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Divergent Development of Gross Motor Skills in Children Who Are Blind or Sighted

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Abstract: This empirical study compared the average ages at which four congenitally blind children acquired 29 gross motor skills with age norms for sighted children. The results indicated distinct developmental delays in the acquisition of motor skills and a high degree of variability in developmental delays within and across the six subdomains that were analyzed.

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The acquisition of gross-motor skills is conceived as a systemic process (Thelen, 1995) in which visual perception and the execution of movements influence each other reciprocally. Although the sequence of acquisition for motor milestones reflects maturational changes in the central nervous system, additional training and practice are decisive for the formation of complex or differentiated motor competencies and for the level of performance that a child can attain.

Primary and secondary functions of vision in the acquisition of motor skills have been identified. The primary functions are (1) an incentive function-to engage in movement (Gibson, 1979; Webster & Roe, 1998); (2) a spatial function-to permit the simultaneous and precise spatial perception of the extent of visible space and the relationships within it (Foulke, 1982); (3) a protective function-to recognize and anticipate dangerous situations sufficiently in advance; (4) a controlling function-to track the performance of a movement, which is particularly decisive for new or complex movements; and (5) a feedback function-to monitor the quality of executed movements; that is, to fine-tune and automatize a sequence of movements. The secondary functions are (1) a social feedback function-to encourage children to try certain motor acts or to desist from others, mainly expressed nonverbally and conveyed through glances, facial expressions, and gestures-and (2) an observation function-to imitate motor acts that are performed by other children or adults.

Delays in the development of motor skills are interpreted from three different, although not mutually exclusive, theoretical perspectives: the comparative deficit approach (Fraiberg, 1977; Warren, 1984), the social interaction approach (Warren, 1994, 2000; Webster & Roe, 1998), and the adaptive compensation approach (Brambring, 2003; Brambring et al., 1995; Ferrell, 1986, 2000; Jan, Freeman, & Scott, 1977). The comparative deficit approach traces delays directly back to blindness-related constraints; that is, the deficit in visual information prevents or restricts the ability to engage in adequate learning experiences while acquiring motor skills. The social interaction approach explains such delays indirectly through unfavorable developmental conditions that are due to low expectations in the social environment of children who are blind. The adaptive compensation approach emphasizes the analysis of the alternative strategies that enable children who are blind to acquire various motor skills by compensatory means. Potential compensations are the use of alternative sensory information or the comprehension of physical assistance or verbal explanations and their transformation into motor acts.

Because of the loss of or major constraints to these primary and secondary functions, one can, in theory, predict that children who are congenitally blind will have severe impairments in acquiring, refining, and performing motor skills. Empirical studies of these children's motor development (Adelson & Fraiberg, 1974;

Brambring, 2005; Celeste, 2002; Ferrell, 2000; Fraiberg, 1977; Hatton, Bailey, Burchinal, & Ferrell, 1997; Jan et al., 1977; Norris, Spaulding, & Brodie, 1957; Pereira, 1990; Troester & Brambring, 1993; Troester, Hecker, & Brambring, 1994) have supported these theoretical assumptions by generally reporting marked developmental delays in the acquisition of gross-motor skills by children who are congenitally blind compared with sighted children.

For example, two studies (Brambring, 2005; Hatton et al., 1997) compared the mean age at which blind and sighted children acquired developmental skills, including motor skills. Hatton et al. tested 186 children (aged 12-73 months) with all degrees of visual impairment and with or without any additional impairment repeatedly with the Battelle Developmental Inventory (Newborg, Stock, Wnek, Guidubaldi, & Svinicki, 1984); 27 of the children were totally blind or had only light perception. Regression analyses revealed that the blind children had the strongest mean developmental delays in the motor domain-a 15.5-month delay, compared with a developmental age of 30 months for the sighted children. Brambring (2005) assessed the acquisition of developmental skills in four children who were completely blind or had only light perception and no noticeable further impairments aged 10-62 months. Regression analyses revealed a developmental delay in motor skills of 11.9 months compared with sighted 30 month olds, that is, a smaller delay than Hatton et al. found. The smaller delay was probably due to a stronger selection effect in Brambring's sample and the purposefully blind-specific presentation of test items.

The weakness of the two studies is that they tell nothing about the variability in the developmental acquisition of single motor skills. This is precisely the information that is needed to perform a differentiated analysis of the reasons for greater or smaller developmental divergences in blind versus sighted children, that is, to ascertain at which stage of development and for which motor skill alternative compensatory means become available.

Adelson and Fraiberg (1976; see also Fraiberg, 1977) were the first to report developmental divergences in the acquisition of gross motor skills. Their longitudinal study of 10 children who were congenitally blind and had no additional impairments revealed that the children acquired the milestones of posture and balance within the standard age range of sighted children, as reported in the Bayley Scales for Infant Development (BSID; Bayley, 1969), but acquired nearly all the skills related to a self-initiated change of position at a later age than the 95% criterion for sighted children. Two studies (Troester & Brambring, 1993; Troester et al., 1994) broadly confirmed Fraiberg's findings in two groups of blind children.

The major disadvantage in earlier comparisons of blind and sighted children is that they mostly assessed only a few motor skills over a limited period (such as only 10 items over two years in Fraiberg, 1977). The study presented here was a longitudinal assessment of the age at which children who are blind acquire 29 motor skills over a period of more than four years. An analysis of these empirical findings may clarify the alternative path of development in the acquisition of gross motor activities by children who are blind and suggest which adaptive strategies the children may apply to compensate for their blindness.

Method

PARTICIPANTS

The sample was recruited from a group of 10 children who participated in a longitudinal early intervention study on the development of children who are blind (Brambring, 1996, 1999; Brambring et al., 1995). Interventions were conducted with the children and their parents during the two- to three-hour home visits every two weeks from ages 1 to 3 and once every four weeks from ages 4-6 to promote the children's development and to discuss any child-rearing or emotional problems that emerged (Brambring 1993, 1996). All the early interventionists were graduate psychologists. Twice a year, weekend meetings were held for all the family members receiving early intervention services to encourage contact and an exchange of information among the families (Brambring, 1997a, 1997b).

The comparisons with sighted children that are presented here were based only on blind children with no other impairments. This "typical development," observed during the course of the longitudinal study, could be confirmed in 4 of the 10 children through IQs, measured by the verbal part of the Hamburg Wechsler Intelligence Scale for Children (HAWIK-R-the German adaptation of the text; see Tewes, 1983) at the end of the project and teachers' ratings before the children were enrolled in school (Brambring, 2005). Of the 4 children (2 boys and 2 girls), three were completely blind (microphthalmos; anophthalmos; and retinopathy of prematurity, Stage 5) and one had minimal light perception (Leber's amaurosis).

ASSESSMENT INSTRUMENTS

Developmental data on the children who were blind

The longitudinal developmental data were gathered through participant observation during early intervention home visits (Brambring, 1999) using specially developed scales for assessing and promoting development in infants and preschoolers who are blind (Entwicklungsbeobachtung und Entwicklungsförderung blinder Klein und Vorschulkinder, EBKV; see Brambring, 1999). The EBKV contains 600 items for observing development from birth to age 6. These items cover the following eight developmental domains: (1) posture and balance, (2) self-initiated movements, (3) orientation and mobility, (4) manual skills, (5) daily living skills, (6) cognitive development, (7) language development, and (8) socioemotional development. An English-language version of these scales (the Bielefeld Observation Scales) will be published soon (Brambring, in press). Data were available on the ages at which the children acquired 371 (61.8%) of the 600 quantitative items (Brambring, 1999).

Items were selected specifically to provide a differentiated assessment of blindness-specific problems (Brambring, 1989). They were also selected so that they could be observed in the children's home environment or embedded in early intervention activities in a standardized form. The interventionists (the same graduate psychologists who had helped to develop the scales and specify evaluation criteria) coded their observations immediately after each home visit. Continuous observation of development by the same persons helped to ensure that the data collection had a high reliability.

Developmental data on sighted children

The age at which the children who were blind acquired gross motor skills was compared with age norms for sighted children (median, lower, and upper cutoffs) from four well-known standardized developmental tests. The first test was the BSID (Bayley, 1969) for ages 2-30 months, which we used because the latest version, BSID-II (Bayley, 1993), gives only age ranges for the single developmental skills, not the exact age at which the skills are acquired. The three other tests were the Denver Developmental Screening Test (DDST, German version; Flehmig, Schloon, Uhde, & von Bernuth, 1954/1973) for ages 0-6 years; the Griffiths Developmental Scales (German version; Brandt, 1954/1983) for ages 1-24 months; and Entwicklungskontrolle für Krippenkinder (Zwiener & Schmidt-Kolmer, 1982), a German-language developmental test for ages 1-42 months.

Selection of comparison items

A total of 157 tasks in the four developmental tests for sighted children corresponded with items for which age reports were available in the observation scales for children who are blind. Some tasks, such as "walks along holding onto furniture," were listed in three of the four developmental tests. In these cases, a mean value for the medians and lower and upper cutoffs for their acquisition were computed. This procedure resulted in a final total of 107 tasks in both the developmental tests for sighted children and the observation scales for children who are blind. Of these 107 items, 29 refer to gross motor skills.

DATA ANALYSIS

Data on the 29 items comparing the acquisition of gross motor skills were analyzed from three perspectives: (1) categories of developmental divergence for children who are blind based on their position within or above the upper cutoff for sighted children, (2) absolute and relative developmental differences in the ages of acquisition of the skills by blind and sighted children, and (3) a regression analysis of the relationship between the ages of acquisition for the children who were blind and the age norms for sighted children.

Categories of developmental divergence

The analysis was based on the median scores for the age of acquisition in both the sighted (Mdnsig) and the blind (Mdnbli) groups, as well as the earliest (Minsig and Minbli) and latest acquisition ages (Maxsig and Maxbli). The earliest acquisition age for the children who were blind was reported when the first blind child in the sample had acquired this skill, and the latest acquisition age was reported when the last blind child had acquired it. For the sighted children, the earliest acquisition age corresponded to the 5% criterion; that is, when 5% of the sighted children had acquired the corresponding skill, and the latest acquisition age corresponded to either the 90% or 95% criterion, depending on the specific test.

The available data could be used to formulate only three categories of the strength of developmental divergences between children who are blind and sighted children: (1) extreme developmental delay, when the age of acquisition for the motor skill for all blind children was above the 90% or 95% criterion for sighted children; (2) strong developmental delay, when the age of acquisition of at least one blind child was within the standard age range of sighted children, but the median for blind children was above it; and (3) slight developmental delay, when the median for blind children was within the standard age range for sighted children but was higher than their median.

Absolute and relative developmental differences

Absolute differences in development (Mdnbli-Mdnsig) are the differences in the mean acquisition ages for the various skills in children who are blind and sighted children. However, equal-sized absolute differences in development should be weighted more strongly at an early acquisition age than at a later age. To overcome this methodological difficulty, almost all developmental tests compute the developmental quotient (DQ = developmental age 4 chronological age x 100) as a relative measure. However, such a DQ was inappropriate in this study because acquisition ages were compared in two different populations. A further problem is that DQs are often interpreted as if they were IQs; that is, a DQ of £ 70 is frequently evaluated as a sign of mental retardation. Such misinterpretations should be avoided because strong developmental delays in children who are blind do not necessarily indicate additional mental impairment, but may well reflect difficulties that are due to blindness and a continuing lack of opportunities to compensate for them.

In light of this issue, the median scores of the blind children were divided by the median scores of sighted children for each developmental skill (Mdnbli/Mdnsig). This value indicates the factor by which the acquisition age in sighted children needs to be multiplied to obtain the acquisition age for blind children on the particular developmental skill. A value greater than 1.0 indicates that children who are blind acquire the specific developmental skill later than do sighted children. For example, a value of 2.0 indicates that children who are blind do not acquire this skill until they are twice as old as sighted children. The third step was a regression analysis of the relationship between the acquisition ages of children and the age norms of sighted children.

Results

Position of Blind Children in Relation to Sighted Norms

Table 1 reports the distribution of developmental divergences in children who are blind in relation to the norms for sighted children. The children who were blind had "strong" developmental delays in approximately 45% of the observed skills and "extreme" developmental delays in about 28%. Only four items (13.8%) revealed a "slight" developmental delay.

Absolute and Relative Developmental Differences

Table 2 reports the developmental data and the absolute (Mdn^{bli} - Mdn^{sig}) and relative (Mdn^{bli}/Mdn^{sig}) differences in development between the children who were blind and sighted children for the single skills. The 29 items were grouped into six categories with a content analysis. A factor analysis was not possible because of the small sample. Four independent raters assigned the items to the six categories. Interrater agreement was high (Kendall's $W = .92$, $p < .001$).

The comparison of the median scores revealed that sighted children acquired all 29 gross motor skills earlier than the children who were blind. The absolute developmental differences ranged from 2.2 months ("Climbs up on the sofa") to 24.9 months ("Can run"). The relative developmental differences also revealed a high variability among the items, ranging from rel. = 1.18 ("Pushes object, such as pushchair") to rel. = 2.38 ("Can run").

A statistical test of the developmental differences between children who are blind and sighted children is meaningful only for the total comparison and for categories containing at least six items. All sign tests revealed significant developmental delays in the children who were blind compared with sighted children: total comparison (Z = -5.199, $p < .001$), dynamic balance ($p < .05$), acquisition of locomotion ($p < .05$), and refinement of locomotion ($p < .01$).

Even categories with similar content revealed strong differences in the mean ages of acquisition, for example, between static and dynamic balance, between change in body position when holding on and when not holding on, and between the acquisition and refinement of locomotor skills. No statistical comparisons were possible because of the small sample. Nonetheless, a modified computation of effect sizes for dependent measures was computed to obtain a comparative statement (Leonhart, 2004), based on the following equation:

$$d = \frac{Mdn_1 - Mdn_2}{Q_{1/2}} \quad Q_{1/2} = \sqrt{\frac{(n_1 - 1) \times Q_1^2 + (n_2 - 1) \times Q_2^2}{n_1 + n_2 - 2}}$$

[Equation Narrative: d equals a fraction with numerator (Mdn subscript 1 minus Mdn subscript 2) and denominator (Q subscript ½) times Q subscript ½ equals the square root of a fraction with numerator (open parenthesis n subscript 2 minus 1 closed parenthesis plus open parenthesis n subscript 2 minus 1 closed parenthesis times Q subscript 2 squared) and denominator (n subscript 1 plus n subscript 2 minus 2).]

This computation integrates the different numbers of items in the categories and the different distribution (quartile measure). Because using this quartile measure (50% of the variance) instead of the standard deviation (68% of the variance) leads to a slight increase when computing effect sizes, only effect sizes of $d > .60$ were assigned any practical significance. Table 3 shows that the largest difference in effect sizes was between Category 3 (change in body position without holding on) and the other categories. With the exception of Category 6 (refinement of locomotion), effect sizes were--in absolute terms--greater than 0.60. In other words, the skills for changing body position without holding on were significantly more difficult for the children who were blind to learn than the skills in the other categories. Category 6 revealed effect sizes (in absolute terms) of $d > .60$ to Categories 1 (static balance), 3, and 5 (acquisition of locomotion), with each mean developmental divergence in Category 6 being stronger than in the other categories. Category 5 revealed only one statistical difference to Category 1, indicating that the mean developmental divergence in acquiring locomotor skills is greater than that in static balance skills.

Figure 1 illustrates the relationship between the size of the mean relative developmental differences in the six categories and the variability in the acquisition of skills by the children who were blind (quartile measures). It shows how higher mean relative developmental differences are accompanied by increasing variability among children who are blind in acquiring the skills. The product-moment correlation between the median and quartile values was $r = .90$.

Regression Analysis

The third step in the analysis was to compute a regression of the acquisition ages of children who are blind to sighted children. Because the analysis of different computation methods (linear, growth curve with weight estimation, and so forth) resulted in comparable *R*-squares as a measure of goodness of fit, the linear regression was selected for ease of presentation.

The developmental delays in blind compared with sighted children are depicted in Figure 2. For example, the children who were blind had an average developmental age of 18.1 months when sighted children already exhibited a chronological or developmental age of 30 months. Despite the markedly slower development in the blind children, there was a high correlation between the acquisition ages for single skills across both groups. In other words, the sequence in which developmental skills are acquired remains broadly the same in children who are blind and sighted children (product-moment correlation: $r = .89$). However, this correlation is bolstered by the fact that the age intervals between single acquisition ages are already, at times, large in sighted children as well, thus reducing the likelihood of any shifts in the ranking.

Comparison with Acquisition Ages in Other Studies

This comparison used only empirical studies in which the assessment of the age at which motor skills were acquired was based on the researchers' observations or test data (Ferrell, 2000; Fraiberg, 1977; Norris et al., 1957). It also used developmental data in these studies only on children who were blind who had no additional impairments (see Table 4). The comparisons show that despite (mostly) large time intervals among the studies and different assessment methods, the ages at which children who were blind acquired motor skills were similar and revealed marked developmental differences compared with the norms for sighted children. The largest deviations emerged in comparison with Norris et al.'s study, perhaps because that study assessed the children at only three-month intervals and included more blind children who were born prematurely than did the other studies.

Discussion

The present findings confirm the importance of vision for the acquisition of gross motor skills in early childhood. That children who are congenitally blind have major delays underlines the advantage for sighted children of being able to use visual information to control and gain feedback on gross motor activities. This finding is based on data from a group of blind children who had no additional impairments who had received intensive early intervention over a period of five years.

Nonetheless, from the perspective of children who are blind, the findings also confirm the central hypothesis of this study: that even in this strongly visually dominated domain of development, no consistently standardized developmental delay can be ascertained compared with the development of sighted children.

Instead, there is a high degree of variability in the relative developmental differences--from almost equal acquisition ages (a relative difference of 1.18) in both groups to ones that are more than twice as high in children who are blind as in sighted children (a relative difference of 2.38). This finding suggests that children who are blind apply alternative strategies to compensate for the loss of vision in the acquisition of single skills. Such compensations can be seen particularly clearly when one compares similar aspects of development with strong or weak relative developmental divergences.

For example, the children who were blind had much lower developmental divergences on static than on dynamic balance (a difference in the effect size of 0.56), perhaps because performing static balance skills ("standing up for a short time" or "standing up confidently") requires "only" stable body posture, whereas performing dynamic skills ("walking along a line" or "bending down") calls for additional locomotor abilities or movements of the whole body. Although static balance control is facilitated by visual feedback on the perceived vertical dimension, vestibular and proprioceptive information also contribute decisively to the acquisition of such skills. The possibility of using such alternative sensory information probably explains the relatively slight developmental divergences on these tasks. In contrast, dynamic balance depends more strongly on components of visual control, which children who are blind seem to be able to compensate for later in their development, for example, when they are able to process physical or verbal guidance. Furthermore, the hypotonia reported in preschool-age children who are blind (see, for instance, Jan, Robinson, Scott, & Kinnis, 1975) has a more significant impact on static than on dynamic balance.

The comparison of the abilities to change body position with and without holding on revealed a particularly large difference in mean relative developmental divergences (a difference in effect size of 1.60). Whereas children who are blind generally learn to change position without holding on ("sitting up and down without support") twice as late as do sighted children, there are much smaller developmental differences for changing position while holding on ("pulls up to stand" or "climbs on the sofa"). This example clearly illustrates the specific impact of blindness on the acquisition of gross motor skills. Shifting position in an open space that one cannot perceive is difficult, and it seems that children who are blind are able to overcome this difficulty only at a later age. Sighted children learn such skills as sitting up or down without support during the preverbal phase because vision provides them with strong incentives to engage in such forms of movement and they can perceive the goal of their efforts precisely. As with dynamic balance, children who are blind seem to acquire these skills only when they are able to comprehend the sequence of movements on the basis of simple verbal instructions and physical guidance.

The comparison of first locomotor skills and refined locomotor skills revealed that children who are blind acquire the latter markedly later than the former (a difference in the effect size of 0.66). They may do so because parents can introduce simple locomotor skills, such as "walks holding on," as well as locomotor skills that are linked to holding on, such as "walking along holding on to furniture" or "pushing a pushchair." In contrast, refined locomotor activities, such as "can run," involve complex motor skills that require the integration of vestibular, proprioceptive, and spatiocognitive components. It is only with better cognitive understanding and the ability to translate verbal instructions into motor acts that children who are blind succeed in carrying out such complex forms of movement.

The analysis of the reasons for the observed developmental differences on what seem to be similar developmental tasks underlines the need for a differentiated approach to blindness-specific problems. One tentative overall conclusion is that early compensation seems to be possible for skills that children who are blind may acquire through their other senses. Moreover, it also seems to be attainable at a relatively early stage, when the acquisition of a gross motor skill can be introduced through early assistance--whether through holding on or going along beside objects or through the physical assistance of adults. Major developmental divergences emerge in skills that require free movement through space. The acquisition of these skills clearly requires verbal and cognitive competencies in children who are blind.

Within the group of children who were blind, an increase in interindividual differences could be observed on the basis of the relative developmental differences with sighted children. The ages of acquisition of motor skills with slight relative developmental differences to sighted children were more homogeneous within the blind group than were those with large developmental divergences. This "scissors effect" is probably due to differences in interindividual competencies in the children and/or parental child-rearing capacities and may be due to the intensive early intervention that the children received.

The regression analysis highlighted the mean developmental delay in children who are blind in the acquisition of gross motor skills. At 30 months, the delay is 11.9 months compared with sighted children. Although slightly lower that the 15.5 months reported by Hatton et al. (1997), the difference is not large enough to suggest contradictory findings. Rather, the convergence in the developmental data for children who were blind in both studies indicates a congruent validity.

The content validity of the developmental data on the children who were blind in this study is supported by data from other studies. All the other studies revealed large developmental delays in children who are blind compared with sighted children. There was also broad agreement on the ages at which blind children acquire skills. The strongest agreement is with Fraiberg's (1977) data, which was also a longitudinal study in which developmental data were obtained through regular observation in the children's homes. The comparable developmental data across different studies suggests that findings on the acquisition of gross motor skills by children who are blind are stable because the ages of acquisition remained unchanged across different generations of blind children and despite progress in medical and educational framing conditions.

The major limitation of the present study was the small sample. A larger sample might well have revealed shifts in the findings on the categorical and quantitative comparison of blind and sighted children. Although it can be assumed that the children who were blind in this study had no further impairments, I cannot say how representative they are for this population. Nonetheless, comparisons with the results of other studies do not suggest otherwise. A further limitation is that only some of the potential gross motor skills could be compared; that is, those that could be found in the diagnostic instruments for children who are blind and sighted children and that could be assessed during the observation period of 8 to 30 months in sighted children and 13 to 50 months in children who are blind. I cannot rule out the possibility that shifts in developmental differences between children who are blind and sighted might have been obtained with a larger range of motor tasks and a longer period of observation. Nonetheless, the study is still the most comprehensive assessment of gross motor skills in children who are blind that has been conducted to date. It confirms that generalizing assumptions about children's development is inappropriate. Only fine-scale analyses like those presented here permit the differentiated perspective on the alternative developmental paths of children who are blind that is needed to conduct realistic and appropriate early intervention.

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