4.3	74.8	12.2
neu	108.8	19.4	5.8	106.7	16.0	11.3	121.2	12.8
χ^2 p-value	$5e-5$			$2e-7$			0.045	

Table 8: Two-way tables for hands, feet or voice reception per cohort.

8 Figures

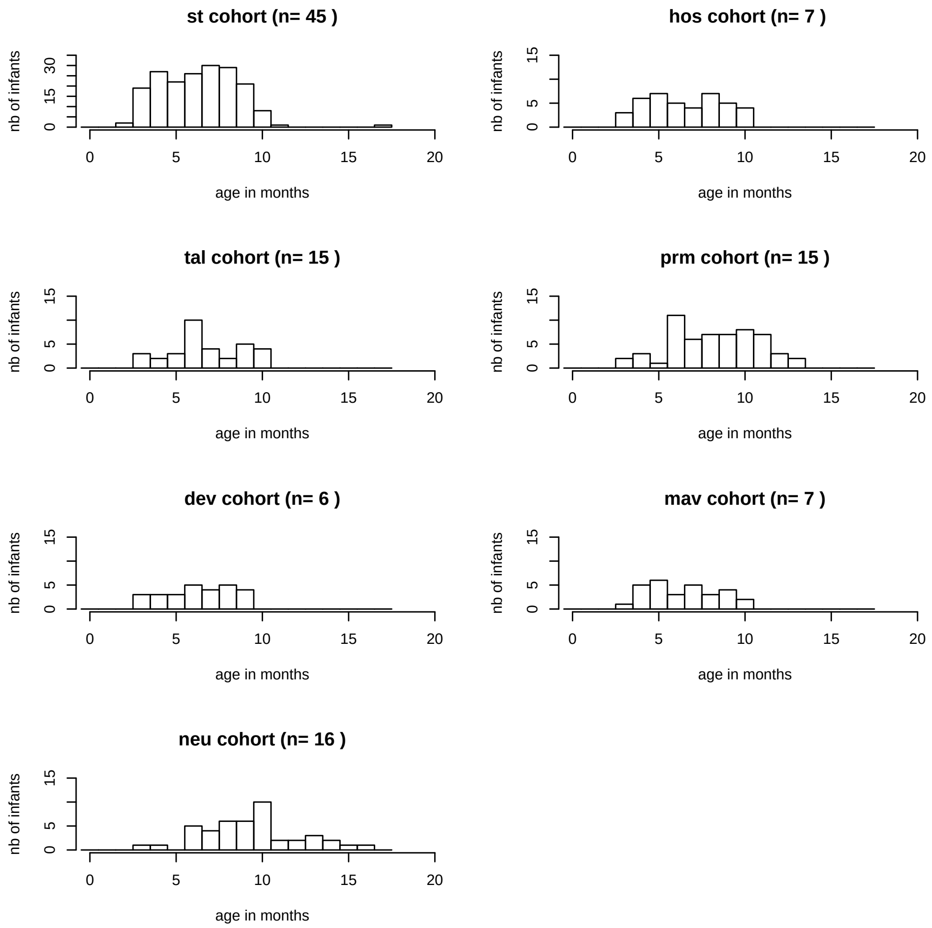

Figure 1: Histograms of the number of sequences per cohort (the vertical scale for the *st* cohort is different for a better reading).

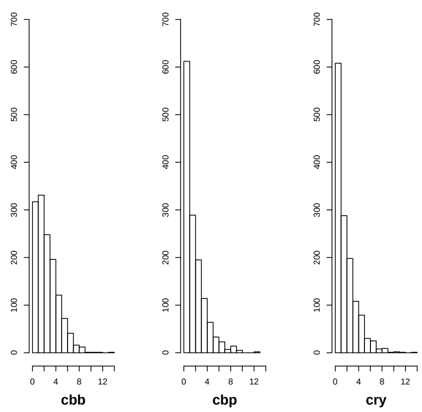

Figure 2: Histograms for the criteria.

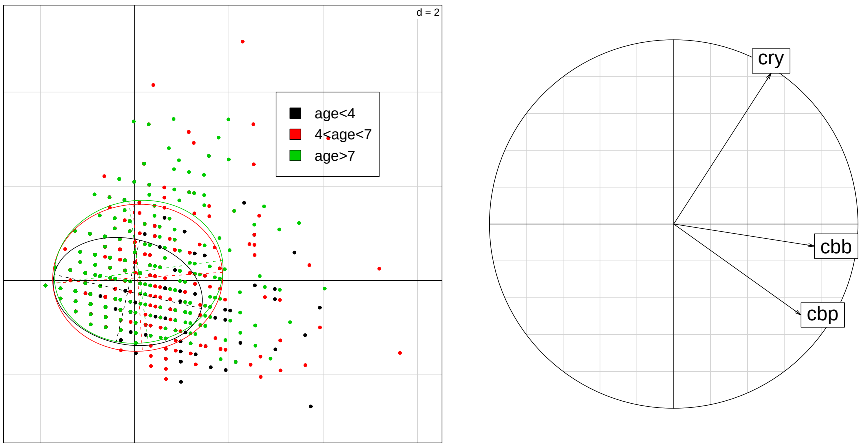

Figure 3: *st* cohort: projection of individuals with ellipses of inertia per age factor levels (left); correlation circle (right).

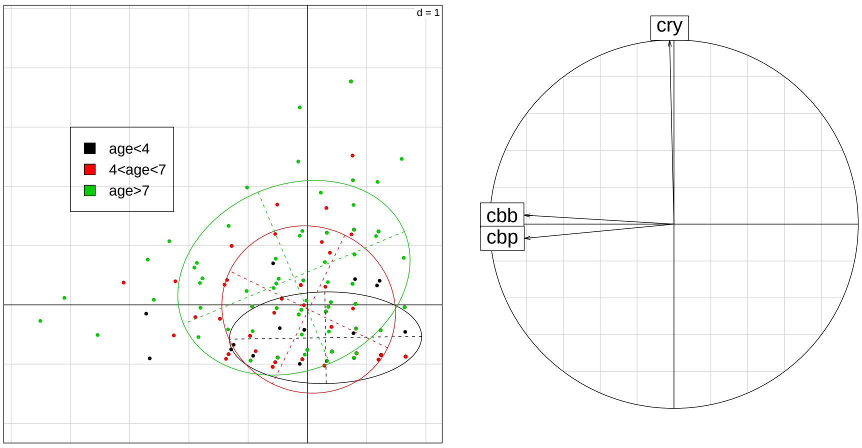

Figure 4: *hos* cohort: projection of individuals with age factor (left); correlation circle (right).

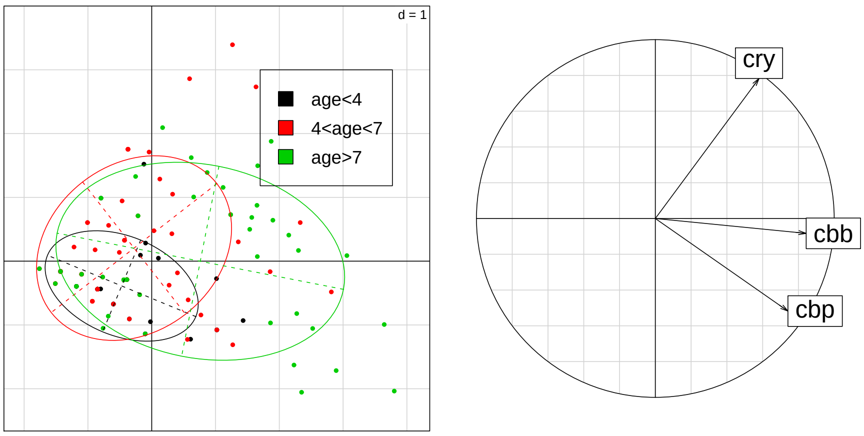

Figure 5: *dev* cohort: projection of individuals with age factor (left); correlation circle (right).

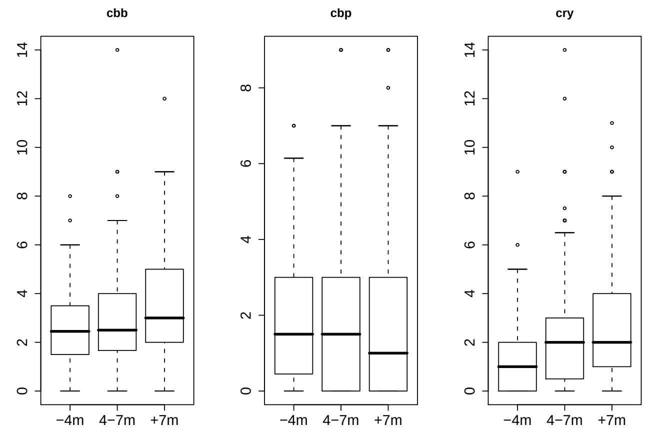

Figure 6: *st* cohort: boxplots per age factor levels.

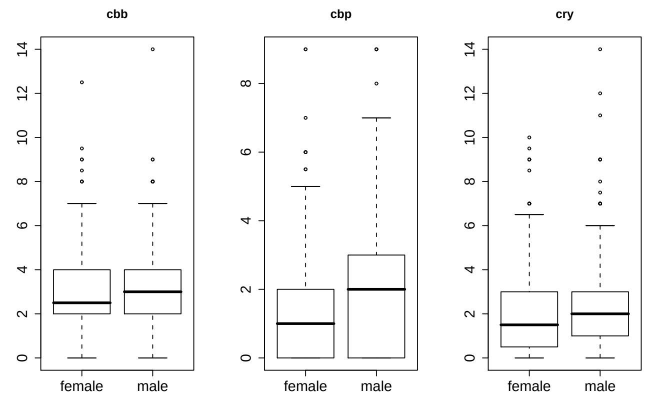

Figure 7: *st* cohort: boxplots per sex.

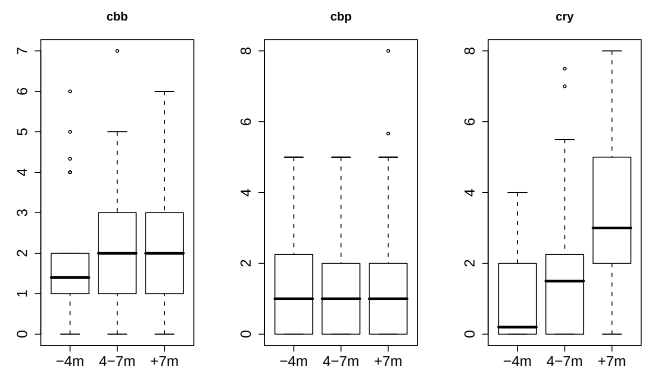

Figure 8: *hos* cohort: boxplots per age factor levels.

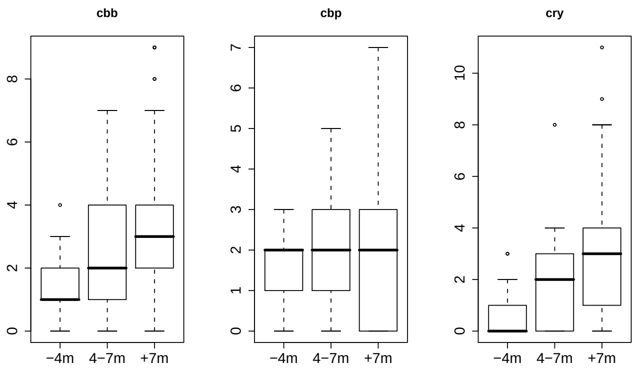

Figure 9: *prm* cohort: boxplots per age factor levels.

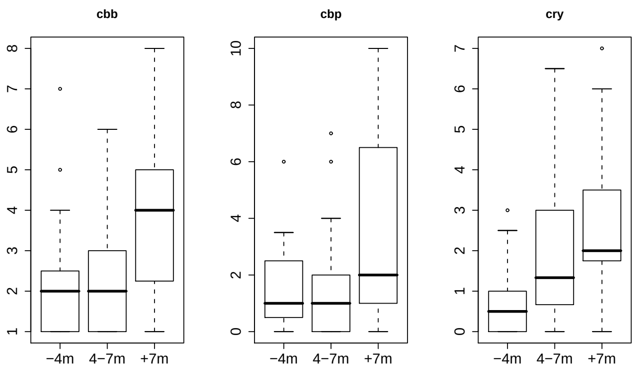

Figure 10: *dev* cohort: boxplots per age factor levels.

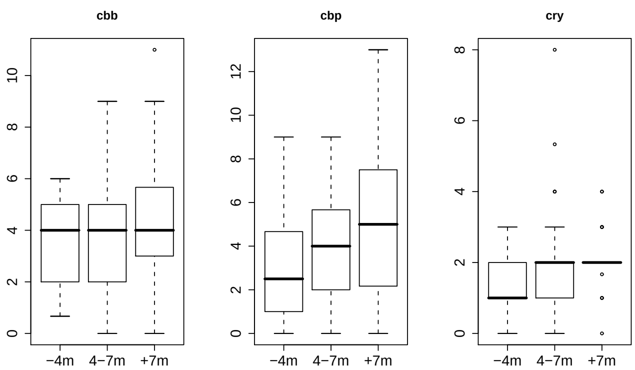

Figure 11: *mav* cohort: boxplots per age factor levels.

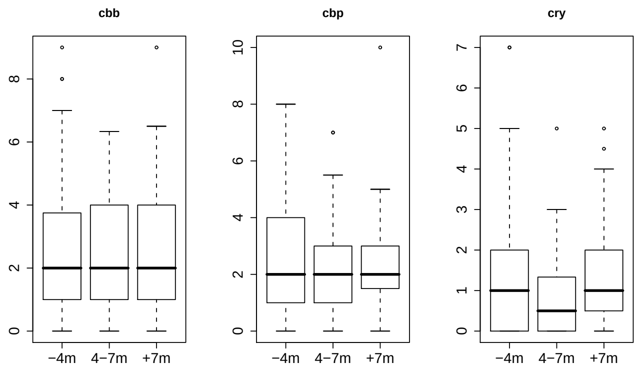

Figure 12: *neu* cohort: boxplots per age factor levels.

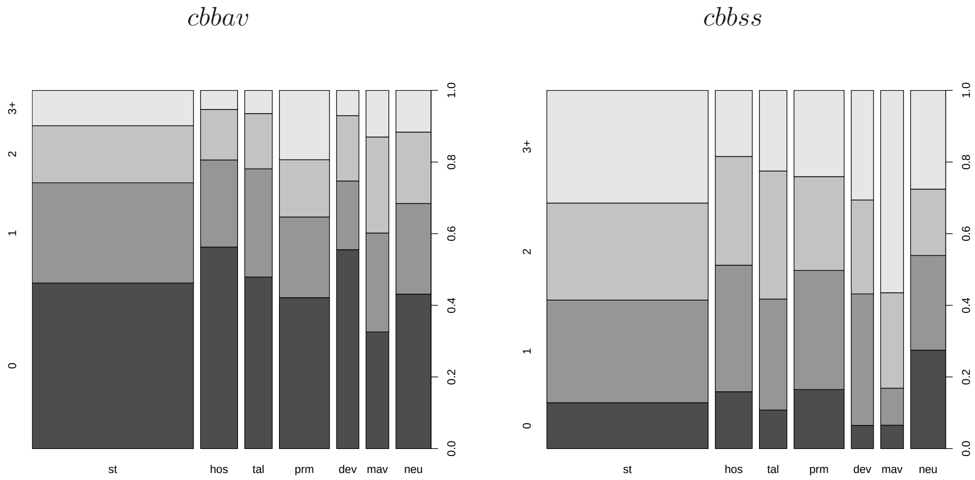

Figure 13: Spineplots for the coordination with vocalization (*cbbav*, left) and without (*cbbss*, right), in each cohort.

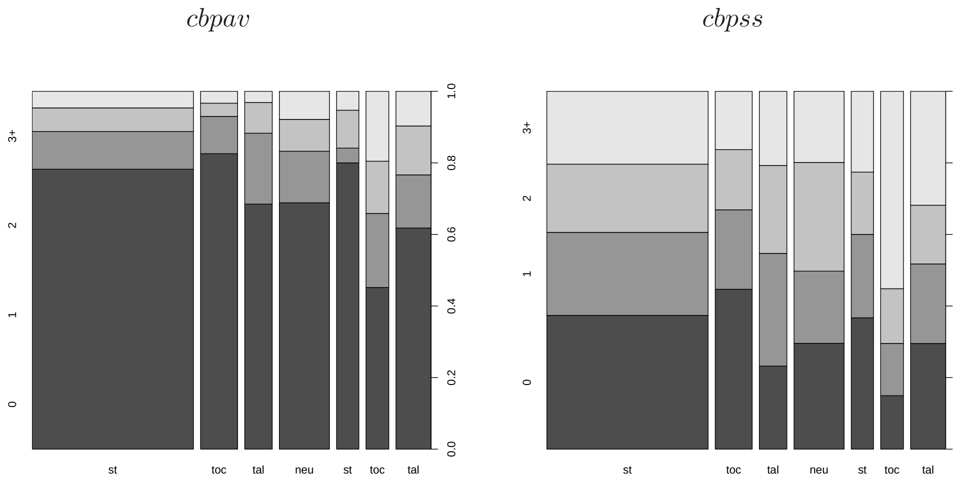

Figure 14: Spineplots for infant-parent coordination with vocalization (*cbpav*, left) and without vocalization (*cbpss*, right) in each chort.

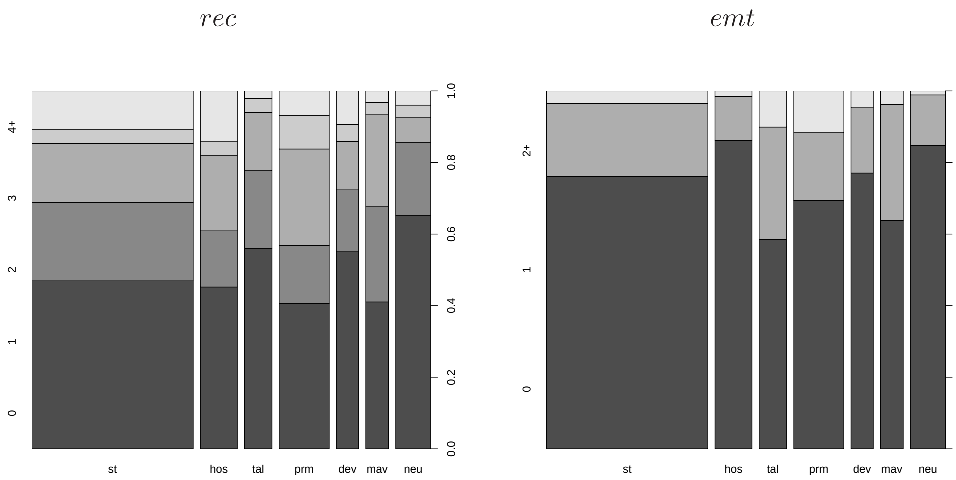

Figure 15: Spineplots for reception (*rec*, left) and emission (*emt*, right) in each cohort. Corresponding p-values for the χ^2 test are $p = 3.6e - 7$ (left) and $p = 4.4e - 9$ (right)

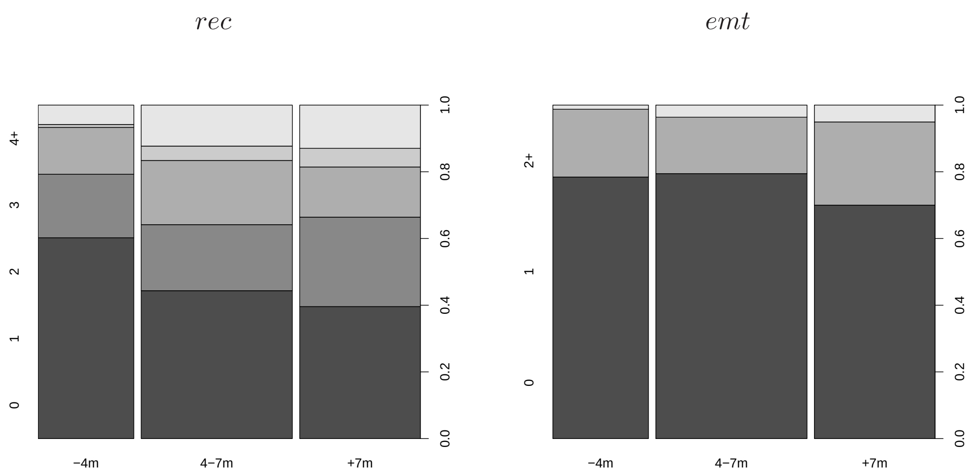

Figure 16: Spineplots for reception (rec) and emission (emt) per age for the st cohort. Corresponding p-values of the χ^2 test are $p = 1e - 3$ (left) and $p = 0.067$ (right).

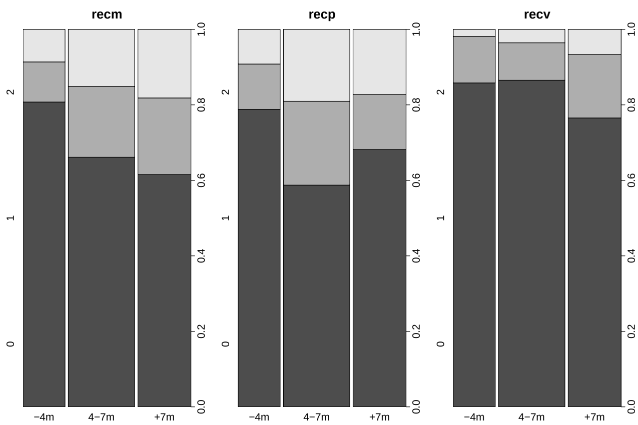

Figure 17: Spineplots for reception by hands ($recm$), feet ($recp$) and voice ($recv$) per age for the st cohort; the p-values of the corresponding χ^2 tests are $p = 0.002$ ($recm$), $p = 6e - 3$ ($recp$), and $p = 0.02$ ($recv$).

9 Appendix

9.1 Description of the Framework and the Protocols

What unifies this research is the global nature of the films. They are global in terms of space: the baby, lying in a baby-lounger, facing its mother, was filmed with eight cameras. Global in terms of time span: the babies were filmed between the ages of 3 to 9 months. The filming took place on average every three weeks. Each session lasted 20 minutes and was made up of five parts.

- Introduction, 0–10 mn: only one camera is filming. During this time the technicians, the family and the clinical psychologist prepare the sequence. This part is kept for an analysis of interactions.

- Spontaneous interaction, 10–13 mn : the parents interact with the child as spontaneously as possible, the psychologist does not give any instructions. Sometimes the parent uses a toy but this remains rare.
- Interaction with Giraffe, 13–16 mn : the clinical psychologist only tells the parents not to keep the giraffe in front of the baby's face for too long.
- Interaction with Song, 16–19 minutes: the parents are asked to sing *ainsi font font* at one point during this sequence; this can be done several times.
- End, 19–20 mn: the clinical psychologist announces the end of the filming by discreetly entering; in some cases the camera continues to film up to 20 mn.

The base is constructed on the basis of interaction sequences called "spontaneous", "with Giraffe" and "with Song". Two judges (at least) select one minute of each videotape according to the following protocols:

- Spontaneous interaction: the selection is automatic since the last minute of the three minutes is taken.
- Interaction with Giraffe: one minute of the giraffe sequence is selected.
- Interaction with Song: the sequence begins with the beginning of the song.

The judges score the three one-minute video sequences and save their scores in the data base.

9.2 Description of the Fields Used in the Analysis

Coordination between the baby and his body, ***cbb*****.** There are actually 22 fields since we distinguish for each field with/without vocalize:

Hand - hand, hand(s) - foot, hand(s) - face, hand(s) - mouth, foot(s) - hand, foot - foot, foot(s) - mouth, hand - others, Regard - hand(s), Regard - foot(s), Regard - others.

Coordination baby-parent, ***cbp*****.** There are actually 20 fields since we distinguish for each field with/without vocalize:

Hand(s), finger baby - hand(s) parent, hand(s), finger baby - face parent, hand(s), finger baby - other section (mother's hair, . . .), foot(s) baby - hand(s), finger parent, foot(s) baby - other section, hand(s), index parent - hand baby, hand(s), index parent - foot baby, hand(s), index parent - mouth baby, hand(s), index parent - face baby, hand(s), index parent - other section.

Rhythm coordination baby-parent, ***cry*****.** There are actually 38 fields since we distinguish for each field with/without object:

Vocalize baby - hands baby, Vocalize baby - foots baby, Vocalize baby - voice parent, Vocalize baby - hands parent, hands baby - voice parent, hands baby - vocalise baby, hands baby - foots baby, hands baby - hands parent, foots baby - voice parent, foots baby - vocalise baby, foots baby - hands parents, foots baby - hands baby, voice parent - hands babys, voice parent - foots babys, voice parent - vocalize baby, voice parent - hands parent, hands parent - vocalize baby, hands parent - foots babys, hands parent - hands baby.