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CHILD DEVELOPMENT AND THE PHYSICAL ENVIRONMENT

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■ **Abstract** Characteristics of the physical environment that influence child development are discussed. Topics include behavioral toxicology, noise, crowding, housing and neighborhood quality, natural settings, schools, and day care settings. Socioemotional, cognitive, motivation, and psychophysiological outcomes in children and youths are reviewed. Necessary methodological and conceptual advances are introduced as well.

CONTENTS

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Thinking about the ecological context in which human development unfolds has focused on the psychosocial characteristics of children's environments (Bronfenbrenner 1979, 2005), largely ignoring the physical context of human development even though many of the underlying processes that connect context to development are similar for physical and psychosocial environmental factors (Wachs 2000, 2003; Wohlwill & Heft 1987). This article summarizes the role of the physical environment in child development. *Children, Youth and Environment* (http://www.colorado.edu/journals/cye/index.htm) is a primary journal on this topic. Children's physical health is not covered in this chapter because of space limitations (see Wigle 2003 for a recent overview on this topic).

Behavioral Toxicology

LEAD Heavy metals, inorganic solvents, and pesticides commonly found in the ambient environment affect child development. Lead, mercury, and polychlorinated biphenyls (PCBs) are the most studied behavioral toxins, with more limited data available on other heavy metals, solvents, and pesticide exposure. Needleman (1979) showed that accumulated body lead burden was associated with IQ deficits in grade school children. The results of this study have been widely replicated with statistical controls for socioeconomic status (SES), prospective designs, and dose-response functions (Dietrich 2001, Hubbs-Tait et al. 2005, Koger et al. 2005, Wigle 2003). Lead exposure early in life reduces IQ on the order of three points per 10 μg/dl of blood. In a follow-up study of the same children, Needleman et al. (1990) demonstrated greater reading deficits, lower class ranks, and more high school dropouts as a function of early childhood lead exposure. Lead levels below current "safe" thresholds produce IQ deficits in three- to five-year-olds (Canfield et al. 2003) as well as in elementary school–aged children (Bellinger & Needleman 2003, Chiodo et al. 2004). The Chiodo study also uncovered deficits in reaction time, visual-motor integration, and attention. Teachers also reported more inattention and social withdrawal as a function of lead exposure. In a national sample of 6- to 16-year-olds, an inverse relation was uncovered between lead levels lower than 5 μg per deciliter and reading and math (Lanphear et al. 2000).

Toxins can also influence socioemotional development. Child lead poisoning survivors subsequently manifest increased hyperactivity, impulsivity, and aggression following their recovery. Moreover, these adverse outcomes often persist throughout adulthood (Bellinger & Adams 2001, Dietrich et al. 2001, Hubbs-Tait et al. 2005). In Needleman's 1979 study, teacher ratings of students' externalizing behaviors were also related to body lead burden. Preschool children with body lead burdens above 15 μg/dl, independent of SES and maternal mental health status, had elevated behavioral problems (Sciarillo et al. 1992). One- to three-year-olds with higher lead body burdens evidenced greater hyperactivity, distractibility, and lower frustration tolerance with SES controls (Mendelsohn et al. 1998). Furthermore, in the 11-year follow-up by Needleman et al. (1990), juvenile delinquency was associated with lead levels assessed in elementary school. In a different cohort, Needleman and colleagues uncovered a significant association between skeletal lead concentration and both teacher and parent ratings of externalizing symptomology among 11-year-olds (Needleman et al. 1996). Prenatal blood lead levels are also associated (independent of SES) with self-reported and parent-reported delinquency in adolescence (Dietrich et al. 2001).

MERCURY Methyl mercury has well-documented influences on cognitive development among children. Male but not female infants manifested sensory-motor difficulties in relation to maternal mercury body burden (McKeown-Eyssen et al. 1983), and 6-year-olds had diminished IQ scores and language development in relation to maternal mercury exposure (Kjellstrom et al. 1989).

In utero, low-level methyl mercury exposure was unrelated to a series of sensory motor and mental status tests from birth through preschool age (Davidson et al. 1998). A second study of low-level, in utero mercury exposure also uncovered no adverse cognitive development sequelae in one-year-olds, but negative outcomes (hand-eye coordination, motor speed, visual attention, memory, language development, and multiple measures of intelligence) began to emerge by age 7 (Grandjean et al. 1997).

PCBs A series of studies of children prenatally exposed to PCBs from maternal ingestion of Lake Michigan fish has also indicated adverse cognitive developmental impacts (Jacobson & Jacobson 2000). Newborns showed hyporesponsiveness to visual and auditory stimulation. These relations were replicated in a study of lower level, background PCB exposure in North Carolina (Rogan et al. 1986). Among the children in the Jacobson & Jacobson study, deficits in visual recognition memory in 7-month-olds, independent of SES, was linearly related to PCB exposure levels in utero and persisted at a follow-up examination among 4-year-olds. By age 11, these children manifested poorer attention regulation, lower IQ, and reading deficits. In the North Carolina sample, higher prenatal PCB exposure was also related to psychomotor performance at ages 12, 18, and 24 months, but no mental deficiencies were noted (Gladen et al. 1988). This study, however, did not find any linkages between PCB exposure and cognitive development among early-elementary school children (Gladen & Rogan 1991). Work in the Netherlands with 3- to 4-year-olds also revealed cognitive deficits related to PCB exposure (Patandin et al. 1999), and a recent study employing more advanced PCB analytic techniques has largely replicated the Lake Michigan findings in a population on Lake Ontario (Darvill et al. 2000, Stewart et al. 2003).

One additional developmental impact of environmental toxins warrants mention. In a series of studies of families discovering they had been exposed to hazardous wastes in their communities, multiple indices of psychological distress, some lasting years, were revealed (Edelstein 1988, 2002). Symptoms included fear and panic, sleep disturbance, feelings of loss of control and helplessness, fatalism, and elevated family conflict.

With the exception of age at exposure, behavioral toxicology research has not paid sufficient attention to possible moderators of adverse impacts (Hubbs-Tait et al. 2005, Koger et al. 2005). Prenatal low-level lead (<10 μg/dl) effects are milder among higher SES infants, whereas at higher lead levels, SES offers no apparent protective effect (Bellinger 2000, Hubbs-Tait et al. 2005). Prenatal exposure to environmental tobacco smoke in 2-year-olds produces deficits in cognitive development that are accentuated by socioeconomic disadvantage (Rauh et al. 2004). Jacobson & Jacobson (2002) reasoned that social class might protect young children from neurotoxicity because of enhanced parental stimulation. Maternal intellectual stimulation during the early postnatal period partially mediated some of the adverse impacts of PCB exposure on young children's cognitive deficiencies.

Noise

READING The primary sources of noise exposure among children are transportation, music, and other people. Noise is typically measured as sound level with decibels, a logarithmic scale. A change in 10 decibels is perceived as approximately twice as loud. Children exposed to transportation noise (principally aircraft) manifest significant delays in reading. Most of the evidence is cross-sectional, comparing airport noise-impacted and nearby, quiet schools, typically with statistical controls for SES (Evans & Hygge 2005, Evans & Lepore 1993). Reading effects occur at sound levels far below those sufficient to produce hearing damage. Several investigators have also prescreened children for normal hearing. Haines et al. (2002), however, found no relation between airport noise and reading. Cross-sectional findings on noise and reading have been supplemented by prospective longitudinal data (Hygge et al. 2002), intervention studies with sound attenuation (Bronzaft 1981, Cohen et al. 1986, Fed. Interagency Comm. Aviation Noise 2004, Maxwell & Evans 2000), and linear dose-response functions between noise exposure and reading deficits (Green et al. 1982, Lukas et al. 1981, Stansfeld 2005).

Children in higher grades are more adversely impacted by ambient noise exposure (Bronzaft 1981, Bronzaft & McCarthy 1975, FICAN 2004, Green et al. 1982, Lukas et al. 1981, Maser et al. 1978). Children with greater exposure duration, independent of grade levels (Cohen et al. 1973, 1986; FICAN 2004; Lukas et al. 1981) and pre-existing reading deficiencies (Maser et al. 1978), and those exposed to noise both at home and at school, suffer greater adverse reading impacts (Cohen et al. 1986, Lukas et al. 1981). In addition, Wachs (1978) found that male but not female 12- to 14-month-olds in noisier homes had deficits in intellectual functioning. Older male infants (15–23 months of age) were not affected by noise levels in the home.

COGNITIVE PROCESSES Long-term memory, particularly for complex verbal materials, is adversely affected by chronic noise exposure (Evans et al. 1995, Haines et al. 2001a, Hiramatsu et al. 2004, Hygge et al. 2002, Matsui et al. 2004, Stansfeld et al. 2005) as well as acute noise exposure (Hygge 2003, Hygge et al. 2003). Several laboratory studies also show that recall is more sensitive to noise interference than is recognition. Meis and colleagues (1998), comparing simulated and actual aircraft noise exposure in the lab and in the field, found parallel adverse impacts on more complex materials. Haines et al. (2001b), however, found no impacts of chronic noise exposure on prose materials varying in difficulty. Children's incidental memory appears fragile to noise exposure (Heft 1979, Lercher et al. 2003). Short-term memory does not appear sensitive to chronic noise unless it is sufficiently loud as to mask encoding of stimuli (Evans & Hygge 2005). Most noise and cognition studies use visually presented stimuli or employ stimuli not loud enough to mask perception of verbal materials. The effects of noise on children's cognition is likely related to more central information processes. One candidate is allocation of attention. Individuals appear to focus their attention on the more critical, important stimuli during noise exposure, but at the cost of attention to more peripheral information (Hockey 1979, Smith & Jones 1992). Several studies with children have uncovered relations between chronic noise exposure and poorer attention as measured by visual search tasks (e.g., finding a target symbol in a visual array) (Heft 1979, Karsdorf & Klappach 1968, Moch-Sibony 1984, Muller et al. 1998) and an auditory search task in relation to school airport noise exposure (Haines et al. 2001c). Failure to replicate effects of noise on visual search (Evans et al. 1995, Hambrick-Dixon 1986, Matsui et al. 2004) could be explained by temporal parameters. Cohen et al. (1986) found that exposure to airport noise for more than two years led to poorer visual search performance, whereas shorter periods of noise exposure had the opposite effect.

There may be a connection between attention reallocation under noise and adverse effects on reading. Children appear to adapt to chronic noise exposure by ignoring or tuning out auditory stimuli. An unintended consequence of this coping strategy, however, is indiscriminate filtering of auditory stimuli in general, including speech, a fundamental building block of reading. Children with no discernable hearing loss who live under chronic noise are less adept at tasks dependent upon speech perception (Cohen et al. 1973, 1986; Evans et al. 1995; Evans & Maxwell 1997; Hygge et al. 2002; Moch-Sibony 1984). The cognitive impacts of noise may begin early. Six-month-old infants with more difficult temperament revealed cognitive deficits to noise, although easygoing babies did not (Wachs & Gandour 1983).

Noise affects adults who in turn may influence children's cognitive development. Teachers in noisy schools report greater fatigue, annoyance, and less patience than do well-matched counterparts teaching in quieter schools (Evans & Hygge 2005, Kryter 1994). Teaching time is lost as instructors pause during noise bursts, and teaching styles may be altered in noisy settings (Evans & Hygge 2005). Parents in noisier and more chaotic homes are less responsive to their children (Corapci & Wachs 2005, Matheny et al. 1995, Wachs 1989, Wachs & Camli 1991).

PSYCHOPHYSIOLOGY Studies have revealed that chronic exposure to loud noise, typically from airports, elevates blood pressure levels in children (Cohen et al. 1986; Evans et al. 1995, 1998, 2001; Ising et al. 1990a,b; Karagodina et al. 1969; Karsdorf & Klappach 1968; Regecova & Kellcrova 1995; Schmeck & Poustka 1993; Wu et al. 1993). Chronic noise exposure also elevates neuroendocrine stress hormones in children (Evans et al. 1995, 1998, 2001; Ising & Braun 2000; Ising & Ising 2002; Ising et al. 2004; Maschke et al. 1995).

MENTAL HEALTH Community noise exposure is a well-established irritant, producing annoyance and interference with some outdoor activities among adults (Job 1988). Noise reliably suppresses altruistic behavior and can accentuate aggression among adults already primed by violent stimuli and/or provocation (Cohen & Sapacapan 1984). Neither affective responses to noise nor interpersonal behaviors have received much attention in children. A few studies on children and psychological distress have yielded mixed results. One team of investigators found prospective evidence for adverse impacts of chronic airport noise on elementary school children's self-reported psychological well-being (Bullinger et al. 1999). Moreover, the longer children had been exposed to noise after the opening of the new airport, the greater the adverse impacts. Lercher et al. (2002) demonstrated a linear dose-response function between self-reported and teacher ratings of psychological distress and community noise levels, independent of SES. Haines et al. were unable to replicate these findings (2001a,c) but did find a link to elevated hyperactivity (2001b). More recently, a large study (Stansfeld et al. 2004) found the same pattern of no impacts on overall psychological symptoms with the exception of elevated hyperactivity.

MOTIVATION In the first human studies of learned helplessness, adults performed a task under escapable or inescapable loud noise or under quiet conditions. Participants who worked under inescapable noise were less likely to perform successfully a subsequent task to avoid noise than those who had previously worked in escapable noise or quiet (Hiroto 1974, Krantz et al. 1974). Adults are also less persistent on challenging tasks following uncontrollable versus controllable noise exposure or quiet conditions (Glass & Singer 1972). Both types of motivational indices among adults are robust, replicated in many laboratory and field studies (Cohen 1980, Evans & Stecker 2004). Fourth-graders exposed to uncontrollable acute noise (Glass 1977) and children as young as four react similarly to chronic noise (Bullinger et al. 1999; Cohen et al. 1986; Evans et al. 1995, 2001; Maxwell & Evans 2000; Moch-Sibony 1984). Wachs (1987) also demonstrated that one-year-old males but not females in noisier homes exhibited less mastery orientation in a toy play task.

METHODOLOGICAL ISSUES Exposure to poor-quality physical conditions is linked to psychosocial conditions, especially poverty. Moreover, some people may drift into poorer living conditions or be less able to escape from them because of prior physical and/or mental health liabilities. These facts raise questions about the causal role of the physical environment in children's well-being. Most studies of environmental conditions and child development are cross-sectional and thus vulnerable to selection bias plus other unaccounted-for variables. On the other hand, nearly all cross-sectional investigations of the physical environment and child development have incorporated statistical controls for sociodemographic characteristics. Furthermore, several of the associations shown in field studies have been replicated in the laboratory. In addition, a few of the ambient environmental effects on children have been shown in prospective, longitudinal studies and in intervention studies. In a few cases, dose-response curves have been generated between physical conditions and child development. Moreover, for many of the behavioral sequelae of environmental exposure reviewed herein, plausible underlying mechanisms have been theorized and in some instances tested.

Some methodological aspects of environment and child development research can lead to underestimation rather than overestimation of effects. Crude estimates of environmental exposure lead to underestimation of environmental effects. Children's exposures to physical conditions often are not well estimated. Children move in and out of settings daily and over their life course. Most studies of children and the physical environment use residential or school location as the marker for ambient exposure. For some physical conditions (e.g., noise), children are protected by building interiors, whereas for others (e.g., crowding), effects are amplified by buildings. Furthermore, range restriction in environmental exposures can truncate estimates of covariance with developmental outcomes. Studies of residential crowding in North America, for instance, have very little range in household densities, effectively underestimating potential impact on children's development. The practice of statistically controlling for social class in studies of children and the physical environment raises important challenges given the high colinearity between poverty and environmental quality, along with exposure to a host of psychosocial risk factors among children (Evans 2004). Furthermore, duration of exposure to environmental conditions may be as important as intensity, yet few studies incorporate temporal parameters into their designs. Another methodological issue that may cause underestimation of environmental effects is reliance upon insensitive developmental outcomes. Simple cognitive tasks or psychiatric illness are two common examples.

Crowding

INTERPERSONAL BEHAVIORS The number of people per room, rather than areal markers of density (e.g., people per acre), is the critical index of crowding related to human well-being (Baum & Paulus 1987, Evans 2001). A number of studies converge on elevated levels of social withdrawal among preschool children when interacting under more crowded conditions. Several of these studies randomly exposed children to different levels of density. Liddell & Kruger, Loo, and McGrew observed the same child under variable density conditions (Hutt & Vaizy 1966; Liddell & Kruger 1987, 1989; Loo 1972; McGrew 1970; Preiser 1972). Liddell & Kruger (1989) found that home density was positively associated with social withdrawal among children at nursery school. Hutt & Vaizy (1966) noted that withdrawal was more marked among autistic children relative to typical 3- to 8-year-olds. The links between density and withdrawal occur among 10- to 12-year-olds living at home (Evans et al. 1998) and among male 14- to 18-year-olds in prison (Ray et al. 1982).

Parents are less responsive to young children in more crowded homes, irrespective of social class, and these relations begin before 12 months of age (Bradley & Caldwell 1984, Bradley et al. 1994, Evans et al. 1999, Wachs 1989, Wachs & Camli 1991). Reduced parental monitoring of children also occurs in higher density homes (Gove & Hughes 1983, Hassan 1977, Mitchell 1971). Social withdrawal may reflect coping with too much unwanted social interaction.

Controlling for SES, both children and their parents report more strained, negative familial interactions in high-density homes (Baldassare 1981, Bartlett 1998, Booth 1976, Chombart de Lauwe 1961, Fuller et al. 1993, Gasparini 1973, Gove & Hughes 1983, Light 1973, Loo & Ong 1984, Saegert 1982, Youssef et al. 1998). Greater child maltreatment among low-income children was uncovered in more crowded homes (Martin & Walters 1982, Wolock & Horowitz 1979). Punitive parenting mediated relations between residential density and psychological distress in low-income 8- to 10-year-olds (Evans & Saegert 2000). Interpersonal strains between parents and children in crowded homes also accounted in part for negative socioemotional and physiological stress outcomes in 10- to 12-year-olds, irrespective of SES (Evans et al. 1998). Residential crowding also erodes social support among adults over time, which in turn leads to greater psychological distress (Lepore et al. 1991).

Elevated aggression and conflict as well as diminished cooperation occurs among more crowded preschoolers (Bates 1970, Rohe & Nuffer 1977, Rohe & Patterson 1974, Ruopp et al. 1979), elementary school children (Ginsburg & Pollman 1975, Murray 1974, Shapiro 1975), and adolescents (Aiello et al. 1979). Some studies have not found links between density and aggression among young children (Fagot 1977, Smith & Connolly 1977). Liddell & Kruger (1987) found diminished cooperation but no changes in conflict among more crowded nursery school children. Loo's (1972) contradictory results may be because of density levels. In subsequent work with higher density levels, male but not female 5-year-olds in more crowded conditions acted more aggressively (Loo & Kennelly 1978). Another factor in crowding and aggression among children is the number of play resources such as toys or play equipment. Although Smith & Connolly (1977) uncovered no links between density in the nursery school and aggressive behavior, resource availability had a strong impact. Rohe & Patterson (1974) showed that when density was high and resources adequate, little impact was seen on aggression in preschoolers. However, if high density was combined with low resources, aggression increased. Higher ratios of preschoolers to activity areas led to more off-task behavior and marginally less constructive play (Kantrowitz & Evans 2004).

Personal characteristics may buffer the impacts of crowding on aggression. Loo & Kennelly (1978) found that boys but not girls responded negatively to crowded conditions. The same interaction was uncovered in 9- to 17-year-olds (Aiello et al. 1979). Loo (1978a) showed that 5-year-olds reacted with greater aggression than did 10-year-olds to similar density conditions, whereas Aiello found no developmental differences among 9- to 17-year-olds. Typical and brain-damaged children between 3 and 8 years of age reacted with more aggression to crowded conditions, whereas autistic children manifested extreme withdrawal (Hutt & Vaizey 1966).

MENTAL HEALTH Elementary school children who live in more crowded homes, independent of social class, reveal higher levels of neuroticism (Murray 1974), psychological distress (Evans et al. 2001, 2002; Evans & Saegert 2000; Rutter et al. 1974), poorer behavioral adjustment at school (Booth & Johnson 1975; Evans et al.

1998, 2002; Saegert 1982), and lower social and cognitive competency (Shaw & Emery 1988). Goduka et al. (1992), however, found no relations between household crowding and self-concept among 5- to 6-year-olds. Daily problem behaviors among adolescents in a crisis shelter fluctuated in response to the census—as the shelter became more populated, behavioral problems increased (Teare et al. 1995). Several adult studies show associations between residential crowding and psychological distress net of SES, including a prospective, longitudinal study (Lepore et al. 1991).

A few findings indicate moderation of density effects on mental health among children. Evans et al. (2002) found that the adverse effect of crowded housing on both self- and teacher ratings of psychological distress among third- and fourth-graders was exacerbated by residence in larger, multifamily structures. Preschoolers in crowded day care centers had greater behavioral disturbances if they also lived in more crowded homes (Maxwell 1996). Bradley et al. (1994) demonstrated that low-density housing contributed to resilience among socioemotional and cognitive development in low-birth-weight babies at age 3. Consistent with these findings, the elevated psychological distress of 8- to 10-year-olds in more crowded homes is exacerbated by family turmoil (Evans & Saegert 2000). Malnutrition early in life is frequently associated with babies who are more apathetic and less responsive. Rahmanifar and colleagues (1993) found that such effects were accentuated in more crowded homes. Finally, the adverse impact of laboratory crowding on behavioral disturbances among 5-year-olds was exacerbated by pre-existing hyperactivity or anxiety (Loo 1978b).

MOTIVATION Laboratory crowding in seventh- and eighth-graders increased vulnerability to helplessness induction from unsolvable word problems (Rodin 1976) and produced less task persistence among high school students (Sherrod 1974). Sherrod found that when adolescents had perceived control over crowding, the motivational deficits were eliminated. Chronic crowding, net of SES, has been linked to lower motivation in task performance paradigms in children ranging from 6 to 12 years of age (Evans et al. 1998, 2001; Rodin 1976). The Rodin (1976) as well as Evans et al. (2001) studies also uncovered dose-response relations between residential density and helplessness. One study with 10- to 12-year-olds found the crowding-helplessness link among girls only (Evans et al. 1998).

COGNITIVE PROCESSES Given the potential for crowding to disrupt ongoing activities such as studying as well as its potential to interfere with exploration and play activities (Heft 1985), several researchers have scrutinized connections between crowding and cognition. Nearly all of these studies statistically control for SES. Psychomotor development (Widmayer et al. 1990) but not mental development (Gottfried & Gottfried 1984) is related to residential density among 12-month-olds. With maturation, however, mental development becomes negatively related to crowding at 18 and 24 months of age (Gottfried & Gottfried 1984). These same investigators also showed negative relations between residential density and

30-, 36-, and 42-month indices of verbal, perceptual, and quantitative performance, and at 39 months with language development. The IQ scores of children 30 months of age were also negatively associated with residential crowding (Wachs 1978). Preschool-age children living in more crowded homes suffer cognitive deficits in verbal and math ability (Goduka et al. 1992). Using a different achievement index, Maxwell (1996) found no association among preschoolers. Elementary school–aged children from more crowded homes do more poorly on standardized reading tests (Evans et al. 1998, Rutter et al. 1970, Saegert 1982, Wedge & Petzing 1970) and perceive themselves as lower in scholastic competency (Evans & Saegert 2000). Essen et al. (1978) showed these relations in both 7- and 16-year-olds and replicated the effect prospectively with the 16-year-olds. In addition, school performance through high school is negatively associated with residential crowding (Booth 1976, Hassan 1977, Ray et al. 1982), as is educational attainment at age 25 (Conley 2001). Older (18 and 24 months) but not younger (7 to 15 months) infants, especially males (Wachs 1979), living in more crowded homes suffer deficits in object spatial relations and understanding of cause and effect (Wachs 1976, Wachs et al. 1971). Toddlers also show impaired semantic memory in more crowded homes (Gottfried & Gottfried 1984). Kindergarten children from higher density homes perform more poorly on visual search (Heft 1979).

Many school districts in the United States are experiencing severe overcrowding (Campaign Fiscal Equality 1999). Crowding in day care centers was associated with attentional deficits (Maxwell 1996). When kindergarten classrooms were more crowded, children were off task more than when classroom density was reduced. Density was manipulated by altering available classroom space over time with class size held constant (Krantz 1974). Poor nutrition may exacerbate some of the harmful impacts of classroom crowding on young children's behaviors (Grantham-McGregor et al. 1998). Although investigators have not conceptualized class size as a manipulation of density, smaller class sizes in the earlier grades enhance concurrent and subsequent standardized test scores for children, particularly for disadvantaged children (Greenwald et al. 1996, Ehrenberg et al. 2001). In addition, teachers spend less time disciplining children in smaller classes (Ehrenberg et al. 2001).

Studies disentangling family size from density typically find that density, not family size, is the critical variable (Booth 1976, Conley 2001, Evans et al. 1999, Gottfried & Gottfried 1984, Gove & Hughes 1983, Loo & Ong 1984, Saegert 1982, Wachs 1979). Similar conclusions emanate from crowding effects in child-care centers (Legendre 2003) and adolescent crisis shelters (Teare et al. 1995). Laboratory studies holding group size constant and manipulating area also indicate that density is salient. Some of the links between crowding and cognitive development might be caused by changes in parent-child interactions. For example, parents in more crowded homes talk less to their infants (Wachs 1979, Wachs & Camli 1991) and use less sophisticated speech from infancy to two and a half years of age (Evans et al. 1999). Children in crowded homes lack a place to study and find it more difficult to get away from their family to be alone (Gove & Hughes

1983). Children with a place to study in crowded homes suffer fewer cognitive consequences (Michelson 1968, Wachs 1979).

PSYCHOPHYSIOLOGICAL Unfortunately, just a handful of studies have examined physiological stress concomitants of crowding among children. Legendre (2003) found cortisol rise over the morning period in day-care children was greater among children in more crowded conditions. Aiello et al. (1979), in a laboratory study, showed that male but not female skin conductance levels were higher under crowded conditions, and the longer the exposure, the greater the elevation. Evans et al. (1998) found the same gender-by-density interaction for blood pressure among 10- to 12-year-olds in terms of residential crowding. Evans & Saegert (2000), in a study of 8- to 10-year-olds, found that both male and female children in higher density apartments had elevated overnight epinephrine and norepinephrine, especially when there was greater family turmoil in the household. Ray and colleagues (1982) found no adverse impacts of prison crowding on adolescent males, but unreliable blood pressure monitoring procedures were used.

Housing and Neighborhood Quality

HOUSING TYPE Housing type, housing quality, structure and predictability of daily routines, and residential mobility have been investigated in relation to child development. Juveniles in census tracts with larger proportions of multiple-dwelling units, controlling for SES, have greater rates of juvenile delinquency (Gillis 1974), and younger children in high-rise compared with low-rise buildings evidence more behavioral problems (Ineichen & Hooper 1974, Richman 1977, Saegert 1982) and weaker academic performance (Michelson 1968). However, Richman (1974) and Homel & Burns (1989) did not replicate these effects, and Saegert (1982) found they held only for boys. The impact of living on higher floor levels may be stronger for preschoolers than for children in primary school (Oda et al. 1989). This may be explained by greater restrictions on outdoor play behavior and the resulting tension and isolation that occur, particularly for younger mothers home with their children (Churchman & Ginsberg 1984, Gittus 1976, Littlewood & Sale 1972, Ranson 1991, Stewart 1970).

HOUSING QUALITY Several studies indicate potential adverse impacts of housing quality on children's socioemotional development (Blackman et al. 1989, Davie et al. 1972, Evans et al. 2001, Hunt 1990, LeClair & Innes 1997, Tracy et al. 1993). Most of these studies incorporate statistical controls for SES. The results hold for adolescents as well (LeClair & Innes 1997, Obasanjo 1998). Gifford & Lacombe (2004) showed that both teacher and parent ratings of elementary school children's levels of psychological distress were influenced by housing quality, independent of SES. Some studies, however, have uncovered no relation between housing quality and young children's psychological well-being (Greenberg et al. 1999, Kasl et al. 1982). Cognitive development also suffers in relation to housing quality. Teacher ratings of first-graders' (Greenberg et al. 1999) and third-graders' (Michelson 1968) social and academic competency along with standardized test scores are significantly linked to housing quality, controlling for SES. Wilner et al. (1962) found that, among a sample of slum dwellers, families who moved into better housing witnessed significant improvements in elementary school performance compared with well-matched families who remained. A nationally representative cohort of British children living in substandard housing had lower standardized test scores in eighth and eleventh grade (Douglas 1964), with SES controls. Furthermore, the longer the children were exposed to substandard housing, the stronger the association. Adolescents in poor-quality housing in two different samples with good controls for SES manifested more absentmindedness and forgetting (Obasanjo 1998).

MEDIATING PROCESSES An interesting question raised by these findings is, What proximal processes are disrupted by inadequate housing? One candidate is strained, interpersonal relationships. Residents of multifamily compared with single-family homes, controlling for SES, report greater marital and parent-child conflict (Edwards et al. 1982, Moore 1975), and high-rise housing is associated with less socially supportive relationships with neighbors (Evans et al. 2003). Adolescents in poorer quality housing perceive less social support from family members as well as from friends (Obasanjo 1998). Children in poor quality housing get sick more often (primarily upper respiratory infections and physical injuries), which translates into more school absenteeism (Shaw 2004). Some aspects of inadequate housing quality may reflect parental organization and efficiency (e.g., clutter and cleanliness). Dunifon and colleagues (2004) showed that links between residential cleanliness and children's educational attainment in adulthood held net of time devoted to housework by parents.

CHAOS With controls for SES, the regularity of events in the home (e.g., homework and bedtime schedule) (Fiese et al. 2002) as well as levels of unpredictability and confusion in the home (Wachs & Corapci 2005) are related to socioemotional functioning. Children ages 6 to 9 in households with more structure and routines have better academic achievement and fewer behavioral adjustment problems (Brody & Flor 1997). Chaotic home environments are associated with multimethodological indicators of psychological distress among middle school children (Evans et al. 2005). Fisher & Feldman (1998) showed that high school students in households with less cohesion, orderliness, and clarity of rules and roles were more emotionally distressed six years later. Children ages 3 to 4 in more chaotic homes reveal cross-sectional and longitudinal deficits in cognitive development as well (Petrill et al. 2004). Elementary school children in a national study of divorce adjusted better emotionally and performed better at school and on achievement tests if their household had more routine and structure (Guidubaldi et al. 1986). Adolescents in remarried families were more satisfied with family life in households with more regular routines (Henry & Lovelace 1995). Temperament may moderate the relation between family routines and adjustment. Sprunger et al. (1985) found that babies with more regular biological cycles (eat, sleep, cry) benefited more from a structured, predictable household routine.

Explanations for the adverse impacts of chaotic early childhood settings have focused primarily on parent-child relationships and on self-regulatory ability. Families in households with more routines are more cohesive, happier, and have less conflict (Jensen et al. 1983). Parents of infants in more chaotic homes, net of SES, are less responsive and offer fewer learning stimulation opportunities (Corapci & Wachs 2005). Six- to nine-year-olds in more chaotic households, independent of income, have more difficulty self-regulating, which in turn accounts for most of the shared variance between chaos and both academic achievement and socioemotional adjustment (Brody & Flor 1997). Moreover, children in more chaotic preschools are less compliant (Wachs et al. 2004). Adolescents from less cohesive, unstructured homes also engaged in riskier health behaviors as young adults (Fisher & Feldman 1998). One final aspect of housing quality, residential stability, is worth mentioning. Numerous studies reveal that children exposed to more frequent residential relocations, independent of SES, experience worse psychological adjustment (for reviews, see Adam 2004, Humke & Schaefer 1995).

NEIGHBORHOOD Housing is embedded in neighborhoods that also have potential developmental consequences. Several adverse child outcomes are related to residence in economically impoverished neighborhoods with individual-level SES statistical controls (Leventhal & Brooks-Gunn 2000), but the role of physical neighborhood characteristics is unclear. Among the potential developmentally salient physical characteristics of neighborhoods are residential instability, housing quality, noise, crowding, toxic exposure, quality of municipal services, retail services (e.g., bars, liquor stores, nutritional foods), recreational opportunities, including natural settings, street traffic, accessibility of transportation, and the physical quality of both educational and health care facilities (Evans 2004, Macintyre et al. 1993, Wandersman & Nation 1998).

Nine- to eleven-year-olds had greater psychological distress in poorer physical-quality neighborhoods, independent of familial SES (Homel & Burns 1989). Similar neighborhood physical quality and mental health trends, controlling for individual SES levels, have been uncovered among adults in cross-sectional (Steptoe & Feldman 2001) and longitudinal (Dalgard & Tambs 1997) studies. Close proximity to street traffic, in addition to raising the risk of pediatric injuries (Macpherson et al. 1998), is correlated with restrictions in outdoor play among 5-year-olds, smaller social networks for these children, and diminished social and motor skills (Huttenmoser 1995). Households on streets with higher traffic volume interact less with their neighbors relative to those residing on less congested streets (Appleyard & Lintell 1972).

NATURAL SETTINGS Children prefer outdoor settings, particularly those predominated by nature, when queried or observed in naturalistic play activities (Chawla

2002, Hart 1978, Korpela 2002, Moore & Schneekloth 1989). One reason for this may be the wider array of motoric and social play opportunities and greater independent mobility afforded by such spaces (Heft 1988; Kytta 2002, 2004). Children and adults also find natural settings more restorative, reducing cognitive fatigue, and enhancing positive affect (Kaplan & Kaplan 1989, Kaplan & Talbot 1983). A meta-analysis of outdoor learning experiences (e.g., Outward Bound) revealed an effect size of 0.34. Moreover, the longer the outdoor experience, the stronger the benefits (Hattie et al. 1997). Access to nearby nature may be beneficial as well. Girls but not boys residing in public housing more proximate to natural outdoor spaces (i.e., trees, grass) evidenced better attentional and emotional self-regulation ability (Faber Taylor et al. 2002). These same male and female children played more and engaged in more complex play (e.g., creative play) in outdoor spaces containing more nature as compared with spaces that were barren (Faber Taylor et al. 1998). Elementary school children play in more complex ways in natural versus built play spaces (Kirkby 1989). Preschool children engaged in more physically demanding play and developed better motor skills when they played in more natural areas compared with traditional playgrounds (Fjortoft 2004). Play in natural areas also benefits children with attention deficit-hyperactivity disorder (Faber Taylor et al. 2001, Kuo & Faber Taylor 2004). Nearby nature may also enhance attention (Wells 2000) and buffer some of the ill effects of chronic stressor exposure among typical children (Wells & Evans 2003).

Schools and Day Care

SCHOOL SIZE In addition to classroom size (see Crowding section above), school size, the quality of school buildings, the degree of openness in classrooms, and various ambient qualities (e.g., temperature, lighting) have been examined in relation to child outcomes (Lackney 2005). Numerous investigators have uncovered evidence on the benefits of smaller schools. Larger schools have worse standardized test scores (typically with statistical controls for population SES) (for reviews, see Cotton 1996, Greenwald et al. 1996, Howley et al. 2000, Lackney 2004, Schneider 2002). The median effect size for school size on standardized tests is $\beta = 0.035$ (Greenwald et al. 1996). The benefits of smaller schools on achievement may be even greater for low-income students (Cotton 1996, Howley et al. 2000). Smaller schools are also consistently related to more positive student attitudes, better attendance, fewer behavioral problems, greater extracurricular involvement, stronger feelings of connectedness (Cotton 1996), and greater parental involvement in school activities (Schneider 2002).

BUILDING QUALITY In 1995, nearly one third of American children attended public schools in disrepair (Gen. Account. Off. 1995), and 3.5 million children attended schools so dilapidated they were labeled nonoperational (Natl. Cent. Educ. Stat. 1999). Both students and teachers find such conditions demoralizing

(Fine et al. 2004, Schneider 2002). There is a burgeoning literature on school facility quality and student achievement. The largest program of research is by Earthman and colleagues (Al-Enezi 2002, Earthman 1998), and it shows modest but consistent negative correlations between facility quality and standardized test scores, with schoolwide SES controls. Staff ratings of structural (e.g., heating and ventilation, wall and floor conditions) and cosmetic (e.g., painting, maintenance) conditions are related to standardized test scores in high schools and elementary schools. Similar results have been uncovered in other sites (O'Neill & Oates 2001, Schneider 2002). More readily discernable conditions (i.e., cosmetic) appear more salient in relation to test scores. Potential validity concerns from reliance upon staff ratings of building quality are mollified to some extent by equivalent findings in other studies relying upon expert ratings of school buildings (Berner 1993, Branham 2004a, Buckley et al. 2004, Lewis 2000). Branham (2004b) also uncovered an inverse association between building quality and attendance and dropout rates in secondary schools. Comparisons between older and improved elementary school facilities across the state of Georgia (McGuffey & Brown 1978), within the same school district (Bowers & Burkett 1988), using a cohort design before and after moving to a new facility (Phillips 1997), and a before/after comparison of test scores for the same building following renovation (Berry 2002), all reveal improved test scores plus better attendance for the latter study.

OPEN-PLAN DESIGN Open schools with few floor-to-ceiling walls have been compared in studies with traditional, enclosed classrooms. The data on achievement converge on little or no impacts of open- versus traditional-plan facilities (Ahrentzen et al. 1982, Gifford 2002, Gump 1987, Weinstein 1979), with parallel results for indices of self-concept (Giaconia & Hedges 1982). Open-plan schools and day care manifest problems with distraction and off-task time (Cotterell 1984, Gump & Good 1976, Moore 1986, Neill 1982). Noise levels are higher in open-plan schools (Kyzar 1977), and teacher complaints about noise in open-plan schools are common (Bennett et al. 1980, Weinstein 1979). Proximity to unshielded circulation systems also contributes to distraction in both preschools (Greenman 1988, Olds 2001) and elementary schools (Evans & Lovell 1979, Lackney 2004). Systematic modifications of open-plan spaces providing greater demarcation and clearer boundaries between learning areas reduced off-task time and interruptions (Evans & Lovell 1979, Weinstein 1977).

Another common difficulty noted in open school designs is uneven use of space, with large areas of unused space often accompanied by space on the periphery where users are cramped together (Propst 1972, Rivlin & Rothenberg 1976). Clustering of activity areas with clear boundaries appears to relieve this problem and fosters comfort in day-care settings (Greenman 1988, Moore & Lackney 1993, Olds 2001, Sanoff 1995, Weinstein 1987). Fourth-graders showed increased but short-lived use of privacy booths when introduced into their classrooms (Weinstein 1982). Preschoolers frequently used secluded spaces, particularly in more crowded classrooms (Lowry 1993), and elementary school children prefer more enclosed spaces (Ahrentzen & Evans 1984, Gramza 1970, Lowry 1993). Small niches and enclosures plus other design elements (lighting, comfortable/soft furniture, flooring materials) appear to support a more homey, less institutional setting for young children (Ahrentzen et al. 1982, Greenman 1988, Lackney 2004, Moore & Lackney 1993, Olds 2001, Sanoff 1995, Weinstein 1987).

Both teaching style and student personal characteristics can moderate the impacts of school architecture on children. Elementary school children with lower task persistence (Reiss & Dydhalo 1975), lower IQ (Grapko 1972), lower academic achievement orientation, greater external locus of control (Solomon & Kendal 1976), and English as a second language (Traub & Weiss 1974) perform more poorly in open-plan schools. Children in open-plan schools with more traditionally oriented teachers fare worse than those with teachers attuned to open education (Gump 1987).

LIGHTING AND INDOOR CLIMATE Illumination in American schools is sufficiently bright that variations in intensity are unlikely to influence performance. Some work suggests potential benefits of exposure to natural light in schools (Heschong Mahone 1999, Nicklas & Bailey 1997). These studies suffer from methodological flaws. More rigorous work comparing Swedish elementary school children in windowless classrooms with children in classrooms with windows in the winter reveals disturbances in diurnal cortisol rhythms along with concomitant shifts in concentration (Kuller & Linsten 1992).

In addition to light, climatic conditions may influence student comfort and performance in school. Well-controlled laboratory studies with children indicate performance decrements that increase over time and with more demanding task requirements among elementary school children exposed to increased levels of heat (Johansson 1975, Schoer & Shaffran 1973, Wyon et al. 1979). Air-conditioning enhances school performance during the warm season but not during cooler periods (Pepler 1971). Teachers in primary schools rate their pupils as more lethargic and less diligent on hot compared with cooler days (Humphreys 1974).

Environmental contaminants in school buildings, such as mold, allergens, and various chemicals found in cleaning products, combustion byproducts, and building materials, are known respiratory irritants and asthma triggers and have been associated with absenteeism levels among school children (EPA 2003). The impacts of these substances are exacerbated by poorly maintained heating, ventilation, and air-conditioning systems and low ventilation rates. Changes in ventilation rates that affected carbon monoxide levels were associated with both objective (Myhrvold et al. 1996) and subjective (Smedje et al. 1996) indices of attention among school children. Implementation of air cleaning technology in two day care centers reduced particulates, which was accompanied by drops in absenteeism (Rosen & Richardson 1999).

SUMMARY AND CONCLUSIONS

The physical environment can influence child development directly and via adult caregivers. In addition to studies with stronger research designs examining the role of environmental qualities in child development, more work is needed on underlying mechanisms to account for developmental impacts of the physical environment. Prime candidates include parent-child interaction and other interpersonal processes, self-regulation, physiological adaptations, and control beliefs. This work should investigate how the intensity—but also the predictability and continuity of such mechanisms—is altered by the physical environment. In addition to examining the role of age, other moderators warranting attention are gender, temperament, nutrition, intelligence, and prematurity.

We also know little about the role of cumulative exposure to multiple environmental conditions upon children. Childhood exposure to environmental conditions is not random. Low-income children are disproportionately exposed to multiple suboptimal physical and social environmental conditions (Evans 2004) that portend adverse developmental impacts (Repetti et al. 2002, Taylor et al. 1997). Multiple rather than singular risk exposure may be a particularly critical aspect of the adverse developmental effects of childhood poverty.

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