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AUDITORY-VISUAL COORDINATION : DOES IT IMPLY AN EXTERNAL WORLD FOR THE NEWBORN ?

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La coordination visuo-auditive implique-t-elle l'existence d'un monde externe pour le nouveau-né ? *Le but principal des auteurs n'est pas de démontrer une nouvelle fois l'efficacité des coordinations visuo-motrice et auditivo-motrice, mais plutôt d'essayer d'en comprendre la signification pour le nouveau-né. Vingt-quatre bébés ont été examinés à un âge moyen de 3 jours. Chaque enfant a été confronté à quatre situations : visage seul, voix seule, visage et voix spatialement concordants, visage et voix spatialement discordants. Les mouvements de la tête et des yeux de l'enfant ont été codés à partir des enregistrements vidéo. Les résultats montrent d'une part que les coordinations visuo-motrice et auditivo-motrice sont également efficientes à la naissance et d'autre part que la vision et l'audition sont coordonnées chez le nouveau-né. Les auteurs ont choisi d'interpréter ce dernier résultat en recourant à la notion d'"anticipation sensorielle" et estiment non nécessaire de postuler l'existence d'un monde externe qui contient des objets aux propriétés définies pour rendre compte des coordinations inter-sensorimotrices présentes à la naissance.*

KEY WORDS : sensori-motor coordination, representation, neonate.
MOTS CLES : coordination sensorimotrice, représentation, nouveau-né.

INTRODUCTION

Our knowledge of the infant's initial abilities has considerably increased over the past two decades and has led to a profound rethinking of the theoretical standpoints regarding early development. Much of the recent research shows that the newborn's behaviours are based upon various sensori-motor coordinations, operating between, for example, vision and motor systems (visual pursuit : Barten et al., 1971 ; prehension : Bower et al., 1970 ; Von Hofsten, 1981 ; imitation : Meltzoff & Moore, 1977 ; Vinter, 1983), audition and motor systems (Wertheimer, 1961 ; Mendelson & Haith, 1976 ; Alegria & Noirot, 1978) or between audition and vision (Aronson & Rosenbloom, 1971 ; Castillo & Butterworth, 1981). Although the existence at birth of some of these coordinations is still the subject of some controversy (e.g. McGurk et al., 1977, for auditory-visual coordination), our primary intention is not to demonstrate once again the efficiency of visuo- or auditory-motor coordinations but rather to understand their significance for the newborn, i.e. their status in the organization of neonatal behaviour.

Within a cognitive framework, behaviour is always considered as being under the control of a central processing. Consequently, it is the very nature of this processing which is important to take into consideration and to characterize in order to account for mechanisms governing behaviour. Most authors revert now to the notion of "representation" in order to explain the complex links between afferences and efferences shown by the infant's behaviours. But only few of them try to explain these representations in terms of the neonate. Bower (1979) treats them as "abstract" or "amodal", which means that auditory-visual coordination, for example, is accomplished through the extraction of information equally available through the visual or the auditory modalities. Mounoud (1979 ; Mounoud & Vinter, 1981) distinguishes between a unique or unitary system of significations to cater for the innate representations and a double system of significations within which the representations elaborated later by the infant would be constructed. The first system is based on sensory coding of information, the second on a perceptive coding. The sensory code organizes at birth a global space in which the sensory and motor systems are coordinated, whereas the perceptive code makes possible the differentiation of this global space into a body space and an external or object space. Transactions between the newborn and the environment result from biunivocal linkages between afferences and efferences based on sensory translations or sensory representations. By means of the perceptive code, the infant will progressively bring out a new sampling and analysis of sensory messages relative both to his actions and to objects. The meanings of these messages will be redefined in terms of the perceptive code and give rise to perceptive representations.

How can auditory-visual coordination be accounted for within this perspective ? This coordination might signify that, on hearing a sound, the baby "expects" to see an object. As far as the infant is concerned, one can legitimately ask whether this bimodal specification belongs to an external object or to a functional coordination between sensory systems. We propose to consider that, upon hearing a sound, the *visual system* of the newborn "expects" and prepares itself to receive *visual stimulation*. This coordination can be conceived as relating different sensory modalities and not as relating sensory modalities with an external space containing audible and visible objects, i.e. relating two properties of a specific object.

By studying the neonate's behaviours in a situation where visual and auditory information is spatially dissociated, we will try to verify that the infant seems to "anticipate" a visual stimulus when confronted with an auditory one, and we will try to show that this searching response is conform with the above suggested interpretation. The choiced behavioural indicators are lateral head and eye movements. Like McGurk & Lewis (1974), we consider that lateral head or eye movements from the auditory stimulus to the visual one and vice-versa are valid indicators of a "distressed" response to the discordant situation, i.e. of the infant's ability to relate one to the other. But our theoretical orientation suggests an asymmetry between the movements going from the face to the voice and those going from the voice to the face. We thus consider the search for a visual information in the discordant situation as a crucial criteria of the existence of a sensory auditory-visual coordination.

A prove of the existence of this coordination may be on the contrary that the neonate, when oriented toward the auditory source, waits for the coming of a visual information, but such a behaviour implies s/he "knows" that a single object must appear in a unique location in space, i.e. that external world "exists". The situation where an isolated auditory stimulus is presented constitutes a condition-test in this respect, because searching movements for another stimulation may also be expected there, according to us. The existence of this auditory-visual coordination requires, of course, that the neonate is able to orient to both a visual and an auditory stimulus ; we will first examine this point.

METHOD

1. Subjects

Twenty-four neonates (13 females and 11 males) participated in the study and were tested at a mean age of 3 days (range 2-4 days). All were healthy full-term infants, and had normal births. Birth weights ranged from 2950 gr to 4100 gr (mean = 3366 gr) and gestational ages from 38 to 41 weeks (mean = 39.8 weeks). Subjects were observed in the hospital nursery, shortly after they had been fed. Data could not be obtained from 7 other infants principally due to sleep.

2. Materials, procedure and experimental design

The experiment was conducted in a small sound-insulated room adjacent to the nursery. Subjects were comfortably seated in an infant seat inclined at approximately 40° to the vertical. The infant's head and neck were supported by a thin foamrubber pillow in order to restrict sagittal head movements. The infant was surrounded by a vertical screen of two pieces of white cloth (each 1.20 high x 2 m. wide), forming a right angle. Each screen was placed at 25 cm. from the neonate such that the infant's midline intersected with the right angle formed by the two screens.

The visual stimuli were two identical females faces projected as slides, one onto each half of the screen. Slides were projected at eye level and were life-size (approx. 18 x 24 cm). The auditory stimulus was a recording of the same female reading an Italian fable (sound pressure level ranged from 50 to 70 db) and was presented through either one of the two loud-speakers placed behind the screen at the same location as the slide-projectors. The source of both the visual and the auditory stimulus was at 45° to the left or right of the infant. Two cameras, located 30° to the left or the right of the infant and approximately 60 cm above her head, permitted a videotape recording of the subject's head, shoulders and eyes. The video output from the cameras was mixed with a digital time-base (to tenths of a second) before being recorded.

Each infant was exposed to four conditions : face alone (F.), voice alone (V.), face and voice spatially congruent (F.V.c.) and face and voice spatially discordant (F.V.d.). Subjects were randomly allocated to one of four groups designed to counter-balance order of presentation : F. → F.V.c. → F.V.d. → V. (N = 6) ; V. → F.V.c. → F.V.d. → F. (N = 6) ; F. → F.V.c. → F.V.d. → V. (N = 6) ; and V. → F.V.d. → F.V.c. → F. (N = 6).

A session began when the infant was fixating the centre of the visual field (the intersection of the two screens). If necessary, the baby's attention was attracted to this point. Each condition was made up of 8 trials (4 with the stimulus on the left, 4 with the stimulus on the right). The order of trials was semi-randomized : 12 different sequences were used, 6 beginning with the stimulus at left, 6 with the stimulus at right. Three different trial duration were used : 10, 20, 30 sec., in order to avoid temporal regularities being induced in the infant's behaviour. The total lenght of each condition was constant : 120 sec. Thus a possible sequence of stimulation might be structured as follows : L (10 sec), R (10 sec), L (20 sec), R (10 sec), L (20 sec), R (30 sec), L (10 sec) and R (10 sec). Even if the infant did not turn towards the stimulus during the first trial (here L (10)), the second trial was started (R (10 sec)). The mean intersession interval was 20 sec (range 9-30 sec) and the mean length of the experiment was 9 min (range 8.30 - 10 min.).

3. Scoring of data

The recordings were scored by two judges working together. The judges were blind as to the side on which the stimulus was presented. The accuracy of the coding response did not improve over trials in session or over sessions. No particular biais associated to the trials structure should be thus suspected. Total agreement between the judges was required for all selected parameters. Divergences between scorers were observed in less than 10 % of cases. As a control, a small sample of randomly-selected video-recordings were coded independently by two different pairs of judges. In this case, judges' agreement was 92 % for the direction and 82 % for the latencies of head movements, 88 % for the direction and 81 % for the latencies of eye movements (differences of + 0.5 sec being ignored).

The judges scored the following parameters from the videotapes :

a) *direction and latency of the first head movement (HM) and eye movement (EM).* A correct response means that the infant performed ipsilateral HM or EM. The latency corresponds to the duration between the beginning of one trial and the time of occurrence of the first HM or EM. HM and EM were scored whether, at the beginning of a trial, the infant was looking at or away from the visual and/or auditory stimulus. If the infant was looking in the direction of the newly presented stimulus, an ipsilateral HM or EM was not scored. If the newborn was looking in the opposite direction, an HM and/or EM was scored when s/he crossed the midline of the body.

b) *occurrence and latency of the first reversed HM and EM,* i.e. of the first HM or EM oriented in the opposite direction to that of the first directed HM or EM (criterion a). A reversed HM or EM was scored when the infant turned to the centre of the visual field or to the controlateral hemifield.

c) *occurrence, direction and amplitude (weak, medium, high) of HM during each trial* and over all the conditions.

It should be noted that the EMs were not always possible to score probably because of the camera positions. EMs were not scoreable in 26 to 30 % of the trials (judges' agreement was of 97 % for the non scoreability of EMs). Thus only those trials where both the HM and EM of a baby could be scored were considered. The excluded trials come from the data of 17 different subjects. Their elimination is not caused by a systematic inter-individual variability. However, analysing EMs and HMs separately gave identical results.

RESULTS

The direction and latency of the first directed HM and EM will be examined first in order to be ensure that the neonates are able to orient equally well to the visual and auditory stimulus. This analysis will also consider towards which stimulus they turn to first when the situation is discordant. Following this an attempt will be made to differentiate the neonate's behaviours in the discordant condition from those exhibited in the others situations by analysing the occurrence and latency of the first reversed HM and EM.

1. Analysis of the direction and latency of the first directed HM and EM

Figure 1 shows the mean percentage of correct or incorrect responses, or of turns to the face or to the voice, for each condition.

Figure 1. Mean percentage of correct or incorrect responses (or of turns to the face, to the voice in the discordant condition) for each condition.

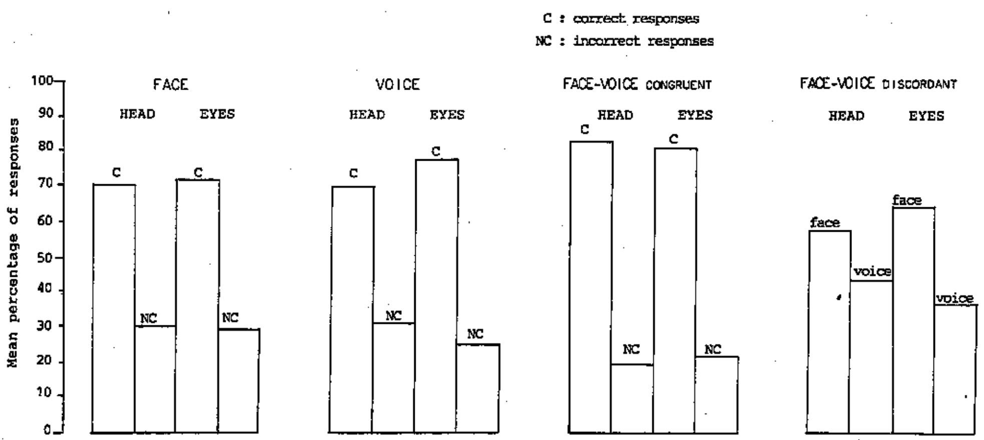

Figure 1. Fréquence moyenne des réponses correctes et incorrectes (ou des orientations vers le visage et vers la voix dans la situation de discordance) pour chaque condition.

From this figure, the following two points can be extracted :

a) The number of correct responses is significantly greater (Wilcoxon-paired test) than the number of non-correct responses in the F. session (T = 10, N = 20, p <.01 for HM ; T = 2.5, N = 15, p < .01 for EM), in the V. condition (T = 3.5, N = 16, p <.01 for HM ; T = 4, N = 16, p <.01 for EM) and in the F.V.c. condition (T = 2.5, N = 19, p <.01 for HM ; T = 3, N = 18, p <.01 for EM).

Thus newborns correctly turned their eyes and heads towards visual, auditory and combined visual-auditory stimuli.

b) While there is no significant difference between the number of HMs towards the face and those towards the voice in the F.V.d. condition (T = 35, N = 14, p >.05), the number of EMs towards the face is significantly greater than towards the voice (T = 35.5, N = 18, p <.05). In some cases in fact, the newborns turn their head towards the voice but their eyes towards the face, the EMs occurring firstly. Let us remark that it also occurs in some cases in the V. condition (the HMs are incorrect and the EMs are correct).

The mean latencies of the first HM and EM do not provide any striking additional information. They are quite similar in the different conditions and to those reported by Muir & Field (1979) : 3 to 4 sec. (mean standard deviation : 3.37). However, the lowest latencies generally occur in the F.V.c. condition.

Comparisons between conditions :

Comparisons between conditions were made by taking the correct or incorrect responses as dependent variables for each pair of conditions. Three comments can be made here.

Firstly, the proportions of correct as well as incorrect HMs and EMs are not significantly different when either V. or F. is compared to F.V.c. (Correct HMs : V/F.V.c. : T = 86, N = 21, p >.05; F/F.V.c. : T = 80.5, N = 21, p >.05 ; Correct EMS : V/F.V.c. : T = 75.5, N = 20, p >.05 ; F/F.V.c. : T = 68.5, N = 22, p >.05) or are compared between each other (Correct HMS : V/F. : T = 69.5, N = 19, p >.05 ; Correct EMs : V/F. : T = 67, N = 18, p >.05).

Thus these sensori-motor coordinations are equally efficient at birth : the introduction of a visual stimulation does not improve the orientation to sound nor does the introduction of auditory stimulation facilitate the orientation to a visual stimulus.

Secondly, turning the head either to the sound or the face in the F.V.d. condition involves orientation movements with equal probabilities of occurrence. They should not to be confused with the incorrect responses appearing in the unimodal conditions (V/F.V.d. : T = 33, N = 17, p <.05 ; F/F.V.d. : T = 29.5, N = 15, p <.05). Nevertheless the neonates orient the eyes to the face as much when the visual stimulus is presented alone as when it is opposed to an auditory stimulus (T = 67, N = 17, p >.05). This result is similar to that obtained by Castillo & Butterworth (1981) who consider that neonates resolve "the spatial conflict between audition and vision in favour of vision".

Thirdly, an order effect is found which involves an increase in the number of no-responses for HMs during the V. condition when presented last (Mann-Whitney U : $U = 22$, $p < .01$) and for EMs during F. when presented last ($U = 30$, $p < .05$).

2. Analysis of the occurrence and latency of the first reversed HM and EM and of the frequency of HM over all the conditions

For each trial in each condition, the occurrence and latency of the first reversed HM and EM were noted. They can be either correct (if the first directed movement was incorrect) or incorrect, or, in the F.V.d. condition, towards the face (if the first directed movement was towards the voice) or the voice. Table 1 shows the percentage of occurrence of such movements with the time intervals between latencies of the first directed movements and of the first reversed movements.

From this table, we can extract the following points :

a) ~~For~~ F. and F.V.c., the percentage of correct movements following an initial incorrectly directed movement (NC → C transition) is higher than the percentage of first incorrect reversed movements (C → NC transition), but this difference is significant only for EM (F. : $T = 11.5$, $N = 22$, $p < .01$; F.V.c. : $T = 19$, $N = 20$, $p < .01$). This is not the case for V., where no consistent difference appears between the frequencies of correct or incorrect reversed movements ($T = 67.5$, $N = 17$, $p > .05$).

The mean time intervals associated with the NC → C transition are lower than those related to the C → NC transition.

Such a finding supports an interpretation of the first correct reversed movements as correctional movements, which occur after 5-6 sec, while the first incorrect reversed movements would indicate the end of the orienting movements (perhaps a sign of disinterest), occurring after 7-8 sec on average. It should be emphasized that the V. condition appears to some extent distinguishable from the F. and F.V.c. conditions : no difference between the first correct or incorrect reversed movements is noted.

b) Movements which are initially oriented to the voice and subsequently to the face (V → F transition) are more frequent than the inverse (F → V transition) as far as the F.V.d. condition is concerned. This difference is again only significant with EMs ($T = 17.5$, $N = 15$, $p < .05$). Nevertheless, time intervals are approximately intermediate between those associated with the NC → C and C → NC transitions.

Thus neonates go more frequently from the voice to the face than from the face to the voice in the discordant condition.

Table 1. Percentage of occurrence of first reversed head and eye movements for each condition and mean time interval (in sec) between latencies of the first directed movements and of the first inversed movement.

(NC → C : the first directed movement is incorrect and consequently the first reversed movement is correct ; V → F : the first directed movement is towards the voice and the first reversed movement is towards the face).

	HEAD		EYES	
	NC → C	C → NC	NC → C	C → NC
FACE	82.00 % (2.40)	69.00 % (3.90)	79.00 % (3.00)	34.50 % (4.10)
VOICE	68.90 (1.40)	65.40 (3.40)	47.80 (0.80)	43.30 (1.70)
FACE-VOICE Congruent	65.10 (2.20)	58.90 (3.90)	43.75 (2.35)	25.40 (4.90)
	V → F	F → V	V → F	F → V
FACE-VOICE Discordant	67.80 % (3.10)	56.20 % (2.60)	52.40 % (2.80)	30.90 % (3.00)

Tableau 1. Fréquence d'apparition du premier mouvement inverse de tête et d'yeux pour chaque condition et de la durée moyenne de l'intervalle (en sec.) entre les latences des premiers mouvements d'orientation et des premiers mouvements inverses.

(NC → C : le premier mouvement d'orientation est incorrect et en conséquence le premier mouvement inverse est correct ; V → F : le premier mouvement d'orientation est vers la voix et le premier mouvement inverse est vers le visage).

The analysis of frequency and direction of HMs occuring during each trial and over all the conditions provides data supporting the above results. This analysis shows that the total number of HMs is similar whatever the condition (F. = 368, V. = 327, F.V.c. = 349 and F.V.d. = 369). In particular, it is not higher in the F.V.d. condition than in the F.V.c. situation ($T = 87.5$, $N = 24$, $p > .05$).

Thus, once the first directed HM has been performed, neonates do not behave differently in terms of HM quantity, even if there is a second stimulus.

Finally in the F.V.d. condition, the frequency of crossing movements associated with the V → F transition (movements of large amplitude) is double that for the F → V transition (T = 13, N = 14, $p < .05$). This finding suggests that the neonates are more "troubled" by hearing something without a simultaneous visual stimulus than being stimulated visually and receiving a contemporary discordant auditory stimulus.

This major difference raises the problem of the meaning of auditory-visual coordination : this coordination cannot be reduced to auditory-motor or visuo-motor coordinations. It implies something more which consists of "anticipating" a visual stimulation upon hearing a sound, which is not the case for the reverse situation. We will discuss this interpretation more precisely in the next part of this article.

DISCUSSION

Our results clearly confirm the neonate's ability to orient correctly with the head or the eyes to a visual stimulus or to an auditory stimulus presented alone or simultaneously if they are spatially congruent. Thus newborns possess pre-constructed motor programmes governing their reactions to visual or auditory stimuli. These relationships between sensory information and motor execution result from representations which have an essential function, namely, to attribute adaptive significations to incoming information.

The principal question is how to interpret these coordinations at birth. Certain authors (e.g. Castillo & Butterworth, 1981) account for the coordinations by saying that the newborn is capable of localising a sound of an object in a visual space. According to us, this would imply an implicit "knowledge" of an external space containing objects which have individual properties (being visible, audible and so on). Our results in the discordant condition suggest the need for caution in interpretating these coordinations. It appears more parsimonious to explain them in terms of orientation to an auditory stimulus rather than in terms of localisation. The first interpretation does not require an external space geometrically organized as does the second, but a structurated body space.

In the discordant condition, the newborn turns the head as much to the voice as to the face but orients the eyes preferentially to the face. This finding is also reported by Castillo & Butterworth (1981) who interpret it in terms of "visual dominance". Furthermore, we found that first oriented movements are followed by reversed movements in both the congruent and the discordant situations. Moreover, the neonates do not make more lateral head movements in the discordant condition than in the others, a result which is in line with the findings of McGurk & Lewis (1974). These authors interpreted such a result as evidence for the absence of coordination between vision and audition at 1 month. We consider that these results reflect the neonate's inability to relate the visual stimulus with the auditory stimulus (or vice-versa) in the sense that both should

comprise two aspects of a single object which must appear in a unique location in space. This inability may be an indication of the adualist relationship that the neonate experiences with the external environment.

In the discordant situation, we have shown that the newborn turns more often from the voice to the face than from the face to the voice. This result is the most difficult to interpret but is possibly the most clear demonstration for the existence of a sensory auditory-visual coordination.

If this coordination signifies that, given a sound, a visual stimulation is expected or anticipated, it is possible to understand why the infant turns towards the face after having been directed towards the voice : his visual "expectation" based upon auditory stimulus *needs* to be fulfilled by a visual stimulation. This is not the case when the neonate turns first towards the face : given a visual display, there should be no particular expectation of auditory stmulation, at least at birth. The neonate may integrate separately the concomittant visual and auditory stimulations in this case, just as one may look at a silent person whilst hearing his neighbours talking.

An alternative interpretation may be suggested for the movements of reorientation towards the face : the infant could try to optimalize the level of stimulation, to gain for the maximum of information (auditory *and* visual) without any capacity to integrate them. Further researchs are certainly necessary to test this eventuality. But let us recall a result obtained in V. alone condition : even if the neonates turn first correctly to the voice, they perform as *many reversed movements* as when they orient first in the wrong direction, suggesting that they are "searching for" another stimulation, a visual one we suspect. Such a result does not appear in the F. condition. If the rule governing the neonate's behaviours is to maximalize the stimulations, why re-orientation movements do not appear in this F. situation ?

The idea of "visual anticipation" is open to criticism. In the discordant condition, when turning towards the sound, newborns get no visual stimulation but when turning towards the face, they receive auditory stimulation, appearing to come from a different location. Thus, if neonates do not orient to the dislocated voice, they may nevertheless perceive the mislocation, but do not do anything about it because of "visual dominance". This alternative interpretation is quite plausible. But let us remark that the idea of "visual dominance" *at birth* is also open to criticism : at birth, the auditory system is more mature than the visual one. Moreover, the ability of "sensory anticipation" appears common to different behaviours present at birth, such as the "looming reaction" or the prehension of virtual objects. These last behaviours may suggest "tactual dominance" over the visual modality. Finally, the newborns' reactions in the discordant condition could also be explained as a lack of precise criteria for auditory localisation. But thereagain they are able to select the correct hemi-field when orienting to the voice in the V. condition.

Nevertheless let us point out how our interpretation takes for granted that similar results would be found if the visual and auditory stimulations were produced by inanimate objects. Would it not be the case, no interpretation in terms of *sensory* coordination would be acceptable. But as long as an experimental evidence in this sense is provided, the results obtained cannot be explained by assuming particular aspects associated to the social characteristics of the stimuli.

The auditory-motor coordination seems to be a very complex behaviour at birth. Alegria & Noirot (1980) showed that neonates exhibit asymmetrical mouth opening upon hearing a sound. This mouth opening is related to their mode of feeding. We just would like to suggest that an auditory-tactual coordination may be established during the first days of life : upon hearing a voice, the neonate's tactual system "expects" an oral stimulation.

Many of the interpretations put forward here are supported by the study of the development of these sensori-motor coordinations. Vinter et al. (1982) confirmed the results obtained by Muir et al. (1979) and Field et al. (1980) on the development of auditory-motor coordination. Like these authors, we found a U-shaped development of function, i.e. a decrease in auditory orientation at 7-8 weeks and a subsequent increase around 17-18 weeks. Furthermore, in the F.V.d. condition, the 17-18 weeks-old-babies perform a lot of lateral head movements, going rapidly and equally from the face to the voice than from the voice to the face, thus indicating the efficiency with which they are able to relate one stimulus to the other. The capacity to coordinate the vision and the audition at 3-4 months is in fact admitted by several authors as Piaget or Spelke (1976) for example. Within our perspective, the infant during the newborn period acquires a new capacity for coding reality, the perceptive code (Mounoud, 1979 ; Mounoud & Vinter, 1981), and will reconstruct initial behaviours by means of this new code. The perceptive code allows a distinction between external and internal spaces. At 17-18 weeks, there is no longer just "sensory anticipation" but rather four-months-old infants "listen (and) look *to* see" (Field et al., 1980). By this age, they have learned that audible objects are also visible, perhaps through the mechanisms described by Spelke (1976, 1979).

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ABSTRACT

The primary intention of the authors is not to demonstrate once again the efficiency of visuo- and/or auditory-motor coordination, but to attempt to understand their functional significance for the newborn. Twenty-four neonates were examined at a mean age of 3 days. Each infant was exposed to four situations : face alone, voice alone, face and voice spatially congruent, face and voice spatially discordant. Response parameters (i.e. head and eye movements) were scored from videotapes. Results demonstrate that, on one hand, visuo-motor and auditory-motor coordinations are equally efficient at birth and, on the other hand, that vision and audition were shown to be coordinated in neonates. The authors chose to interpret the latter result utilizing the concept of sensory anticipation and postulate that there seems no necessity to assume the existence of an external world containing objects to account for newborn sensory coordination.

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