ASSESSMENT OF GRATING VISUAL ACUITY IN INFANTS AND YOUNG CHILDREN WITH SIGNIFICANT PERINATAL RISK-FACTORS

MHAIRE ELIZABETH BYARS

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Assessment of Grating Visual Acuity in Infants and Young Children with Significant Perinatal Risk-Factors

BY

© Mhaire Elizabeth Byars, B.A.(Honours)

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Abstract

The purpose of the present study was to investigate the relationship between visual acuity and perinatal risk-factors. The Teller Acuity Card Procedure was used to obtain visual acuity estimates for 166 infants and young children (83 females, 83 males) between 3 and 36 months of age. All subjects were enrolled in the Newfoundland and Labrador Provincial Perinatal Clinic because of significant perinatal complications. The data were compared to those of a normative sample which were collected in the same laboratory (Courage & Adams, 1990). Results indicated a different pattern of visual acuity development for the two samples, with the "at-risk" sample below the normative sample between approximately 6 and 24 months of age. Multivariate analysis indicated that (1) very-low-birthweight (VLBW) and respiratory distress syndrome (RDS) had relatively less detrimental impact on the visual acuity of the at-risk sample than the 14 other risk-factors that were investigated and, (2) that bronchopulmonary dysplasia (BPD) and pneumothorax had relatively greater detrimental impact on visual acuity. Results are discussed in terms of implications for early intervention and future research.

Acknowledgements

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Finally, I would like to thank all those people who offered me encouragement when I needed it the most: Chris, my friends, my family and Dr. Olga Heath. I would especially like to thank Chris, not only for his invaluable practical assistance, but for his unwavering and unconditional support.

Dedication

I would like to dedicate this work to my grandmother, Mary Begg. Her wisdom, her strength, her energy and her love have always been so freely given and so greatly appreciated.

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Assessment of Grating Visual Acuity in Infants and Young Children with Significant Perinatal Risk-Factors

It is now well established that, relative to full-term infants, very-low-birth-weight (VLBW) babies have a higher incidence of perinatal mortality and morbidity (Usher, 1987). The World Health Organization defines VLBW as a birthweight of less than 1500 grams. Although they represent less than one percent of all live births, VLBW infants account for 85 percent of neonatal deaths resulting from causes other than lethal malformations (Usher, 1987). For those infants who do survive, the risk of perinatal and long-term complications increases both with the degree of prematurity and with decreased birthweight (Usher, 1987). Long-term complications can be manifested as either medical and/or neurological dysfunction and can be the result of birth immaturities and/or of the medical interventions required to sustain life.

As a group, VLBW infants may suffer immaturities in every metabolic system. These underdeveloped systems often require that the infant receive life-saving medical intervention. For example, it is very common that VLBW infants suffer respiratory distress syndrome (RDS). This and other related respiratory problems, such as birth asphyxia and apnea, often dictate the need for immediate mechanical ventilatory therapy. Although necessary for survival, mechanical ventilation can produce a variety of

other complications, such as pneumothorax, bronchopulmonary dysplasia (BPD), pulmonary infection, and a higher than average incidence of abnormal central nervous system (CNS) sequelae (Usher, 1987). Other common, but significant, medical difficulties in VLBW babies include hypo- and hyperglycemia, hydrocephalus, jaundice, high bilirubin levels and deficient body-fat levels (Mohn & van Hof-van Duin, 1986a; Usher, 1987).

In addition to medical problems, VLBW infants also face an increased risk of neurological difficulties, many of which are secondary to the above medical complications. For example, periventricular and intraventricular hemorrhages (bleeding in the brain) often occur subsequent to complications such as birth asphyxia, RDS and pneumothorax (Usher, 1987). These intracranial hemorrhages are found in nearly one half of all VLBW infants in neonatal intensive care facilities and, in severe cases (Grades III and IV), appear to be a major determinant of neurologic morbidity (Volpe and Hill, 1987). Another common, but more serious form of intracranial insult is periventricular leukomalacia (PVL), the occurrence of lesions in the periventricular white matter. PVL often results in spastic diplegia, a debilitative and permanent motor deficit (Volpe & Hill, 1987). In addition to brain hemorrhages and lesions, VLBW infants are also at risk for neonatal seizures which,

likewise, often occur secondarily to other significant medical complications (Volpe & Hill, 1987). Apnea spells are another common neurological sign in this population and can result in hypotonia and brain injury (Volpe & Hill, 1987).

Yet another sign of neurological impairment in VLBW infants is the presence of sensory deficits. As a group, VLBW infants have a high incidence of auditory and visual disorders. Common auditory disorders include selected frequency losses and sound conduction deficits. Common visual disorders include congenital strabismus, poor visual acuity, amblyopia, cataracts, retinopathy of prematurity (ROP), and severe myopia (Dobson, Mayer & Lee, 1980; Fitzhardinge, 1987; Friendly, 1987). These disorders may stem from either ophthalmologic and/or cortical abnormalities which typically result from the same insults that cause other complications such as ICH, PVL, BPD and pneumothorax. That is, oxygen insufficiency (e.g., apnea, hypoxia, asphyxia), fluctuating or increased systemic cerebral blood flow (e.g., hypertension, exchange transfusion, seizure activity, nonsynchronous respiratory efforts of an infant on a ventilator) increased cerebral venous pressure (from vaginal delivery, RDS, hypoxia), an immature vascular system, and hypoxic ischemic injury can all lead to neurological complications, including deficits

in visual-perceptual and visual-motor coordination (Bernbaum, et al., 1991, chap. 7). Furthermore, the high incidence of ophthalmological disorders in infants born prior to 34 weeks of age and/or weighing less than 2000 g often stems from the effects of oxygen toxicity on the immature retina (Karones, 1988; Crosse, 1975, chap. 14; Bernbaum et al., 1991, chap. 4; Harper & Yoon, 1987, Chap. 13). At birth, the retina is exposed to relative hyperoxygenation which is greatly compounded if the infant receives mechanical ventilatory assistance. ROP occurs when hyperoxygenation results in vasoconstriction and subsequent obliteration of the immature retinal blood vessels. Once arterial oxygen returns to normal, vascular growth resumes but the retinal blood vessels become dilated and tortuous, promoting hemmorhages which can leak into the vitreous. If the disease does not resolve at this point, membranes start to form between the retina and the vitreous, leading to partial or complete retinal detachment (Karones, 1988; Crosse, 1975, chap. 14; Bernbaum et al., 1991, chap. 4). Even fully resolved ROP can leave subtle changes in the retina that result in refractive errors, strabismus or amblyopia. Moderate or severe scarring can lead to problems such as nystagmus, glaucoma, cataracts and blindness (Bernbaum, 1991, chap. 4).

In particular, the visual functioning of VLBW infants

has been a topic of research in recent years (e.g., Dobson et al., 1980; Morante, Dubowitz, Levene & Dubowitz, 1982; Mohn & van Hof-van Duin, 1986(a);1986(b); Brown & Yamamoto, 1986; Sebris, Dobson, McDonald, & Teller, 1987; Mohn, van Hof-van Duin, Fetter, de Groot, & Hage, 1988; van Hof-van Duin & Mohn, 1985; van Hof-van Duin & Mohn, 1986; van Hof-van Duin, Evenhuis-van Leunen, Mohn, Baerts & Fetter, 1989). Such research is important for several theoretical and practical reasons. Theoretically, there exists an ongoing question as to whether otherwise healthy, very premature infants are accelerated or retarded in their development as compared to fullterm infants. Intuitively, it might be expected that very premature infants are at a long-term disadvantage because, at birth, their bodily systems are less mature, and are more vulnerable to injury. Conversely, it could be argued that healthy, very premature infants have an advantage because they receive more extra-uterine experience than do their fullterm peers of the same gestational age. In fact, there has been some evidence to suggest that, whereas healthy, premature infants, who are free of complications, have poorer visual acuity than fullterm infants of the same postnatal age, they have acuities similar to, and perhaps greater than those fullterm infants of the same conceptional age, (e.g., Fantz, Fagan & Miranda, 1975: as cited by Dobson, et al., 1980; Dobson et

al., 1980; Mohn & van Hof-van Duin, 1986(a)). Nonetheless, this issue is not fully resolved, particularly for at-risk infants, and consequently merits more attention.

There are also practical reasons for studying the visual development of very premature and VLBW infants. First, researchers have established that these infants are at risk for visual disorders, especially if additional complications are experienced (e.g., birth asphyxia, intracranial hemorrhage, mechanical ventilation) (van Hof-van Duin & Mohn, 1985; Usher, 1987). However, studies of human infants and animal models (Teller, 1983) have demonstrated that, if defects are detected and treatment is initiated at a very young age, visual outcome can improve substantially (Lewis, Maurer & Brent, 1986; van Hof-van Duin, et al., 1989; Fitzhardinge, 1987). Therefore, early vision screening of very premature and VLBW babies may help reduce the prevalence and/or magnitude of later visual dysfunction. Second, vision disorders are considered to be early "markers" of other neurological dysfunction that may not already by evident (Volpe & Hill, 1987). Accordingly, early detection of vision problems in very premature and VLBW infants could aid in the early diagnosis of many widespread neurological problems. Thirdly, it is presently unknown which perinatal risk factors (e.g., VLBW, BPD, RDS, duration of mechanical ventilation) are the best predictors

of visual disorders and of longterm neurological dysfunction. Therefore, isolating these critical risk factors is important for early detection and intervention. Finally, very premature and VLBW infants are believed to be at an increased risk for future academic and behavioural problems (e.g., learning disabilities), perhaps resulting from the above mentioned visual, and neurological difficulties and other developmental problems (van Hof-van Duin et al., 1989; Drillien, 1972; Fitzhardinge, et al., 1976; Fitzhardinge, 1987). Whether visual problems lead directly to academic and behavioural problems, or have an indirect influence, the early detection of these difficulties could be an important first step in intervention. A reliable procedure for assessing the level of an infant's visual functioning is therefore required.

An estimate of visual acuity is the single most effective index of visual functioning (Courage & Adams, 1990). Visual acuity is a measure of a subject's maximal visual resolution (i.e., the finest pattern the eye is capable of resolving). Traditionally, an adult's visual acuity is measured with Snellen letter charts which characteristically have a large "E" at the top and lines of progressively smaller letters below. This test is based on visual recognition: that is, the smallest letter that the subject can recognize (i.e., report to the tester) is taken

as an index of his/her visual acuity. Simpler tests, also based on the idea of recognition acuity, are available for testing children over the age of three. These tests include the illiterate E test, Landolt C Test, Sjogren Hand Test, and the Allen Picture Cards. However, children under the age of three are more difficult or impossible to test with recognition acuity tests because they are preliterate, inattentive, sleepy, unable to understand instructions, and/or are unable to consistently generate the required verbal and motor responses. Reliable tests of visual acuity for small children and infants are necessary for early detection of vision disorders in this population.

In response to the need for new methods of assessing infants' visual acuity, investigators have developed a variety of innovative electrophysiological and behavioural measures that do not rely on recognition acuity (e.g., Dobson & Teller, 1978; Mayer & Dobson, 1982). Instead of reading a series of progressively smaller letters from a chart, subjects in a resolution acuity test are shown a series of vertical line gratings of decreasing spatial frequencies, until the he/she is no longer able to discern the gratings. The thicker gratings correspond to the larger letters used in recognition tests and the thinner gratings correspond to the smaller letters.

One behavioural technique, the forced-choice

preferential looking technique (FPL), has received the most attention, likely because it has been purported to be the most accurate and the most consistent of the methods to date (Teller, 1979; Adams and Courage, 1990). FPL is a test of grating acuity, and is based on an infant's tendency to prefer patterned over unpatterned stimulation. For example, using Teller's version of FPL (Teller, 1979) an observer shows an infant sets of stimulus pairs. The stimulus on one side of the display is a grating composed of black-and-white stripes of a given width (spatial frequency) and the stimulus on the other side is an unpatterned grey square, or the "blank", which matches the space-average luminance of the stripes. Spatial frequency is defined as the number of cycles per 1 degree (cpd) of visual angle: the higher the number of cpd, the thinner the stripes. It is assumed that if the infant is able to discern the stripes he/she will look at them longer or orient to them faster (i.e., show a preference for them) than he/she will to the blank. For each trial, the observer makes a forced-choice judgement about whether the infant did or did not see the stripes. The smallest set of stripes for which the infant shows a consistent preference (i.e., the observer is correct on at least 75 % of the trials) is taken as an estimate of the baby's visual acuity. Researchers using FPL techniques to assess the development of visual acuity have reported

remarkably consistent results, even despite substantial variation in apparatus and method. The results of these studies indicate that, in normal, fullterm infants, acuity increases substantially during the first year of life, from approximately 1 cpd (Snellen equivalent = 20/600) at birth to about 3 cpd (20/200) at 3 months, 6 cpd (20/150) at 6 months, 12 cpd (20/50) at 12 months, and reaches adult levels of 30 cpd (20/20) at about 3 to 5 years (Mohn & van Hof-van Duin, 1986(a); van Hof-van Duin & Mohn, 1986; Birch, Gwiazda, Bauer, Naegele, & Held, 1983).

Although the FPL procedure has provided valuable information about the development of visual acuity in fullterm infants, a number of problems still exist with this method. The required equipment is complex, expensive and not easily portable. Moreover, because of the statistical variability of two-alternative forced-choice threshold estimates, a large number of trials is necessary to produce statistically reliable estimates of visual acuity (McDonald, Sebris, Mohn, Teller & Dobson, 1986). Typically, 45-60 minutes are required to test one subject, and consequently the number of infants that can be tested in a session is restricted. Additionally, because of the lengthy procedure, valuable information is often lost when the child falls asleep or becomes too inattentive to continue.

Because of these limitations, researchers recognized

the need for a simpler and faster method of obtaining highly reliable and valid estimates of infants' visual acuity. As a first step in assessing infants' visual functioning more efficiently, Dobson and her colleagues (Dobson, Mayer & Lee, 1980) developed the "diagnostic grating procedure". This procedure is a clinically oriented variation of the FPL procedure, in which only a single grating, rather than a number of gratings, is used to test the subject's visual acuity. Each child is shown the grating, which 95 percent of same-aged children showed evidence of "detecting". Although the diagnostic grating procedure is more convenient to use than the full FPL procedure, it still has shortcomings. Most notably, it is simply a gross measure of acuity that is more categorical than quantitative. That is, the procedure can assign an infant's visual acuity to the categories of "normal" or "below normal" but it does not allow for a precise estimate of actual visual acuity nor of any quantitative change with age.

Given these concerns, Dobson, Teller and their colleagues developed a technique called the "Teller Acuity Card" (TAC) procedure (Teller, McDonald, Preston, Sebris & Dobson, 1986: Dobson, McDonald & Teller, 1985; McDonald, Dobson, Sebris, Baitch, Varner & Teller, 1985; McDonald, Ankrum, et al., 1986), which is an entire modification of the stimulus, apparatus and method of previous procedures.

The TAC test consists of a set of rectangular grey cards, each of which contains a black-and-white grating of a particular spatial frequency (SF) on one side of a small, centrally located peephole. An adult observer who is blind to the location and SF of the stripes, presents each card to the infant, beginning with a card containing a grating of low SF. The observer views the subject's behaviour through the peephole. Over a series of typically rapid trials for each card, the observer uses a variety of cues, such as length of fixations, eye movements, head movements and/or pointing, in order to judge whether the subject shows a preference for one side of the card (presumably the side containing the grating). Like the traditional FPL method, the finest grating the child is judged to be able to "see" is taken as an estimate of his/her visual acuity. However, the TAC procedure is much faster than traditional FPL because the decision about whether the infant can detect each grating can be made much more rapidly. As well, the tester can use his/her judgement to skip cards if the grating on the card just tested seemed too "easy". As a result, it is possible to arrive at the acuity threshold more quickly. In fact, researchers report average test times of less than 4 minutes with full-octave cards (i.e., the stripe width, in cpd, doubles with each successive card)(e.g., McDonald et al., 1985), and less than ten

minutes using half-octave cards (Courage and Adams, 1990). These test times compare favorably to traditional FPL methods, which can take as long as an hour for each subject to complete (e.g., Birch et al., 1983). Shorter test times not only mean greater efficiency but also less attrition due to subject boredom, sleepiness and fussiness.

Several laboratories have used the Teller Acuity Card procedure to measure infants' and toddlers' visual acuity both in experimental and in clinical settings. In the first set of investigations, McDonald and her colleagues (McDonald, et al., 1985; McDonald, Ankrum, et al., 1986; McDonald, Sebris, et al., 1986) tested 68 normal, fullterm 1- to 12-month-olds, and 36 normal, 18- to 36-month-olds. The acuity estimates were roughly normally distributed at each age and, as expected, the means of the distributions shifted toward higher spatial frequencies with age. Increases were substantial in the first six months (M = 0.95 cpd for 4-month-olds versus 5.0 cpd for 6-month olds) but there was only a minimal increase in acuity at 12 months of age (M = 6.3 cpd). Acuity then increased dramatically at 12 24 months (M = 14.9 cpd) and 36 months (M = 27.7 cpd). At all ages, 93 to 100 percent of the subjects had binocular acuity estimates within one octave of the mean. As well, the authors found that their means and standard deviations agreed well with previously established FPL norms (e.g.,

Mayer & Dobson, 1982; Gwiazda, Brill, Mohindra & Held, 1980; van Hof-van Duin & Mohn, 1986a). Perhaps of greatest interest, the test times, averaged 3.53 minutes across all of the groups, a considerable improvement over FPL methods. Subsequently, in the most comprehensive normative study to date, Courage and Adams (1990) used the Vistech Consultants Inc. (Dayton OH) version of the TAC to test 140 healthy infants and children aged 1 week to 3 years and found that their estimates of visual acuity were consistent with previously published norms obtained with the earlier version of the TAC.

Tests of the TAC procedure in clinical settings (Dobson, McDonald, Kohl, Stern, Samek & Preston, 1986; Mohn & van Hof-van Duin, 1986(b); Sebris, et al., 1987; Preston, McDonald, Sebris, Dobson & Teller, 1987; Mohn, van Hof-van Duin, Fetter de Groot & Hage, 1988), with low- and high-risk children up to 18 months of age, have produced comparable success rates (90 to 100 %) and test times (under 15 minutes, even for multiple tests) as those reported in the above mentioned laboratory studies.

In summary, the acuity card procedure has proven to be an effective and efficient method for estimating visual acuity in normal and some at-risk populations of infants and children. In fact, it is fast becoming the standard tool for assessing visual acuity in preverbal and non-verbal

populations. However, we still know very little about the visual development of VLBW children past 18 months of age or about what other groups of infants might be at risk for visual impairment. Therefore, the present study seeks to expand on previous research in three ways: (1) by testing visual acuity in a larger, more diverse group of at-risk infants and children; (2) by testing at-risk children beyond 18 months of age, and (3) by investigating which risk factors (e.g., RDS, BPD, seizures, pneumothorax, apnea, hypoglycemia, intracranial hemorrhage) might be predictive of poor visual acuity. Specifically, visual acuity will be tested in a large sample of VLBW and at-risk infants and children ranging from 3 months to 3 years (corrected age) and the results will be compared with a sample of like-aged normal infants and children tested in the same laboratory.

Method

Subjects

The subjects for this study were 171 infants and toddlers (86 males and 85 females) registered with the Newfoundland Perinatal Program. This program is run by the Charles Janeway Children's Hospital in St. John's to provide regular, postnatal, developmental assessments of high-risk infants born in Newfoundland and Labrador. The children are seen by a pediatrician at the clinic, typically when they

are 3, 6, 12, 24, and 36 months of age (corrected for prematurity). All of the subjects in this study attended the Perinatal Clinic from November, 1989 until August, 1990. With the exception of a few children whose parents were eager to leave immediately after the developmental check-up with one of the Clinic's pediatricians, testing was attempted with all children who attended the Clinic during this time period. Criteria for inclusion in the Perinatal Program are one of following; infants with: (1) birthweight less than or equal to 1500 grams; (2) neurological signs persisting beyond six hours after birth; (3) neonatal seizures; (4) meningitis occurring in the first 28 days of life; (5) an Apgar Score of five or less at five minutes; (6) head circumference two standard deviations below the mean at birth and remaining so at time of discharge from hospital; (7) significant hypoglycemia; and (8) significant metabolic acidosis at birth. An attempt was made to test all children who attended the Perinatal

Acuity estimates could not be obtained for five subjects (3 males and 2 females): one because of a procedural error, two because they were tested at an improper viewing distance, and two because they were inattentive. Of the two subjects who were too inattentive to be tested, one was very young (6 weeks old) and the other (4.5 months old) was quite severely delayed. In both cases

it might have been possible to obtain an acuity estimate given more time, but the parents were reluctant to continue. Of the 166 successful tests, 5 subjects (3 females and 2 males) were not included in the final analysis because it was later discovered that none of the required risk-factors were mentioned in the medical records.

Apparatus

To assess visual acuity, we used the Teller Acuity Cards (Vistech Inc, Dayton, Ohio, U.S A.). A complete set of cards consists of 17 25.5 x 51 cm cards. Fifteen of these cards contain a 12.5 x 12.5 cm patch composed of a black-and-white square-wave grating, that is located 10 cm either to the left or to the right of a 5 mm central peephole. When viewed from 55 cm, the gratings range in spatial frequency from 0.32 to 38.0 cpd in approximately half-octave steps. A cycle consists of one black and one white stripe, and an octave is defined as a halving or doubling of the spatial frequency in cpd. The 16th card, the "anchor" or "low vision card" contains a larger, 25.5 cm x 23 cm, grating with very large stripes [0.23 cpd (i.e., 2.2 cm/stripe from a viewing distance of 55 cm)]. The 17th card is a blank gray control card containing no grating.

Each grating is matched to the surrounding gray

background to within 1% in space-average luminance. This is to help ensure that any fixation preference shown by the infant is based on detection of the pattern, not on detection of a brightness difference between the grating and the background. In order to eliminate as many distractions as possible, and to hide the edges of the card and the tester's fingers, the cards were presented from behind a screen which matched the colour and luminance of the card's background. The 142 x 120 cm screen has a central panel flaked by two hinged side panels (35 x 120 cm) that open out at a 45 degree angle. The cards are presented behind a 53 x 23 cm opening located 30 cm from the top of the screen (see Figure 1). Testing took place in a quiet room illuminated according to the conditions specified in the testing manual which accompanies the Teller Acuity Cards (Vistech Inc., Dayton, Ohio, U.S. A.). All children were tested at a distance of 55 cm.

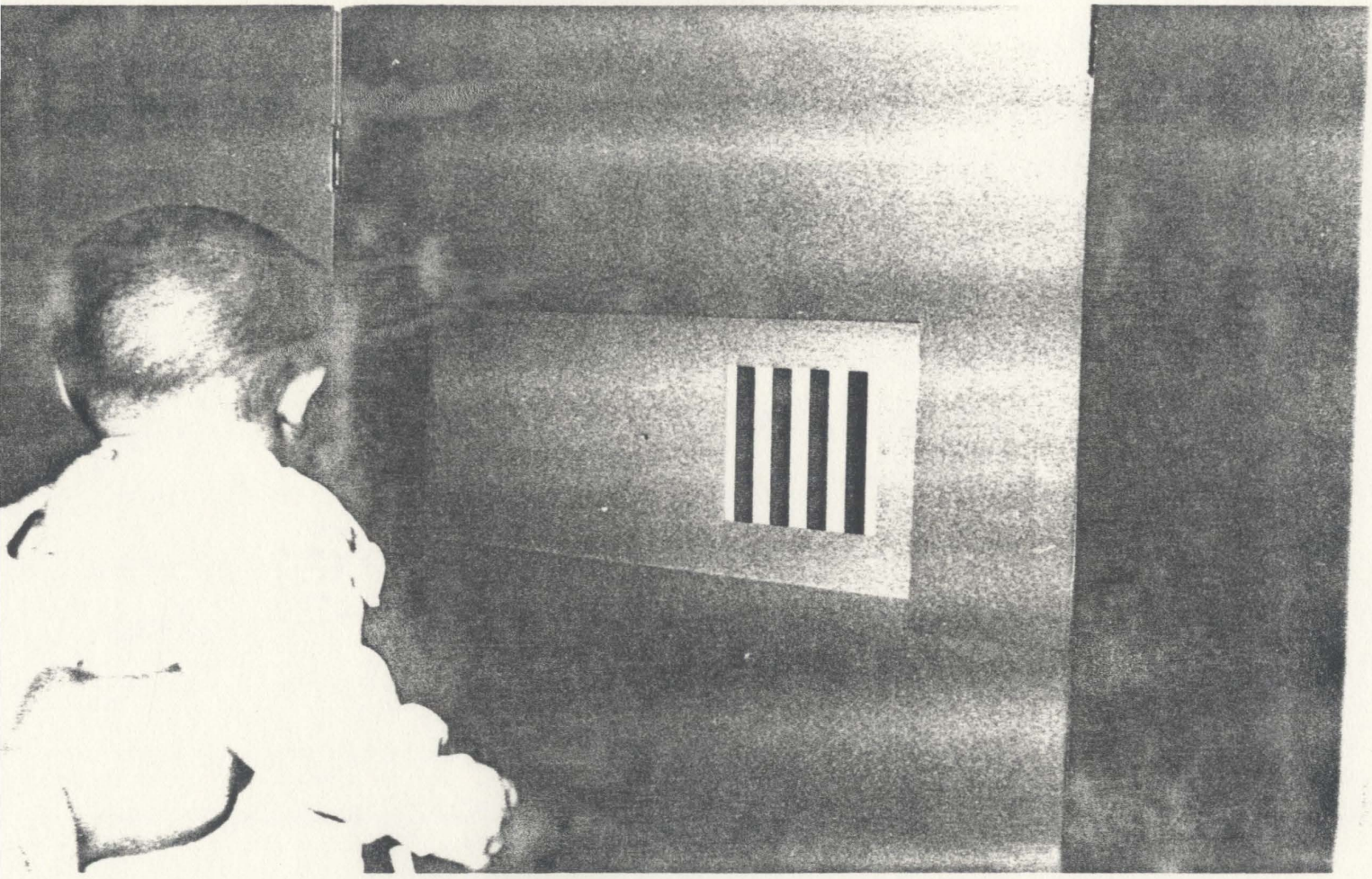
Insert Figure 1 about here

Procedure

Parents of the infants and toddlers who were at the clinic for scheduled developmental assessments were approached by either the experimenter or by one of the pediatricians at the clinic and asked if they would give permission for their child to participate in the study. The

Figure 1

Visual Acuity Assessment in a 6-month-old Infant using the TAC.



nature and purpose of the testing was explained by the experimenter. Once consent was obtained, the subject was seated on the parent's lap, or alone, so that his/her eyes were 55 cm away from the screen. The experimenter was positioned behind the screen and acted both as observer and as recorder. The acuity cards, a record form, and an assortment of toys to attract the child's attention, were behind the screen with the experimenter. The pile of acuity cards was always placed face down in order to keep the experimenter blind to the location and spatial frequency of the cards.

First, during the "orientation phase", the experimenter attracted the attention of the child so that he/she was looking straight ahead, and then quickly placed the "anchor card" within the rectangular opening in the screen. The grating on this card is easy to see, and was shown to determine how the subject responded when he/she was able to see a grating. For this card only, the experimenter knew in advance on which side of the peephole the grating was located, and paid careful attention to the child's "looking behaviour" when the card was presented. Once the child oriented to the grating, the card was rotated 180 degrees so that the grating was then on the other side of the peephole. The experimenter observed how the subject reacted to the change in stimulus location (e.g., if the child turned

his/her whole head, clearly shifted the eyes, or subtly moved his/her glance toward the stimulus) and whether he/she looked at it for a number of seconds or just briefly. The card was rotated a few more times until the observer felt confident that the subject responded in a reliable manner. Next, the experimenter presented the blank control card. The purpose of this card was to determine how the child reacted when he/she could not see a grating. The card was rotated and, once again, the child's "looking behaviour" was noted (e.g., staring straight ahead, looking at the ceiling, fussing).

During the subsequent "test" phase, both the spatial frequency and the location of the grating of the remaining cards was unknown to the experimenter. Prior to the testing session, the parent or a member of the Clinic's staff took an arbitrary number of cards off the top of the pile and placed them on the bottom so that the experimenter did not know where in the pile she was starting. However, she did know that each new card would have a higher spatial frequency than the last one. Typically the experimenter used several presentations of the stimulus to guess the location of each grating. The cards were always presented at least three times, with the stripes on at least one side presented at least twice. Once a firm decision had been made as to the location of the grating, the experimenter

then verified the accuracy of her guess by very quickly flipping the card over and back again, to check the actual location of the grating, while trying not to attend to the width of the stripes.[1] If it appeared that the infant could easily resolve the last grating, the experimenter would skip some cards to save time and to keep the child from becoming bored or tired.

In the event that the experimenter decided incorrectly that the child could see the stripes (i.e., she judged the wrong location), she then repeated testing with the two previously shown cards before repeating the one she had made the mistake with. If a "mistake" occurred again, the test would be abandoned and the subject's data would be excluded. In actual fact, this never happened.

Testing continued until the subject showed no consistent preference for either side of the card. At this time, the anchor card was presented again to determine if the child truly could not see the grating or was just bored. If the subject did not attend to the grating in the anchor card, or show a preference, it was decided that he/she was bored and attempts were made to recapture the child's attention. Sometimes testing had to be discontinued because

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[1] Being entirely blind to the grating size is optimum, but not mandatory for unbiased testing (Teller Acuity Manual, 1988; Teller et al., 1986).

the child was clearly not paying attention, despite any efforts on the part of the experimenter and/or the parent. If the subject attended to the anchor card, either initially or after some entertaining by the tester, the last card for which there was no preference was presented once more. Then, if the child still did not indicate a preference for one side of this card, it was determined that he/she could not see the grating and testing was concluded. If, however, the subject did show a preference, testing continued with additional cards, of higher spatial frequency, until it was finally decided that the child could not see a particular grating. An estimate of the subject's visual acuity was the grating with the highest spatial frequency for which the child showed a clear preference.

Results

The TAC procedure was completed successfully by 166 of the 171 (97%) participants in this study. Of the 166 successful tests, 5 subjects were not included in the analysis because it was later found that none of the required risk-factors were documented in their medical records. Twenty-two subjects were tested at two different ages, and four more were tested three times, for a total of 196 successful tests out of 201 attempts (98%). For those

subjects tested two or three times, only the data from the first test was shown in the figures and used in the statistical analyses. A total of 161 subjects (81 males and 80) females were thus included in the analysis.

Comparison with normative studies

In order to determine if the visual acuity of at-risk infants and children in the present study differed from healthy, fullterm children, the present data were compared to that reported by Courage and Adams (1990). The data from Courage and Adams (1990) were chosen for comparison for two reasons: (1) because they were collected in the same laboratory with the same apparatus and procedures; and (2) because the Courage and Adams (1990) "norms" are the most comprehensive obtained to date. Figure 2 shows a scatterplot of the individual 161 acuity estimates, in cpd, as a function of age (corrected for prematurity), superimposed over the distribution of the mean acuity estimates (bold line) and standard deviations (thin lines) of the normative data (Courage & Adams, 1990). Seventy-three percent of the acuity estimates from the present sample lie within +/- 2 standard deviations of the mean of the normative sample. Nineteen percent of the estimates (31/161) lie more than 2 standard deviations below the mean of the normative sample and 8 % (13/161) lie more than 2

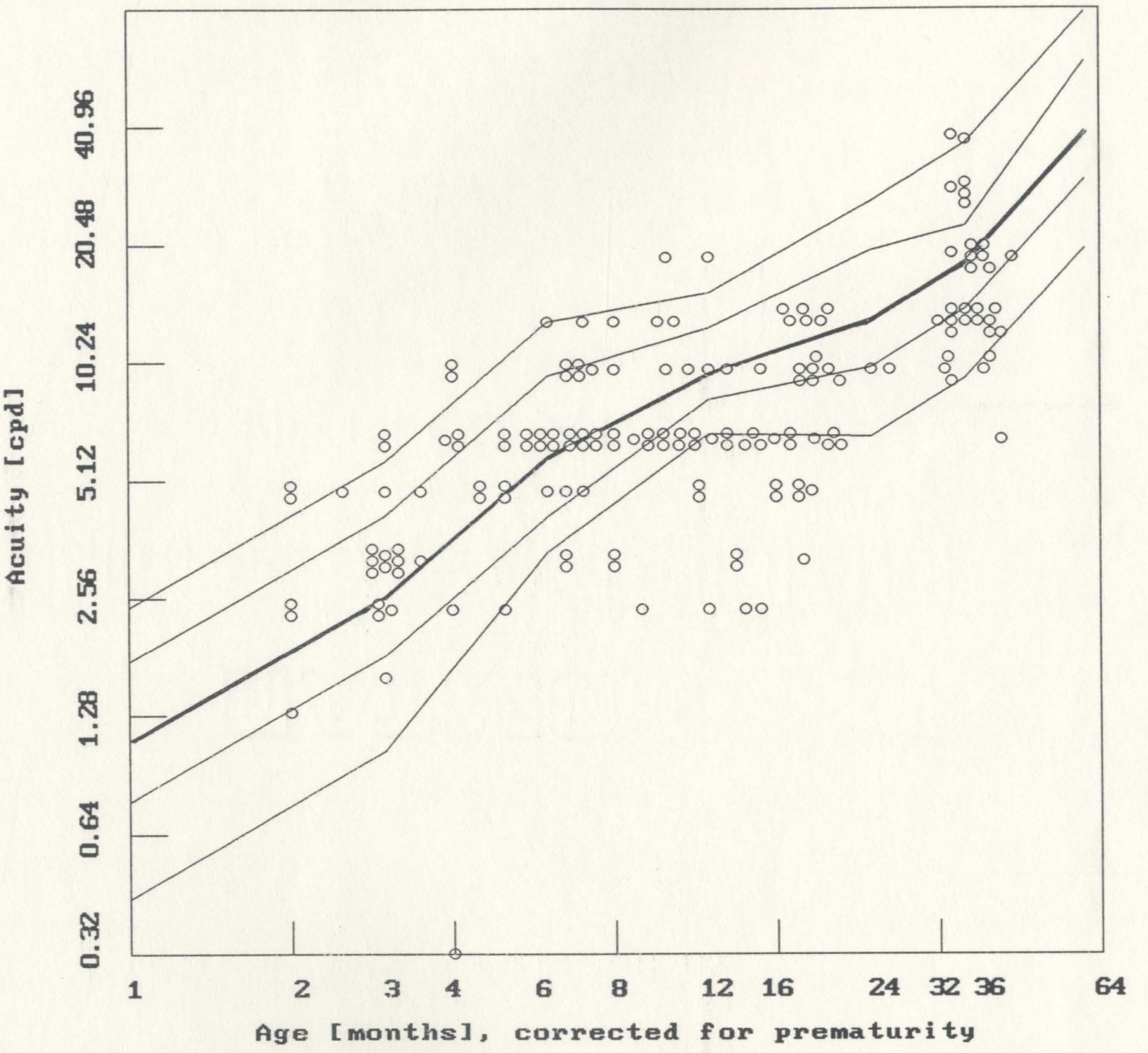
standard deviations above the mean. Inspection of Figure 2 shows that most of the "highliers" (> 2 S.D. above the norm) appear to be found at both ends of the range of ages tested, whereas the "lowliers" (< 2 S.D. below the norm) are more prevalent in the middle of the age range.

Insert Figure 2 about here

For ease of comparison with the normative group, the present sample was subdivided into 5 age groups: "3 months" (includes ages 2 to 4 months); "6 months" (ages 4.5 to 9 months); "12 months" (ages 10 to 18 months); "24 months" (ages 18.5 to 26 months) and "36 months" (ages 32 to 42 months). The range of ages in each of these 5 categories is not identical to that of the normative group, but in most cases is close, thus allowing approximate comparisons to be made. Table 1 shows the percentage of successful tests, mean acuities (in cpd), standard deviations (in octaves), and mean Snellen equivalents, for each age group in the at-risk sample compared to those of Courage and Adams (1990). The standard deviations for the at-risk group were similar to those of the normative sample except at approximately 12 months. In accordance with the findings of Courage and Adams (1990), mean visual acuity of the at-risk sample was relatively poor around 3 months of age (3.4 cpd) and increased progressively to near-adult levels (15.8 cpd) by

Figure 2

Comparison of Visual Acuity Estimates of At-Risk Infants with Normative Developmental Data



o acuity estimates, at-risk sample

= mean acuity, Courage and Adams (1990)

- 1 and 2 standard deviations, Courage and Adams (1990)

about 3 years. The percentages of successfully completed tests was high at all ages (93 to 100%) and comparable to those of Courage and Adams (1990).

Insert Table 1 about here

Figure 3 shows the mean acuities and standard deviations of the different age groups within the at-risk sample compared to the means and standard deviations of the normative sample. The mean acuity of the groups within the at-risk sample is represented by "x", and the "o"'s indicate 1 standard deviation above or below the mean. For both the normative sample and the at-risk sample, mean visual acuity increases with age, but the rate of development differs. The mean of the at-risk sample lies above that of the healthy fullterm sample at three months, is very similar to it at 6 months, and dips below it at 12, 24, and 36 months. Developmentally, from 3 to 6 months, mean visual acuity increases by approximately 1 1/4 octaves in the normative group but by less than 1 octave (5/6 of an octave) in the at-risk group. Between 6 and 12 months, and between 12 and 24 months visual acuity continues to increase by approximately 1/2 an octave or more in the normative group, but essentially plateaus between 6 and 24 months in the at-risk group. Finally, the normative group shows a further increase of slightly less than 1/2 an octave between 24 and

Table 1

Descriptive Statistics

Mean Age (and Range) in months	Sample Size	Completed (%)	Mean Acuity (cpd)	SD (octaves)	Snellen Equivalent (20/x)
3.1* (2.0-4.0)	32	94	3.4	1.0	177
3.0** (2.7-3.3)	20	100	2.6	0.6	231
6.8* (4.5-9.0)	41	93	6.1	0.6	98
6.1** (5.5-6.5)	20	100	5.9	0.6	101
13.9* (9.5-18.0)	42	100	6.9	0.8	87
12.0**(11.0-13.0)	20	91	9.6	0.3	64
20.3* (18.5-26.0)	14	100	8.6	0.4	70
24.6**(23.5-25.5)	20	95	13.2	0.5	46
37.1* (32.0-42.0)	32	100	15.8	0.6	38
36.7**(35.0-37.0)	20	100	18.6	0.5	32

* This study, age corrected for prematurity
** Courage & Adams, 1990

36 months, whereas the at-risk group shows a dramatic increase of almost 1 octave.

Insert Figure 3 about here

In order for statistical comparisons to be made with the normative data (Courage & Adams, 1990), each subject's acuity estimate was first transformed to a z-score, based on the estimate of the age-appropriate mean and standard deviation from the normative data. Two-tailed t-tests were then conducted on the z-scores for each age-group. Table 2 displays the sample size, mean visual acuity, and standard deviations (in z-scores), as well as the observed value of "t" and the probability level of the statistic, for each age group of the at-risk sample. Results show that the at-risk sample had significantly higher mean acuities than the normative sample at 3 months ($\underline{t}(50) = 2.965$, $p < .01$), lower mean acuities at 12 months ($\underline{t}(60) = -4.926$, $p < .01$) and at 24 months ($\underline{t}(32) = -5.125$, $p < .01$); and did not differ from it at 6 months ($\underline{t}(59) = .577$, $p > .05$) or at 36 months ($\underline{t}(50) = -1.229$, $p > .05$).

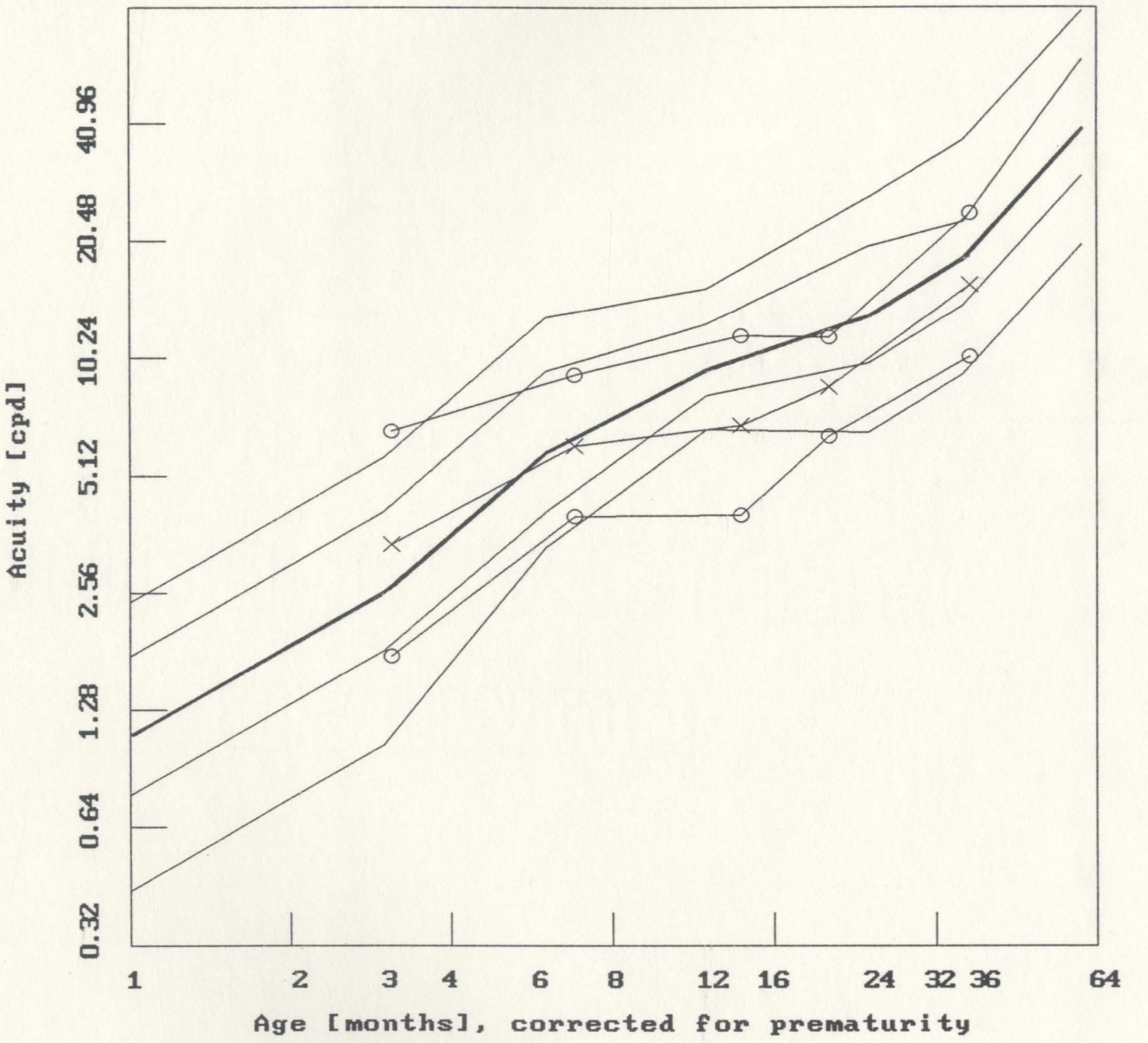
Insert Table 2 about here

Evaluation of risk factors

One of the primary aims of the present study was to determine if an infant's later visual acuity could be

Figure 3

Comparison of Developmental Rate for Normative and At-Risk Sample



(x) group mean, at-risk sample

(o) standard deviation, at-risk sample

\- mean acuity, Courage and Adams (1990)

\- 1 and 2 standard deviations, Courage and Adams (1990)

Table 2

Results of t-Tests Comparing Standard Scores of At-risk Sample to Norms (Courage & Adams, 1990) for 5 Age Groups

Age Group in months*	Sample size	Mean Acuity (z-score)	SD (z-score)	Observed Value of t	Probability Level (two-tailed)
"3"	32	.675	1.29	2.965	$p < .01$
"6"	41	-.102	1.13	-.577	n.s.
"12"	42	-1.480	1.95	-4.926	$p < .001$
"24"	14	-1.214	.89	-5.125	$p < .001$
"36"	32	-.401	1.85	-1.229	n.s.

* corrected for prematurity

predicted by any of the risk-factors (e.g., very-low-birthweight [VLBW], respiratory distress syndrome [RDS], and bronchopulmonary dysplasia [BPD]) that he/she presented with during the neonatal period. Ideally, it would be best to analyze only those children who presented with only a single risk-factor so that the effects of each risk-factor could be examined in isolation, and compared to the normative group. However, many of the risk-factors involved are interrelated, making it impossible to study some of them (e.g., BPD, metabolic acidosis) in isolation and, for others, dictating the need for testing very large numbers of children (likely thousands) to have enough subjects with that risk-factor alone. This ideal situation was not possible in the present study. Consequently, the best approach is to examine the relative impact of the risk-factors on visual acuity within the at-risk sample.

Because of the multidimensional nature of the present data set, a stepwise multiple regression analysis was conducted in order to tease out which individual risk-factors were most closely associated with poor acuity among the at-risk group. These risk-factors include 7 of the 8 criteria for inclusion into the Newfoundland Perinatal Program: (1) birth weight less than or equal to 1500 grams; (2) neurological signs persisting beyond 6 hours of age; (3) neonatal seizures; (4) an Apgar score of 5 or less at 5

minutes; (5) head circumference 2 standard deviations below the mean at birth and remaining so at time of discharge; (6) significant hypoglycemia; and (7) significant metabolic acidosis. None of the subjects in the sample had neonatal meningitis, the 8th risk-factor. An additional 9 perinatal complications commonly thought to be associated with poor developmental outcome (ventilation longer than 2 days, respiratory distress syndrome, bronchopulmonary dysplasia, patent ductus arteriosus, apnea, birth asphyxia, pneumothorax, necrotizing enterocolitis, and hypercalcaemia) were also included in the analysis.

In order for the analysis to be age-independent, the acuity value for each subject in the at-risk sample was converted to a z-score. This z-score represented the dependent variable. For each child, the presence or absence of each risk-factor, plus his/her score on the Griffiths Mental Development Scale (D.Q.), were the independent variables. Table 3 shows a summary of the stepwise regression report, indicating the number of subjects with each risk-factor, the proportion of additional variance accounted for when each predictor variable is entered into the stepwise regression equation in the order indicated, whether the risk-factor was positively or negatively related to visual acuity, and the probability level. The results of this analysis indicate that, for the at-risk sample, VLBW,

RDS, BPD and Pneumothorax were all significant predictors of visual acuity (all values, p, < .05). However, collectively, they accounted for only 11.4 % of the variance (R^2 = .1144, p < .05). The VLBW and RDS variables are associated with higher visual acuity estimates relative to the rest of the at-risk sample, whereas BPD and pneumothorax are associated with lower visual acuity estimates relative to the rest of the sample.

Insert Table 3 about here

Discussion

The main purpose of this preliminary study was to compare the visual acuity of a heterogeneous sample of at-risk infants and young children, to that of a healthy, fullterm sample. The results of the present study suggest that, like fullterm healthy infants of the same corrected age, visual acuity of infants with significant perinatal risk-factors does increase with age throughout the first three years of life. However, the developmental pattern differs, at least up until the corrected age of three years. Surprisingly, at-risk infants appear to have higher or similar mean visual acuity than normals over the first few months of life and then start to lag behind normals at about 12- and 24-months of age. At three months, the at-risk

Table 3

Summary of Stepwise Regression Report

Step	Predictor	n	R^2 Added	+/-[a]	Probability
1	Very Low Birthweight (VLBW)	39	.026	+	.0402*
2	Respiratory Distress Syndrome (RDS)	60	.025	+	.0426*
3	Bronchopulmonary Dysplasia (BPD)	20	.038	-	.0133*
4	Pneumothorax	16	.037	-	.0142*
5	Developmental Quotient (DQ)	161	.001	+	.6373
6	Persistent Neurological Signs (PNS)	32	.001	+	.6797
7	Seizures	26	.001	+	.6999
8	Mechanical Ventilation	54	.000	+	.9776
9	Low Apgar Score	11	.004	+	.4097
10	Low Head Circumference/SGA	22	.003	+	.4527
11	Hypoglycemia	20	.004	+	.4168
12	Metabolic Acidosis	12	.000	+	.8368
13	Patent Ductus Arteriosis (PDA)	24	.000	+	.8600
14	Apnea	26	.001	+	.6916
15	Necrotizing Enterocolitis (NEC)	12	.006	+	.1088
16	Hypercalcemia	10	.000	+	.8087

[a] direction of relationship between the predictor variable and visual acuity

* $p<.05$

group appears to catch-up to the healthy, fullterm group. Of particular interest is the finding that, among the at-risk infants, BPD and pneumothorax significantly predict poorest visual acuity in the first three years of life, whereas VLBW and RDS seem to predict better visual acuity than the other risk-factors.

Success of the Procedure

The Teller Acuity Card procedure proved to be a very successful tool for assessing visual acuity in infants and young children at risk for visual and developmental deficits. The high success rate (97%) is comparable or somewhat greater to that reported previously for healthy, fullterm infants and children (e.g., Courage & Adams, 1990; McDonald et al., 1985; McDonald, Sebris et al., 1986; McDonald, Ankrum et al., 1986), and for preterm and otherwise at-risk babies (e.g., Sebris et al., 1987; Mohn et al; 1988). In the present study, test times were not measured precisely, but most tests were completed within ten minutes, a duration which is consistent with other studies.

Developmental Trends

The group with significant perinatal risk factors showed a different pattern of visual acuity development than did a sample of healthy, fullterm infants. Relative to the

normative sample, the at-risk sample actually had a higher mean acuity estimate near three months of age than did the normative sample. This difference disappeared at about six months and then the trend reversed so that mean acuity was significantly lower than that found for the normative sample at 12 and 24 months. A significant proportion (46%) of the subjects between approximately 12 and 24 months obtained an acuity estimate more than 2 standard deviations below the mean of the normative group. At some point between the second and third year of life, the at-risk sample started to "catch-up" to their fullterm, healthy peers, such that by about 3 years of age, the difference was no longer statistically significant, and only 9% (3/36) of subjects had acuities more than two standard deviations below the mean of the normative sample. This pattern of development suggests a period of "delayed maturation" (Fielder, Moseley, & Ng, 1988) beginning about 12-months of age and ending before 36 months of age. This same pattern is described by Landry and her colleagues (Landry, Zarling, Chapieski & Fletcher, 1984) who found that children with hydrocephalus and BPD scored in the delayed range of development at 12 and 24 months and in the borderline range by 36 months, on measures of mental and motor development.

Taken at face value, the above findings, particularly for the first few months of life, do not easily fit with

what is reported in the literature about the development of visual acuity in at-risk populations, possibly because of the heterogeneity of the present sample (i.e., both low- and high-risk infants). For example, in previous studies which compared groups of at-risk infants to healthy fullterm infants, those classified as low-risk (e.g., Apgar score of 6 or greater at 5 minutes postpartum; mechanical ventilation for no more than 7 days postpartum; no peri- or post-natal hypoxia; no neurological or ophthalmological abnormalities; and no surgical intervention for PDA or NEC) generally lag behind normals during the first 4 to 5 months of corrected age, but then catch up (van Hof-van Duin & Mohn, 1986; Mohn & van Hof-van Duin, 1986a; van Hof-van Duin et al., 1992). On the other hand, in studies of infants aged 5 weeks to 18 months, those infants who are considered to be high-risk based on certain risk-factors (e.g., Apgar score of 5 or less at 5 minutes postpartum; mechanical ventilation or phototherapy more than one week; evidence of intracranial insult; hypoxia; clear neurological symptoms perinatally; obstetric intervention because of fetal distress; surgical intervention for PDA or NEC) and/or who are showing signs of neurological abnormality, tend to lag behind normals (Mohn & van-Hof-van Duin, 1986a; Mohn et al., 1988; van Hof-van Duin et al., 1989). In fact, Getz, Dobson and Luna (1992) found some evidence to suggest that by age 3, even <u>low</u>-risk

preterm children may start to have slightly poorer acuity than fullterm children of the same age. Similarly, Sebris, Dobson and Hartmann (1984) found that the visual acuity of their sample of low-risk preterm 3- to 4- year-olds was significantly poorer than that of like-aged fullterm children.

The present results are both consistent and inconsistent with these previous findings. Based on the reports in the literature, one would expect that mean visual acuity for the at-risk sample would be below that of the healthy fullterm group for the first few months of age, regardless of whether the present sample consisted of low-risk or high-risk infants. However, the present at-risk sample actually had a mean acuity estimate that was significantly higher than that of the normative sample. It should be noted, however, that the mean acuity estimate of 2.6 cpd for the 3-month age group reported by Courage and Adams (1990) is considerably lower than that of 4.1 cpd reported by van Hof-van Duin and Mohn (1986) for the same age group. Similarly, the mean acuity estimate for the "3-month" group (3.4 cpd) in the at-risk sample lies between the estimates for the 2- (2.0 cpd) and 4-month (4.5 cpd) age groups reported by McDonald and her colleagues (McDonald et al., 1896). As such, the at-risk sample may not differ from healthy, fullterm infants at 3 months of age.

Selection bias may be another possible explanation for both the relative superiority of the at-risk group around 3 months of age, and the similarity between the two samples near 6 months of age. More specifically, there may be a bias for parents who were more concerned about their child's developmental progress to bring their child back to the Perinatal Clinic for further developmental assessment. Initially, one might expect that the parents of most of the infants enroled in the program, regardless of degree of risk and the rate of development, would be highly motivated to have their child attend the clinic for his/her first assessment. However, if they are told that their child is developing normally, and/or they themselves see no overt evidence for concern, parents may be less likely to bring their child for further follow-up assessments. Thus, perhaps the 3-month-old and 6-month-old age groups had a higher proportion of low-risk and neurologically normal children than did the 12- and 24-month-old groups. If the 3- and 6-month age groups had a high proportion of low-risk and neurologically normal premature infants, and the 12-, 24-, and 36-month age groups had a high proportion of high-risk and neurologically abnormal children, then most of the present results would be consistent with the previous findings mentioned above. The present sample of at-risk infants and young children did demonstrate below average

visual acuity at 12 and 24 months, as is consistent with previous findings for high-risk and neurologically abnormal children.

The present finding that the 36 month-old, at-risk group's visual acuity did not differ significantly from the normative sample suggests that sometime between the second and third year of life, the at-risk infants start to "catch-up" to their healthy, fullterm peers. However, the mean acuity value for the 36 month-olds in the normative sample (Courage & Adams, 1990) is somewhat lower than that reported in other normative studies (18.6 cpd versus 27.7 and 28.3 cpd) (Mcdonald et al., 1986; Heersema & van Hof-van Duin, 1988) and is considerably lower than the value (39.8 cpd) subsequently found with a group of 48 month-olds tested in the same laboratory (Adams, 1994, unpublished data). This suggests that perhaps the mean for the 36-month normative sample was an underestimate. This being the case, the present sample of 36 month-olds may still represent a group with significantly below-average visual acuity. This outcome would be consistent with the findings of Dobson and her colleagues mentioned above (Sebris, Dobson & Hartmann, 1984; Getz, Dobson & Luna, 1992). Follow-up investigation with at-risk children older than 36 months would help clarify the question of whether this population continues to exhibit poor acuity beyond 3 years of life. There is

already some evidence to suggest that teenagers born prematurely and/or with low birthweight show visual acuities in the lower end of the normal range (Fleidelius, 1981).

Ability of Risk-Factors to Predict Visual Acuity

There is general agreement that VLBW infants and fullterm infants with neonatal and perinatal complications, are at-risk to develop visual/neurological abnormalities, and that early detection is essential to minimize longterm deficits (Dobson, Mayer & Lee, 1980; van Hof-van Duin & Mohn, 1984; Mohn & van-Hof van Duin, 1986a; van Hof-van Duin, 1988; Usher, 1987). However, it is not clear which, among a myriad of common risk factors, can best predict later visual outcome. One of the goals of the present study was to determine which of a variety of medical complications and early lifesaving interventions predict the visual acuity of an already identified developmentally-at-risk sample. The results indicate that children who developed bronchopulmonary dysplasia (BPD) or pneumothorax after birth were more likely to have poor visual acuities than other at-risk children who did not have these particular risk factors. The results also indicated that, among the sample of at-risk children, those with very low birth weight (VLBW) or respiratory distress syndrome (RDS) tended to have better visual acuity than their at-risk peers who had other risk

factors. This is not to say that children with VLBW or RDS perform better than healthy fullterm infants, but rather that these risk-factors appear to have less detrimental impact on the visual acuity of at-risk children than the other risk factors that were studied. To compare the effect of VLBW, RDS, BPD or pneumothorax to normal children, one would need to use subjects with each of these risk factors in isolation, which would be virtually impossible to do because the they are interrelated.

Children with VLBW have long been recognized as at-risk for perinatal morbidity and mortality. Many of these neonates develop serious medical complications and often require life-saving medical intervention. Specifically, children with VLBW have been shown to be at-risk for visual impairment (e.g., van Hof-van Duin, 1988; van Hof-van Duin et al., 1989). However, these studies did not statistically control for the variety of perinatal complications commonly found in children with VLBW. The present findings, suggest that VLBW may be less detrimental to visual function than some of the other risk-factors a child may be affected by after birth, either instead of, or in addition to, VLBW. In fact, some preliminary work from an extended version of the present database indicates that the visual acuity of children with only VLBW (n = 12) does not differ significantly from that of the normative sample (Peddle,

1991).

RDS is another risk factor identified in the present study as having less detrimental impact on the visual acuity of the present sample than the other investigated risk factors. RDS is an acute pulmonary disease that correlates closely with degree of prematurity and birthweight (Osterlund and Riegel, 1984). It is caused by an inadequate supply of pulmonary surfactant in the alveoli of the infant's lungs, which results in non-compliance of the lungs and improper exchange of carbon-dioxide and oxygen. Each breath becomes more and more difficult, and without intervention, the infant tires and dies (Sammons and Lewis, 1985, chap. 26). The present finding that RDS is associated with better visual acuity, among an at-risk sample of infants and young children, is in accordance with the finding of Picco (1992) who investigated the visual acuity of 16 subjects, aged 3 months to 3 years, having a primary diagnosis of RDS with no other perinatal complications. She compared these data with the Courage and Adams (1990) norms and found that the visual acuity of the RDS infants did not differ significantly from that of the normative group. Similarly, Luna, Dobson and Guthrie (1992) found no significant difference in visual acuity between 54 infants with hyaline membrane disease (RDS) and 81 healthy, preterm infants.

Bronchopulmonary dysplasia, however, is a more serious respiratory problem than RDS. It is a chronic lung disease, of varying duration and severity, seen most frequently in newborn, VLBW infants with severe RDS who have been treated for 24 hours or more with supplemental oxygen. Prolonged exposure to high, potentially toxic levels of oxygen can damage both the airway and the lungs and is usually implicated in the development of BPD. Paradoxically, the pulmonary insufficiency that results requires the infant to receive ongoing oxygen therapy or mechanical ventilation. A diagnosis of BPD usually necessitates hospitalization of 3 to 12 months duration and is often associated with neurodevelopmental delay (Sammons & Lewis, 1985, Chap. 26; Northway, 1984). VLBW infants who develop BPD show delayed mental and motor development up until at least 24 months of age and borderline development at 36 months of age (Landry, Zarling, Chapieski & Fletcher, 1984), especially if they required supplemental oxygen for more than 28 days during the neonatal period (Skidmore, Rivers & Hack, 1990). With regard to visual acuity, however, Luna, Dobson and Guthrie (1992) found no significant difference in the acuity development of 48 infants with BPD as compared to that of 81 healthy, preterm infants. The present findings, however, suggest that at-risk children who develop BPD have poorer visual acuity than children with other risk factors. It is

possible that the two samples differ somehow and that this difference accounts for the discrepant findings. Specifically, Luna, Dobson and Guthrie (1992) excluded children with neurological abnormalities from their sample, whereas in the present study, 3 of the 20 subjects with BPD were also diagnosed with grade III intraventricular hemorrhage and 8 suffered sustained periods of apnea.

Like BPD, pneumothorax is a serious respiratory complication common among VLBW infants. It involves a rupture and consequent "air leak" in the infant's lungs and is primarily associated with aspiration syndromes, mechanical ventilation, RDS, and BPD (Philip, 1980). To date, the relationship between pneumothorax and visual acuity (nor any other neurological function) in infants has not been investigated. The present results are the first to implicate pneumothorax as a significant risk factor for abnormal visual/neurological development.

Despite the finding that VLBW, RDS, pneumothorax and BPD were significant predictors of visual acuity in the present study, they still only accounted for a very small percentage of the variance in the multiple regression analysis. There are many other variables (e.g., medical conditions, ophthamological abnormalities, reproductive factors, maternal behaviours such as smoking or consuming alcohol during pregnancy, environmental and social factors)

not investigated in this study that could potentially influence visual acuity development in this population. It is also possible that the TAC procedure is not a sensitive instrument for detecting small variations in visual acuity.

In summary, the results of the present study demonstrates that a heterogeneous sample of at-risk infants and children had a different pattern of visual acuity development than that of a sample of healthy, like-aged children. Despite having good visual acuity for at least the first 6 months after term, the at-risk group had significant deficits by one and two years of post-term age. On a positive note, however, these deficits were no longer evident by age three, when the at-risk sample had a mean acuity estimate in the lower portion of the normal range. Future research with at-risk children up to 5 years of age would be helpful in determining if indeed these children "catch up" to their healthy peers after 36 months or if they continue to lag behind. If this population of infants is in fact predisposed to longterm visual handicap, the finding that BPD and pneumothorax are more related to poor visual outcome than the other risk factors studied is quite profound. This knowledge would enable more accurate prediction of which children would benefit from early intervention to improve their vision. In order to <u>better</u> predict which children are at greatest risk for visual

impairment, however, it will be necessary for future studies to find ways to control for multiple risk factors. One way of doing this could be to have two at-risk groups, matched according to a specific combination of risk factors (as few as possible), but differing by one (e.g., BPD). The two groups could then be compared not only to a normative sample, but to each other. If the group with the extra risk factor differed from the other group, this difference could be attributed to the risk factor in question. For now, the results of the present study indicate the need for ongoing vision assessments during the preschool years for this population in general, and for children who develop BPD and pneumothorax in particular.

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