Early educational and health enrichment at age 3–5 years is associated with increased autonomic and central nervous system arousal and orienting at age 11 years: Evidence from the Mauritius Child Health Project

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Early educational and health enrichment at age 3–5 years is associated with increased autonomic and central nervous system arousal and orienting at age 11 years: Evidence from the Mauritius Child Health Project

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Abstract

Little is known about the effects of environmental enrichment on psychophysiological measures of arousal and orienting in humans. This study tests the hypothesis that early educational and health enrichment is associated with long-term increases in psychophysiological orienting and arousal. One hundred children were experimentally assigned to a two-year enriched nursery school intervention at ages 3–5 years and matched at age 3 years on psychophysiological measures, gender, and ethnicity to 100 comparisons who received the normal educational experience. Children were retested 6–8 years later at age 11 years on skin conductance (SC) and electroencephalogram (EEG) measures of arousal and attention during pre- and postexperimental rest periods and during the continuous performance task. Nursery enrichment was associated with increased SC amplitudes, faster SC rise times, faster SC recovery times, and less slow-wave EEG during both rest and CPT conditions. This is believed to be the first study to show that early environmental enrichment is associated with long-term increases in psychophysiological orienting and arousal in humans. Results draw attention to the important influence of the early environment in shaping later psychophysiological functioning.

Descriptors: Skin conductance, EEG, Orienting, Arousal, Nursery, Nutrition, Health, Educational enrichment, Continuous performance task

Psychophysiological measures of autonomic and central nervous system functioning have been shown to be effective instruments for investigating the development of attention, emotion, and temperament in both infants and children (Fox & Fitzgerald, 1990; Kagan, 1994; Scarpa, Raine, Venables, & Mednick, 1997; Zahn-Waxler, Cole, Welsh, & Fox, 1995). Furthermore, psychophysiological measures have been successfully applied to the field of developmental psychopathology in helping to understand mechanisms underlying the development of behavior problems and antisocial behavior (Cole, Zahn-Waxler, Fox, Usher, & Welsh, 1996; Fox, Schmidt, Calkins, & Rubin, 1996; Raine, Venables, & Williams, 1996; Zahn & Kruesi, 1993). Behavioral genetic studies have demonstrated a significant contribution of genetic factors in shaping psychophysiological functioning (Bouchard, Lykken, McGud, Segal, & Tellegen, 1990; McGuire, Katsanis, Iacono, & McGue, 1998; Venables, 1993) while also indicating environmental influences on electroencephalographic and skin conductance (SC) activity. In contrast, there has been surprisingly little research on the specific ways in which the environment shapes and modulates psychophysiological processes in humans, even though such influences have potential implications for developmental psychophysiology.

Two measures of psychophysiological functioning frequently used in studies of developmental psychophysiology and developmental psychopathology, and which index arousal and attention, are skin conductance and the electroencephalogram (EEG). One

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fundamental form of basic information processing is the orienting reflex. Orienting occurs when preattentive processes make a "call" for additional controlled processing of the stimulus (Ohman, 1979). In this model, orienting reflects a change from automatic to controlled processing as a result of initial preattentive processing of (a) the novelty or (b) the significance of the stimulus (Ohman, 1979, 1986). The amplitude of the SC orienting response to both neutral and more attention-grabbing stimuli has been shown in a series of experimental studies to be a sensitive measure of attentional resource allocation (Dawson, Filion, & Schell, 1989), with reduced SC orienting interpreted as indicating poor resource allocation. Increased SC orienting has been found to correlate positively with indices of working memory (arithmetic and digit span subtests of the WAIS) in two independent samples (Raine, 1987), whereas decline in recall performance for verbal material across trials is closely associated with a decline in SC amplitude (Siddle & Kroese, 1985), again indicating that SC orienting is a valid measure of information processing (Hugdahl, 1995; Venables, 1993).

Temporal characteristics of the SC response have also been related to information processing. Fast SC half-recovery time is thought to reflect attentional processes involving "openness to the environment" and goal-orientated performance (Venables, 1974; Hare, 1978). Boucsein (1992), Janes, Strock, Weeks, and Worland (1985), Levander, Schalling, Lidberg, Bartfai, and Lidberg (1980), and Venables and Fletcher (1981) have all viewed SC half-recovery as a measure of information processing that is largely independent of SC amplitude, although this conclusion is debated in the field (e.g. Edelberg, 1993; Fowles, 1993). There has been less empirical research on SC rise time (time from response onset to peak amplitude), but it has been found to correlate with reduced heart rate acceleration, suggesting that fast rise time reflects an open attentional stance to the environment (Venables, Gartshore, & O'Riordan, 1980).

The EEG is a classic psychophysiological measure of the electrical activity of the brain and cortical arousal. Increased slow-wave activity in particular is thought to reflect an underaroused EEG, as indicated by excessive delta and theta power (Hugdahl, 1995). In children, with increasing age from 7–14 years, theta power decreases and alpha power increases (Tanimura et al. 1996), reflecting maturation of the brain with age. Children with attention deficit hyperactivity disorder have been found to show increased resting theta activity compared to controls (Clarke, Barry, McCarthy, & Selikowitz, 1998), whereas intracarotid sodium amobarbital administration (which depresses central nervous system [CNS] functioning) results in increased delta activity (McMackin, Dubeau, Jones-Gotman, & Gotman, 1997). Thus, increased resting delta and theta power in children are indicative of cortical immaturity/low CNS arousal and characterize children with attention deficits.

The very limited literature on environmental correlates of psychophysiological functioning in children has focused on negative environmental influences on functioning. Three correlational studies have shown that poverty (as indexed by low socioeconomic status) is related to an increase in EEG slow-wave activity in both infants (18–30 months) and children (4 years) in Mexico (Otero, 1994; Otero, Aguirre, Porcayo, & Millan, 1997), with delta power also being increased in low social class 6–22 year olds (Harmony, Marosi, Diaz de Leon, & Becker, 1990). A prospective study by Wadsworth (1976) showed that coming from a broken home prior to age 4 years was associated with lower resting heart rate at age 11 years. Conversely, Hill et al. (1989) showed that 7–15-year-old abused children showed greater heart rate deceleratory responses to neutral visual stimuli, and Hibbs et al. (1992) showed that 11–16-year-old children with parents high on expressed emotionality have increased autonomic arousal. In addition, infants of depressed mothers have been repeatedly shown to have atypical patterns of frontal EEG activity (including reduced left relative to right frontal EEG activity) across diverse social contexts (Dawson et al. 1999; Dawson, Klinger, Panagiotides, & Hill, 1992; Dawson, Panagiotides, Klinger, & Spieker, 1997), and it is conceivable that maternal depression negatively impacts the infant's social environment (e.g., reduced or impaired mother-infant interaction), which in turn influences EEG and autonomic functioning (Dawson, Hessl, & Frey, 1994). Thus, the few limited studies conducted to date suggest that social deprivation is related to autonomic/cortical underarousal and atypical EEG functioning, although the direction of effects are not entirely consistent.

One main difficulty in interpreting this literature is that it is unclear whether the environment causes changes in psychophysiological functioning, or whether third factors correlated with both environment and psychophysiological functioning underlie environment–psychophysiology relationships. Experimental manipulations of the environment are essential for clarifying a cause–effect relationship. A second problem is that, although there has been fairly extensive research showing the beneficial effects of early enriched environment on physiological activity in animals (Mohammed, Henriksson, Soederstroem, & Ebendal, 1993; Paylor, Morrison, Rudy, & Waltrip, 1992), few if any human studies have explored the effects of a *positive* environment on psychophysiological functioning. In particular, there appears to be no studies that have experimentally manipulated the environment to test the causal effect of environmental enrichment on psychophysiological functioning in young children.

To address this issue, we took advantage of data from a longitudinal study of child health in Mauritius (started in 1972) to test the effects of an experimental environmental enrichment conducted at age 3–5 years on SC and EEG measures of arousal and orienting at age 11 years. Originally, this study was set up with funding from the World Health Organization (WHO) with the goal of bringing psychiatrically at-risk children together in nursery schools where "drugs could be used to bring their autonomic functions within normal range" (WHO, 1968, p. 381). Ethical considerations precluded the use of drugs to change autonomic functioning (WHO, 1975, p. 39), and instead of drugs, the research team developed nursery schools to provide an enriched, stimulating experience for an experimental versus matched control group containing psychiatrically unselected children drawn from the community (Venables et al., 1978).

Two competing predictions about the effects of nursery experience on psychophysiological functioning were considered. Animal studies have generally shown that environmental enrichment results in heightened physiological activity (e.g. Mohammed et al., 1993; Paylor et al., 1992), whereas the limited human literature generally indicates negative environmental influences (e.g., low social class) to be associated with reduced arousal. These data, together with the positive effects of some early educational interventions on cognition (Ramey & Ramey, 1998), suggest that environmental enrichment would be associated with increased autonomous nervous system (ANS) and CNS arousal and orienting. Alternatively, because the nursery intervention was similar to Head Start interventions in the United States that have with a few exceptions produced few lasting positive changes (Zigler & Styfco, 1994), a counterhypothesis is that the intervention would result in null findings. This study sets out to test between these two hypotheses using an opportunity sample.

Method

Participants

The larger population from which the experimental and control subjects were drawn consisted of 1,795 children from the island of Mauritius (a country lying in the Indian Ocean between Africa and India). All children born in 1969–1970 in two towns on the island were recruited into the study when aged 3 years between September 1972 and August 1973. The two towns (Vacoas and Quatre Bornes) were chosen to be representative of the ethnic distribution of the whole island. Informed consent was obtained from the mothers of the participants.

The total sample consisted of both boys (51.4%) and girls (48.6%). Ethnic distribution was as follows: Indian 68.7%, Creoles 25.7%, and others (Chinese, English, French, and ethnically unidentified) 5.6%. Creoles are predominantly descendants from slaves brought over by the French between 1670 and 1810 from Madagascar (45%), the East African coast (primarily Mozambique, 40%), India (13%), and West Africa (2%) (Barker, 1996; Filliot, 1974). This group is described by Bowman (1991) as being constituted as follows: 85.2% African or Malagasy origin, 11.1% mixed origin ("gens du couleur"), and 3.7% Franco-Mauritians. The Indian group are largely descendants of indentured laborers brought over by the English after slavery was abolished in 1835, and constitute Hindus (from northern India, especially Bihar and Uttar Pradesh), Tamils (Madras), and Muslims (Gangetic plain of north India, and west India) (Bowman, 1991). Census data for the island as a whole indicated 66% Indian, 29% Creole, and 5% other, indicating that the study largely achieved its goal of sampling a population representative in sex and ethnicity.

From this larger sample, 100 Nursery (entering the experimental nursery schools) and 100 matched Comparisons (entering traditional Mauritian petites ecoles) were selected to evaluate the effects of the experimental environmental enrichment conducted at ages 3–5 years on age 11 psychophysiological functioning. Selection was made by the experimenters solely on the basis of electrodermal functioning (amplitude, frequency, and half-recovery data) at age 3 years with no input from parents or other sources (Venables, 1978); all parents of the 100 children selected for nursery schooling by the experimenters agreed to participate. Pairs of subjects were carefully matched on a one-to-one basis on (a) sex, (b) ethnicity, and (c) autonomic psychophysiological reactivity measured at age 3 years to an orienting paradigm, with participants being selected to show a range of responding on SC amplitude (including nonresponding and hyperresponding) and half-recovery time (Venables, 1978). Once the 100 pairs had been established, random number tables were used to determined allocation to either the experimental or the control group.

Means and standard deviations for skin conductance level amplitude, and half-recovery time data at age 3 years for the Nursery and Control groups are given in Table 1 and show close matching of the two groups with no significant differences or trends (all p values $> .42$). The two groups had the following composition with respect to sex and ethnicity: Nursery (51% boys and 49% girls; 32% Creole, 38% Hindu, 20% Moslem, 9% Tamil, and 1% Other); Comparisons (49% boys and 51% girls; 30% Creole, 39% Hindu, 23% Moslem, 7% Tamil, and 1% Other). There were no group differences on either sex, chi-square $= 0.08$, $df = 1$, $p > .77$, or ethnicity, chi-square $= 0.5$, $df = 4$, $p > .96$.

Psychophysiological retesting at age 11 was conducted on 93 of the Experimental group and 95 of the Control group. Not all children were assessed because a major cyclone hit the island in December, 1979, destroying over 7,000 homes, and bringing the data collection to a premature end. Data were additionally missing for six subjects on SC due only to equipment failure. From the end of the educational/health intervention at age 5–6 until psychophysiological testing at age 11, there was no differential treatment of the two groups, with both going through the same primary school education that was typical of all Mauritian children.

Table 1. *Initial Matching of Comparison and Nursery Groups on Age 3 Years Electrodermal Activity*

	Comparisons	Nursery	*t*	*p*
SCL	2.87 (1.86)	2.66 (1.86)	.65	.51
Amplitude (OR)	0.099 (0.100)	0.099 (0.125)	.79	.43
Amplitude (DR)	0.252 (0.251)	0.245 (0.235)	.20	.84
Frequency (OR)	2.68 (1.86)	2.47 (1.88)	.79	.43
Half-recovery time (OR)	2.05 (1.39)	2.22 (1.67)	.64	.52
Half-recovery time (DR)	3.07 (1.85)	3.26 (1.93)	.65	.51

Notes. OR = orienting response (75-dB stimuli), DR = defensive response (90-dB stimuli). Measures are averaged across trials.

Experimental Educational and Health Intervention

Overarching goals. Features of the nursery intervention consisted of preschool education, nutrition education and nutritional meals, physical exercise, health screening and referral, parental involvement, remediation of behavioral and learning problems, and home visits to the family. As such, it contained many of the components that have been traditionally required of Head Start programs in the United States (Zigler & Styfco, 1994). Particular emphasis was placed on cognitive development, nutrition and health development, social and emotional development, and parental involvement in the educational and health goals. Included in the philosophical aspirations of the intervention were the promotion of better socialization of the child, the encouragement of imaginative and creative play to foster cognitive development, early identification of and intervention for problem behavior, and a structured daily schedule with varied activities.

Formation of nursery schools. The educational intervention was set up from the end of 1973 to the beginning of 1974 when children were aged 3–4 years and extended over a two-year period until 1975–1976 when the child was aged 5–6 years. Because Mauritius did not have any state nursery education at that time (children entered primary school for the first time at ages 5–6 years), two nursery schools were built, "Red Roses" in Vacoas, and "Forget-Me-Not" in Quatre Bornes, the two towns from which the sample had been originally selected. The success of these two experimental nursery schools and its teachers was such that they became the models upon which the Ministry of Education in Mauritius based its system of nursery education throughout the country in the mid-to-late 1970s (Venables 1989).

Staff levels. The two nursery schools were started and supervised by two experienced Danish kindergarten teachers. These teachers trained and supervised on an ongoing basis the Mauritian student-teachers who taught the children. Each school provided an educational enrichment program to 50 children and was staffed by 7 student teachers (five women, two men), two teaching assistants, one cook, one administrative assistant, and one driver. In addition, one administrative officer served both schools. The teacher/pupil ratio ranged from 1/5.5 to 1/10 depending on the activity being undertaken during the day.

Staff training. The 14 student teachers were recruited from over 200 applicants and represented the different ethnic groups of the island. Student teachers underwent a basic course consisting of the following six components: (1) basic kindergarten knowledge (e.g., administration, involvement of parents, use of toys); (2) psychology (child development from infancy to age 6, methods of observation, childhood behavior problems); (3) physical health (anatomy and physiology, nutrition, hygiene, childhood disorders); (4) social welfare (counseling, social institutions, social legislation in Mauritius); (5) practical kindergarten activities: (a) art materials, (b) handicraft techniques, (c) motoric activities (gymnastics and rhythm activities), (d) drama (puppet theater, mimic games, sense games), (e) outdoor activities; and (6) musical activities (instruments, singing).

Training of student teachers continued throughout the period of intervention and included seminars, lectures, and courses on cognitive stimulation techniques, creativity, language stimulation, special education (including intervention), multimodal stimulation, social welfare, parents in education, methods of teaching, curriculum development, methods of remediation, child development, psychodiagnostics, behavior problems, pediatrics, physiotherapy, and socialization. Training was undertaken by lecturers from the University of Mauritius, British Council teachers from the United Kingdom, and staff of the Mauritius Child Health Project. Teachers logged their daily activities in diaries and submitted to their manager case studies on individual children and additionally conducted project work. On Saturdays, classes were held to increase the teachers' repertoire of skills and educational activities, and teachers visited institutions that interfaced with the nurseries. Every three months, the student teachers wrote critiques of three of their course books. Student teachers were examined by faculty at the Institute of Education to ensure a high level of proficiency.

Introductory first term. In the first term of the first year, the focus was placed on gradually acclimatizing the child to the new nursery environment. Children were familiarized with the new environment, the other children, and the student teachers. Free play was encouraged to facilitate social interaction between the children. Simple educational activities such as encouraging each child to talk about their families and to describe weekend activities took place at this time, gradually building up to the full curriculum by the end of the term.

Structure of the teaching day. After the first term, the daily schedule of activities was as follows:

9:00–9:30: conversation period: the teacher introduced and described concepts such as sadness, independence, milk, teeth, sleep, hygiene, prevention of accidents, love, and money, posing questions to the children to stimulate discussion, with a recapitulation at the end of the week.

9:30–10:00: constructional activities/educational games (e.g., counting exercises, memory games, puzzles, models, construction blocks, drawing, coloring, painting, collage, motoric games).

10:00–10:10: fruit squash.

10:10–10:30: constructional activities/educational games (continued).

10:30–11:30: cognition/drama/trips: object naming and recognition, story-telling, conversation in French, conservation exercises, thematic sessions, exploring sensory modalities, drama and puppet theater, baking and gardening, short-trips.

11:30–12:00: music and singing.

12:00–12:30: lunch.

12:30–2:00: sleeping.

2:00–2:10: milk.

2:10–2:30: structured play/creative skills/physical games: sand play, ball play, climbing, looking after pets, water play, swinging, running, building, musical instruments.

2:30–4:00: continuing outdoor activities, free play, and departure.

Field trips and gardening. In addition to the framework described above, a special feature of the nurseries was the incorporation of field trips and gardening into the curriculum. One short trip was undertaken each week (e.g., visiting father at work, market place, dentist, doctor) and experiences from this trip were incorporated into conversation periods. One long trip was made each month (e.g., seaside, tea factory). These trips were also incorporated into conversation periods and additionally used as material for conceptual learning and the development of thematic sessions. Field trips were further used to educate the children on their environment and the ecological system, and also to help broaden their horizons. Each nursery was also equipped with a garden and gardening tools. Children sowed seeds, grew vegetables, and learnt to identify leaves, flowers, and vegetables. Again, these activities were incorporated into more formal learning exercises in class.

Cognitive component. Verbal skills were encouraged through conversation sessions, singing, practicing simple English and French languages (children were taught in their normal language of Patois Creole), and object identification/naming. *Visuospatial skills* were encouraged with constructional activities (Meccano, Lego, building bricks), jigsaw puzzles, other puzzles, and model building (e.g., roads, villages). *Visuomotor coordination* was developed with the aid of ball games, skipping ropes, climbing, dancing, pegboards, simple musical instruments, and free play. *Creativity* was stimulated through painting, clay, dough, collage, puppet and drama productions, and creative play sessions. *Conceptual skills* were fostered during conservation exercises, number and time-of-day exercises, games (rule learning), conversation sessions, thematic sessions (e.g., learning about other cultures), and field trips. *Memory skills* were encouraged through memory games, recollection of stories from book-reading classes, and end-of-week rehearsal of activities. *Sensation and perception* was promoted with drama sensory games, and also on field trips, gardening, and thematic sessions by drawing attention to texture, taste, smell, sight, and shape of fabrics, plants, and food.

Nutrition and hygiene component. A special feature of the experimental nurseries was the emphasis on health care, basic hygiene, nutrition, and exercise. Children were taught *basic hygiene* *skills* such as how to brush teeth, use of toilets, washing hands before their meals and after toilet use, and the use of handkerchiefs. Children were also taught *healthy eating habits* and the use of their own plate and eating utensils (as opposed to the more frequent practice of eating from a communal plate with hands). A structured *nutritional program* was instituted that included the provision of fruit juice in the morning, a hot main meal at lunchtime (usually consisting of chicken, fish, mutton, or rice, and a fresh salad), and milk in the afternoon. Following lunch, the children slept for 1–1.5 hrs.

Health screening/referral and physical exercise. Medical inspections were made by doctors who visited the nurseries every two months and referred the child to hospital where necessary. Teachers also monitored physical health of the child and referred children with health problems for medical follow-up. A program of *physical exercise* was incorporated into the afternoon session of each day. Nurseries were equipped with climbing frames and skipping ropes, and gym lessons and structured outdoor games were organized.

Social-emotional component. In cognitive-behavioral and socialization terms, an important feature of the experimental schools was the use of *time-out* in place of the more traditional physical punishments for misbehavior, and the provision of one-to-one explanations for why behavior was not appropriate. Particular efforts were made to ensure that individual children were never left on their own or socially isolated. *Conversation sessions* included the discussions of emotion concepts such as sadness and love. *Drama and puppet sessions* were used to enhance the child's emotional sensitivity. *Game sessions* were used to help the children understand the importance of following rules. These sessions were also used to illustrate life problems and how they may be successfully resolved. *Identical dressing* of the children (by provision to the parents of a uniform) was made in an attempt to reduce social divisions among the children.

Programs for slow learners and behavior problems. In addition to normal educational classes, a *remedial program for slow learners* was set up in each nursery so that one-on-one time could be spent with such children. This program was associated with the visits teachers made to parents as described below. Each nursery also had a program geared to deal with children with *social-emotional problems* that was linked to the counseling service (see below).

Home visits and counseling service. Teachers paid *visits to the families* of the children to help establish rapport with the parent, learn more about the childrens' backgrounds, and to discuss any special needs of the child or emerging behavioral problems. A *weekly counseling service* was offered for those parents wishing to discuss problems that the parents were experiencing with their children, including learning disabilities and behavior problems. Parents who made use of the counseling service were also invited to attend regular monthly meetings.

Parental involvement. Parents were encouraged to take active interest and involvement in their child's education in several ways. A *parent-teachers' association* was formed and initially used both to introduce to the parents the philosophy and goals of the nursery intervention, and also to provide a question-and-answer session on practical matters such as the provision of transportation. These meetings were later used to discuss problems arising in the school, including absenteeism and hygiene issues. Parents were encouraged to make *visits to the nurseries* to receive explanations of the daily activities. The help of parents was enlisted at nurseries to facilitate and encourage appropriate behavior of the children, such as drinking milk and toilet training. Parent-teachers meetings were so successful that parents in both towns formed their own *Parents' Committee*, which organized social events around the nurseries including fairs, dinner parties, exhibitions, and dances.

Preparation for transfer to primary schools. In the last term, prior to entry into primary school, primary school teachers came to the nurseries to provide initial primary education to the children and also to familiarize the children with their new teachers. After joining their new primary school, children were visited by their original nursery teacher to help facilitate the transition and overcome problems.

Comparison Group Education

The Comparison group underwent the traditional Mauritian experience, which consisted of attendance at one of the 1,500 petites ecoles or "Dame" schools. In contrast to the purpose-built nursery schools, these kindergartens were privately run and staffed by "petites misses" who were essentially untrained child-minders. Inspection of these schools by an independent schoolteacher observer from England indicates that these units were of poor educational quality and provided traditional and very rudimentary education. The median pupil/teacher ratio was 30/1. The curricula were fundamental and as follows: ABC, writing, and counting (65.9% of units); ABC, counting, and drawing (17.1%), drawing and playing (9.8%); writing only (4.8%); writing and counting (2.4%). The median school day was 5.0 hr, including 1 hr of play. English was practiced in only 17.1% of the units.

Lunch was not provided, with children either returning home for lunch or bringing a packed lunch. Children typically ate bread only (81.8%), rice and bread (15.9%), or rice only (2.3%), but on some occasions would receive no food. No milk was provided. Children at 98.0% of the petites ecoles did not sleep and were observed to be frequently tired. Physical punishment was used in 55.2% of the units. Due to the poor quality of these units, in April, 1977 (i.e., after the intervention period) a major training course was launched to increase the training of the petites misses and the consequent educational quality of the petites ecoles units.

Psychophysiological Testing

All EEG and SC recordings were made using a Grass Model 79 polygraph. All subjects were tested in a sound-insulated, temperature-controlled cubicle in a research-dedicated building in a quiet, residential area of Quatre Borne. A dehumidifier was used to minimize fluctuations in humidity. The temperature in the cubicle was maintained at 30 °C ($SD = 1.44$). This temperature was chosen because pilot work found that the lower temperature commonly used in Western psychophysiological laboratories (20 °C) was too cold for subjects who were used to a high ambient outside temperature, resulting in artificially high levels of electrodermal nonresponding. Data were recorded from the polygraph onto a Racal Store 4 FM tape recorder for off-line analysis.

Skin Conductance

Recording. Skin conductance was recorded from bipolar leads on the medial phalanges of the first and second fingers of the left hand and right hands. A constant voltage system (Venables & Christie,

1973) was used in conjunction with Grass 7P1 preamplifiers and 7DA driver amplifiers. Beckman miniature Ag/AgCl type (4 mm diameter) electrodes were filled with 0.5% KCl in 2% agar-agar as the electrolyte. Prior to testing of each subject, each pair of electrodes were checked for unacceptable levels of bias potential. In addition, a series of calibration pulses were inserted and recorded through both of the SC channels for subsequent scoring to ensure gain equivalence for the two channels.

Stimuli. Full details of the stimulus tape used at age 11 years are given in Venables (1978). Briefly, three classes of tone stimuli were used: (a) six orienting tones of 1000 to 1311 Hz frequency, 75 dB intensity, 25 ms rise time; (b) six synthetic consonant-vowel (CV) speech stimuli, of 85 dB intensity, 5-ms rise time, and 0.36-s duration; and (c) six 90-db stimuli (with frequencies ranging from 500, 4,000, to white noise) 5-ms rise time, and 1-s duration. In all cases, the interstimulus intervals ranged from 30-45 s. Ninety-decibel stimuli were used to elicit defensive responses, whereas CV stimuli were used to elicit responsivity to more meaningful speech-like stimuli. Stimuli were presented against a 55-dB white-noise background.

Data reduction. Digitization of the analogue data took place on a PDP 11/40 computer, with data sampled at 20 Hz. For each stimulus, 500 samples were taken for each hand, representing 5-s pre- and 20-s poststimulus data. Calibration pulses prior to each stimulus allowed calibration of levels and amplitude. SCLs were automatically scored and logged by the computer. Amplitude, latency, rise time, and quarter-recovery were scored by an automated program with the option of a manual override if data were not clean. A latency window of 0.5–3.0 s was used with a minimum amplitude criterion of responses $> .005\ \mu$S. Quarter-recovery time was scored using criteria outlined by Fletcher, Venables, & Mitchell (1982) because it significantly reduces the amount of missing data incurred with the use of half-recovery time, and because it correlates highly (0.84) with half-recovery time.

Key arousal (SCL) measures derived from data reduction were as follows: SCLs averaged over trials to (1) OR stimuli, (2) CV stimuli, and (3) 90-dB stimuli. Similarly, the key derived variables for SC orienting were as follows: averaged amplitudes, rise times, and quarter-recovery times to (1) orienting tones, (2) CV tones, and (3) 90-dB stimuli.

EEG

Recording. EEG was recorded using Beckman silver-silver chloride disc electrodes from bipolar leads T3-P3 and T4-P4 of the International 10–20 system (Jasper, 1958) with Fz as ground. Bipolar leads at more posterior sites were selected to minimize eye movement artifacts in the 11-year-olds. Electrodes were filled with Cambridge electrode jelly (Camjel) and attached using collodion glue. The scalp was cleaned with acetone and abraded to keep all resistances below 5 KΩ. Recordings were made on a Grass Model 79 Polygraph using wide-band AC Grass 7P5 preamplifiers and 7DA DC driver amplifiers with a bandpass of 0.3–100 Hz (−6 dB). EOG was recorded with a Grass Model 7DA driver amplifier and a 7P1 DC amplifier, with bipolar electrodes placed on the supra- and infraorbital ridge of the left eye. For the CPT, the longest time constant of 0.92 s was used.

EEG data reduction. Before A/D conversion, the analogue signal was low pass filtered at 45 Hz (Kemo Variable Type Filter VBF/8). The filtered signal was digitized at a rate of 100 Hz and sampled in epochs of 2.56 s. For each paradigm (beginning rest, end rest, and continuous performance task) 25 artifact-free epochs were sampled, providing a total sample of 64 seconds. A fast Fourier transform (FFT) was applied to each epoch to obtain estimates of spectral power, and power values averaged across all epochs for each condition. Power was summated into 6 frequency bands as follows: delta (0.5–3.5 Hz), theta (3.5–7.5 Hz), alpha 1 (7.5–9.5 Hz), alpha 2 (9.5–12.5 Hz), beta 1 (12.5–17.5 Hz), and beta 2 (17.5–30 Hz).

Continuous Performance Task (CPT)

Stimuli consisted of digits ranging from 1 to 9 presented via a 22.5 mm × 33 mm red, 7-segment LED display unit situated 1 m in front of the child. The display unit was driven by an electronic control system programmed from a random access memory and designed to output trigger pulses (1 V, 50 ms) 200 ms prior to stimulus presentation. The digit “5” was designated as the target stimulus and was presented on 57 trials. The remaining digits were designated as nontargets and were presented on 193 trials in total. The probability of a target was therefore .23. Stimulus presentation was pseudorandomized with the constraint that no more than three consecutive targets could occur. The interstimulus interval was 1.5 s and stimulus display time was 100 ms.

Tasks and Procedure

Order of testing was the same for all subjects.

Rest periods. EEG and SC were recorded in two 5-min rest periods. The first (rest 1) preceded the orienting and CPT paradigms, and the second (rest 2) followed all testing. In both conditions the subject was instructed to relaxed with eyes closed and to keep still.

Orienting. Participants were told that headphones would be placed on them and that after a brief period they would hear a series of sounds. Subjects were to try to keep still and to close their eyes.

Continuous performance task. Participants were told that numbers from 1 to 9 would be presented on the display unit, and that their task was to press the response button (held in the preferred hand) as quickly as possible as soon as they saw the figure “5.” It was stressed that only the number 5 should be responded to and that all other numbers should be ignored. Before the full test procedure, 20 practice trials were given to ensure that the child understood the task. Behavioral data were originally collected but not scored.

Results

Data were analyzed using repeated measures analysis of variance using the multivariate approach (MANOVA; Vasey & Thayer, 1987), and the effect sizes reported are Cohen’s d (Cohen, 1988). Effect sizes of 0.20 are deemed as “small,” 0.50 as “medium,” and 0.80 as “large” (Cohen, 1988). T test comparisons were two tailed in all cases. Means and *SD* for both groups for SC data are shown in Table 2, and for EEG data in Table 3.

Skin Conductance Arousal

Nursery school children showed a significant shift toward increased right-hand arousal relative to Comparisons. A significant Group × Hand interaction, $F(1,181) = 8.8$, $p < .003$, $d = 0.44$,

Table 2. *Means and SD (in Parentheses) for Left- and Right-Hand SC Activity for Comparisons (N = 87) and Nursery (N = 96) Groups to Neutral Tone, (CV) Stimuli, and 90-dB Stimuli*

		Comparisons		Nursery School	
		Left Hand	Right Hand	Left Hand	Right Hand
Skin Conductance	Condition	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Level	Neutral	2.74 (1.45)	2.56 (1.63)	2.71 (1.59)	2.91 (1.78)
	Consonant-Vowel	2.77 (1.62)	2.59 (1.62)	2.85 (1.73)	3.05 (2.03)
	90 dB	2.87 (1.61)	2.65 (1.67)	2.91 (1.79)	3.24 (2.48)
Amplitude	Neutral	0.14 (.15)	0.13 (.014)	0.22 (0.30)	0.21 (0.24)
	Consonant-Vowel	0.35 (0.32)	0.31 (0.27)	0.51 (0.48)	0.49 (0.44)
	90 dB	0.30 (0.29)	0.26 (0.20)	0.52 (0.57)	0.50 (0.50)
Rise Time	Neutral	2.45 (1.10)	2.55 (1.11)	2.13 (0.67)	2.31 (0.67)
	Consonant-Vowel	2.57 (0.94)	2.72 (1.07)	2.38 (0.64)	2.42 (0.72)
	90 dB	2.36 (0.56)	2.38 (0.57)	2.25 (0.69)	2.21 (0.55)
Quarter Recovery	Neutral	1.91 (1.26)	1.91 (1.27)	1.61 (0.85)	1.56 (0.61)
	Consonant-Vowel	2.18 (1.32)	2.17 (1.23)	2.03 (1.15)	2.01 (1.32)
	90 dB	1.93 (0.99)	1.93 (0.88)	1.68 (0.71)	1.69 (0.71)
Latency	Neutral	1.67 (0.35)	1.74 (0.41)	1.62 (0.30)	1.68 (0.39)
	Consonant-Vowel	1.29 (0.30)	1.30 (0.29)	1.23 (0.22)	1.26 (0.28)
	90 dB	1.24 (0.24)	1.25 (0.19)	1.20 (0.24)	1.23 (0.21)

indicated that whereas Comparisons show a trend for right-hand levels to be lower than left, $t = 1.9$, $p < .07$, $d = 0.28$, Nursery children show significantly higher right-hand relative to left SC levels, $t = 2.37$, $p < .02$, $d = 0.35$, and a trend towards higher right SC levels relative to Comparisons, $t = 1.7$, $p < .09$, $d = 0.25$ (see Figure 1). Analysis of SC levels averaged over the three types of stimuli indicated a main effect for Stimulus, $F(2,180) = 4.8$, $p < .01$, $d = 0.32$, indicating that SC levels increased from OR to CV to 90 dB stimuli (see Table 2). No other effects were significant, $p > .28$.

Skin Conductance Orienting

Amplitude. Nursery children showed significantly higher orienting than Comparisons. Analyses showed a main effect for Group, $F(1,181) = 12.5$, $p < .001$, $d = 0.52$, and a Group $\times$ Stimulus interaction, $F(2,180) = 6.3$, $p < .002$, $d = 0.37$. A breakdown of

Table 3. *Means and SD (in Parentheses) for Left and Right Hemisphere EEG Power in Three Experimental Conditions for Comparisons (N = 93) and Nursery (N = 95) Groups*

		Comparisons		Nursery School	
		Left Hemisphere	Right Hemisphere	Left Hemisphere	Right Hemisphere
Test Session	EEG Band	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
Preexperimental Rest	Delta	724.87 (247.85)	613.87 (226.49)	651.69 (233.15)	589.49 (221.58)
	Theta	188.04 (84.44)	202.65 (98.84)	179.83 (87.6)	194.50 (89.01)
	Alpha 1	226.80 (207.22)	273.30 (228.94)	274.17 (290.47)	274.04 (241.30)
	Alpha 2	180.39 (140.10)	222.17 (170.58)	215.02 (178.11)	247.54 (212.40)
	Beta 1	58.22 (27.67)	72.48 (39.05)	62.26 (32.91)	77.21 (59.91)
	Beta 2	22.12 (13.48)	32.48 (27.69)	24.62 (20.83)	34.43 (44.67)
Postexperimental Rest	Delta	754.59 (311.40)	632.35 (232.03)	635.69 (230.99)	606.42 (285.23)
	Theta	188.52 (70.09)	193.81 (80.76)	151.87 (70.90)	164.67 (73.65)
	Alpha 1	247.00 (237.69)	271.73 (237.65)	216.67 (217.24)	237.75 (207.02)
	Alpha 2	187.71 (139.98)	209.79 (153.71)	193.18 (180.61)	211.94 (171.03)
	Beta 1	60.33 (29.98)	76.55 (45.24)	54.02 (30.09)	67.62 (36.55)
	Beta 2	22.92 (14.60)	35.05 (31.19)	23.75 (20.01)	32.15 (26.67)
CPT	Delta	724.87 (247.85)	613.87 (226.49)	651.69 (233.15)	589.49 (221.58)
	Theta	188.04 (84.44)	202.65 (98.84)	179.83 (87.60)	194.50 (89.01)
	Alpha 1	226.80 (207.22)	273.30 (228.94)	274.17 (290.47)	274.04 (241.30)
	Alpha 2	180.39 (140.09)	222.17 (170.58)	215.02 (178.11)	247.54 (212.40)
	Beta 1	58.22 (27.67)	72.48 (39.05)	62.26 (32.91)	77.21 (59.91)
	Beta 2	22.12 (13.48)	32.48 (27.69)	24.62 (20.83)	34.44 (44.67)

Note. CPT = Continuous performance task.

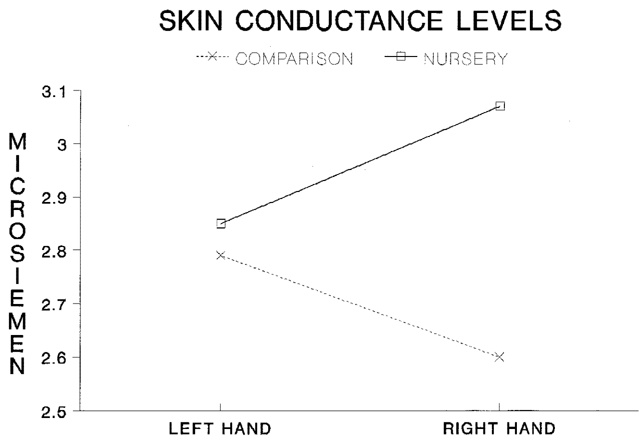

Figure 1. Increased right-hand SC levels in Nursery children.

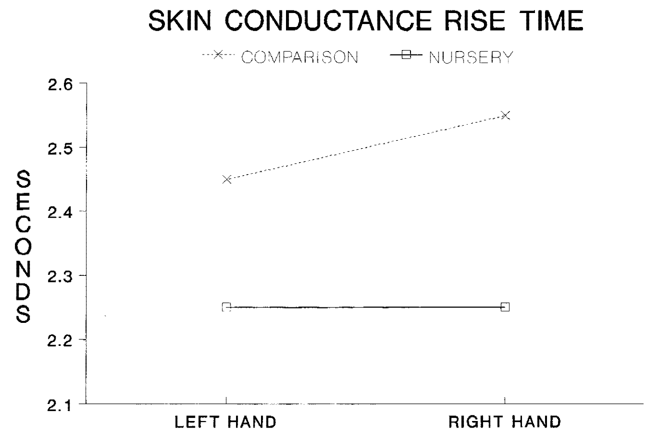

Figure 3. Faster right-hand SC rise times in Nursery children.

this interaction averaging data across hands showed that although the Nursery group showed significantly higher orienting across all stimulus types, these differences were magnified for the 90-dB stimuli, $t = 4.0$, $p < .0001$, $d = 0.59$. As indicated in Figure 2, group differences increased linearly from OR to CV to 90 dB stimuli. No other effects were significant, $p > .11$.

Rise time. Nursery children had a faster rise time than Comparisons, which was maximal on the right hand. Analysis of averaged rise time data showed a main effect for Group, $F(1,168) = 6.3$, $p < .02$, $d = 0.38$, indicating faster rise times in the Nursery group. However, there was also a significant Group × Hand interaction, $F(1,168) = 5.3$, $p < .03$, $d = 0.35$, indicating that the group differences were stronger on the right hand than the left hand (see Figure 3). Specifically, on the right hand, Nursery children had significantly faster rise times than Comparisons to orienting, $t = 3.1$, $df = 175$, $p < .002$, $d = 0.48$, CV, $t = 2.0$, $df = 175$, $p < .05$, $d = 0.31$, and 90-dB stimuli, $t = 2.6$, $df = 175$, $p < .01$, $d = 0.40$. In comparison, on the left hand, Nursery children had faster rise times than Comparisons only for orienting stimuli, $t = 2.4$, $df = 173$, $p < .02$, $d = 0.37$, with only a trend for CV stimuli, $t = 1.7$, $df = 173$, $p < .09$, $d = 0.26$, and no effect for 90-dB stimuli, $p > .26$. The main effect for Hand, $F(1,168) = 3.9$, $p < .05$, $d = 0.30$, indicated faster rise times on left than right hand. There was a main effect for Stimulus, $F(2,167) = 13.6$, $p < .0001$, $d = 0.57$, indicating that rise times to the CV stimuli were longer than either OR, $t = 4.0$, $df = 171$, $p < .0001$, $d = 0.62$, or 90-dB stimuli, $t = 4.5$, $df = 170$, $p < .0001$, $d = 0.69$. No other effects were significant, $p > .71$.

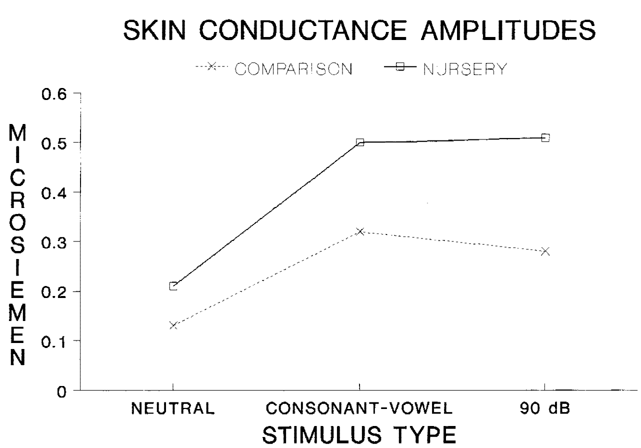

Figure 2. Increased SC orienting in Nursery children with particularly increased responsivity to 9-dB stimuli.

Recovery time. Nursery children had faster recovery times. An analysis ($N = 164$) of averaged quarter recovery showed a main Group effect, $F(1,162) = 3.8$, $p < .05$, $d = 0.31$. As can be seen in Table 2, Nursery children tended to have faster recovery times than Comparisons. The main effect of Stimulus, $F(2,161) = 10.2$, $p < .0001$, $d = 0.50$, indicated that recovery times to CV stimuli were longer than for orienting, $t = 4.8$, $df = 167$, $p < .0001$, $d = 0.75$, or 90-dB stimuli, $t = 3.1$, $df = 165$, $p < .002$, $d = 0.48$. No other effects were significant.

Latency. The main effect for Group was nonsignificant, $F(1,167) = 2.1$, $p > .14$, $d = 0.22$. The significant main effect for Hand, $F(1,167) = 7.3$, $p < .008$, $d = 0.42$, indicated faster latencies on the left hand. The main effect for Stimulus, $F(2,166) = 168.6$, $p < .0001$, $d = 2.0$, indicated that 90-dB latencies were shorter than CV latencies, $t = 3.0$, $df = 170$, $p < .002$, $d = 0.46$, which were shorter than OR latencies, $t = 16.5$, $df = 169$, $p < .0001$, $d = 1.67$. The Hand × Stimulus interaction, $F(2,166) = 4.4$, $p < .013$, $d = 0.32$, indicated that latencies were faster on the left and right hands for OR, $t = 3.3$, $df = 170$, $p < .001$, $d = 0.51$, but not CV, $p > .36$, or 90-dB stimuli, $p > .26$.

Resting EEG

Nursery children had less slow-wave EEG especially at the end of experimentation. For the preexperimental rest, in addition to the main effect for Band, $F(5,182) = 541.0$, $p < .0001$, $d = 3.4$, there was a Hemisphere × Band interaction, $F(5,182) = 8.9$, $p < .0001$, $d = 0.44$, indicating relatively more left than right delta power, but relatively more right than left theta, alpha 1, alpha 2, beta 1, and beta 2 power (see Table 3). There was no effect for Group ($p > .94$) but there was a Group × Hemisphere × Band interaction, $F(5,182) = 2.8$, $p < .02$, $d = 0.24$. As indicated in Figure 4, a breakdown of this effect indicated that group differences were confined to left hemisphere delta power, with Nursery children

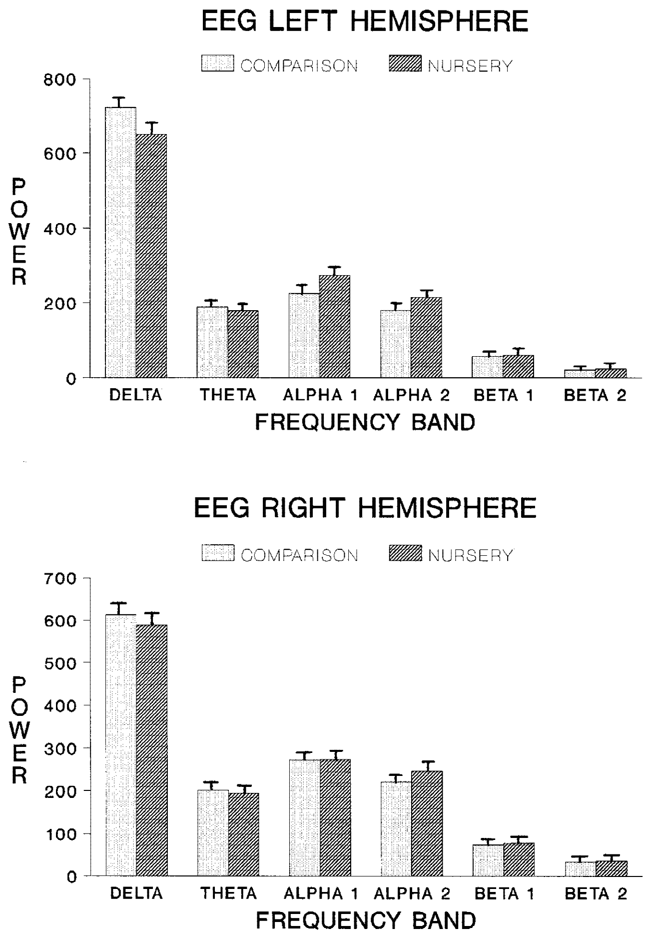

Figure 4. Reduced left hemisphere delta power in Nursery children during the preexperimental rest.

having less left hemisphere delta than Comparisons, $t = 2.1$, $df = 186$, $p < .04$, $d = 0.31$. All other effects were nonsignificant, $p > .12$.

For the postexperimental rest period, there was a main effect for Band, $F(5,182) = 502$, $p < .0001$, $d = 3.30$, and a Hemisphere $\times$ Band interaction, $F(5,182) = 7.0$, $p < .0001$, $d = 0.39$. As indicated in Table 3, there was relatively more left than right delta power, but relatively more right than left theta, alpha 1, alpha 2, beta 1, and beta 2 power. There was a main effect for Group, $F(1,186) = 7.1$, $p < .008$, $d = 0.39$, and a Group $\times$ Band interaction, $F(5,182) = 3.1$, $p < .01$, $d = 0.26$. As indicted in Figure 5, Nursery children had reduced power specifically in the slow-wave EEG bands, specifically in delta, $t = 2.3$, $df = 186$, $p < .03$, $d = 0.34$, and theta, $t = 3.5$, $df = 186$, $p < .001$, $d = 0.51$. No other effects were significant, $p > .24$.

EEG During the Continuous Performance Task

Nursery children has reduced theta activity and reduced right hemisphere EEG voltage. There was no main effect for Group, $p > .15$, but there was a significant Group $\times$ Band interaction, $F(5,182) = 4.6$, $p < .0001$, $d = 0.31$. As indicated in Figure 6, a breakdown of the interaction averaging across hemispheres indicated that Nursery children had significantly less delta power than Comparisons, $t = 2.4$, $df = 186$, $p < .02$, $d = 0.35$, with no significant differences in other bands, $p > .26$. There was also a Group $\times$ Hemisphere

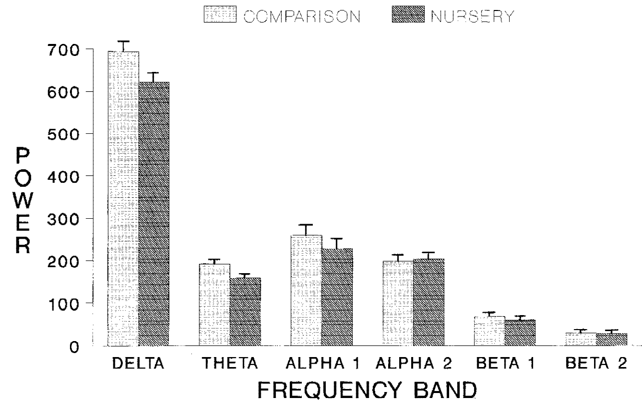

Figure 5. Reduced delta and theta power in Nursery children during the postexperimental rest.

interaction, $F(1,186) = 4.7$, $p < .04$, $d = 0.32$. A breakdown of this interaction (see Figure 7) indicated that although groups had almost identical left hemisphere power, $p > .97$, the Nursery group had reduced power relative to Comparisons over the right hemisphere, $t = 2.6$, $df = 186$, $p < .009$, $d = 0.38$. There was a main effect for Band, $F(5,182) = 287$, $p < .0001$, $d = 2.5$, and a Hemisphere $\times$ Band interaction, $F(5,182) = 17.6$, $p < .0001$, $d = 0.61$. All other effects were nonsignificant, $p > .14$.

Interaction of Age 3 Electrodermal Grouping Status with Nursery Intervention

To assess whether initial electrodermal grouping status interacted with nursery group status in influencing later psychophysiological activity, all analyses reported above were rerun after inclusion of initial electrodermal group status as a factor. All interactions were nonsignificant, $p > .15$.

Discussion

The key finding of this study is that an early environmental enrichment at age 3–5 years was associated with enhanced psychophysiological arousal and orienting at age 11 years. Specifically, the Nursery group compared to the Control group had increased

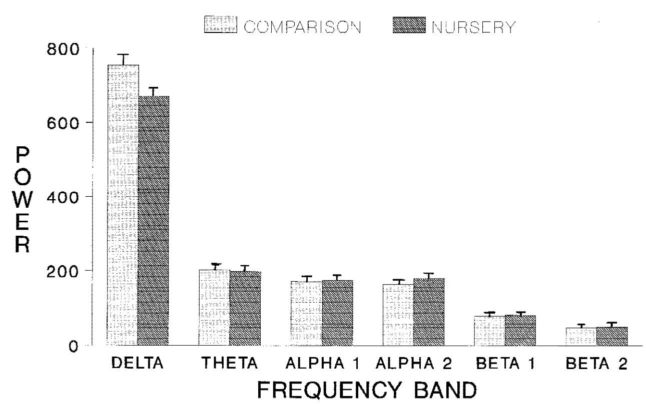

Figure 6. Reduced delta power in Nursery children during the continuous performance task.

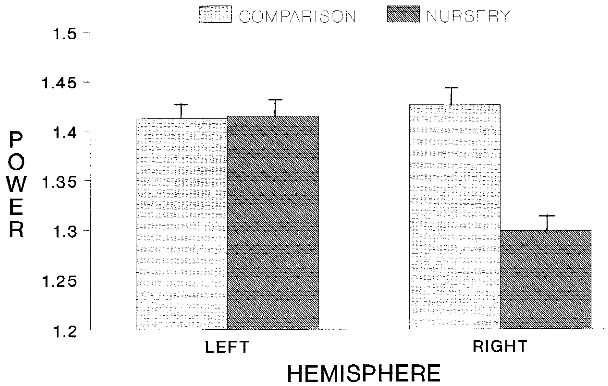

Figure 7. Reduced right hemisphere voltages in Nursery children during the continuous performance task.

SC amplitudes, faster SC rise and recovery times to orienting, speech-like, and aversive stimuli, and less slow-wave EEG during both rest and attention conditions. On average, enriched nursery experience was associated with increases of 61% in SC orienting and 10% in EEG arousal. Effect sizes were small to medium, with sizes of 0.52 for SC orienting, and 0.36 for EEG arousal, and 0.44 for the Group × Hand interaction for SC arousal. In addition these appear to be the first findings to show that an experimental environmental manipulation is associated with long-term increases in basic psychophysiological measures associated with information processing and arousal.

A relatively consistent finding across the three EEG paradigms was a reduction in slow-wave EEG in the Nursery group. The Nursery group had reduced delta and theta power in the postexperimental rest, lower left delta activity in the preexperimental rest period, and reduced delta power in the CPT activation task. These results indicate that nursery experience is associated with less slow-wave EEG and consequently increased cortical activation in both rest and activation conditions. More specifically, the reduction in delta and theta power during rest in the experimental group suggests that the intervention is associated with faster maturation of the cortex, as EEG delta and theta reduction occurs with increased age in children.

Paralleling findings for EEG, nursery experience was associated with significantly increased autonomic arousal as indicated by a significant Group × Hand interaction for SC levels, favoring increased right-hand SC arousal in the Nursery group. In addition, nursery experience was characterized by increased SC amplitudes to orienting, consonant-vowel, and 90-dB stimuli. Enhanced information processing was also indicated by faster SC rise times to stimuli. Faster rise time has been interpreted as indicating openness to the environment (Boucsein, 1992; Venables et al. 1980) and is thus consistent with other SC data in indicating better information processing in Nursery children. Nursery experience also led to shorter SC recovery times, which have also been viewed as reflecting an open psychophysiological attentional stance (Boucsein, 1992; Janes et al. 1985; Levander et al., 1980; Venables & Fletcher, 1981; although see Edelberg, 1993 and Fowles, 1993 for an alternative interpretation). Taken together, therefore, SC measures indicate that the nursery intervention was associated with enhanced information processing of neutral, speech-like, and aversive stimuli.

Nursery experience was associated with lower voltage EEG over the right hemisphere during the CPT, suggesting a more alert and mature right hemisphere. Two autonomic findings also suggested a lateralized effect. There was a reversal of SCL hand asymmetry such that, although Comparisons tended to show higher left- than right-hand arousal, Nursery children showed significantly higher right- than left-hand arousal. Consistent with these data, SC rise time data showed a Group × Hand interaction in which Nursery experience resulted in faster rise time specifically on the right hand. The traditional view of hemisphere–hand connections has emphasized ipsilateral excitation (or contralateral inhibition), and the SC data would thus be consistent with the right hemisphere EEG finding in suggesting relatively greater right hemisphere activation (Lacroix & Comper, 1979; Mangina & Beuzeron-Mangina, 1996). It is possible that components of the nursery intervention that emphasized visuospatial abilities may have contributed to a particular increase in right hemisphere arousal. Brain stimulation research on humans has shown that stimulation of the right amygdala and hippocampus results in increased right hand SC activity (Mangina & Beuzeron-Mangina, 1996), thus suggesting that the increased right- relative to left-hand SC activity in the Nursery group indicates greater right limbic hemisphere activity. On the other hand, the ipsilateral excitation position has been recently challenged, with studies suggesting a contralateral excitation model for electrodermal activity (Davidson, Redio, Smith, Aureille, & Martin, 1992; Hugdahl, 1995; Rippon, 1990). Clearly, any laterality interpretations must be tempered by the caveats that asymmetries in SC are relatively indirect indices of brain asymmetries, and, furthermore, a right hemisphere effect for EEG was shown in activation but not rest conditions.

It must be emphasized that arousal and attention are broad, nonunitary constructs and that directional fractionation was observed in this study. EEG measures did not correlate with SC, with average correlations between delta/theta EEG power and SC variables as follows: levels, .09 (range .18 to −.01), amplitude, .11 (range .23 to −.01), rise time, .05 (range .08 to −.02), and recovery time, .04 (range .21 to −.09). This independence suggests that the findings are robust; the fact that nursery experience impacts statistically independent physiological systems in both rest and activation conditions in the same theoretically consistent direction strengthens the overall results.

This statistical independence also suggests that the nature of the process by which nursery experience impacts psychophysiological functioning is likely to be broad, impacting different psychophysiological processes that are mediated by different multiple brain systems. For example, the EEG variables measured at T3-P3 and T4-P4 in part reflect activity in temporal/parietal cortical regions. Skin conductance orienting is mediated in part by the lateral and ventromedial prefrontal cortex, primary motor cortex, and anterior cingulate gyrus (Fredrikson et al., 1998; Hazlett, Dawson, Buchsbaum, & Nuechterlein, 1993; Hugdahl, 1998; Raine, Reynolds, & Sheard, 1991; Tranel & Damasio, 1994), in addition to subcortical systems that include the hypothalamus, amygdala, and hippocampus (Hugdahl, 1995; Mangina & Beuzeron-Mangina, 1996; Raine et al., 1991). The orienting-arousal system is controlled by the lateral frontal cortex, amygdala, hippocampus, and reticular formation (Dahl, 1996; Hugdahl, 1995), whereas attention is controlled importantly by the thalamus and prefrontal cortex (Benedict et al., 1998; Newman, 1995). Consequently, nursery experience appears to exert a wide impact on brain development because it is associated with improvements in basic psychophysiological processes that are subserved by diverse cortical and subcortical networks.

The environmental enrichment involved numerous components, including better nutrition, physical exercise, and cognitive stimulation. Recent work on rats has shown that physical exercise and environmental enrichment results in the growth of new neurons in the hippocampus (van Praag, Kempermann, & Gage, 1999), a brain area in humans that both lesion and stimulation studies in humans suggest has an important excitatory role for the SC orienting response (Knight, 1996; Mangina & Beuzeron-Mangina, 1996). It is possible, but by no means certain, therefore, that the increase in SC orienting associated with the environmental enrichment may have been produced by the emphasis on physical exercise, which, in animals, increases neural hippocampal growth (van Praag et al. 1999). Alternatively, it is conceivable that increased nutrition in the experimental group contributed to increased SC orienting, as better nutrition has been repeatedly associated with increased cognitive ability in children (Ricciuti, 1993; Sigman & Whaley, 1998). Similarly, educational enrichment has been associated with short-term IQ gains (Ramey & Ramey, 1998), and it is possible that educational enrichment also contributed to heightened SC orienting in the experimental group.

Although enhanced arousal and orienting have been interpreted with respect to their potential benefits in enhancing information processing in the Nursery group, it is conceivable that these psychophysiological changes could have adaptive advantages to the individual other than enhanced information processing. Good autonomic functioning, especially SC orienting, has been argued to be an essential component of good decision making, emotional processing, and adaptive social behavior (Bechara, Damasio, Tranel, & Damasio, 1997; Damasio, 1994). Similarly, high autonomic arousal and orienting have been found to be protective factors against the development of criminal behavior (Brennan et al. 1997; Raine, Venables, & Williams, 1995, 1996). Consequently, the beneficial effects of nutritional, physical, and educational enrichment may extend beyond enhanced information processing into the realm of emotional, behavioral, and social functions, and could be expected to reduce future rates of psychopathology associated with low arousal and orienting.

Finally, three limitations of the study should be highlighted. First, it cannot be determined from this study which component of the intervention (nutritional or educational) is responsible for later changes in psychophysiological functioning. Nevertheless, because pairs of matched subjects were randomly assigned to Nursery versus Control groups, it seems reasonable to conclude that *some* component of the intervention was responsible for the increased arousal and orienting observed six years later. Second, there was some variability in the experience of the control group within the petites ecoles. On the other hand, as outlined in the methods section, there are clear differences in education, nutrition, and health experiences between the experimental and control groups, and variability in the experience of children *within* the control group cannot easily account for the resulting *between*-group differences in psychophysiological arousal and orienting. Third, because the outcome measures are psychophysiological (not behavioral) indices of information processing, no effects of the enrichment on other forms of information processing can be claimed. Nevertheless, we believe this study to be of some significance, because to our knowledge, it is the first to demonstrate that early environmental enrichment is associated with long-term increases in psychophysiological orienting and arousal in humans, with results highlighting the potential importance of the early environment in shaping later psychophysiological functioning.

REFERENCES

Barker, A. J. (1996). *Slavery and Antislavery in Mauritius, 1810-1833.* London: Macmillan Press.

Bechara, A., Damasio, H., Tranel, D., & Damasio, A. R. (1997). Deciding advantageously before knowing the advantageous strategy. *Science*, *275*, 1293–1294.

Benedict, R. H. B., Lockwood, A. H., Shucard, J. L., Schucard, D. W., Wack, D., & Murphy, B. W. (1998). Functional neuroimaging of attention in the auditory modality. *Neuroreport*, *9*, 121–126.

Bouchard, T. J., Lykken, D. T., McGue, M., Segal, N. L. & Tellegen, A. (1990). Sources of human psychological differences: The Minnesota study of twins reared apart. *Science*, *250*, 223–250.

Boucsein, W. (1992). *Electrodermal activity*. New York: Plenum.

Bowman, L. W. (1991). *Mauritius: Democracy and development in the Indian Ocean*. London: Westview Press.

Brennan, P. A., Raine, A., Schulsinger, F., Kirkegaard-Sorensen, L., Knop, J., Hutchings, B., Rosenberg, R., & Mednick, S. A. (1997). Psychophysiological protective factors for male subjects at high risk for criminal behavior. *American Journal of Psychiatry*, *154*, 853–855.

Clarke, A. R., Barry, R. J., McCarthy, R., & Selikowitz, M. (1998). EEG analysis in attention-deficit/hyperactivity disorder: A comparative study of two subtypes. *Psychiatry Research*, *81*, 19–29.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd. ed.). Hillsdale, NJ: Lawrence Erlbaum.

Cole, P. M., Zahn-Waxler, C., Fox, N. A., Usher, B. A., & Welsh, J. D. (1996). Individual differences in emotion regulation and behavior problems in preschool children. *Journal of Abnormal Psychology*, *105*, 518–529.

Dahl, R. E. (1996). The regulation of sleep and arousal: Development and psychopathology. *Development and Psychopathology*, *8*, 3–27.

Damasio, A. R. (1994). *Descartes' Error: Emotion, reason, and the human brain.* New York: Grosset/Putnam.

Davidson, R. A., Fedio, B. D., Smith, E., Aureille, E., & Martin, A. (1992). Lateralized mediation of arousal and habituation: Differential bilateral electrodermal activity in unilateral temporal lobectomy patients. *Neuropsychologia*, *30*, 1053–1063.

Dawson, G., Frey, K., Self, J., Panagiotides, H., Hessl, D., Yamada, E., & Rinaldi, J. (1999). Frontal brain electrical activity in infants of depressed and nondepressed mothers: Relation to variations in infant behavior. *Development and Psychopathology*, *11*, 589–605.

Dawson, G., Hessl, D., & Frey, K. (1994). Social influences of early developing biological and behavioral systems related to risk for affective disorder. *Development and Psychopathology*, *6*, 759–779.

Dawson, G., Klinger, L. G., Panagiotides, H., & Hill, D. (1992). Frontal lobe activity and affective behavior of infants of mothers with depressive symptoms. *Child Development*, *63*, 725–737.

Dawson, G., Panagiotides, H., Klinger, L. G., & Spieker, S. (1997). Infants of depressed and nondepressed mothers exhibit differences in frontal brain electrical activity during the expression of negative emotions. *Developmental Psychology*, *33*, 650–656.

Dawson, M. E., Filion, D. L. & Schell, A. M. (1989). Is elicitation of the autonomic orienting response associated with allocation of processing resources? *Psychophysiology*, *26*, 560–572.

Edelberg, R. (1972). Electrodermal recovery rate, goal-orientation, and aversion. *Psychophysiology*, *9*, 512–520.

Edelberg, R. (1993). Electrodermal mechanisms: A critique of the two-effector hypothesis and a proposed replacement. In J. C. Roy, W. Boucsein, D. C. Fowles, & J. H. Gruzelier (Eds.), *Progress in electrodermal research* (pp. 7–30). New York: Plenum.

Filliot, J. M. (1974). *La traite des esclaves vers les mascareignes au XVIIIe siecle.* Paris: ORSTOM.

Fletcher, R. P., Venables, P. H., & Mitchell, D. A. (1982). Estimation of half from quarter recovery time of SCR. *Psychophysiology*, *19*, 115–116.

Foster, J. J., Eskes, G. A., & Stuss, D. T. (1994). The cognitive neuropsychology of attention—A frontal lobe perspective. *Cognitive Neuropsychology*, *11*, 133–147.

Fowles, D. C. (1993). Electrodermal activity and antisocial behavior: Empirical findings and theoretical issues. In J. C. Roy, W. Boucsein, D. C. Fowles, & J. H. Gruzelier (Eds.), *Progress in electrodermal research* (pp. 223–238). New York: Plenum.

Fox, N. A., & Fitzgerald, H. E. (1990). Autonomic function in infancy. *Merrill-Palmer Quarterly*, *36*, 27–51.

Fox, N. A., Schmidt, L. A., Calkins, S. D., & Rubin, K. H. (1996). The role of frontal activation in the regulation and dysregulation of social behavior during the preschool years. *Development and Psychopathology*, *8*, 89–102.

Fredrikson, M., Furmark, T., Olsson, M. T., Fischer, H., Andersson, J., & Langstrom, B. (1998). Functional neuroanatomical correlates of electrodermal activity: A positron emission topographic study. *Psychophysiology*, *35*, 179–185.

Hare, R. D. (1978). Electrodermal and cardiovascular correlates of psychopathy. In R. D. Hare & D. Schalling (Eds.), *Psychopathic behavior: Approaches to research* (pp. 107–144). New York: Wiley.

Harmony, T., Marosi, E., Diaz de Leon, A. E., & Becker, J. (1990). Effect of sex, psychosocial disadvantages and biological risk factors on EEG maturation. *Electroencephalography & Clinical Neurophysiology*, *75*, 482–491.

Hazlett, E. A., Dawson, M. E., Buchsbaum, M. S., & Nuechterlein, K. H. (1993). Reduced regional brain glucose metabolism assessed by positron emission tomography in electrodermal nonresponder schizophrenics: A pilot study. *Journal of Abnormal Psychology*, *102*, 39–46.

Hibbs, E. D., Zahn, T. P., Hamburger, S. D., Kruesi, M. P. J., & Rapoport, J. L. (1992). Parental expressed emotion and psychophysiological reactivity in disturbed and normal children. *British Journal of Psychiatry*, *160*, 504–510.

Hill, S. D., Bleichfeld, B., Brunstetter, R. D., & Hebert, J. E. (1989). Cognitive and physiological responsiveness of abused children. *Journal of the American Academy of Child & Adolescent Psychiatry*, *28*, 219–224.

Hugdahl, K. (1995). *Psychophysiology: The mind-body perspective.* Cambridge, MA: Harvard University Press.

Hugdahl, K. (1998). Cortical control of human classical conditioning: Autonomic and positron emission tomography data. *Psychophysiology*, *35*, 170–178.

Janes, C. L., Strock, B. D., Weeks, D. G., & Worland, J. (1985). The effect of stimulus significance on skin conductance recovery. *Psychophysiology*, *22*, 138–146.

Jasper, H. H. (1958). Report of committee on methods of clinical examination in EEG: Appendix: the ten-twenty electrode system of the International Federation. *Electroencephalography and Clinical Neurophysiology*, *10*, 371–375.

Kagan, J. (1994). *Galen's prophecy.* New York: Basic Books.

Knight, R. T. (1996). Contribution of human hippocampal region to novelty detection. *Nature*, *383*, 256–259.

Lacroix, J. M., & Comper, P. (1979). Lateralization in the electrodermal system as a function of cognitive/hemispheric manipulation. *Psychophysiology*, *16*, 116–129.

Levander, S. E., Schalling, D. S., Lidberg, L., Bartfai, A., & Lidberg, Y. (1980). Skin conductance recovery time and personality in a group of criminals. *Psychophysiology*, *17*, 105–111.

Mangina, C. A., & Beuzeron-Mangina, J. H. (1996). Direct electrical stimulation of specific human brain structures and bilateral electrodermal activity. *International Journal of Psychophysiolog*, *22*, 1–8.

McGuire, K. A., Katsanis, J., Iacono, W. G., & McGue, M. (1998). Genetic influences on the spontaneous EEG: An of 15-year-old and 17-year-old twins. *Developmental Neuropsychology*, *14*, 7–18.

McMackin, D., Dubeau F., Jones-Gotman, M., & Gotman J. (1997). Assessment of the functional effect of the intracarotid sodium amobarbital procedure using co-registered MRI/HMPAO-SPECT and SEEG. *Brain & Cognition*, *33*, 50–70.

Mohammed, A. H., Henriksson, B. G., Soederstroem, S., & Ebendal, T. (1993). Environmental influences on the central nervous system and their implications for the aging rat. *Behavioral Brain Research*, *57*, 183–191.

Newman, J. (1995). Thalamic contributions to attention and consciousness. *Consciousness and Cognition*, *4*, 172–193.

Ohman, A. (1979). The orienting response, attention, and learning: An information processing perspective. In H. D. Kimmel, E. H. van Olst, & J. F. Orlebeke (Eds.), *The orienting reflex in humans* (pp. 443-471). Hillsdale, NJ: Lawrence Erlbaum.

Ohman, A. (1986). Face the beats and fear the face: Animal and social fears as prototypes for evolutionary analyses of emotion. *Psychophysiology*, *23*, 123–145.

Otero, G. A. (1994). EEG spectral analysis in children with sociocultural handicaps. *International Journal of Neuroscience*, *79*, 213–220.

Otero, G. A., Aguirre, D. M., Porcayo, R., & Millan, L. (1997). Neurobehavioral development of children living in poverty environments. *Revista Interamericana de Psicologia*, *31*, 185–201.

Paylor, R., Morrison, S. K., Rudy, J. W. & Waltrip, L. T. (1992). Brief exposure to an enriched environment improves performance on the Morris water task and increases hippocampal cytosolic protein kinase C activity in young rats. *Behavioral Brain Research*, *52*, 49–59.

Raine, A. (1987). Effect of early environment on electrodermal and cognitive correlates of schizotypy and psychopathy in criminals. *International Journal of Psychophysiology*, *4*, 277–287.

Raine, A., Reynolds, G., & Sheard, C. (1991). Neuroanatomical mediators of electrodermal activity in normal human subjects: A magnetic resonance imaging study. *Psychophysiology*, *28*.

Raine, A., Venables, P. H. & Williams, M. (1995). High autonomic arousal and electrodermal orienting at age 15 years as protective factors against criminal behavior at age 29 years. *American Journal of Psychiatry*, *152*, 1595–1600.

Raine, A., Venables, P.H., & Williams, M. (1996). Better autonomic conditioning and faster electrodermal half-recovery time at age 15 years as possible protective factors against crime at age 29 years. *Developmental Psychology*, *32*, 624-630.

Ramey, C. T., & Ramey, S. L. (1998). Early intervention and early experience. *American Psychologist*, *53*, 109–120.

Ricciuti, H. N. (1993). Nutrition and mental development. *Current Directions in Psychological Science*, *2*, 43–46.

Rippon, G. (1990). Individual differences in electrodermal and electroencephalographic asymmetries. *International Journal of Psychophysiology*, *8*, 309–320.

Scarpa, A., Raine, A., Venables, P. H., & Mednick, S. A. (1997). Heart rate and skin conductance in behaviorally inhibited Mauritian children. *Journal of Abnormal Psychology*, *106*, 182–190.

Siddle, D. A., & Kroese, B. S. (1985). Orienting, habituation, and short-term memory. *Psychophysiology*, *22*, 535–544.

Sigman, M., & Whaley, S. E. (1998). The role of nutrition in the development of intelligence. In U. Neisser (Ed.), *The rising curve: Long-term gains in IQ and related measures* (pp. 155–182). Washington, DC: American Psychological Association.

Tanimura, R., Sonoda, H., & Ogawa, T. (1996). Developmental characteristics of topographic EEG in school-age children using an autoregressive model. *Brain Topography*, *8*, 261–263.

Tranel, D., & Damasio, H. (1994). Neuroanatomical correlates of electrodermal skin conductance responses. Psychophysiology, *31*, 427–438.

van Praag, H., Kempermann G., & Gage, F. H. (1999). Running increases cell proliferation and neurogenesis in the adult mouse dentate gyrus. *Nature Neuroscience*, *2*, 266–270.

Vasey, M. W., & Thayer, J. F. (1987). The continuing problem of false positives in repeated measures ANOVA in psychophysiology: A multivariate solution. *Psychophysiology*, *24*, 479–486.

Venables, P. H. (1974). The recovery limb of the skin conductance response. In S. A. Mednick, F. Schulsinger, J. Higgins, & B. Bell (Eds.), *Genetics, environment and psychopathology* (pp. 117–133). Oxford: North-Holland.

Venables, P. H. (1978). Psychophysiology and psychometrics. *Psychophysiology*, *15*, 302–315.

Venables, P. H. (1989). Childhood markers for adult disorders. *Journal of Child Psychology and Psychiatry*, *30*, 347–364.

Venables, P. H. (1993). Electrodermal indices as markers for the development of schizophrenia. In J. C. Roy, W. Boucsein, D. C. Fowles, & J. H. Gruzelier (Eds.), *Progress in electrodermal research* (pp. 187–206). New York: Plenum.

Venables, P. H. & Christie, M. J. (1973). Mechanisms, instrumentation, recording techniques, and quantification of responses. In W. F. Prokasy & D. C. Raskin (Eds.), *Electrodermal activity in psychological research* (pp. 1–124). New York: Academic Press.

Venables, P. H. & Fletcher, R. P. (1981). The status of skin conductance recovery time: An examination of the Bundy effect. *Psychophysiology*, *18*, 10–16.

Venables, P. H., Gartshore, S. A., & O'Riordan, P. W. (1980). The function of skin conductance response recovery and rise time. *Psychophysiology*, *10*, 1–6.

Venables, P. H., Mednick, S. A., Schulsinger, F., Raman, A. C., Bell, B., Dalais, C., & Fletcher, R. P. (1978). Screening for risk of mental illness.

In G. M. Serban (Ed.), *Cognitive deficits in the development of mental illness*. New York: Brunner/Mazel.
Wadsworth, M. E. J. (1976). Delinquency, pulse rate and early emotional deprivation. *British Journal of Criminology*, *16*, 245–256.
Wechsler, D. (1955). *The Wechsler Adult Intelligence Scale*. New York: Psychological Corporation.
World Health Organization. (1968). *Neurophysiological and behavioral research in psychiatry*, Technical report No. 381. Geneva: Author.
World Health Organization. (1975). *Working group on primary prevention of schizophrenia in high risk groups: Summary report*. Geneva: Author.
Zahn, T. P., & Kruesi, M. J. P. (1993). Autonomic activity in boys with disruptive behavior disorders. *Psychophysiology*, *30*, 605–614.
Zahn-Waxler, C., Cole, P. M., Welsh, J. D., & Fox, N. (1995). Psychophysiological correlates of empathy and prosocial behaviors in preschool children with behavior problems. *Development and Psychopathology*, *7*, 27–48.
Zigler, E., & Styfco, S. J. (1994). Head Start: Criticisms in a constructive context. *American Psychologist*, *49*, 127–132.

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