

## Effects of Vestibular-Proprioceptive Stimulation on the Neurobehavioral Development of Preterm Infants: A Pilot Study

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### Abstract

This paper reports the results of an intervention study which assessed the effects of compensatory vestibular-proprioceptive stimulation provided by waterbed flotation on the neurobehavioral development of preterm infants. The subjects, who were randomly assigned to experimental and control groups before they were four days old, consisted of infants who were on ventilators for severe RDS. Twenty infants were tested with a new neurobehavioral assessment procedure when they were between 34 and 35 weeks conceptional age. The examiner, a pediatric neurologist, was unaware of the group status of the subjects he examined. The results showed that infants in the experimental group performed significantly better in attending and pursuing animate and inanimate visual and auditory stimuli, demonstrated more mature spontaneous motor behavior, showed significantly fewer signs of irritability and/or hypertonicity and were more than twice as often in the visually alert, inactive state. The assessment procedure, which can be used for longitudinal evaluation of infants ranging between 24 and 36 weeks conceptional age, shows promise of becoming generally useful as a research instrument. Our preliminary results show that the procedure discriminated between an experimental and control group, that inter-observer reliability was readily established and that test-retest reliability is very high in a number of important areas of neurobehavioral functioning.

### Introduction

Waterbeds for preterm infants were developed in our laboratory as a result of more than a decade of developmental research with human newborns and rat pups (Korner and Thoman 1970, 1972, Gregg et al 1976, Thoman and Korner 1971). This research pointed to the fundamental importance of vestibular-proprioceptive stimulation for very early development. Evidence from the animal literature suggests that deprivation of movement stimulation may lead to serious developmental deficits (Erway 1975, Mason 1968, 1979).

While the fetus experiences a great deal of movement stimulation through its continuous flotation in the amniotic fluid, its own motions, as well as through the pattern of its mother's periodic movements, the preterm infant who resides on a hard and stationary surface in the incubator, experiences relatively little. Our rationale in developing waterbeds for preterm infants was thus to provide compensatory movement stimulation to make up for an experiential deficit.

Our previous studies primarily addressed two issues: one was to test the safety of changing the infant's environment on a 24 hour basis by using waterbeds and the other was to explore the potential short-range clinical benefits that this change in care might bring about. No detrimental effects were found from waterbed flotation, but reduction of apnea and bradycardia was observed in infants diagnosed as having apnea of prematurity (Korner et al 1975, 1978). The present study is our first attempt to assess the developmental effects of waterbed flotation. This was done in the course of a longitudinal study of 56 preterm infants who, at the time of selection, were all on ventilators for severe respiratory distress (RDS).

For the purpose of this study, we were obliged to develop our own assessment procedure, because none was available to test a population as young as ours at weekly intervals. Some of the infants were only 22 to 24 weeks gestational age at birth. Except for the neurological examinations by Saint-Anne Dargassies (1966) and by Amiel-Tison (1974), there were no neurobehavioral assessment procedures for longitudinal testing of small preterm infants. While these examinations are longitudinal neurological assessments for evaluating very young infants, we were unable to use these procedures because they were not designed to discriminate performance at less than two week age intervals. Because it is unlikely that an intervention would produce differences in functioning by as much as two weeks or more, we needed an instrument that potentially could demonstrate more subtle differences in performance between an experimental and control group.

### Material and methods

Description of our longitudinal neurobehavioral assessment procedure for preterm infants (LAPPI)

The prime purpose of our examination was to test the maturity of the infant's functioning. Because of its longitudinal

nature, the procedure relies heavily on items from the *Amiel-Tison* examination (1974). It also includes some *Dubowitz* items (1970) and, for older babies, *Brazelton* (1973) and *Prechtl* (1964) items. Built into the examination are several new features. The procedure consists of three parts which can be used cumulatively in stages tailored to the conceptional ages of the subjects. By virtue of its cumulative structure, the procedure is applicable to infants ranging between 24 and 36 weeks conceptional age, and permits within-subject longitudinal comparison over time. Also, this procedure utilizes a point scoring system that has the potential of discriminating more subtle differences in functioning than do the other two neurobehavioral assessment procedures, which differentiate performance only in two week age intervals. Further, the procedure utilizes a standard sequence of administering the individual scales that makes maximum use of the types of state manipulation necessary to obtain the best possible response from preterm infants. By building into the procedure a standard sequence of rousing, soothing and alerting items, the need to intervene with some infants more than with others is minimized.

The cumulative use of the procedure is geared to the infant's conceptional age. Depending on the infant's age, either Stage I, I and II, or I, II and III are administered. Briefly, the following is a description of the three stages of the examination:

*Stage I* is a very short procedure which assesses with a minimum of manipulation the tone, motor patterns, and the states of the infants. Because Stage I of the examination relies heavily on observational and nonmanipulative items, it can be used with the smallest, intubated, preterm infants, whenever they are sufficiently stable to be examined.

*Stage II* begins with the items of Stage I and is followed by more manipulative items to test passive and active tone, motor reflexes, vestibular responses, sucking and other maturational functions. This examination is suitable for infants 30 weeks conceptional age or older who are in room air.

*Stage III* begins with the scales of Stages I and II of the examination. Vestibular tests consisting of the upright rotation of the infant (*Prechtl* 1964) are then administered to produce alertness (*Korner* and *Thoman* 1970), prior to testing the infant's ability to orient to animate and inanimate visual and auditory stimuli (*Brazelton* 1973). In evaluating the infants' performance on the orientation items, both their best and their usual or modal responses were scored (*Horowitz et al* 1978).

All three parts of the examinations assess the amount, speed, vigor and quality of the infants' spontaneous motor activity; the amount and quality of the infants' crying; the quality and duration of visual alertness noted during the examination; the range and predominance of the infants' states as assessed at standard points during the examination; the infants' stamina or persistence as measured by the percentage of trials to which the infants give any response; and infants' readiness to respond with their best performance on items entailing three trials (this was designed as a measure of how readily the infants warm up to a given task).

Because the infants in our longitudinal study frequently were too unstable to be tested in weekly intervals, we used Stage I of the examination exclusively until they were 33 weeks conceptional age. The longitudinal data from the Stage I part of the examination are currently being used to develop a mathematical model that can deal with the longitudinal char-

acter of the data, irrespective of the varying conceptional ages at which the subjects entered the study and irrespective of the number of weeks the infants could not be examined due to acute illness. Reported in the present paper are the results of the Stage III examination which was used to assess the outcome of our intervention and which was administered just prior to the infants' hospital discharge. Twenty infants, all ranging between 34 and 35 weeks conceptional age, were available for testing at that time.

The following are a few additional details about the Stage III examination. This assessment consists of 98 items. State is assessed 14 times at predetermined places in the sequence of the examination. The administration of the examination takes approximately 35 minutes. Not all the items in the examination require handling of the baby. Many of the items are observational or are ratings derived from the total data gathered (e.g., persistence is derived from the percentage of responses to the trials given; asymmetry of response is judged from the infant's performance on any of the motor or tone items, etc.).

In assessing the infant's states, state definitions were adapted from *Wolff's* (1966) and from those used in our previous studies (*Korner* 1969, 1972):

1. *Quiet sleep.* The infant's eyes are closed and respirations are regular; there is little or no movement except for occasional startles or jerks.
2. *Active sleep.* The infant's eyelids are closed; respirations are irregular and faster than in quiet sleep. Motor activity varies from gentle limb movements to general stirring and writhing. Grimaces and other facial expressions are frequent. Interspersed and recurrent, rapid eye movements (REMs) can be seen through the eyelids.
3. *Drowsiness.* The infant is relatively inactive. The eyes open and close intermittently and have a dull glazed appearance. The eyelids appear to be heavy.
4. *Alert-inactive.* The infant's face is relaxed, does not grimace and the eyes are open and have a bright, shining appearance.
5. *Awake-active.* In this state, the infant frequently engages in diffuse motor activity involving the whole body. The eyes are usually open but not alert. The face may be in a cry face. Respirations are grossly irregular.
6. *Crying.* This state is characterized by crying vocalizations associated with vigorous, diffuse motor activity.
7. *Unclassified state.* The infant's state does not clearly meet the criteria of any of the above states.

#### Sample

The original sample for this study consisted of 56 infants who were on ventilators for severe RDS. These infants were selected because they had a common diagnosis at the outset of the study and also because they represented the largest populations available to us. Even though the subjects were selected for homogeneity in diagnosis, infants with severe RDS frequently develop a variety of complications. The medical course of these infants was therefore quite heterogeneous. The subjects, whose estimated gestational ages ranged from 22 to 33 weeks, were randomly assigned to experimental and control groups before they were four days old. Random assignment was made after seeking consent to include the infant in the study, first from the pediatrician in charge of the care of the baby and then from the parents of the child. Until both

consents were obtained, the group to which the baby was to be randomly assigned was known to no one, including the person obtaining the consent, lest prior knowledge of the group would influence the choices made. Birthweights, gestational ages and Apgar ratings at 1 and at 5 minutes did not differ significantly between the groups. By chance, transport infants were somewhat overrepresented in the control group.

Table I shows the sample characteristics of the infants who were still available for testing when they were between 34 and 35 weeks conceptional age. The birth characteristics of these babies were very similar to those infants who were originally randomly assigned to groups.

Table I Sample characteristics of 20 subjects

	Means	
	Experimental (N=12)	Control (N=8)
Estimated gestational age (in weeks and days)	29-3	27-6
Birthweights (grams)	1309	1149
Weight when examined (grams)	1640	1662
Apgar at 1 minute	4.8	5.4
Apgar at 5 minutes	7.2	7.1

As can be seen from Table I, the mean estimated gestational age of the infants in the experimental group was slightly older (11 days) and the birthweights were slightly higher (160 grams). At the time both groups were tested, their mean weights were almost identical. Mean Apgars at 1 minute and at 5 minutes were very close, with Apgars at 1 minute being slightly higher in the control group. None of the differences between the infants in the experimental and control group were statistically significant. The infants' medical records reflected a great variety of postnatal complications in both groups. While it is difficult to compare the severity of the complications between the two groups, it is noteworthy that the number of hours the infants were intubated and received oxygen did not differ significantly between the groups. At the time of the outcome evaluation which included the assessment of the infants' visual and auditory responsiveness, none showed any signs of retrolental fibroplasia (RLF) and all had passed an auditory screening test.

Sixteen of the 20 infants were born at Stanford. Of the 4 transported infants, 3 belonged to the control group. Infants in the transport group actually were slightly heavier and older at birth. Their weights at the time of the examination and their medical history showed no remarkable differences from the inborn group. The only reason why these transports were still at Stanford when they were between 34 and 35 weeks conceptional age, was that all these infants came from a town where the local hospital was not equipped to care for them.

#### Apparatus

Figure 1 shows the waterbed used in this study. It was built by Narco Air-Shields, Inc., and is a streamlined adaptation of the Stanford designed waterbed for preterm infants.

Anchor points for restraints which are commonly used with intubated infants are provided through holes in a plastic flap which is attached to the sides of the waterbed. The nurses caring for the infants showed great ingenuity in anchoring the

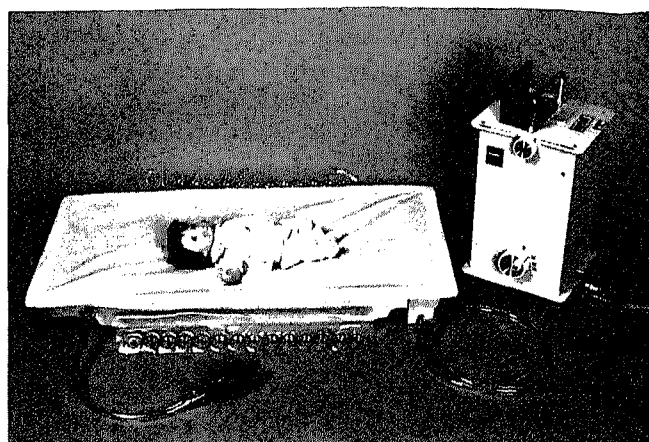


Fig. 1 Waterbed and oscillator

endotracheal tubes on the styrene rim of the waterbed, using small sandbags as supports. Lightweight plastic boards were provided to slide over the waterbed to create a stable surface as needed for such procedures as lumbar punctures, resuscitation, etc. Because many of the infants were nursed on open treatment beds with radiant overhead heaters which, unlike the incubators, do not maintain the waterbed temperature, a half-inch layer of foam was inserted under the sheet to insulate the infant from the waterbed.

Gentle, continuous, head-to-foot, irregular oscillations were provided by the compact electronic oscillator pictured in Figure 1. The amplitude of the oscillations was no more than 2.4 millimeters at the surface of the bed without an infant in place. The rate of oscillations chosen was between 12 and 14 pulses per minute. This rate is within the average range of maternal respirations in the third trimester of pregnancy (Goodlin 1972). For further details regarding the rationale of the stimulus characteristics chosen for the waterbeds, see Korner et al (1975), and Korner (1979).

#### Procedure

All infants in the experimental group were removed from the waterbed at least 48 hours prior to the neurobehavioral assessment. They were examined at the bedside by a pediatric neurologist (T.F.) who was "blind" to the group status of the subjects he examined. The examination was administered approximately 45 minutes prior to a feed to control for the infant's prandial condition and to maximize the chance that the infant would wake up for scales that required waking states. The room temperature at which the infants were examined ranged between 80 and 85 degrees F.

#### Observer reliability

Intermittently, throughout the period the neurobehavioral assessments were made, the inter-observer concurrence of the observations was checked. Paired observers reached an average agreement of 98% within one point of the scaled scores, 88% within 1/2 a point, and identical scores were assigned 71% of the time.

#### Data reduction

In order to reduce the number of comparisons made and the likelihood of "significant" chance findings, the large number

Table II Differences between the experimental and control group means  
13 Comparison, Total N = 20

Variables	Means		t (df 18)	P value
	E	C		
Orientation to visual and auditory stimuli	4.7	2.7	2.99	< .01
Maturity of spontaneous motility	3.3	3.0	2.78	< .02
Readiness to respond with best performance	2.0	1.4	2.76	< .02
Irritability and/or hypertonicity	0.8	2.4	2.73	< .02
Percent of visually alert-inactive state	41.0	19.0	2.18	< .05
Number of optimal responses	31.2	25.6	1.91	< .08

E = experimental group, N = 12  
C = control group, N = 8

of individual items in the examination was reduced to 13 clusters and/or summary scores containing items that had conceptual coherence and face validity. These were:

1. *Active tone*, consisting of 13 items.
2. *Passive tone*, consisting of 7 items.
3. *General maturity*, consisting of 18 items.
4. *Maturity of spontaneous motility*, consisting of 5 items.
5. *Adequacy of vestibular responses*, consisting of 7 items.
6. *Sucking and rooting*, consisting of 3 items.
7. *Orientation to visual and auditory stimuli*, consisting of 10 items. These were the five Brazelton orientation items, scored both for best and modal performance.
8. *Readiness to respond with best performance*, consisting of one score. This score represents the infants' readiness to respond with their best performance averaged over items entailing three trials.
9. *Persistence of response*, consisting of the percentage of trials to which the infants gave any response.
10. *Irritability and/or hypertonicity*, consisting of the total number of extreme scores reflecting irritability and/or hypertonicity over the whole examination.
11. *Number of very immature and/or pathological responses*, consisting of the total number of extreme scores over the whole examination, reflecting infant immaturity and/or pathological responses.
12. *Prevalence of the visually alert, inactive state*, expressed in the percentage of times the infant's state was rated as such within 14 ratings of state.
13. *Number of optimal responses*, consisting of the infant's total number of optimal responses over the whole examination. This was a summary score of how well the infant performed over all functions. Optimal scores were given when the infant performed at the highest one or two points of each scale.

Some of the cluster scores were derived from only one test item (Clusters 8 and 9). Clusters 10-13 were made up of a number of items that were scored dichotomously as either present or absent. The number of positive items were then added up to form a cluster score. Clusters 4, 6 and 7 were made up of several scales, all of which contained the same number of interval scores. The scores of each scale were ordered from the worst to the best response. Cluster scores were derived by averaging the scores of the different scales. Clusters 1-3 and 5 were made up of scales that contained a different number of interval scores. Again, the scores of each scale were ranked so that the lowest score represented the worst and the highest score the best performance. To make these scales comparable, the infants' scores on each scale were first normalized by converting their scores into percentile ranks. To obtain a cluster score, the infants' percentile ranks on the different scales within a cluster were then averaged. For statistical analysis, each of the 13 cluster scores was then compared to ascertain whether or not the differences between the groups were significant.

**Results**

Two-Factor Analyses of Variance for Unbalanced Samples were first used to test for differences between the experimental and control groups and the Stanford and transport infants. This was done to make certain that any differences between the transport and inborn infants would not be mistaken for treatment-control differences. None of the differences between the transports and inborns were significant. Reported in Table II are those clusters in which reliable treatment-control differences were found. Of the 13 comparisons made, five were significant and one was borderline significant.

Table III Day-to-Day stability of clusters and summary scores  
(Spearman Rank Correlations, N = 10)

Active tone	.93	.0001	Reflex smiles	.55	.10
Passive tone	.92	.0001	Persistence	.38	NS
Predominant state (N = 7)	.87	.01	Duskiness	.34	NS
Mottled skin	.85	.005	Spontaneous motility	.30	NS
General maturity	.81	.005	State of visual alertness	.22	NS
Hand-to-mouth coordination	.75	.02	Number of optimal scores	.15	NS
Irritability and/or hypertonicity	.74	.02	Immature and/or pathological responses	.01	NS
Sucking and rooting	.63	.06	Orientation items	-.14	NS
Vestibular responses	.58	.08	Readiness to respond	-.37	NS

As can be seen from Table II, infants in the experimental group performed significantly better on the orientation items. Scoring of this cluster was done by averaging the infants' best and modal responses to each of the *Brazelton* orientation items. The infants in the experimental group also demonstrated more mature spontaneous motor behavior in that the cluster scores composed of five dimensions reflected movements that were more moderate in speed, quantity and amplitude and, at the same time, were more vigorous and more smoothly executed than those of the control group. Infants in the experimental group showed significantly fewer signs of irritability and/or hypertonicity in that their cluster scores reflected fewer incidents and shorter durations of crying, less waking activity, less tremulousness and frenetic activity and less hypertonic resistance to leg extension than did the controls. At the same time, the infants in the experimental group were more than twice as often in the visually alert, inactive state on the 14 occasions that the infants' states were assessed. The experimental group also accumulated more optimal scores over the entire examination, a difference that was of borderline significance ( $p < .08$ ). While all the infants responded with their best performance between the first and second trial on items with three trials, infants from the experimental group consistently tended to be somewhat slower in giving their best response, a trend that was significant.

The most marked difference between the experimental and control groups was in the area of orientation to visual and auditory stimuli. We explored this difference further by assessing whether the experimental group excelled primarily in the visual or auditory responsiveness or in both. Combining the infants' best and modal performance in each modality, we found that, while the difference in visual tracking between the groups approached significance, it was in the auditory modality that the experimental group scored significantly higher (mean E: 4.7; mean C: 3.0;  $t = 2.86$ ;  $DF = 18$ ,  $p < .02$ ). The largest difference between the groups was seen on the orientation item that combined visual and auditory responsiveness (mean E: 5.4; mean C: 2.7;  $t = 4.90$ ;  $DF = 18$ ,  $p < .001$ ).

#### Test-retest reliability of the measures

A sub-population of 10 infants could be tested on the day following the first examination, just before they were discharged from the hospital. The day-to-day stability of their performance is shown in Table III. Included in this table is the test-retest reliability of several important items contained in the assessment procedure which, conceptually, did not fit with any of the clusters. These items were: the infant's tendency to respond with physiologic stress expressed in skin color changes such as the infant becoming dusky or mottled; the predominant state of the infant over the whole examination; the number of spontaneous reflex smiles and hand-to-mouth coordinations observed over the entire examination.

#### Discussion

The results of this study suggest that compensatory vestibular-proprioceptive stimulation as provided by waterbed flotation tended to enhance the neurobehavioral development of preterm infants as measured by a new assessment procedure. Twenty infants, who on recruitment were randomly assigned to an experimental or control group, were assessed when they were between 34 and 35 weeks conceptional age. The infants'

performance was compared on 13 clusters and summary scores. Five group differences were significant and one was borderline significant. This is well beyond what would be expected to occur by chance.

The performance of the infants in the experimental group excelled the most in the capacity to attend and pursue animate and inanimate visual and auditory stimuli. The experimental group thus performed more like full-term infants on the orientation items than did the control group. The experimental group showed more mature motility patterns in that their movements were, on the average, smoother, more vigorous, and more moderate in speed, amplitude, and frequency. The experimental group showed fewer signs of irritability and/or hypertonicity, and was more than twice as often in the visually alert, inactive state when rated at standard points during the administration of the examination. Further, the experimental group tended to accumulate more optimal scores over the whole examination. Overall, the results thus suggest that the infants in the experimental group functioned more maturely and were more available to respond to the environment. The latter may be of special importance at a time when these infants were ready to be discharged from the hospital to go home. Alert and responsive infants have been shown to be more rewarding to their mothers (*Sameroff* 1978) and they thus contribute favorably to establishing their first relationship.

A significant group difference was found in the infants' readiness to respond with their best performance. While all infants responded with their best performance between the first and second trials on items with three trials, infants from the control group were, on the average, consistently a little faster in doing so. While the readiness to warm up to a task seemed like a meaningful variable when we introduced it in our assessment procedure, on testing infants it became apparent that some responded quickly with their best performance and stayed at about this level of functioning on subsequent trials, while others quickly fatigued and declined in their performance. The meaning of this variable is thus difficult to interpret and it should, in the future, either be changed in structure or eliminated from the procedure.

Of particular interest from a theoretical point of view was the finding that response to auditory stimuli by infants in the experimental group was significantly better than that of the control group, whereas in the visual modality, the differences in functioning only approached significance. This pattern fits well with *Gottlieb's* (1971) work on the ontogeny of the maturation of the sensory functions. According to *Gottlieb*, auditory functions mature earlier than the visual functions. This was supported by our finding that none of the infants in either group failed to respond to the auditory items, whereas a few infants failed to respond to the visual tasks. The fact that the infants in the experimental group responded significantly better to auditory and combined auditory and visual stimulation than did the controls, suggests that the intervention may have facilitated the maturation of a function that was ontogenetically the most ready to mature. Also of theoretical interest was the finding that by providing vestibular-proprioceptive stimulation, effects were seen primarily in a different sensory system. Even though our results showed that, on the average, the vestibular responses of the infants in the experimental group were more mature, the group differences were not statistically significant. The finding that there appears to be a transfer of effect from one sensory modality to another is a

confirmation of *Gottlieb's* hypothesis (1971) that stimulation through one sensory modality may affect the maturation of another sensory system. Our finding also confirmed *Neal's* (1967) results which showed that rocking preterm infants significantly enhanced their visual and auditory performance.

Our preliminary results also showed that the neurobehavioral assessment procedure which we had to develop to follow the progress of the young preterm infants in our longitudinal study, shows promise as a potentially useful research instrument for evaluating the outcome of intervention studies. While the assessment of the validity of this instrument for measuring the longitudinal progression of the preterm infant's expanding behavioral repertoire is currently in progress, there are indications from the results of this study that this instrument is sufficiently sensitive to discriminate between an experimental and control group, that interobserver reliability can readily be established, and that test-retest reliability is, in large part, more than adequate. As can be seen from the results presented in Table III, the clusters and summary scores involving motor and tone items, predominant state, general maturity and irritability and/or hypertonicity have very high test-retest reliability. On the other hand, there were some functions which showed very poor day-to-day stability. This pattern of response is not unlike that seen in fullterm infants (*Sameroff* 1978), where the highest test-retest correlations are seen in the motor and tone items and in predominant state and where some of the lowest correlations are found in the important orientation items. In testing infants, both preterm and term, it appears that some infants are uniformly quite unresponsive to sensory stimuli, no matter how hard the examiner tries to elicit a response, while others are highly capable of responding, but cannot be relied upon to perform equally well at all times. The capability of attending and pursuing visual and auditory stimuli, even when highly developed, seems easily compromised by stress reactions just prior to the administration of the orientation items and by minor fluctuations of state.

In concluding, we would like to stress that we consider the findings of this study as preliminary. The available sample was small and composed of infants who were critically ill when recruited and who, after selection, had many serious medical complications. Both the test-retest reliabilities and the suggestive evidence that compensatory vestibular-proprioceptive stimulation enhances the neurobehavioral development of preterm infants, are therefore in need of replication with a larger and healthier sample of premature babies.

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