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Visual performance in preterm infants with brain injuries compared with low-risk preterm infants

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ABSTRACT

Background: Neonatal brain injuries are the main cause of visual deficit produced by damage to posterior visual pathways. While there are several studies of visual function in low-risk preterm infants or older children with brain injuries, research in children of early age is lacking.
Aim: To assess several aspects of visual function in preterm infants with brain injuries and to compare them with another group of low-risk preterm infants of the same age.
Study design and subjects: Forty-eight preterm infants with brain injuries and 56 low-risk preterm infants.
Outcome measures: The ML Leonhardt Battery of Optotypes was used to assess visual functions. This test was previously validated at a post-menstrual age of 40 weeks in newborns and at 30-plus weeks in preterm infants.
Results: The group of preterm infants with brain lesions showed a delayed pattern of visual functions in alertness, fixation, visual attention and tracking behavior compared to infants in the healthy preterm group. The differences between both groups, in the visual behaviors analyzed were around 30%. These visual functions could be identified from the first weeks of life.
Conclusion: Our results confirm the importance of using a straightforward screening test with preterm infants in order to assess altered visual function, especially in infants with brain injuries. The findings also highlight the need to provide visual stimulation very early on in life.

1. Introduction

Many preterm infants are at a higher risk of neurodevelopmental and visual impairment than term-born infants. Visual deficits may be due to retinopathy of prematurity, or to brain lesions in the optic pathways and associated areas [1]. The behavioral aspects of visual function have mainly been studied after the neonatal period, when more mature aspects of this function can be assessed [2]. In preterm infants at term-equivalent age, aspects of visual function are directly related to the maturation of white matter in the optic radiations [3].

The early detection of visual disorders is important in order to minimize the consequences of visual impairment, especially in children with brain injury [4]. Research into visual function has been carried out using magnetic resonance imaging (MRI) [5–7], visual evoked potentials techniques (VEP) [8] and various batteries of optotypes [9,10]. At all events, the assessment of visual function has become part of any neurological examination and is now included in most widely used methods, such as the Amiel-Tison standardized neonatal neurological assessment [11], which records information about the type of ocular movements, visual alertness (in response to a red ball or black and white target) and the ability to fix and follow the same target horizontally, vertically, or in a complete arc. The Brazelton neonatal Behavioral assessment scale [12] also examines visual alertness, as well as orientation to animate or inanimate visual targets.

Leonhardt [13,14] reported the use of the ML-Leonhardt Optotypes Battery to explore visual functions in low-risk preterm newborns. In those studies, visual responses were assessed in 50 term and 130 preterm newborns aged between three and 48 days using optotypes and the human face. It was found that preterm infants reacted to the visual stimulus, giving responses of alertness, fixation and tracking to the human face and to the high and low contrast optotypes. The study concluded that both preterm and term newborns showed visual abilities from birth. Between 80% and 100% of term infants showed alertness and fixation to the stimulus, and between 75% and 95% were able to attend to the stimulus [15]. The study concluded that visual functions are present from a very early stage.

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Recent studies have provided evidence that early visual abilities are present in both preterm and full-term new-borns, and have described a functioning model of diverse systems that imply vision [10,16]. For example, Ricci and her research group conducted an in-depth exploration of visual function by applying a newly developed clinical assessment battery to a cohort of low risk-full-term newborns [9,17].Their findings showed that around 90% of low-risk term-born newborn could conjugate ocular motility, showed stable fixation, could track patterns horizontally, vertically and in arc, reacted to tracking colored stimulus, discriminated between black and white stripes (0.86 cycles/degree or higher) and kept attention on a distant stimulus. This group compared preterm visual function at term-equivalent age with those of term-born infants [18]. They also found that the early extrauterine experience of low-risk infants of 35 to 40 weeks post-menstrual age accelerated the maturation of visual function as regards stability and tracking. In their longitudinal assessment of visual function in low-risk preterm infants at 3, 5 and 12 months [19], they found that more than 85% of infants were able to fix and follow, and presented normal results on acuity, visual fields, and attention at distance, which suggest that the maturation of these visuals function was not affected by preterm birth when adjusted for prematurity.

However, to the best of our knowledge there are no studies comparing the visual function of low-risk preterm infants with those of preterm infants with brain injury during the first 2 months post-menstrual age. Consequently, the main objective of the present study was to analyze the visual behavior of two groups of preterm newborn: a low-risk group, and a group with brain injuries. The analysis focuses specifically on their visual abilities related to alertness, fixation and visual attention triggered by the presentation of an optotype battery. It was hypothesized that the use of ML Leonhardt Optotype Battery would allow the identification of certain differences in visual function between preterm newborns with and without brain injury.

2. Methods

2.1. Subjects

Subjects were classified into two groups of preterm infants, with and without brain injuries. The brain injury group (BIG) comprised 48 children (52.1% boys and 47.9% girls) recruited via the Neonatal Intensive Care Unit (NICU) of three maternity hospitals in Barcelona (Spain). Of these, 46.34% were considered to be at high risk (gestational age (GA) $<$ 33 weeks and weight $<$ 1.500 kg), and 53.65% at a moderate risk (GA $\geq$ 34 weeks and weight $\geq$ 1.501 kg). All preterm infants were evaluated at 72 hours ($\pm$5 hours) with cranial ultrasound scan, and those suspected of having brain injury underwent neonatal serial brain MRI and neurological examination by the team of neurologists at each hospital. This exploration was conducted at gestational ages between 35 and 42 weeks. The group with brain injury presented the following conditions: intraventricular hemorrhage (IVH) stage II ($n=6$), intraventricular hemorrhage stage III ($n=6$), intraventricular hemorrhage stage IV ($n=3$), hydrocephalus ($n=9$), hypoxic-ischemic encephalopathy ($n=4$), periventricular leucomalacia ($n=1$), meningitis encephalomalacia ($n=2$), brain malformations such as holoprosencephaly or lissencephaly and others ($n=17$). In this group 14.6% had retinopathy of prematurity (ROP) stage I and II, but this did not prevent them from giving a visual response to the optotypes.

Preterm infants without brain injuries were chosen as the control preterm group (CG). This group comprised 56 children (51.8% boys and 48.2% girls) recruited through the Neonatology Units of three maternity hospitals in Barcelona (Spain). In this case, 45.28% were considered to be at high risk (GA $<$ 33 weeks and weight $<$ 1.500 kg), and 54.72% at moderate risk (GA $\geq$ 34 weeks and weight $\geq$ 1.501 kg). All the infants included in this study had a normal retinal condition.

2.2. Instrument

The instrument used to assess the visual function of the preterm infants was the ML Leonhardt Optotype Battery [13]. This test involves eight high contrast stimuli that are shown consecutively, one optotype at a time, at a distance of 15–20 cm. in front of the newborn's eyes. The first stimulus (the human face) served to analyze the baby's response to the examiner's face. The first optotype consisted of three black concentric circles of 1 cm. stripe-width (equivalent to 0.50 cycles per degree, as suggested by Teller [20] over a white background, and corresponded to a classical model used in neonatology to assess newborns' visual response. The second optotype consisted of three black concentric squares of 1 cm. stripe-width over a white background. The third and fourth optotypes were wide, black and white horizontal and vertical stripes of width to 2 cm. (equivalent to 0.25 cycles per degree). The fifth and sixth optotypes were narrow, black and white horizontal and vertical stripes of width 1 cm. (corresponding to 0.50 cycles per degree). The seventh optotype presented a drawing of a face in black and white.

The ML Leonhardt Optotype Battery analyzes the visual behavioral responses of alertness, fixation, attention and tracking. The responses were recorded on a Register Proforma (Fig. 1). Alertness, fixation and attention behaviors were coded as 0 = absent and 1 = present. Alertness to the optotype was coded positively when, in a reflex form, the infant showed a minimum response to the presentation of the stimulus (reflex movements of eyes towards stimulus), indicating that he/she was aware and realized that something is there. The positive signals of alertness may be very slight (a slight tilt toward the stimulus, eye opening, small changes in normal breathing, color changes, and so on). Fixation was coded positively if the optotype was detected and if the child focuses on it (with one eye, monocularly, or with both eyes, binocularly) showing some visual adjustment to the stimuli. Adjustment was considered as an adaptation of the eyes to converge the light rays and obtain a clearer image; the baby tried to guide the vision clearly and directly to an object. If during fixation the child changed the focalization of one eye but maintained that of the other, this was considered monocular vision. Fixation marked the beginning of the attention stage. Attention was coded positively when the child focused on the stimuli for at least three seconds. Hyperfixation was not considered as an attentional behavior to the object. Tracking was achieved if the child turned his/her eyes (or eye), or both the head and eyes towards a moving stimulus. The stimulus moved horizontally from left to right and vice-versa. Tracking behavior was coded as: A = absent, B = brief (tracking the object is characterized by discontinuous glances), C = incomplete (continuous movement along the object with the eyes, at an angle of between 30 and 90 degrees), and D = complete (continuous tracking of the object with eyes and head, within the defined angle.

When applying the battery, the examiner adapted to the conditions of fragility and vulnerability of these neonates. Specifically, the battery was applied gently and slowly, taking care at all times to avoid causing stress to the baby. The application therefore requires appropriate training.

Stress was identified as irregularity of breathing (breathing pauses, slow and/or fast), skin color (pale, cyanotic, crosslinked), visceral signs (vomiting, choking, hiccups, gasps), motor behavior (extension of the arms and legs), SNA responses (tremor, shocks, spasms). If during the application of the test signs of stress appeared, a small break was taken to facilitate the recovery of the child before continuing the application.

2.3. Procedure

The study was carried out at the corresponding NICU or Neonatology Unit from 2006 to 2009. The assessment was performed with the infant in either the mother's or the examiner's arms, or in their usual incubator or cradle in a lateral or supine position.

	OPTOTYPUS	BEHAVIORS									
		ALERTNESS		FIXATION		ATTENTION		TRACKING			
1		Present	Absent	Present	Absent	Present	Absent	Absent	Brief	Incomplete	Complete
2		Present	Absent	Present	Absent	Present	Absent	Absent	Brief	Incomplete	Complete
3		Present	Absent	Present	Absent	Present	Absent	Absent	Brief	Incomplete	Complete
4		Present	Absent	Present	Absent	Present	Absent	Absent	Brief	Incomplete	Complete
5		Present	Absent	Present	Absent	Present	Absent	Absent	Brief	Incomplete	Complete
6		Present	Absent	Present	Absent	Present	Absent	Absent	Brief	Incomplete	Complete
7		Present	Absent	Present	Absent	Present	Absent	Absent	Brief	Incomplete	Complete
8		Present	Absent	Present	Absent	Present	Absent	Absent	Brief	Incomplete	Complete

Alertness: infant minimum responses to the presentation of the stimulus, showing that he/she is aware and realizes that something is there.
Fixation: infant detects and focalizes mono or binoculary on the stimulus, showing some adjustments to the stimulus.
Attention: infant focuses on the stimuli during a minimum of 3 seconds.
Tracking: A = absent, B = brief (tracking the object is characterized by discontinuous glances), C = incomplete (continuous movement along the object with the eyes), and D = complete (continuous tracking of the object with eyes and head).

Fig. 1. Register Proforma of visuals functions.

When it was necessary to apply the battery in the incubator, the evaluator held the baby with one hand while presenting the stimuli with the other, so that the child could move freely in order to respond optimally. The infants were tested in a quiet environment with low background lighting, facilities eye-opening, and with few stimuli in the surroundings. To attract their visual awareness, a slight movement was made with a given optotype. Administration time was not limited, but it normally took around 10 minutes. The test was administered in a single session, although breaks were also introduced in order to obtain the best performance from the newborn. The infant's comfort was a preliminary requirement throughout the administration of the test.

The ML Leonhardt Optotype Battery [13] starts with the presentation of the human face (that of the examiner) followed by the high contrast patterns. In order to obtain the 'best performance', the infants were examined in a quiet and awake state (state 4, according to the classification proposed by Brazelton) [12]. In the brain injury group, the neonatologist indicates the time the child was stable, based on biological data of heart rate, breathing and oxygen saturation.

While the visual stimuli were presented, the examiner avoided talking to the infants and kept her face outside their line of vision. The reliability of the instrument was analyzed in 20 full-term newborns by two neonatal specialists with experience of the ML Leonhardt Battery. The instrument was applied between three and 48 hours after birth. This analysis yielded a mean Kappa coefficient of .94. Depending on the visual behaviors and optotypes analyzed, kappa values ranged between .80 and 1.00, thus indicating good reliability. In the current study, the battery was administered in all the cases by its author. The research protocol was approved by the Ethics Committee of each hospital. Informed parental consent was obtained for all infants.

2.4. Statistical analysis

Firstly, the chi-squared or Mann–Whitney *U* test was used to examine differences between the brain injury and control groups as regards gender, gestational age, birth weight, days of life and post-menstrual age at time of examination. Secondly, visual function behaviors related to alertness, fixation and attention were analyzed, according to the percentage differences between the groups for each stimulus. Finally, differences in tracking behavior between the groups were analyzed for each stimulus by means of a chi-squared test. Significance was set at $p<0.05$. All data were analyzed using SPSS® (version 16.0) for Windows.

3. Results

3.1. Neonatal and child characteristics

There were no significant differences between the brain injury group (BIG) and the control low-risk preterm group (CG) as regards gender, gestational age, and birth weight. However, the requirement to administer the test in the best awake state, so as to obtain the best performance, did produce a significant difference in application time between the two groups: the BIG was examined at a mean age of 53 days while the CG was examined at a mean age of 31 days. Maturation times in the two groups were thus different. Specifically, administration times for the BIG were as follows: 38.3% in the first month, 27.7% in the second month, and 22% in the third month, while for the remaining infants (12%) the administration was delayed (between the fourth and seventh month). For the CG the administration times were as follows: 64.3% in the first month, 21.4% in the second and 14.3% between the third and fourth months. Despite age corrections according to standard criteria, the BIG infants were significantly older than their CG counterparts (Table 1).

3.2. Visual functions

The percentage success rates for alertness, fixation and attention behavior in the BIG and the CG are shown in Fig. 2.

–Alertness. Infants in the CG showed alert behavior towards a human face in 96.4% of the cases. Almost all the infants (>98.2%) showed alertness behavior when looking at the concentric optotypes (of 0.50 cycles per degree). Between 87.5% and 89.3% also showed alert behavior when looking at stripe models of 0.50 cycles per degree, while between 67.9% and 71.4% did so with the stripes of 0.25 cycles per degree. The rate of alert behaviors towards a drawing of a high contrast face reached 66.1%.

In the BIG, 76.9% of infants were able to display alert behavior towards a human face. Between 76.9% and 88.5% of this group showed alert behavior to the presentation of concentric patterns of 0.50 cycles per degree. For the stripe patterns of 0.25 cycles per degree, 71.2% of infants showed alert behavior when looking at horizontal stripes while 50% did so when looking at vertical stripes. When presented with stripe patterns of 0.50 cycles per degree, between 35.5% and 42.3% showed alert behavior. The infants had more difficulty with vertical than with horizontal stripes. Just under a third (32.7%) displayed alert behavior towards a drawing of a high contrast face. The differences between the groups in the percentages of alert behavior were statistically significant ($p<0.008$) for all stimuli.

–Fixation. In the CG, 94.6% of infants displayed fixation behavior towards the human face. The rate of fixation behavior when presenting concentric optotypes of 0.50 cycles per degree was over 98.2%. A high percentage of infants, between 83.9% and 89.3%, showed fixation behavior to optotypes with stripes of 0.25 cycles per degree, while between 67.9% and 69.6% did so when looking at stripes of 0.50 cycles per degree. Fixation behaviors with respect to the drawing of a high contrast face were observed in 62.6% of infants.

In the BIG, 71.2% of infants were able to fix their gaze on the human face. The percentages of fixation on the concentric optotypes of 0.50 cycles per degree were 73.1% for the square and 77.1% for the circle. With regard to the stripe optotypes of 0.25 cycles per degree, 59.62% of infants fixed on the horizontal stripes and 48.1% on the vertical stripes. For the stripe optotypes of 0.50 cycles per degree, 34.6% of infants fixed on the vertical stripes, and 42.3% on the horizontal stripes. Fixation to the drawing of a high contrast face was displayed by 30.8% of infants. Of the 48 infants analyzed, 22.9% could not present a fixed gaze. The analysis of differences between the CG and the BIG for each of the optotypes used revealed that they were all significant ($p<0.002$).

–Attention. In the CG, 92.9% of infants showed attention behavior toward the human face. The rate of attention on the concentric optotypes of 0.50 cycles per degree was 96.4%. Attention behavior was displayed by 80.4% of infants when looking at the vertical stripe patterns of 0.25 cycles per degree, and by 87.5% on the horizontal stripes of the same frequency. With the optotypes of 0.50 cycles per degree, 67.9% of infants showed attention behavior, while 58.9% did so with the drawing of a high contrast face.

In the BIG, 55.8% of infants showed attention to the human face. The rate of attention behavior toward the concentric optotypes of 0.50 cycles per degree was between 63.5% and 69.2%. With respect to the horizontal stripes of 0.25 cycles per degree, attention behavior was shown by 57.7% of infants, and by 44.2% in response to the vertical stripe optotypes of the same frequency. The maximum rate of attention behavior with the optotypes of 0.50 cycles per degree was 34.6%. Attention behavior was shown by 25% of infants when presented with a drawing of a high contrast face. The difference between the CG and BIG in terms of the percentages of attention behavior was significant

Table 1
Gender, neonatal characteristics and time of assessment for brain injury preterm group (BIG) and low-risk preterm control group (CG).

	Brain injury preterm group ($n=48$)	Low-risk preterm control group ($n=56$)	Comparison between groups	
			Chi-square or Mann–Whitney *U* test	*p*
Gender: female/male	23/25	27/29	$\chi^2=0.001$	$p=0.976$
Gestational age (Weeks) M (SD)	32.88 (5.62)	31.60 (3.48)	$U=998.0$	$p=0.223$
Birthweight (kg) M (SD)	1.85 (0.89)	1.57 (0.55)	$U=1044.0$	$p=.259$
Days of life at time of assessment M (SD)	52.68 (39.58)	31.07 (29.85)	$U=726.0$	$p=.001$
Post-menstrual age at time of assessment (Weeks) M (SD)	40.1 (7.17)	36.4 (3.68)	$U=763.5$	$p=.001$

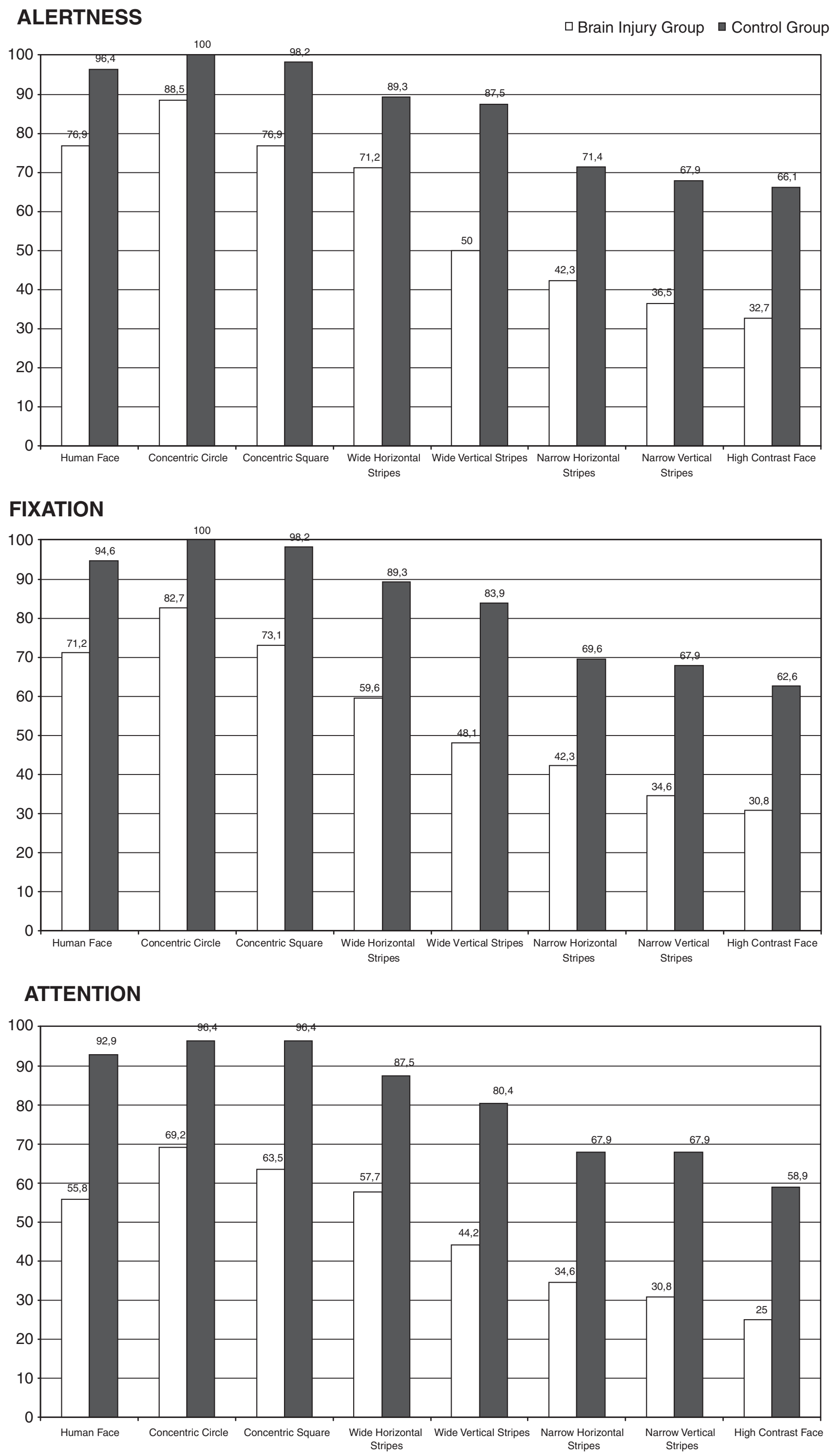

Fig. 2. Percentages of alertness, fixation and attention behavior for each optotypes by brain injury preterm group and low-risk preterm control group.

($p<0.001$) for all the optotypes used. A large number of infants in the BIG had difficulty in paying attention for a minimum of 3 s.

–Tracking behavior. Fig. 3 shows the percentages for each one of tracking responses for each pattern and group. Tracking behavior with the eyes (incomplete behavior) was the predominant type of response in the CG (between 35.7% and 67.9%). For this group the absence of tracking behavior was observed in between 3.6% and 42.8% of infants. In contrast, the predominant type of response for the BIG was the absence of tracking, detected in between 30.7% and 75% of infants. The percentage of infants who were able to perform complete tracking with face and eyes was similar in the two groups and did not exceed 18% in any case. Once again, the concentric circle was the optotype that obtained the best tracking response. The Chi-squared analysis of the four tracking responses by groups, and for all the patterns, revealed significant differences in all cases (with $p \leq 0.01$).

4. Conclusion and discussion

The objective of this research was to describe the visual functioning of preterm newborns with and without brain injury. The instrument used, the ML Leonhardt Optotypes Battery, allows the identification of early visual impairment in children with brain injury. The results confirmed that low-risk preterm infants show better responses for the visual functions of alertness, fixation, attention and tracking than preterm infants in the brain injury group.

More than 90% of the low-risk preterm infants looked at the human face. Atkinson [2] noted that newborns are adapted for rapid response towards a stimulus such as a human face. Here, when a human face was presented in a two-dimensional drawing after other optotypes, the observed outcomes were less successful than when a real human face was presented, in the control group and especially in the BIG. This may be because brain injured infants are unlikely to be attracted by the stimulus (due to the complexity of the pattern) or to maintain attention, with fatigue appearing very quickly (only about 4–6 minutes elapsing between the presentation of the human face and the high contrast face drawing). In the future, it would be interesting to explore whether this difference is due to the characteristics of stimulus presentation (real face or drawing of a face) or to a fatigue effect.

As regards alert, fixation and attention behaviors in relation to a concentric stimulus (circle and square) the responses of low-risk preterm infants of 36.4 weeks PMA showed a success rate > 96% with a spatial frequency of 0.50 cycles per degree. Our results corroborate those of Ricci [18,21], who reported that over 91% of low-risk preterm infants showed stable fixation at 35 weeks PMA, rising to 97% at 40 weeks. However, we found that the success rate on corresponding concentric stimuli (circle and square) was much poorer in the BIG. The percentages differences in success between the CG and the BIG on concentric forms become progressively more pronounced. The brain injury group thus showed less mature responses than CG in the visual behavior analyzed. Nevertheless, with regard to the low-risk preterm infants group our results agree with the presence of an early initial maturation of the visual function.

The current study also confirmed that in low-risk preterm infants of 40 weeks PMA the rate of alert, fixation and attention behaviors to wide stripes of 0.25 cycles per degree (horizontal and vertical) showed levels of success of between 80% and 89%. When this stripe stimulus increased in spatial frequency up to 0.50 cycles per degree, the level of success decreased. We note that the figures enclosed (circle and square) of .50 cycles per degree obtain better rates of success than striped figures (horizontal and vertical) of greater amplitude (.25 cycles per degree) which would seem to better capture the attention of children. The difference in performance does not seem to be only linked to the spatial frequency of cycles per degree. We should study the influence of the “good form”, in terms of Gestalt, as in the processes of perception at these early ages.

The difference in the percentage success rate between the BIG and CG, in the visual behaviors analyzed to date, was around 30%. This finding of lower visual ability in the BIG on all the stimuli presented may reflect difficulties in subcortical maturation, and may also be due to associated pathologies or impairment in other brain systems. Ricci et al. [22] indicated that visual abnormalities were higher in preterm infants with brain lesions, specifically in those with PVL. It would therefore be beneficial to promote the stimulation of visual function in all infants who present difficulties as soon as possible, not only in the optical functions but also in the ventral visual pathways, which are linked to the identification and selection of objects, and the dorsal pathways, which are linked to the system of movement, space and action [22].

Our findings are at odds with those of other researchers such as Ricci et al. [18,21] with regard to the narrow horizontal and vertical stripe stimulus. Ricci [18,21] indicated that 97% of preterm newborns at 35 weeks PMA and 100% at 40 weeks PMA showed accentuated maturation in terms of discriminating striped black/white targets of spatial frequencies of at least 0.64 cycles per degree. Our low-risk preterm group had a poorer result, although the test card used is somewhat broader (0.50 c/degree) than the ones used in Ricci's studies. In addition, less than half of the brain injury group attained good visual performance, thus indicating notable difficulties in visual function. Our data should be reanalyzed in more homogeneous groups, specifically for the BIG, taking into account the different subtypes of brain injury. In the meantime, in addition to the interpretation that the difficulties may reflect subcortical impairment, we attribute this delay to attention impairment and to a fatigue effect that appears during the application of the test.

As regards tracking behavior, the current study found that low-risk preterm infants showed a very different pattern of responses than the brain injury group in which the category of “absent” was the predominant response, as shown in Fig. 3. When considering

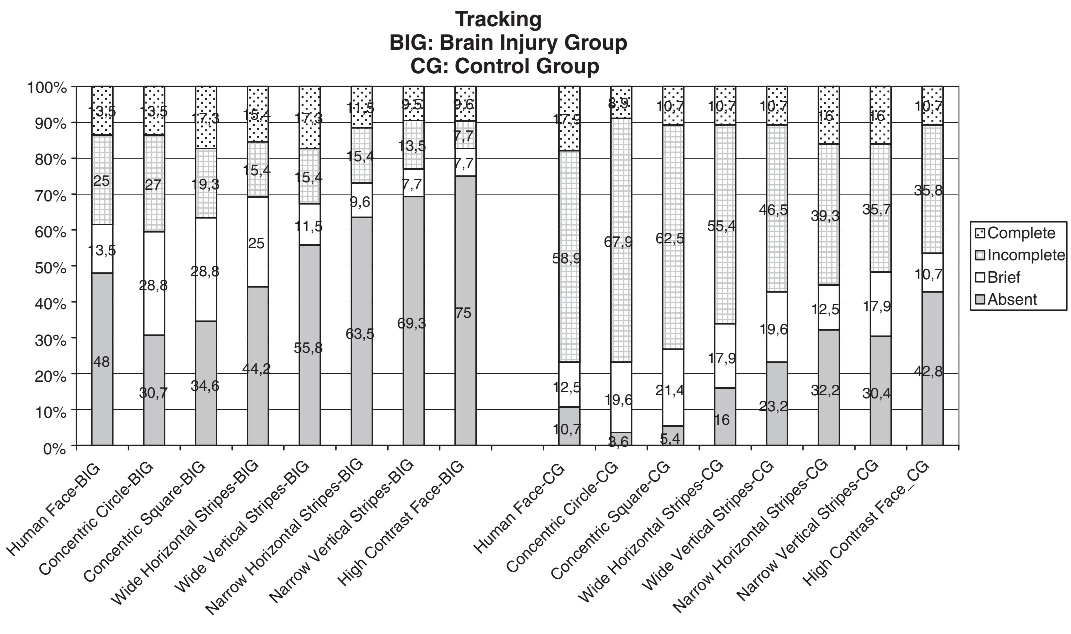

Fig. 3. Percentages of tracking behaviors by both preterm groups.

complete, incomplete and brief tracking responses all together, the range of success for the BIG was between 25% and 69%, depending on the optotype. The results of Ricci [18] were much better: she reported that 97% of low-risk infants at 35 weeks and 100% at 40 weeks presented correct horizontal tracking behavior. We agree with these data for low-risk preterm infants if we consider the addition of the percentages of complete, incomplete and brief tracking responses, but our study highlights a much poorer performance in the BIG.

Figs. 2 and 3 show a downward curve in the achievements obtained during the application of stimuli of the battery. The descending curve suggests the presence of fatigue especially early in the brain injury group, an aspect that requires further study.

In conclusion, brain injured infants showed visual difficulties than can be identified in the first weeks of their life. This highlights the importance of early intervention with this population in order to improve both visual functions and attention behavior [5,21,23]. Furthermore, any intervention needs to be implemented as part of the baby's daily life, especially through stimuli strengthens his/her relationship and communication with, for example, the face, hands and body of the parents.

4.1. Limitations

The main limitation of this study was that the battery could not be administered at the same time point to the two groups of infants. Obviously, there are many reasons why such a battery cannot be applied to brain injured infants very early on (for example, they may be undergoing clinical interventions or may even be in life-threatening situations). Despite the older age of brain injured infants, however, the results highlight that they display greater visual difficulties. A tighter control of the weeks of application of the test must be achieved in future research. Because of this limitation, the data presented here should be considered with caution.

Another limitation of our work affects the domain of interpretation. We noticed a delay and variability in visual maturation, but the heterogeneity of the group, especially for the BIG, and the small sample size does not allow us to draw unique interpretative conclusions. The delay may be due to visual immaturity, to cerebral impairment or to other physical conditions. Further research is needed to clarify this question.

Despite these limitations, the study demonstrates that the ML Leonhardt Battery [13] is a useful instrument to assess the visual capabilities of both low-risk and brain-injured preterm infants. Furthermore, its ease of administration means that only a few minutes are required to screen for visual difficulties. This is important because the early identification of impaired visual function enables early visual stimulation to be initiated, and also identifies those infants who will require subsequent examination with neurophysiological and neuroimaging techniques. In addition, the simplicity and low cost of the ML Leonhardt Battery allows it to be applied in underdeveloped regions such as Anantapur (India; Rural Development Trust), Cuzco (Peru; Colegio de Ciegos Nuestra Señora del Carmen), and Oruro (Bolivia; Oruro University), as a screening measure of visual function.

Visual analysis at this early age may be a good predictor not only of neurodevelopmental outcome [22] but of cognitive development as well [23].

Conflict of interest statement

None declared.

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