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The physical environment and child development: An international review

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Abstract

A growing body of research in the United States and Western Europe documents significant effects of the physical environment (toxins, pollutants, noise, crowding, chaos, housing, school and neighborhood quality) on children and adolescents' cognitive and socioemotional development. Much less is known about these relations in other contexts, particularly the global South. We thus briefly review the evidence for relations between child development and the physical environment in Western contexts, and discuss some of the known mechanisms behind these relations. We then provide a more extensive review of the research to date outside of Western contexts, with a specific emphasis on research in the global South. Where the research is limited, we highlight relevant data documenting the physical environment conditions experienced by children, and make recommendations for future work. In these recommendations, we highlight the limitations of employing research methodologies developed in Western contexts (Ferguson & Lee, 2013). Finally, we propose a holistic, multidisciplinary and multilevel approach based on Bronfenbrenner's (1979) bioecological model to better understand and reduce the aversive effects of multiple environmental risk factors on the cognitive and socioemotional development of children across the globe.

Keywords

physical environment; child development; global South; chaos; Bronfenbrenner

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The majority of the world's children live in the global South (countries with a low to medium Human Development Index score, including Africa, Central and Latin America, and most of Asia), yet nearly all of the research on relations between the physical environments experienced by children and their cognitive and socioemotional development has taken place within North America and Western Europe. The purpose of this review is to

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call attention to this important gap in the literature and to introduce readers to emerging scholarship on children's environments in the global South. We do not cover work on the physical environment and children's physical health because this literature is extensive (cf., Wigle, 2003). We do, however, discuss physiological indicators of stress in explaining relations between components of the physical environment (e.g., crowding, noise) and children's development.

We organize our review into a discussion of the impacts of toxins and pollutants (heavy metals, pesticides, air and water pollution), noise, crowding, chaos, housing quality, school and childcare quality, and neighborhood quality on the cognitive and socioemotional development of children and adolescents across the globe. For each of these commonly studied physical environment factors, we briefly review what is currently known in Western (North American and Western European) contexts and, where appropriate, discuss some of the known mechanisms linking each factor and children's development. We also identify when the evidence is especially strong for particular influences. We provide a more extensive review of the research to date outside of Western contexts, with a specific emphasis on research in the global South. As we do so, we discuss the strength of the evidence for each influencing factor and, where there are gaps in the extant research, we briefly discuss what we do know (including available statistics) and make recommendations for future work. In these recommendations, we pay particular attention to the limitations of employing the same research methodologies and predicting similar results in previously under-studied contexts (Ferguson & Lee, 2013; Nsamenang, 1992; 2004). We close with a call for a holistic, multidisciplinary and multilevel approach to investigate the impacts of the physical environment on child and adolescent development that employs an extension of Bronfenbrenner's bioecological model (Bronfenbrenner, 1979; Bronfenbrenner & Evans, 2000; Ferguson & Lee, 2013; Ferguson, Kim, Dunn, & Evans, 2009) as a theoretical framework.

Toxins and pollutants

Lead

Needleman et al. (1979) documented the impacts of lead exposure on young (grade school) children's IQ and externalizing behaviors. Since then, many studies have shown that lead significantly impacts the cognitive functioning of children and adolescents in the United States and Western Europe, even when controlling for socioeconomic status (SES) and other confounding factors (Evans, 2006; Hubbs-Tait, Nation, Krebs, & Bellinger, 2005; Koger, Schetteler, & Weiss, 2005, Surkan et al., 2007; Wigle, 2003). More recently, a significant body of research has documented the effects of prenatal and childhood exposure to lead on children's current and prospective developmental functioning in middle-income, newly industrial countries such as China (Wang, Xu, Zhang, & Wang, 1989; Shen et al., 1998; Tang et al., 2008), India (Ahamad et al., 2007; Patel, Mamtani, Thakre, & Kulkarni, 2006), the Philippines (Solon et al., 2008) and Malaysia (Zailina, Junidah, Josephine, & Jamal, 2008). Similar impacts have been documented in Egypt (Mostafa, El-Shahawi, & Mokhtar, 2009), Mexico (Acosta-Saavegra, 2011; Hu et al., 2006; Kordas et al., 2006), Peru (Vega-Dienstmaier et al., 2006) and Bolivia (Ruiz-Castell et al., 2012). Importantly, lead levels in these and other countries in the global South are still high and largely unregulated (Karrari et al., 2012; Shen et al., 1998; Tong, von Schirnding, & Prapamontol, 2000; Walker et al., 2007). In fact, it is estimated that around 40% of children living in economically developing countries have elevated blood lead levels (Walker et al., 2007). In addition, some of the most recent work across the globe has found that even very low levels of lead exposure can be toxic to infants and young children (Canfield et al., 2003; Lanphear, Dietrich, Auinger, & Cox, 2000; Lanphear et al., 2005; Patel et al., 2006; Ruiz-Castell et al., 2012; Zailina et al., 2008).

An important characteristic of many toxins is that even after emissions are eliminated (e.g., removal of lead from gasoline and paint, the banning of the pesticide dichlorodiphenyltrichloroethane – DDT – in North America), they remain in the ecosystem for a very long time (Meyer, Brown, & Falk, 2008). There are several pathways that enable this to occur. Heavy metals settle into the ground, and so lead is still found in the soil and in older houses that were painted prior to the banning of lead over three decades ago in the US. Lead used to be incorporated in plumbing (e.g., sodder) and thus can potentially leach into water supplies. Many toys and other common household products used to be made with lead, a practice that unfortunately continues today in China, for example (Meyer et al., 2008). Another pathway that is perhaps more insidious is the cross-generational transmission of toxins. Some toxins are lipophilic, which means they can be stored in body fat. Thus prior exposure to some toxins, even preconception, can eventually affect the developing organism (Hubbs-Tait et al., 2005; Koger et al., 2005). Finally, even when children themselves are not exposed to toxins, they may be susceptible to indirect exposure via parental exposures (Bouchard et al., 2011). A common example of this is from agricultural workers who absorb pesticides into their skin and/or their clothes (Koger et al., 2005). Tragically, child laborers in many parts of the world remain in direct contact with toxins in agricultural, construction, and manufacturing sectors.

Numerous studies in North America document a dose-response function between body lead level burdens and IQ reductions. These findings have been replicated and demonstrated in prospective research designs, and hold true even when statistical controls rule out alternative explanations such as social class (Evans, 2006; Hubbs-Tait et al., 2005; Koger et al., 2005). For example, Canfield et al. (2003) found that, after controlling for socioeconomic status and other demographic variables, three- to five-year-olds' blood lead levels were significantly negatively associated with IQ, even at levels of exposure below the US regulated 10 μg/dl level. Teachers also report more attentional problems among children who have been exposed to lead (Evans, 2006), and at least one North American study uncovered lead related deficits in attention, reaction time, and visual-motor integration among elementary school aged children (Chiodo et al., 2004).

Estimates of developmental impacts of toxins such as lead may underestimate effects because of genetic differences in vulnerability. As an illustration, Nigg et al. (2008) showed that blood lead levels among 8- to 17-year-old American children were weakly associated overall with hyperactivity and impulsivity. However, these symptoms were significantly more accentuated in the subset of youth with abnormalities in a catecholamine receptor gene.

In the global South, most of the work to date has considered the impacts of lead on general cognitive functioning. Mostafa et al. (2009) showed that nearly half (43%) of a middle-class sample of 6- to 12-year-olds in Cairo had blood lead levels at or above the US Centers for Disease Control and Prevention limit of 10 μg/dl. A large proportion (37%) of these children were diagnosed with cognitive dysfunction. The most significant independent predictor of cognitive dysfunction was a blood lead level at or above 10 μg/dl. Similar to research in other contexts, a 1-μg/dl increase in blood lead level was associated with a two-point decline in IQ. Similarly, in a study of 6.5- to 8.5-year-old urban Malaysian children, Zailina et al. (2008) found that blood lead levels, statistically controlling for parents' education, household income, and other family demographic factors, predicted children's cognitive functioning. Studies in China across a wide age range have documented similar effects (Ling et al., 1989; Shen et al., 1998; Tang et al., 2012), as have recent studies of 6- to 8.5-year-old children in Peru (Vega-Dienstmaier et al., 2005) and Ecuador (Counter, Buchanan, & Ortega, 2008).

The evidence for long-term effects of lead on children's cognitive functioning following prenatal exposure is equally strong. Most recently, Yorifuji et al. (2011) found that, after controlling for SES and other potential covariates, 7- and 14-year-old children living in the Faroe Islands exposed to high levels of lead had deficits in short-term memory and attention compared to children exposed to lower levels of lead. Hu et al. (2006) found that maternal blood lead levels in the first trimester, but not in the second or third trimester, predicted 12- and 24-month-old Mexican infants' general cognitive functioning (Mental Development Index, MDI). These effects were large; a 1-SD increase in first-trimester maternal plasma lead level was associated with a 3.5-point decrease on the MDI. Shen et al. (1998) similarly found that, after statistically controlling for confounding factors such as family SES and parental exposure to lead at work, 3-, 6-, and 12-month-old Shanghai infants with high umbilical cord lead levels received significantly lower MDI scores than those with lower lead levels. Current blood lead levels were not associated with MDI scores. In contrast, Solon et al. (2008) found that 6- to 30-month-old Filipino infants' current blood lead levels significantly predicted their MDI scores. And Patel and colleagues (2006) found that the cord blood lead levels of neonates living in Nagpur, India, significantly predicted autonomic stability and abnormal reflexes. In addition, amongst infants with cord blood lead levels of 5–10 μg/dL, lead levels significantly predicted arousal state regulation, motor functioning and autonomic stability. These findings suggest that lead exposure has important effects on early motor functioning, even at very low levels.

Much less work on behavioral toxins has examined potential adverse socioemotional consequences. However, in Needleman et al.'s (1979) classic Boston school children study of lead and IQ, teachers, blind to the pupil's lead dentine levels, rated children with higher lead burdens with more overt classroom behaviors indicative of behavioral problems such as inhibitory control. Eleven years later, these same children had higher rates of juvenile delinquency (Needleman, Schell, Bellinger, Leviton, & Allred, 1990). Several other studies have shown linkages between early lead exposure and impulsivity, aggression, and hyperactivity in children (Chandramouli, Steer, Ellis, & Emond, 2009; Chiodo et al., 2004; Evans, 2006; Hubbs-Tait et al., 2005).

The research on associations between lead exposure and children's socioemotional functioning outside of the Western world is even more limited. However, in an early study of the impacts of prenatal lead exposure on both cognitive and socioemotional functioning at ages 2, 4 and 7 years in Kosovo, Factor-Livak et al. (1999) found that children's behavior problems were associated with blood lead levels. Similarly, Bao et al. (2009) found that levels of lead and zinc in 7- to 16-year-old Chinese children's hair samples predicted their behavioral functioning. And, in an intervention study in which 6- to 8-year-old children living close to a metal foundry in Torreón, Mexico, were given iron, zinc, both or placebo nutrition supplements over a period of 6 months, Kordas et al. (2006) found that blood lead levels were positively associated with passive off-task behaviors within classroom settings and negatively associated with activity levels during recess.

Mercury

The impacts of exposure to mercury on children's cognitive functioning are well documented. Low-level maternal mercury exposure damages infant sensorimotor functioning (Mckeown-Eyssen, Ruedy, & Neims, 1983) and 6-year-old children's IQ scores and language development (Kjellstrom, Kennedy, Wallis, & Mantell, 1989). In addition, high-level maternal mercury exposure in Japan (Matsumoto, Koya, & Takeuchi, 1965; Takeuchi, 1968) and Iraq (Cox et al., 1989; Cox, Marsh, Myers, & Clarkson, 1995; Marsh et al., 1980) has been reported to adversely affect cognitive and physical prenatal and neonatal development. Two major longitudinal projects, one in the Seychelles (e.g., Myers et al., 2009; Stokes-Riner et al., 2011) and one in the Faroe Islands (e.g., Debes et al., 2006), have documented the adverse impacts of prenatal exposure to mercury from maternal consumption of seafood on young children's cognitive functioning. Little work has documented impacts on socioemotional functioning, suggesting that further work in this area is needed.

In the Seychelles Child Development Study, maternal and child methylmercury (MeHg) levels, children's cognitive and behavioral development, and various demographic factors have been assessed at the ages of 6, 19, 29, 66 and 107 months (Myers et al., 2009) following an assessment of prenatal MeHg exposure. In the Faroe Islands study, postnatal MeHg exposure and children's cognitive and behavioral functioning have been measured at ages 1, 7 and 14 years (Debes et al., 2006), following an assessment of prenatal levels. In both studies, significant relations between prenatal and current MeHg and children's early motor development and later cognitive functioning have been found, although the results are more consistent in the Faroe Islands study (Myers et al., 2009; Stokes-Riner et al., 2011). These differences may have resulted from differential sources of MeHg (primarily fish in the Seychelles; primarily pilot whale meat in the Faroe Islands), as well as lower levels of aquatic food consumption in the Seychelles. Nevertheless, together these projects suggest that young children's motor and cognitive development, and language, attention and memory in particular, are compromised following prenatal exposure to methylmercury.

Polychlorinated biphenyls (PCBs)

Prenatal exposure to polychlorinated biphenyls (PCBs), which are used in the manufacture of vinyl and other plastic compounds, has been linked with children's cognitive and socioemotional functioning (Evans, 2006; Lai et al., 2002; Ribas-Fito, Sala, Kogevinas, & Sunyer, 2001; Williams & Ross, 2007). In contrast, postnatal exposure appears to have few effects, except in the case of severe poisoning (Ribas-Fito et al., 2001). These compounds have been banned in most high-income countries, but they continue to persist in environments across the globe, particularly as they tend to bioaccumulate in fish and other animals (Faroon, Keith, Smith-Simon, & De Rosa, 2003; WHO, 2010).

A series of studies at two different American sites indicate that prenatal PCB exposure due to fish ingestion from polluted lakes has consistent adverse effects on neonatal developmental status (especially hyporesponsiveness) and memory among preschool and elementary school aged children (Evans, 2006). In a more recent set of studies among Native American adolescents, Newman and colleagues (2006; 2009) found that PCB body burden was associated with memory impairments and poorer comprehension/reasoning. This replicates some prior work with preadolescents (Evans, 2006). An important and sobering aspect of these recent data is that, although indigenous populations in both the global North and South are frequently exposed to higher levels of toxins than are other populations, the Native American youths' levels of PCBs were well within the "normal" range found in American children. Most research on PCBs and development has focused on highly exposed populations.

No known research has investigated the impacts of PCB exposure on the cognitive functioning of children living in the global South, and in fact levels of exposure are also largely unknown (Faroon et al., 2003; WHO, 2010). However, presumably the effects would be consistent with those reported in other contexts. This was found to be the case in a longitudinal study assessing Taiwanese children's cognitive and behavioral development every year through age 12 following prenatal exposure to PCBs in contaminated cooking oil (Lai et al., 2002). In comparison to matched unexposed children, children exposed to PCBs had long-term deficits in IQ.

Much less is known about PCB exposure and various aspects of socioemotional development. There may be problems with executive functioning such as attentional control (Evans, 2006; Hubbs-Tait et al., 2005; Koger et al., 2005). And Lai et al. (2002) found that Taiwanese children exposed to high levels of PCBs prenatally exhibited a greater number of externalizing and internalizing symptoms than did matched unexposed children.

One other developmental aspect of toxin exposure and children's maturation worth mentioning is that lower SES contexts appear to accentuate the harmful impacts of toxins on children's development (Evans, 2006). This might occur for several reasons, including chronic stress, levels of cognitive stimulation in the home, co-occurrence of other toxin exposures, co-occurrence of other risk factors, and, for older children, poorer quality school environments.

Pesticides

Research on the developmental impacts of direct residential pesticide exposure or indirect prenatal or occupational exposure (on the skin or clothing of exposed caregivers) is somewhat limited. However, there is an extensive research literature documenting severe impacts of pesticide exposure on both rats and *in vitro* models of the mammalian brain (see, e.g., Aldrige, Meyer, Seidler, & Slotkin, 2005; Jameson, Seidler, & Slotkin, 2007). Since pesticides are neurotoxic agents, they may well have serious effects on the developing brain. Indeed, in a recent review, Jurewicz and Hanke (2008) conclude that there is good evidence for the impact of various pesticides on motor functioning (abnormal reflexes) in the newborn human and both motor and cognitive functioning (particularly reaction times, attention and short-term memory) on children. We also know that the developing fetus and young children have lower levels of the detoxifying enzymes that may deactivate organophosphate compounds in adults (Furlong et al., 2006). This suggests that the effects of agricultural pesticides on children may be particularly problematic.

Dichlorodiphenyltrichloroethane (DDT) and related organochlorine compounds used as pesticides have been largely phased out in the US and Europe (Rohlman et al., 2005). Thus their impacts on children's developmental functioning in these contexts are understudied. However, a longitudinal study in the early 1990s in the United States found that prenatal dichlorodiphenyldichloroethylene (DDE) exposure impacted motor functioning at 18 and 24 months, but did not impact cognitive development at ages 3, 4 and 5 years (Jurewicz & Hanke, 2008). Two more recent studies in Spain (Ribas-Fito et al., 2003; 2006) and one in the United States (Eskenazi et al., 2006), however, using similar assessment tools, did find significant relationships between cord blood and maternal serum levels of DDE, DDT and related compounds on the cognitive and psychomotor functioning of both infants and young children.

More contemporary organophosphate pesticides may similarly impact reflexes in infants (Jurewicz & Hanke, 2008), reaction times in early childhood (Rohlman et al., 2005), and infant and early childhood psychomotor development (Jurewicz & Hanke, 2008; Rauh et al., 2006; Ruckart, Kakolewski, Bove, & Kaye, 2004). There is also some evidence for effects on specific cognitive skills, particularly short-term memory and attention (Jurewicz & Hanke, 2008; Lizardi, O'Rourke, & Morris, 2008; Rauh et al., 2006; Ruckart et al., 2004). In addition, these effects appear to persist over time: Rauh et al. (2006) found that low-income, urban minority children in New York City who were exposed to high levels of the insecticide chlorpyrifos were more likely than other children to have delays in their overall cognitive and motor development at 12, 24 and 36 months, and were also more likely to exhibit attention problems.

DDT and DDE are currently commonly used in the global South (Jurewicz & Hankel, 2008; Mishra & Sharma, 2011), yet there is almost no research documenting the impacts of these compounds on children's developmental functioning. However, a longitudinal study of infant cognitive and psychomotor functioning following prenatal exposure to DDE in Mexico found that maternal serum levels during the first trimester were negatively associated with infants' motor development at 1, 3, 6 and 12 months of age (Torres-Sanchez et al., 2007). Similarly, Grandjean et al. (2006) and Harari et al. (2010) found that prenatal exposure to pesticides adversely impacted Ecuadorian children's cognitive functioning at ages 6–9 years. Children's current exposure was negatively associated with reaction times, but not with other cognitive measures. Likewise, Guilette et al. (1998) found that Mexican 4- and 5-year-olds' prenatal and current exposure to pesticides delayed their motor development and some aspects of cognitive functioning. In a study using a similar design, comparing children living in rural areas with high pesticide use to those residing in low pesticide use areas, 4- to 5-year-old Indian children showed a similar profile (Kuruganti, 2005). And Rodríguez (2012) found that 7- to 9-year-old children of Nicaraguan agricultural workers who were exposed to a variety of pesticides prenatally had deficits in working memory, verbal comprehension, and overall IQ. Eckerman et al. (2007) demonstrated similar impacts on 10- to 18-year-old Brazilian children's memory and attention resulting from current exposure. Thus there is some evidence that prenatal exposure may be particularly problematic, but that later exposure may also impact some aspects of children's cognitive development. In addition, there is good evidence for high levels of prenatal and childhood exposure to both organochlorine and organophosphate compounds in low- and middle-income countries, including India (Mathews, Reis, & Iacopino, 2003; Mishra & Sharma, 2011), Kazakhstan (Zetterström, 2003), Ghana (Mull & Kirkhorn, 2005), Nigeria (Okafor, 2010) and Egypt (Kishk, Gaber, & Abd-Allah, 2004). In Ecuador, Corriols and Aragón (2010) estimated that there have been 18,516 cases of acute pesticide poisonings between 1995 and 2006 among children aged 5–14 years, based on the 2069 reported cases. Many of these were due to occupational exposure, which is in fact a primary mode of exposure for young children working in agricultural settings in the global South (Dorman, 2008).

The research documenting effects of pesticide exposure on children's socioemotional development is limited, and the findings are mixed (Ruckart et al., 2004). Rodríguez (2012), however, found that ADHD symptoms were more common amongst pesticide-exposed girls, but not boys, in a sample of 7- to 9-year-old Nicaraguan children. These findings make sense, given other results documenting the impacts of pesticide exposure on children's attention processes. Clearly, more research on the impacts of pesticide exposure on the socioemotional functioning of young children is warranted.

Air pollution

With ongoing rapid industrialization and urban growth, poor air quality is a serious concern in much of the global South, as well as in newly industrial countries in general (Bartlett, Hart, Satterthwaite, de la Barra, & Missair, 1999). Here we discuss work in both the global North and South documenting the impacts of exposure to air pollution, primarily resulting from proximity to industrial plants and to air and road traffic, on children's cognitive and socioemotional development.

Among the most common pollutants to be studied for its effect on cognition is nitrogen dioxide (NO_2), a toxicant produced by fossil fuel combustion and thus closely linked to road traffic as well as gas stoves. In Quanzhou, China, exposure to traffic-related pollution was found to be associated with poor performance on neurobehavioral tests (Wang et al., 2009). Similarly, Dutch children exposed to high levels of NO_2 at home were found to score lower on memory evaluations, while no similar correlation was found between NO_2 exposure at school and cognitive outcomes (van Kempen et al., 2012). A related study of children living near London's Heathrow airport, however, found no association between exposure to NO_2 and cognitive performance in nine- to ten-year-olds (Clark et al., 2012).

In other work on air pollution, prenatal exposure to environmental tobacco smoke was negatively associated with cognitive performance at age two in African American and Dominican children in New York City (Rauh et al., 2004). Within the same populations, exposure to high levels of airborne polycyclic aromatic hydrocarbons (PAH) (largely from road traffic fuel combustion) was associated with lower cognitive scores and moderate developmental delay at age three (Perera et al., 2006), and lower IQ scores at age five (Perera et al., 2009). Similarly, exposure to PAHs was significantly associated with lower non-verbal IQ scores among five-year-olds in Poland (Edwards et al., 2010). In China, children living within proximity of a coal-fueled power plant were found to have higher cord PAH levels than those in both the New York City and Poland studies, and these levels were associated with a greater risk of delay in motor development and language abilities at age two (Tang et al., 2008). There are also potentially prolonged consequences of overexposure to PAHs. Noting that children highly exposed to PAHs were 2.89 times as likely to have lower MDI scores than unexposed children at the age of three, Perera et al. (2006) suggested that greater exposure to such high levels of pollution could adversely affect language, reading and math abilities later on.

Changes in brain structure as a result of exposure to high levels of air pollution have been proposed as a possible explanation for resulting cognitive defects. In Mexico City, urban air pollution was found to be associated with prefrontal white matter hyperintense lesions in both children and dogs; these lesions are believed to be associated with poor cognitive outcomes (Calderón-Garcidueñas et al., 2008). Calderón-Garcidueñas and colleagues found that 56.5% of children living in highly polluted Mexico City possessed such lesions, in comparison to just 7.6% of children living in Polotitlan, an area with lower levels of pollution. The former also performed more poorly on psychometric tests. However, seven- and eight-year-olds in Mexico City exposed to high pollution levels generally scored lower in evaluations of short-term memory, attention and learning ability than those in Polotitlan, whether they possessed such lesions or not (Calderón-Garcidueñas et al., 2011). Thus, as Calderón-Garcidueñas and Torres-Jardon (2012) note, exposure to high levels of air pollution is just one aspect of the environmental inequalities experienced by children from lower socioeconomic backgrounds in both the global North and South (Evans, 2004).

Against the backdrop of such settings as New York City, Mexico City, and the rapidly growing cities of China, the majority of the literature on the subject seems to suggest that the relation between air pollution and developmental outcomes is one largely tied to industrialization and urbanization. A notable exception is Munroe and Gauvain's (2012) investigation of the association between indoor open-fire cooking—a common practice in the global South—and cognition in four communities: Garifuna in Belize, Logoli in Kenya, Newar in Nepal, and Samoans in American Samoa. A moderate negative correlation between indoor open-fire cooking and block building performance, memory, pattern recognition and structured play was found.

Water pollution, sanitation and access

Many families in the global South have limited access to clean water and sanitation facilities (Bartlett, 1999; Bartlett et al., 1999; Walker et al., 2007). This section will outline the effects of water quality (specifically pollution and sanitation) on children's cognitive and socioemotional development in the global North and South.

The most common water pollutant studied in relation to children's development is arsenic. Rosado et al. (2007) found that amongst 6- to 8-year-old children attending school near a smelter complex in Torreón, Mexico, those with higher concentrations of urinary arsenic performed worse on several measures of cognitive and language development than did children with lower concentrations. This relationship was not impacted by lead exposure, demographics, or nutritional factors, although lower SES children had higher levels of urinary arsenic. Likewise Tsai et al. (2003) found that young Taiwanese adolescents exposed to arsenic in well water had lower scores than unexposed adolescents on cognitive assessments of memory and attention switching, even after controlling for education and gender. And in a study of 9.5- to 10.5-year-old children using tubewells in Bangladesh, Wasserman et al. (2004) found that water arsenic levels were associated with poorer cognitive functioning. Asadullah and Chaudhury (2011) similarly found that eighth grade children exposed to arsenic-contaminated tubewells in rural Bangladesh had lower mathematics scores than those not exposed, even when controlling for schooling history, prior arsenic exposure, and parental factors. Wang et al. (2007) likewise found that rural Chinese eight- to twelve-year-olds living close to wells with high levels of arsenic received lower IQ scores than those who did not, although it should be noted that this relationship was only documented for children with high levels of exposure, and sociodemographic factors were not controlled for.

High manganese levels in the public water system may also impact children's behavior, as documented by Bouchard et al. (2007) in a study of 6- to 15-year-old children's behavioral functioning in Canada. After controlling for potential confounding variables (age, sex and income), they found that hair manganese was significantly associated with hyperactivity and oppositional behavior, as measured by teachers' report. Interestingly, the positive relationship between hair manganese and hyperactivity was greater for older children (above 11 years old).

Research suggests that a lack of proper water sanitation and waste management exposes many children to water-borne diseases. For example, Copeland et al. (2009) found that 30% of households in Brazilian shantytowns had fecal contaminated drinking water. Besides their health effects, water-borne diseases also have adverse developmental consequences for children. Guerrant and colleagues (1999) explored the relationship between diarrheal illness (a common water-borne disease) early in childhood and the cognitive functioning of 6.5- to 9-year-old children living in a Brazilian shantytown. A significant negative correlation was found between children's cognitive functioning and early childhood diarrhea (see also Niehaus et al., 2002 for similar results). And Lima et al. (2004) found that the availability of garbage collection and access to a toilet partially explained differences in cognitive and psychomotor performance of low-income 12-month-olds living in northeast Brazil. Likewise, in an investigation of the environmental conditions (including poor access to drinking water, an inconsistent electricity supply and inadequate sewage drains) impacting 7- to 8-year-old children's cognitive development in war-torn Baghdad City, Ghazi and colleagues (2012) found that below average water quality (as reported by parents) was associated with lower IQ scores, and that access to services (including water quality, electricity supply and access to grocery stores) independently predicted IQ, after adjusting for parent education and income.

In addition to direct impacts on cognitive functioning, diarrhea and intestinal parasites resulting from bacteria-contaminated water (often from sewage) contribute towards malnutrition and stunting, both of which impact children's IQ and school performance, and may also contribute towards behavioral problems (Bartlett, 2003). These associations may result as early malnutrition and exposure to environmental toxins and stress can alter both brain structure and function, thus leading to long-term changes in cognitive and socioemotional functioning (Grantham-McGregor et al., 2007). In addition, both illness and malnutrition may lead to increased absences from school and attention problems when in school. Further, access to water may impact school attendance directly, particularly for girls in the global South, who frequently have to walk long distances to collect clean water (Bartlett, 2003). Finally, it is worth noting that global climate change is likely to affect access to clean water for millions of low-income families in the global South, particularly in Africa and parts of Asia, in the next 20 years (Bartlett, 2008).

A recent article suggests that contaminated drinking water in childhood may have lasting effects. Aschengrau et al. (2011) conducted a retrospective study of children from eight towns in the US who were exposed to water contaminated with tetrachloroethane (PCE, a solvent used in dry cleaning) during the prenatal period and/or early childhood. They found that, after controlling for parental SES and other potential covariates, highly exposed individuals had higher rates of cigarette, alcohol, and other drug use in adolescence and early adulthood.

Noise

Numerous studies in high-income countries reveal that chronic noise exposure early in childhood interferes with reading acquisition (Evans, 2006). Although most studies are cross-sectional with statistical controls for SES, several studies have demonstrated a dose-response function. Adverse impacts on reading have also been replicated in prospective longitudinal studies with the introduction of a new major noise source such as an airport, as well as in experiments with noise attenuation interventions. Children in higher elementary school grades suffer greater adverse reading outcomes; this has been attributed to longer duration of exposure (Evans & Hygge, 2007) but might also reflect greater awareness of noise (Dockrell & Shield, 2004). Some studies have also shown worse reading outcomes for children exposed to noise at home and school, bolstering the duration of exposure explanation. Children with poorer cognitive skills also appear more vulnerable to the induction of reading deficits from noise exposure (Evans, 2006; Dockrell & Shield, 2006).

Several cognitive deficits reliably associated with noise exposure are candidate mechanisms for the well-documented noise – reading link. Long-term memory is adversely affected by noise, and attentional strategies are altered by noise exposure (Evans, 2006). Interestingly, a few studies have also shown linkages between chronic noise exposure and deficits in auditory discrimination (e.g., phoneme perception), a critical aspect of speech perception

(Evans, 2006; Evans & Hygge, 2007). Speech perception is a major building block of reading acquisition. Finally, emerging work in neuroscience indicates potentially detrimental noise effects on brain speech function and structure (Kujala & Brattico, 2009).

Chronic noise exposure, similar to many of the environmental conditions described herein, is not only aversive but also uncontrollable and sometimes unpredictable as well. Repeated exposures to uncontrollable as well as unpredictable events can undermine human motivation (Cohen, Evans, Stokols & Krantz, 1986), thus impacting the persistence and effort needed (amongst other things) for academic achievement. The first human studies of learned helplessness employed uncontrollable noise as the induction stimulus (Hiroto, 1974; Krantz, Glass & Schneider, 1974). Since then, many studies have shown that uncontrollable noise exposure can cause learned helplessness (Evans & Stecker, 2004).

The bioecological perspective (Bronfenbrenner & Morris, 1998) suggests a complementary set of processes that might also be related to noise and reading acquisition. Noise might alter caregiving behaviors salient to reading acquisition. We know, for example, that teachers in high noise impact schools alter their teaching methods and also complain about interruption and fatigue (Evans, 2006). It is conceivable that parents might talk less to their children, be less responsive to children’s verbalizations, and not read aloud as much to their children in high noise settings.

Research on the relation between noise and children’s cognitive development outside of the United States and Europe is extremely limited. However, what evidence there is suggests that noise levels impact children in varying contexts similarly. Seabi, Goldschagg, and Cockcroft (2010) found that 9- to 13-year-old South African children attending a public school in a high aircraft noise area had poorer reading comprehension and reduced visual attention in comparison to a matched group of children attending a public school with typical levels of noise exposure. No differences in working memory were found, however. Clearly, further work in the global South is desperately needed, particularly as there is some evidence to suggest that noise levels might be significantly higher than in higher-income countries. For example, in a recent comparison of quiet versus noisy public schools in urban India, Lepore, Shejwal, Kim and Evans (2010) recorded a decibel level of 85 dBA. Since decibels is a logarithmic scale, and about 45 dBA is considered appropriate, this is very loud.

Outside of the global South, Hiramatsu and colleagues (2004) found deficits in long-term but not short-term memory among 8- to 11-year-olds residing proximate to a large air force base in Okinawa, Japan compared to their peers living in quiet areas. Similarly, Karsdorf and Klappach (1968) found that secondary school aged children attending noisy schools (proximate to road traffic) in Halle, former East Germany, had more focused attention problems compared to their peers in relatively quiet secondary schools. Finally, recent work in Belgrade, Serbia indicates that chronic residential noise exposure from road traffic can interfere with executive functioning, but only among elementary school aged boys (Belojevic et al., 2012).

Evidence from both laboratory and field studies in North America and Western Europe shows that noise exposure is stressful, creating irritation and annoyance and elevating cardiovascular indicators of stress such as blood pressure and neuroendocrine stress hormones (e.g., cortisol) (Evans, 2006; Paunovic et al., 2011). In most of these studies, resting physiological stress measures were taken under quiet conditions. Thus the indications of elevated stress are in relation to chronic noise exposure. There are more studies of aircraft relative to street traffic noise, with evidence for the former having stronger physiological impacts than the latter (Evans, 2006). However, Babisch et al. (2009) found that a nationally representative sample of 8- to 14-year-old German children whose bedrooms faced a high traffic street had higher blood pressure than those with a bedroom facing a low traffic street. These relations were independent of various sociodemographic factors.

Studies in Slovakia (Regecova & Kellcrova, 1995) and Serbia (Belojevic et al., 2008; Paunovic et al., 2009) also revealed adverse impacts of road traffic noise on children's blood pressure, even after statistically controlling for variables such as maternal education. Nine- to 13-year-old children residing near airports in Russia in the mid 1960s had higher blood pressure than their peers in quiet areas (Karagodina, Soldatkin, Vinokur, & Klimukhin, 1969). In a study also conducted in the mid 1960s in former East Germany, Karsdorf and Klappach (1968) found that secondary school children attending urban schools located proximate to busier streets with higher noise levels had significantly higher resting blood pressure. Finally, Wu et al. (1993) found that, amongst 7- to 12-year-old Taiwanese children attending schools in high road traffic noise areas of Taipei, those with typical hearing had significantly higher blood pressure than those who were deaf.

Data are mixed on chronic noise exposure and children's socioemotional development. Prospective, longitudinal data show that German elementary school children report lower levels of psychological well being with increases in noise exposure from aircraft (Bullinger et al., 1999). A cross-sectional Austrian study of traffic noise reported a dose-response function between noise levels and teacher ratings of psychological well being among elementary school children if the child had biological risk factors such as prematurity or low birth weight (Lercher et al., 2002). Two different cross-sectional studies of European school children have uncovered relations between aircraft noise exposure and elevated symptoms of hyperactivity (Haines, Stansfeld, Brentnall et al., 2001; Stansfeld et al., 2009; but see Haines, Stansfeld, Job et al., 2001). None of these European studies found a link between noise levels and general, overall indices of psychological well being. Finally, Ristovska et al. (2004) compared several measures of mental health among 4th grade children in Macedonian schools varying in traffic noise exposure. Children in the noisier schools had decreased social skills and more oppositional behaviors but were similar in levels of anxiety compared to their peers attending quieter schools. Recall also that, as indicated above, several studies have shown a link between chronic noise exposure and elevated learned helplessness among children (Evans, 2006).

Crowding

The most consistent crowding metric with human consequences is people per room. Indices of external density such as people per census tract typically yield no associations with human behavior (Evans, 2006). Studies that have teased apart residential density from family size find the former rather than the latter to be the more critical variable. Although many believe there are differences in tolerance for crowding across different cultural contexts, the cognitive and behavioral development of children living in as diverse contexts as the United States, India, Thailand, Egypt, Hong Kong, South Africa, and Jamaica indicates similar developmental correlates of crowding in both residential and school settings (Evans, 2006; Liddell & Kruger, 1987; 1989; Wachs & Corapci, 2003).

It is important to note that children in the global South, relative to North America and Western Europe, tend to live in more crowded home environments. For example, Evans, Lepore, Shejwal and Palsane (1998) found that densities (people per room) among primarily working class Indian families ranged from .67 to 5 persons/room, with a mean of 1.81. The US Census considers > 1 person/room to be crowded.

Significant research across multiple contexts documents the impacts of crowding on general school achievement and IQ, reading comprehension, and object spatial relations (Evans, 2006). In a study of low-SES rural Eygptian 3- to 6-month-olds, Rahmanifar et al. (1993) found that infants in more crowded households were more lethargic and drowsy, conditions associated with delayed development. In their examination of 12-month-old children of recent Haitian immigrants to the US, Widmayer and colleagues (1990) found similarly that residential crowding was linked to delays in psychomotor, but not cognitive development. These associations may result from disruptions of children's exploration, play and engagement with both objects and people in their immediate environments (Heft, 1985; Liddell & Kruger, 1987; 1989).

Crowding in educational environments has also been linked to more off-task time (Kantrowitz & Evans, 2004; Krantz, 1974). For example, Liddell and Kruger (1987) found that levels of crowding within a crowded urban South African childcare center were negatively associated with 32- to 64-month-old children's levels of cooperative play and positively associated with the percentage of time spent unoccupied. In a follow-up study, they found that children from more crowded homes spent less time engaged in play with objects, more time unoccupied, and more time as onlookers (Liddell & Kruger, 1989). Similarly, in an investigation of relationships between the home environment and Egyptian toddlers' adaptive behavior, Wachs et al. (1993) found that 24- to 29-month-olds' simultaneous involvement with persons and objects in their environment was negatively correlated with density.

Residential crowding can also disrupt parent-child interactions (Evans, 2006; Wachs & Corapci, 2003). In more crowded homes, parents talk less with their infants and toddlers (Wachs et al., 1993) and use less complicated vocabulary and sentence structures with their toddlers (Evans, Maxwell, & Hart, 1999). Not surprisingly, in an investigation of the influences of parental SES on South African children's outcomes, Goduka et al. (1992)

found that crowding predicted 5- to 6-year-old vocabulary scores. Children's physical development and quantitative skills were also adversely associated with household crowding.

Evans et al. (1998) showed that some of the adverse effects of residential crowding, statistically controlling for SES, on Indian elementary school children's academic achievement were mediated by heightened family conflict. Another variable that may help account for the link between household crowding and diminished academic achievement is inadequate space to do homework. In a study of low-income families living in apartments in Singapore, Hassan (1976) found an inverse relationship between apartment square footage and school performance among children. More crowded apartments also had inadequate privacy for students to study. The latter relation was also reported among secondary school pupils living in apartments in Hong Kong (Mitchell, 1971). These effects of crowding on children's cognitive functioning have similarly been reported in North America and Western Europe (Evans, 2006), with consistent differences found for standardized achievement scores in grade school children. Moreover, the adverse associations uncovered between residential density and diminished academic achievement continue through secondary school, independent of family SES (Evans, 2006). In addition, in an instrumental variable analysis of national data in France, Goux and Maurin (2005) showed that the probability of having to repeat a grade among 15-year-olds was strongly linked to overcrowding in the household.

Crowded home and school environments significantly impact the behavior and socioemotional functioning of both children and their parents (Evans, 2006; Wachs & Corapci, 2003). For example, Ani and Grantham-McGregor (1998) found that crowding independently predicted Nigerian elementary school boys' levels of aggressive behavior in school. Parental perceptions of residential crowding were inversely associated with positive social behavior amongst 3- to 35-month-old Burundian refugee children living in the United States (McAteer, 2012). Interestingly, in a study of feeding practices in Jamaican primary schools, Grantham-McGregor, Chang, Walker, and Powell (1998) found that the negative impacts of classroom crowding on children's behavior were exacerbated by poor nutrition.

One of the effects of high-density living may be greater difficulty monitoring and regulating children's behaviors. Less parental monitoring is a well-documented predictor of behavioral conduct disorders, including juvenile delinquency. Parents in both Singapore (Hassan, 1976) and Hong Kong (Mitchell, 1971) noted greater difficulties monitoring their children as a function of household crowding, and in the former case this appeared to contribute to greater juvenile delinquency rates.

Greater family conflict and tension have been reported among crowded Indian and Thai families (Evans et al., 1998; Fuller et al., 1993), and a number of studies in low-income countries have documented positive associations between household crowding and physical punishment of children (Afifi, El-Lawindi, Ahmed, & Basily, 2003; Youssef et al., 1998; Gage & Silvestre, 2010; Sumba & Bwibo, 1993; Vega-Lopez et al., 2008). In a survey of parenting values conducted in 34 low- and middle-income countries around the globe, Cappa and Kahn (2011) documented a relatively consistent link between household crowding and maternal endorsement of the need for physical punishment in child rearing.

In high-income countries both children and parents report more strained, negative familial interactions in high-density homes (Evans, 2006), as well as instances of elevated punitive parenting practices. Children in more crowded preschools and elementary schools also evidence more aggressive behaviors towards their classmates (Evans, 2006). One of the factors believed to drive part of the crowding – aggression link is conflict over scarce resources such as toys (Evans, 2006).

One of the ways in which crowded family members appear to cope with crowding is to socially withdraw from one another, which can have the unintended consequence of diminishing socially supportive relationships (Evans et al., 2001). A number of studies, including some with random assignment, have shown that crowded children tend to be more socially withdrawn (Evans, 2006). Parents in more crowded homes are also typically less responsive to their children (Evans, 2006).

Given greater social withdrawal among children in high-density homes and lower levels of parental responsiveness in similar situations, some investigators have explored whether crowding might also be linked to psychological distress among children. As indicated above, there is already evidence of elevated rates of aggression, withdrawal, and behavioral conduct disorders such as juvenile delinquency. A small number of studies in North America and Europe have shown that children in more crowded homes have higher levels of psychological distress (Evans, 2006). They are also more susceptible to learned helplessness (Evans, 2006; Evans & Stecker, 2004). This effect has been produced in a laboratory experiment on crowding and persistence on puzzles, and at least two field studies showed a dose-response function between residential density and learned helplessness (Evans, 2006).

In a study of 10- to 12-year-old Indian children, Evans et al. (1998) showed that residential density was inversely related to teacher ratings of behavioral adjustment at school, and elevated conflict and lower levels of social support within the family. SES was included as a statistical control. For girls but not boys, density was also related to learned helplessness. Family conflict partially mediated these relationships. The authors also found that resting blood pressure was elevated among more crowded boys, but not girls. This matches several studies indicating elevated indices of physiological stress among children living in more crowded homes or attending more crowded schools/childcare (Evans, 2006).

Chaos

Household chaos

Research on children’s environments focuses on the intensity of exposures, largely ignoring temporal issues such as duration and stochasticity. The paucity of research on duration of exposure is unfortunate, particularly in thinking about the maturation of developing processes over time. This section brings attention to another largely unexamined property of children’s environments – their degree of structure and predictability. One of Urie Bronfenbrenner’s fundamental contributions to child development was the insight that proximal processes, the exchanges of energy between the developing child and the persons and objects in their immediate settings, need to occur on a regular, sustained basis in order to be effective (Bronfenbrenner & Morris, 1998). Bronfenbrenner also argued that proximal processes need to be reciprocal between the child and her surroundings and become progressively more complex as she matures. Settings that are unpredictable and unstructured may destabilize children's development because they interfere with effective proximal processes (Bronfenbrenner & Evans, 2000; Bronfenbrenner & Morris, 1998). This thinking has led to emerging interest in chaos and children's development (Evans & Wachs, 2010; Fiese, 2006). Most studies use parental or observer ratings of levels of structures and routines coupled with indications of noise, crowding, and various other interruptions of household activities to evaluate levels of chaos. Evans and Wachs (2010), in a recent volume on chaos and child development, provide an in-depth discussion of the measurement of chaos.

Chaos has been linked, primarily in cross-sectional studies in North America, to academic achievement and socioemotional development, including behavioral conduct difficulties and symptoms of internalization (e.g., depression, anxiety) (Ackerman & Brown, 2010; Fiese & Winter, 2010). Chaos has also been linked to deficits in self-regulation and learned helplessness (Brody, Flor, & Gibson, 1999; Evans, Marcynyszyn, Gentile, & Salpekar, 2005) and comprehension of social cues (Dumas et al., 2005).

Although the majority of the work on chaos and child development has been conducted in Western contexts (Wachs & Corapci, 2003; Weisner, 2010), a recent study by Shamama-tus-Sabah, Gilani, and Wachs (2011) found that levels of chaos in the homes of 8- to 11-year-old Pakistani children uniquely predicted internalizing and externalizing behavioral problems and lower levels of adaptive behavior, as rated by both mothers and teachers. No relations between chaos and cognitive development were found. Using the same data set, Shamama-tus-Sabah and Gilani (2010) also found that home chaos predicted children's conduct problems. Clearly, further work in low-income countries is warranted, particularly as at least some components of chaotic environments (specifically the interruption of daily routines, and thus children's proximal processes) likely impact children growing up in the global South in similar ways to their American and European counterparts (Wachs & Corapci, 2003; Weisner, 2010).

Residential mobility

Poverty, substandard housing, and slum dwellings without security of legal tenure often lead to excessive residential mobility. Reliable housing is critical for children's security and stability, and is essential if families are to establish daily routines (Bartlett et al., 1999). High levels of residential mobility in North America are associated with poorer psychological adjustment, less socially supportive peer relationships, and deficits in academic achievement (Adam, 2004; Jelleyman & Spencer, 2008; Oishi, 2010). In addition, students and teachers in classes with high levels of mobility face considerable challenges because of the instability of their members. Early childhood residential instability can also influence developmental trajectories. Adolescents with more frequent moves tend to have diminished social networks and hold comparatively less central positions therein (South & Haynie, 2004), and are vulnerable to earlier onset of sexual activity (South, Haynie, & Bose, 2005). Bures (2003), using a nationally representative sample of middle-aged American adults found that more frequent moves during childhood were associated with poorer mental health and more strained social relationships in midlife, independent of race, income, and education.

In the global South, residential mobility is high, particularly for low-income families living in urban areas (Bartlett et al., 1999), who frequently face forced evictions (Chatterjee, 2007). Although little work in the global South has directly evaluated the impacts of high residential mobility on children's cognitive and socioemotional functioning, it is likely that high mobility disrupts proximal processes (Bronfenbrenner & Evans, 2000). Further, children whose families are evicted from their homes in a violent manner may experience trauma. For example, Dizon and Quijano (1997) have documented the impact of violent forced evictions in Manila on young children's emotional functioning, noting that many children report recurring nightmares and/or become withdrawn.

Housing

An extensive body of international research, much of it employing adapted versions of the HOME scale (Bradley & Caldwell, 1980), has documented the impacts of the quality of the home environment on children's cognitive and socioemotional development (Bradley & Corwyn, 2005; Evans, Wells, & Moch, 2003; Iltus, 2007). The HOME scale and its variants, however, primarily consist of indices of parent-child interactions, with fewer items focused on the physical environment. Furthermore, most studies with the HOME do not look at the impacts of individual physical environment items on children's developmental outcomes. Wachs and colleagues' Purdue Home Stimulation Inventory (PHSI, Wachs, Francis, & McQuiston, 1979) provides more detailed information about the quality of the physical environment experienced by children, but it has not been employed as widely. In addition, although the HOME has been widely used in various cultural contexts, the scale as a whole, and the physical environment items in particular, may not adequately assess the full range of physical affordances offered by housing for children, particularly in the global South (Hayes, 1997; Iltus, 2007; Ngorosho, 2010). In this section, we focus on what is currently known regarding the effects of housing type, physical housing quality, and the availability of resources for children, such as books and toys in the home.

Housing type

Research on housing type in more affluent countries has focused primarily on the potential developmental implications of high-rise housing. There is a long history of popular discourse about the allegedly harmful effects of living on the upper floors of large buildings on children's development. These concerns are rooted in the association of large, multistory housing blocks with crime in public housing in the US, and with well-documented associations between building scale and crime (Newman, 1972; Taylor & Harrell, 1996). However, although a few studies in high-income countries have shown an association between children's academic achievement and residence in high-rise compared to low-rise buildings, there are also several non-replications of these relations (Evans, 2006; Evans et al., 2003). One study showed that the effects held only for boys, which could also explain the mixed set of findings since most studies have not investigated gender differences in response to high-rise housing (Saegert, 1982).

Several studies in high-income countries have found that children and youth in high-rise buildings manifest greater levels of behavioral conduct disorders (e.g., delinquency, aggression) (Evans, 2006; Evans et al., 2003). In an investigation of relationships between high-rise dwelling and Japanese children's behavior, Oda, Taniguchi, Wen, and Higurashi (1989) found that infants living on lower floors received higher scores on independent behaviors (such as greeting and potty training) than did those living on higher floors. However, these differences were not significant for kindergartners. These findings largely mirror those in Western contexts (Evans, 2006; Evans et al., 2003). In addition, although children's outcomes were not measured, Levi, Ekblad, Changhui, and Yuequin (1991) found that parents living in high-rise apartments in Beijing showed anxiety regarding the lack of easily monitored play spaces for children. In a study of families living in high- versus low-rise apartments in Israel, Churchman and Ginsberg (1984) similarly found that the outdoor play behavior of 4- to 5-year-old children living in high-rises was more restricted than that of other children, although it should be noted that these effects were not found at other ages (within the range of 2–13 years).

In the global South, housing type is inextricably connected to housing quality. There is little research investigating the impacts of housing type alone. Further, the variations in housing type are somewhat different from those in the global North, with high-rise dwellings being uncommon. However, there is some evidence that a high percentage of families, particularly low-income families in urban areas, live in informal housing, and that such housing often lacks basic amenities such as access to clean water (Bartlett et al., 1999; Hall & Lobina, 2006). The implications of an unclean water supply have already been discussed above. In addition, informal housing is typically unstable, and children living in such areas frequently face eviction and therefore frequent residential mobility (Bartlett et al., 1999), the implications of which have already been discussed. In addition, children living in informal housing may be more vulnerable to injury, and are more likely to be exposed to toxins from industrial waste. And children who are homeless or who live in informal housing may be less likely to attend school, as they lack a formal address (Wegelin & Borgman, 1995). For example, a recent survey in Delhi found that only 54.5% of children in slums enrolled in school, as compared to 90% across the city as a whole (Aggarwal & Chugh, 2003). For those in school, homelessness has significant impacts on school performance and socioemotional well being (Hicks-Coolick et al., 2003; Neil & Fopp, 1992). There is also some evidence that children's self-esteem is negatively impacted by residence in slum dwellings and other informal settlements (Kruger, 2002).

In addition to direct effects, housing type may interact with other physical characteristics of children's early environments to influence human development. Delays in cognitive development associated with residential density among preschool children are attenuated if children have access to a room where they can spend time alone (Wachs & Gruen, 1982). Negative self- and teacher-ratings of Austrian primary school children's psychological well being in more crowded homes are exacerbated by residence in multi-family complexes in comparison to living in either single family or small row family housing units (Evans, Lercher & Kofler, 2002).

Housing quality

With ongoing urbanization, the number of families living in substandard housing in the global South is only likely to increase (Chawla, 2002; Meng & Hall, 2006). In addition, there is some evidence that indigenous populations in Australia, for example, are disproportionately exposed to substandard housing (Dockery et al., 2010). Yet most research to date on housing quality and children's development has been conducted in the US and Europe (Bradley & Putnick, 2012; Evans, 2006; Leventhal & Newman, 2010). There is a desperate need for further work in this area.

A small number of studies in North America and Europe have examined housing quality and cognitive development. A few, including a large national British cohort, reveal that, independent of SES, children living in substandard housing have lower academic competency (Evans, 2006, Evans et al., 2003). These effects are amplified by duration of exposure to substandard housing (Douglas, 1964), and one study showed that when families moved into better housing, elementary school performance improved (Wilner, Walkley, Pinkerton, & Tayback, 1962). Dunifon, Duncan and Brooks-Gunn (2004), using a US national data set, also showed that residential clutter during childhood predicted adult educational attainment.

A number of cross-sectional studies in North America and Europe show that children living in substandard housing suffer from greater psychological distress (Evans, 2006; Evans et al., 2003). Nearly all of these studies incorporate statistical controls for SES, and the effects replicate in longitudinal studies examining changes in housing quality (cf., Blackman & Harvey, 2001). Learned helplessness is also greater among children living in substandard housing, with statistical controls for SES (Evans, Saltzman & Cooperman, 2001), and two studies reveal elevated physiological stress among low-income children inhabiting poorer quality housing. In a cross-sectional study, low-income primary school children living in substandard housing coupled with noise and crowding had higher levels of overnight stress hormones (e.g., cortisol) (Evans & Marcynyszyn, 2004). In a second, longitudinal study, low-SES children residing in lower quality housing had elevated cortisol over their first four years of life (Blair et al., 2011). Differences were already present at 7 months of age.

An important conceptual limitation of North American and European research is the rather limited range of variation in housing quality. Because of building codes and general levels of affluence, "bad" housing in these contexts is a lot better than most of the housing found in the global South. Note that, unlike the potential problem of unaccounted for confoundings in cross-sectional research that might lead us to over-estimate the impacts of housing quality on children's development, the truncated range in housing quality leads to the opposite estimation bias.

A high percentage of children growing up in the global South live in substandard housing (Bradley & Putnick, 2012; Govender et al., 2010) constructed with inferior building materials, leaking pipes, and cracks or holes in the walls and ceilings (Chaudhuri, 2004). In

2002 it was estimated that more than half the housing units in Zimbabwe, 52.6%, were considered semi-permanent dwellings (United Nations Statistics Division, 2012). In 2010, 30.6% of the housing units in Mexico did not posses basic amenities such as bathrooms, kitchens, and piped water within the household.

Substandard living conditions lead to higher levels of exposure to lead and other toxins, air pollutants and pests (Govender et al., 2011). In addition, poor quality housing, and particularly unsafe dwellings, place additional stress on low-income parents already facing multiple stressors (Evans & English, 2002). This may result in parental fatigue and thus reduce caregivers' capacity to be warm and responsive (Bartlett et al., 1999; Bradley & Putnick, 2012; Evans et al., 2003; Leventhal & Newman, 2010). Furthermore, in unsafe home environments parents and other caregivers may constrain children's play and other activities, so as to reduce the risk of injury (Bartlett et al., 1999; Bradley & Putnick, 2012; Evans et al., 2003; Ferguson, 2002). Such constraints are not unfounded: Dal Santo et al. (2004) found that preschoolers' estimated risk of unintentional injury is almost four times greater for a child living in a household needing repair. In rural sub-Saharan African contexts, limited space renders household items like kerosene easily accessible for children, and open fires for heating and cooking pose a serious injury risk (Munro et al., 2006). Play constraints in particular likely have important implications for children's cognitive and socioemotional development, given the importance of play for healthy development (Bartlett, 1999; Milteer et al., 2012).

Research on direct impacts of housing quality on children's cognitive and socioemotional development in the global South is very limited. However, in one study Ferguson (2008) found that the quality of Malawian orphanages appears to be associated with infants' cognitive functioning. Space and furnishings (e.g., room arrangement, displays for children) predicted children's cognitive outcomes. This effect may partially be explained by the fact that the provision of separate, soft, cozy areas for children may both offer comfort and help regulate social interaction. Such processes may help counter some of the negative effects of crowding and institutionalization on children. In addition, separate, enclosed areas with comfortable furnishings provide a more homey, and less institutional, setting for young children (Evans, 2006; Greenman, 1988; Olds, 2001; Sanoff, 1995).

Given the limited work directly linking housing quality to children's developmental outcomes in the global South, further research in this area is desperately needed. One useful data source may be the Multiple Indicator Cluster Survey (MICS), an international household survey that has been implemented across a large number of countries in the global South.

Resources for children

Another aspect of the physical environment that may influence young children's development is the availability of learning materials (Bradley & Corwyn, 2005; Bradley & Putnick, 2012). However, the availability of such materials is seldom disentangled from parent-child interactions in the literature. Nevertheless, there is a strong relation between income and the provision of both stimulating materials and experiences for young children from birth through adolescence (e.g., Bradley, Burchinal & Casey, 2001; Evans, 2004;

McLoyd, 1998). And, several studies have shown that cognitive enrichment in the home mediates much of the co-variation between parental income and child cognitive development (Duncan, Brooks-Gunn, & Klebanov, 1994; Linver, Brooks-Gunn, & Koben, 2002; Smith, Brooks-Gunn, & Klebanov, 1997). Access to other material resources such as electricity, a radio, a television, a telephone and transportation may also impact children's cognitive development in particular (Bradley & Putnick, 2012).

There is much debate over what constitutes appropriate learning materials in the home, particularly cross- culturally (Bornstein et al., 2012; Bradley & Putnick, 2012; Ferguson, 2008). Nevertheless, the UNICEF-developed MICS, which has been adopted for use in evaluating factors contributing towards the well being of women and children by a large number of governments worldwide, includes items evaluating the number of books, the number of children's books, and the availability of various types of homemade and store-bought toys and other play materials. There is some evidence that such materials are rarely available in the global South and in rural areas of newly industrial countries such as India, Thailand and China (Bradley & Putnick, 2012). The availability of other material resources in the home is likewise limited.

A retrospective evaluation of developmental impacts of the availability of learning materials and material resources associated with modernity (writing tablets, books, electricity, piped water, a radio, a television, and a transportation vehicle) on children's cognitive development at ages 3, 5, 7 and 9 years in Belize, Kenya, Nepal and American Samoa was conducted by Gauvain and Munroe (2009). Access to these resources was positively correlated with children's general cognitive functioning, perspective taking, and levels of exploratory play. Similarly, Hamadani et al. (2010) found that, after controlling for socioeconomic variables, the variety of play materials and the availability of magazines and newspapers in rural Bangladeshi homes independently predicted 18-month-olds' cognitive development. And, in Ferguson's (2008) investigation of relations between the quality of the physical environments of Malawian institutions and infants' developmental functioning, access to learning materials independently predicted infants' language and socioemotional development.

Schools and childcare

Unfortunately, continual innovation in the design of schools and classrooms throughout the world is typically not based on evidence, instead reflecting current trends in architecture and design (Lackney, 2005). Much of instructional facility innovation at present is driven by the infusion of information technology into learning environments. Although this practice has some potential benefits, we simply do not know how to train teachers and designers in the use and configuration of learning environments to take advantage of the affordances offered by information technology in schools. This explosion of learning technologies in the West inevitably will be transported to the global South. Yet evidence to date from low-income countries indicates no clear impacts of exposure to computers and other related technologies on children's academic achievement (Glewwe, Hanushek, Humpage, & Ravina, 2011; Riddell, 2008).

There is a significant body of research investigating the impacts of school quality on children's school achievement (Evans, 2006; Glewwe et al., 2011; Irwin, Siddiqi & Hertzman, 2007; Riddell, 2008). However, as is true for the work on home environments, little research has specifically investigated the impacts of the physical environment of schools on children's developmental outcomes, particularly in the global South. Most research in the US and Europe on the physical characteristics of educational settings has focused on open versus traditional plan configurations (Evans, 2006). Because this issue has tangential relevance at best to children throughout most of the world, we focus here instead on school and classroom size; the quality of building infrastructure (structural quality, lighting, and indoor climate, and access to electricity, water and sanitation); and access to basic resources (classroom furniture, blackboards, books, computers, laboratories and libraries), as these have the clearest documented impact on children's school achievement in the global South (Glewwe et al., 2011; Riddell, 2008).

School and classroom size

There is a large body of research on school and classroom size. Because nearly all of this work has been conducted within the US and Western Europe, we do not know what happens when much larger scale schools or bigger classrooms occur. Although there is some variation across regions, primary school pupil-teacher ratios (PTRs) in the global South are typically much higher than those in the global North. For example, compare PTRs of 81:1 (Central African Republic), 76:1 (Malawi), 61;1 (Chad) and 58:1 (Rwanda) to 18:1 (UK), 14:1 (US) and 13:1 (Germany) (World Bank, 2012). Notably, though, PTRs in East Asia and the Pacific (average: 17.9:1) and Latin America (22:1) are much lower than in South Asia (40:1) and sub-Saharan Africa (42.5:1).

Students in smaller schools in the US and Western Europe perform slightly better on standardized tests and feel more connected to their school (Evans, 2006). There is some evidence that the benefits of smaller school size are greater for low-income children, and for children in lower grades (Woessmann & West, 2006). Similarly, classroom size research yields a relatively consistent picture of small, adverse effects on children in both high- and low-income countries with increasing size (Blatchford, 2003; Ehrenberg, Brewer, Gamoran, & Willms, 2001; Woessmann & West, 2006). For example, in an investigation of linkages between school physical quality and rural Kenyan first grade children's cognitive functioning and behavior, Daley et al. (2005) found that the number of students per classroom predicted levels of off-task behavior and teachers' ratings of general behavioral functioning. There is also some evidence that smaller classrooms support more student- as opposed to teacher-directed learning and, similar to school size, are associated with more socially supportive settings (Blatchford, 2003; NICHD Early Child Care Research Network, 2004).

It is worth noting that both school and classroom size are confounded with crowding. Work on household size and density shows that the critical variable is density, not family size (Evans, 2006). Insufficient work exists to tease apart school/class size from crowding.

Physical quality

A surprisingly large number of school spaces for American children are in disrepair. In a 2000 survey of school principals in 32 countries in both the global North and South, nearly 30% of US principals noted that the quality of their school's buildings and grounds impacted student learning, and almost 40% noted the same for available instructional space (Ahlehfeld, 2007). Estimates were much higher for the majority of other participating countries, including the United Kingdom, Norway, Turkey, Uruguay and the Slovak Republic. In the global South, the majority of rural schools in particular have inadequate building facilities, including a lack of finished flooring (Glewwe et al., 2011; Riddell, 2008). In many countries, half to two thirds of schools lack electricity, water, and basic sanitation facilities (UNICEF, 2010). For example, the 2005 UNESCO EFA Global Monitoring Report found that just 39% of classrooms in Senegal had sanitation facilities, and even fewer (33%) had access to drinking water.

One important limitation in most work on educational settings and student achievement, however, is over-reliance on school professionals' ratings of building quality. Since teachers and administrators are well aware of children's achievement profiles in their own schools and are themselves likely affected by building quality, the potential for spurious associations in this measurement approach is considerable. However, assessments of building quality conducted by independent raters (e.g., structural engineers) have also been consistently associated with standardized test scores (Evans, 2006). Further strengthening these conclusions are several studies comparing performance before and after building improvements (Evans, 2006). In two recent studies utilizing the New York City school facilities building quality database, Duran-Narucki (2008) showed that the significant association between these expert rating measures of school building quality and academic achievement in elementary school children was largely mediated by attendance. Moreover children in New York City primary schools with higher rates of student mobility suffer even worse achievement outcomes as a function of substandard school facilities (Evans, Yoo, & Sipple, 2010).

Given that nearly all of the research on school facility quality and student performance emanates from wealthy countries where the range of school quality is truncated, this is an area of particular importance to examine in the global South where the range of quality is considerably broader. And, in fact, improvements in the physical structure of schools in the global South do appear to positively impact students' test scores (Glewwe et al., 2011). However, the research to date in this area is very tentative, and typically the schools being compared have multiple factors that differ in quality, making it difficult to clearly identify individual influences on children's outcomes.

In a recent meta-analysis of the research to date on the impact of school quality, including both physical and psychosocial factors, on children's school achievement in low-income countries, Glewwe et al. (2011) found that there appears to be good evidence for the impact of access to electricity on children's educational outcomes. And, in their investigation of the relations between school physical quality and rural Kenyan first grade children's cognitive functioning and behavior, Daley et al. (2005) found that the availability of natural light (in schools without electricity) predicted students' test scores. In high-income countries, where lighting is typically sufficient, research has focused more on potential benefits of exposure to natural light. Although the work on natural light exposure and children's health and performance is limited, some rigorous work suggesting the potential importance of natural light for young children has been conducted in Sweden (Küller & Lindsten, 1992). These investigators found evidence for the importance of sufficient natural light exposure for primary school children's well being during periods of the year when daylight hours are limited.

In North America, upper respiratory infections, asthma and allergies are the most common cause of primary school absenteeism and have been routinely linked to exposure to mold and other allergens as well as ambient pollutants inside both schools and children's homes (EPA, 2003). Poorly maintained heating and ventilation systems as well as low levels of indoor:outdoor air exchange exacerbate these adverse indoor climate impacts on children (Evans, 2006). Although work in this area in the global South is limited, similar impacts of poor quality ventilation and heating would be expected.

Consistent with the bioecological perspective (Bronfenbrenner & Morris, 1998), in addition to focusing on the direct effects of school setting physical conditions on children themselves, it is important to keep in mind that substandard working conditions influence labor satisfaction and retention, and the same holds true for teachers. Several studies have shown that poor quality school physical conditions adversely influence teacher satisfaction and retention (Buckley et al., 2004).

Resources

In the global South, there is some evidence that access to basic resources in school environments, such as a sufficient number of desks, tables and chairs; access to blackboards; access to textbooks and other books; and the availability of a school library all impact children's school achievement (Glewwe et al., 2011; Riddell, 2008). However, frequently these physical environment factors are correlated with each other and with other physical and psychosocial factors such as class size, building quality and teacher training, and so it can be difficult to clearly identify key factors impacting child outcomes. In addition, the mechanism explaining learning outcomes is somewhat unclear; perhaps the availability of these resources partly signals a commitment on the part of the school administration and relevant local and national government agencies to quality education (Glewwe et al., 2011). Nevertheless, a number of carefully controlled studies across multiple contexts document the importance of having a desk, chair and textbook per student. For example, in their investigation of the relations between school physical quality and rural Kenyan first grade children's cognitive functioning and behavior, Daley et al. (2005) found that the number of books per student independently predicted standardized test scores.

In preschool and childcare settings across the global South, there is a growing interest in improving the quality of both physical and psychosocial environments for children (Engle et al., 2007; Hyde & Kabiru, 2003; Irwin et al., 2007; Myers, 1992; van der Gaag & Tan, 1998). And, indeed, the most commonly used assessment of the quality of childcare environments, the Early Childhood Environment Rating Scale (ECERS, Harms, Clifford & Cryer, 1998), includes two rating scales that assess children's interactions with the physical environment: Space and Furnishings and Activities (which includes both the availability of learning materials and their use). However, although a significant body of research in the United States indicates an association between childcare quality and children's cognitive and socioemotional outcomes (e.g., Sylva et al., 2006), there is little research that considers the impact of the physical environment directly.

There is almost no work documenting the impact of the quality of childcare environments on children's developmental outcomes in the global South. However, as part of a preschool intervention program in rural Bangladesh, Moore, Akhter and Aboud (2008) implemented a series of changes, including increasing the availability of learning materials for reading and mathematical problem-solving. They found that preschool scores on the Activities subsection of the ECERS-R increased, and that children's cognitive outcomes and school readiness improved. However, it should be noted that the Activities subscale does not separate the availability of learning materials from their use. In addition, many researchers in the global South debate the applicability of the ECERS-R in evaluating childcare and preschool quality in non-Western contexts (Aboud, 2006; Moore et al., 2008).

Neighborhood quality

Sadly, most children growing up in the global South live in neighborhoods of poor physical quality (Bartlett, 1999; Chawla, 2002; Hardoy, Mitlin, & Satterthwaite, 2001). Physical characteristics of these environments include high levels of air and water pollutants; nonexistent or inadequate collection of household waste; poor drainage; poor sanitation; proximity to busy street traffic; and limited or absent access to childhood resources such as open green space, grocery stores, schools and hospitals and play space (e.g., Bartlett, 1999; Bartlett et al., 1999; Chawla, 2002; Hardoy et al., 2001; Kruger & Chawla, 2002). Many of these neighborhoods are also unsafe because of high traffic volumes and limited street lighting (e.g., Bartlett et al., 1999; Kruger, 2002; Kruger & Chawla, 2002). However, the research linking children's cognitive and socioemotional development to neighborhood physical conditions, beyond those already discussed (exposure to toxins, air and water pollution, sanitation, and high mobility) is very limited. The situation is similar in high-income countries. There is a large literature on neighborhood quality and human health and well being (Diez-Roux & Mair, 2010) and more specifically child development (Leventhal & Brooks-Gunn, 2000), but this work is bereft of considerations of the physical environment of neighborhoods. In nearly all of the extant research, neighborhood quality is defined by the socioeconomic profile of the population. Two areas of neighborhood physical environment that are receiving considerable attention because of the obesity epidemic are access to places for physical activity and proximity to healthy food sources. This work, although still in its early stages, indicates that both of these neighborhood characteristics are related to obesity in children and are much more likely to be wanting in low-SES neighborhoods (Diez-Roux & Mair, 2010; Evans, Wells, & Schamberg, 2010).

UNESCO's *Growing Up in Cities* (Chawla, 2002) provides some interesting insights into children's experiences in neighborhood environments in Argentina (Cosco & Moore, 2002), India (Bannerjee & Driscoll, 2002) and South Africa (Kruger, 2002). In all three contexts, children aged 10–15 years reported a keen awareness of the physical quality of their neighborhood environments, noting specific aspects of these environments (e.g., high traffic, litter, poor sanitation, a lack of open green spaces) that limited play opportunities. Similar data have been found among Australian primary school children (Homel & Burns, 1989). Perhaps most salient in children's narratives across these and the other contexts studied (Australia, the United Kingdom, the United States, Norway, Poland, South Africa) was the importance of access to green play spaces. Other work in low-income countries has similarly documented the importance of play spaces and access to natural settings for children (e.g., Bartlett et al., 1999). However, little work has specifically investigated the impacts of natural settings on the cognitive and socioemotional development of children in the global South.

Neighborhood physical quality

Parents rated their 9- to 12-year-old children in two Canadian cities as higher in psychological distress if the neighborhood was rated by trained observers as lower in physical quality (Gifford & Lacombe, 2006). Both longitudinal and cross-sectional studies (Diez Roux & Mair, 2010) show that neighborhood upkeep influences adults' psychological distress. To illustrate the potential power of neighborhood physical quality on adult mental health, adjusting for income, race and neighborhood poverty, New York City adults living in poor quality neighborhoods were more than 30% more likely to suffer from depression in the past six months compared to adults residing in better physical quality neighborhoods (Galea et al., 2006). Psychological distress in adults is a central risk factor for healthy parenting.

Close proximity to street traffic caused Zurich parents to restrict children's outdoor play activities, which in turn was associated with diminished social and motor skills among preschoolers (Hüttenmoser, 1995). High levels of street traffic have also been associated with less social interaction among neighbors in San Francisco neighborhoods (Appleyard & Lintell, 1972).

Natural settings

As has been discussed above, the majority of research on the impacts of access to the natural environment on children's well being has taken place in the US and Europe. Parallel to findings in North America and Western Europe (Evans, 2006), children across the global South prefer natural areas and engage in more complex levels of play in such settings (Bannerjee & Driscoll, 2002; Bartlett, 1999; Bartlett et al., 1999; Chawla, 2002; Cosco & Moore, 2002; Kruger, 2002; Kruger & Chawla, 2002). Given the potential for access to natural play spaces to mitigate some of the impacts of poor quality physical environments on low-income children's cognitive and socioemotional development, further work in this area is warranted. A few North American studies suggest that children's executive functioning may be enhanced by access to nearby natural outdoor play spaces (Evans, 2006), and a meta-analysis revealed that the greening of school yards across multiple sites in North America and Western Europe has been associated with improved academic performance and better psychological well being among pupils (Bell & Dyment, 2008).

Evaluations of outdoor nature experiences such as Outward Bound in high-income countries reveal consistent, positive associations with psychological well being (Hattie et al., 1997). Part of the apparent psychological benefits of access to outdoor play areas is likely related to enhanced physical activity, which has been consistently linked in both children and adults to proximate, outdoor recreational spaces (Evans et al., 2010). In a recent WHO study of approximately 1200 6- to 18-year-olds residing in eight European cities, the well-documented, inverse relation between household income and childhood obesity was explained, in part, by proximity to open green space. Children from wealthier households had greater access to open green spaces, which in turn was linked to higher levels of physical activity. The latter largely accounted for the inverse, household income – body mass index correlation (Evans et al., 2012).

Adults living in Los Angeles neighborhoods with more parks, independent of SES characteristics, perceived greater collective efficacy, an index reflecting greater social cohesion and social control (Cohen, Inagami, & Finch, 2008). There are also several studies showing that adults' physiological stress responses to aversive stimuli are attenuated by natural surroundings (Evans, 2003). Thus some of the benefits of nearby nature for children may also operate via their parents. One study also revealed that children's psychological reactions to stressful life events were attenuated by proximity to outdoor nature (Wells & Evans, 2003).

Conclusions and future directions

As can be seen upon reviewing the current state of the evidence on the physical environment and child development, very little work has documented the impacts of environmental conditions on the development of children growing up in the global South and other low-income countries. This is unfortunate for many reasons. Foremost, the majority of the world's children grow up outside of the affluent countries where most of the work has transpired. In fact, Bornstein and colleagues (2012) argue that less than 10% of developmental science research has studied communities that account for 90% of the world's population.

What we do know suggests that the physical environment experienced by children impacts their cognitive and socioemotional development across the lifespan, from the prenatal period through adulthood. The development of interventions to improve the physical environments experienced by children across the globe is thus warranted. Interventions would also offer tremendous research opportunities to examine how environmental improvements can change developmental trajectories. This would also help address perhaps the major methodological weakness in most work on children and the physical environment: potential selection bias. Comparisons between children living in different environmental conditions nearly always face the alternative explanation that some individual characteristic rather than environmental conditions might be the root cause of developmental changes. Another critical reason for studying children in the global South and elsewhere outside of high-income countries is the severely restricted range of environmental conditions typically monitored in research on child settings in North America and Western Europe. Essentially every single environmental factor reviewed herein exists in a substantially greater range in low-income countries. Thus not only is 90% of the research on children and the environment from samples of less than 10% of children, the same goes for the environmental side of the equation. We know a reasonable amount about how variability within the top 10 or 20% of conditions matters. We know almost nothing about how variability from the top to the bottom 10% of environmental conditions affects children.

With these caveats in mind, the evidence to date documents adverse impacts of individual environmental risk factors, particularly environmental toxins and pollutants, on children's cognitive development. However, the impacts on socioemotional functioning are less certain. In addition, the documented evidence for impacts of noise, crowding and chaos on the cognitive and socioemotional development of children growing up in the global South is tentative at best. And, across the globe, the impacts of individual aspects of the physical environment of housing, schools and neighborhoods are unclear, primarily because multiple factors tend to be correlated. This is especially true for low-income families, underfunded schools and poor neighborhoods in both the global North and South, where poverty is frequently associated with multiple environmental risks (Evans, 2004; Ferguson et al., 2009). It is also important to recognize that when cumulative, environmental insults have been studied, they typically reveal worse outcomes than singular environmental risks (De Fur et al., 2007; Evans, Li & Whipple, in press). Furthermore, for low-income children, the confluence of deteriorating physical conditions along with inadequate psychosocial conditions is a primary, underlying pathway that helps account for the ill effects of poverty on child development (Evans & Kim, 2013).

In order to better understand the effects of multiple environmental risk factors on children's cognitive and socioemotional development, a holistic, multidisciplinary and multilevel approach that encompasses the complex interactions between biological, physical, and psychosocial factors impacting children's developmental outcomes is needed. Such an understanding will allow us to more effectively intervene in children's actual lived environments. In other work (Ferguson & Lee, 2013), we have proposed a bioecocultural framework that integrates key components of Bronfenbrenner's bioecological model (Bronfenbrenner & Evans, 2000; Bronfenbrenner & Morris, 1998) with Nsamenang and colleagues' ecocultural approach (e.g., Nsamenang, 1992; Nsamenang & Dawes, 1998), and Li's (2003) cross-level dynamic biocultural coconstructivist paradigm (see also Boivin & Giordani, 2009). We thus focus here on outlining key steps involved in utilizing this framework to better understand and address the impacts of the physical environment on the cognitive and socioemotional development of children living in multiple contexts.

Developing and implementing a bioecocultural framework

The first step in developing and implementing a bioecocultural framework is to identify what is known and what is not yet known about the impacts of individual and intersecting environmental factors on children's development. The present review, in conjunction with Evans' (2006) earlier review that focused on Western contexts, does just that. We summarize the evidence to date below, while at the same time considering when the methodologies employed in related work are appropriate for filling in the gaps in the research literature, and when they are not. When they are not, it is important to identify what is currently known in a particular context, for example identifying relevant country-level statistics and databases. In addition, new tools for assessing children's development in varying cultural contexts might be needed (Ferguson & Lee, 2013; Nsamenang, 1992). Second, key factors, what public health researchers call "leverage points", influencing children's developmental outcomes should be identified (see Ferguson et al., 2009). Where possible, those leverage points most susceptible to change should be noted. Third, all of this information can be incorporated into an overarching bioecocultural framework, as outlined above, that identifies all known and hypothesized factors influencing a particular developmental outcome (e.g., literacy), key leverage points, known interacting influences between factors and, when possible, the mechanisms behind the relations between each factor and children's development. Once this is done, interdisciplinary, international research teams should develop and implement a collaborative research program to test the model, with a specific focus on filling in the gaps in the research literature in understudied contexts, namely the global South. In doing this work, the intimate involvement of individuals, communities, local and national governmental agencies and researchers living in each context studied is essential (Dawes & Donald, 2000; Weisner, 2010). In fact, ideally relevant individuals and communities should be involved in every stage outlined above. This will ensure that similarities and differences between contexts are adequately considered. Finally, in collaboration with all of these important constituents, key leverage points can be confirmed and leveraged in implementing a holistic program of reform that will effectively address current environmental inequalities, so as to ensure healthy developmental outcomes for all children.

Phase 1: Identifying influencing factors

Conceptually, given their direct impact on children's biological systems, it is likely that environmental toxins and pollutants (specifically lead, mercury, PCBs, various pesticides, NO_2, polycyclic aromatic hydrocarbons, environmental tobacco smoke, arsenic, manganese, and tetrachloroethane) impact the cognitive and socioemotional development of children living in different contexts similarly. The limited evidence to date indicates that this is the case. Further work on factors impacting socioemotional development is warranted, however, especially in the global South. Similarly, despite differences in adults' perceptions of crowding and chaos, the evidence we have reviewed here suggests that factors contributing to chaos, including noise and crowding, likely impact children and adults across the globe in similar ways. However, given the limited work in this area, particularly in considering socioemotional development, these predictions need to be tested more thoroughly in low-income countries.

In terms of home and school environments, adequate building quality seems essential, but determining what this should entail in differing contexts is challenging. Home, classroom and school designs that reduce chaos may be particularly important. In addition, adequate lighting and comfortable climatic conditions (temperature, indoor air quality) are important for effective learning in school environments. Finally, the availability of key material and learning resources in both home and school environments appears to be particularly important for cognitive development, but the specific resources needed in differing contexts is unclear. Further work in this area is needed. Likewise, although it is clear that children growing up in low-income neighborhoods in both the global North and South encounter numerous disadvantages that impact their cognitive and socioemotional development, little is currently known regarding the specific components of the physical environment of neighborhoods impacting these developmental outcomes. Neighborhood physical quality is the most understudied aspect of the environmental characteristics discussed herein.

An important caveat at this point is that the majority of the work discussed in this review, with a few notable exceptions (discussed throughout), employs environmental and outcome measures developed in the West. Yet the specific components of the physical environment impacting child development in the global South may differ from those in the global North, as we have noted throughout. In addition, different cultural contexts, values and beliefs in the global South may mean that although, for example, there are documented impacts of lead on Egyptian children's IQ scores, this aspect of children's development may be less important than socioemotional competency in this context. Thus a consideration of what engenders competence within particular cultural contexts is essential (Ferguson & Lee, 2013; Weisner, 2010).

The development of culturally appropriate assessments of both environmental quality and children's developmental outcomes in the global South is sorely needed. This could, and should, go hand-in-hand with an evaluation of the effectiveness of a larger bioecocultural model in capturing the multiple environmental factors impacting children's specific developmental outcomes in particular contexts, so as to provide a good test for the effectiveness of these methodologies in each context (Ferguson, 2008; Ferguson & Lee, 2013; Nsamenang, 1992). The questionnaires developed for the MICS, an international household survey, may be a useful beginning. The involvement of key stakeholders living within each context studied will also be essential in this process. UNESCO's *Growing up in Cities* project (Chawla, 2002) provides a nice illustration of a participatory process in which research questions and assessment tools were developed jointly by researchers and community stakeholders.

Phase 2: Identifying leverage points and mechanisms

Bronfenbrenner noted that proximal processes, the exchanges of energy between the developing child and the persons and objects in her immediate settings, are the "engines of development" (Bronfenbrenner & Morris, 1998; Bronfenbrenner & Evans, 2000). In order for these processes to be effective, they need to occur on a regular, sustained basis and become increasingly complex as the child matures. Given this, a starting point for identifying key leverage points is the identification of environmental factors that clearly interrupt proximal processes for children. Factors that contribute towards chaos, including noise, crowding, and residential mobility (partially instantiated by informal housing facilities), are likely candidates here, as they are likely to interfere with effective proximal processes (Bronfenbrenner & Evans, 2000; Evans & Wachs, 2010). As we have discussed above, housing and school design may also contribute towards chaos, particularly when a large number of people live or study in a small number of open plan rooms. In addition, schools and neighborhoods characterized by high residential instability may contribute towards chaos at the macro level.

We have noted above that one of the unintended consequences of various coping strategies for dealing with crowding, noise, and chaos may be deteriorations in socially supportive relationships and less responsive parenting. The design of spaces, not simply the presence of stressors like chaos, can also influence interpersonal relationships, thus affording or inhibiting ease of interpersonal interactions. For example, are typical travel routes likely to lead to unplanned, impromptu interactions? Are there spaces that people feel comfortable spending time in such as cafes and common facilities (e.g., a communal laundry area, community play spaces)?

In addition to proximal processes such as parent-child interactions (e.g., responsiveness, monitoring), several other candidate mechanisms are worthy of further examination both in the global North and South. One of the common qualities of many of the suboptimal physical settings children encounter is their uncontrollability. We need more examination of mastery, self-efficacy and other control-related processes in relation to the environment and children's development. Some of the ways in which physical settings can influence mastery include: uncontrollable stressors such as noise and crowding; highly unpredictable and variable conditions such as chaos; the degree of inflexibility and regimentation of settings such as school; the scale and manipulability of settings for children; and design and planning features that afford crime, such as undifferentiated spaces lacking in ownership and defensibility.

Considerable work shows that time spent in nature and other restorative spaces can help counteract cognitive fatigue and stress engendered by the fast-paced, multitasking demands of modern life, increasingly common throughout the world, regardless of economic development (Kaplan & Kaplan, 1989). Fascination or the experience of involuntary attention (e.g., curiosity) is not the sole purview of natural elements but can include human-made objects and spaces that attract and hold attention effortlessly (e.g., people-watching in a plaza, gazing at a fountain, meandering through a museum or good bookstore, or enjoying street entertainment).

Stressors such as crowding, noise, traffic, and chaos can directly strain physical and psychological systems, but they also have the ability to alter regulatory processes such as coping and executive functioning (Evans & Kim, 2013). Thus another area worthy of further scrutiny in considering children's environments is the role of coping and self-regulatory processes. When children and their parents encounter various suboptimal environments, they often adapt strategies, be they behavioral, cognitive, or both, to right the balance between environmental demands and human comfort and well being. These adjustments and adaptations to the environment, in and of themselves, can lead to developmental changes. For example, parents who cope with too much unwanted social interaction by withdrawing from their children are likely to be less responsive.

The impact of the environment on adult caregivers is a particularly important underlying process to consider. Parents in crowded homes are typically less responsive and less patient (Evans et al., 2001). Teachers in noisy schools report more fatigue and frustration, and observations of noisy schools show substantial reductions in teaching time (Evans & Hygge, 2007). The stress and anxiety engendered by knowledge of toxic exposures or parental struggles with substandard housing are bound to translate into less than ideal parent-child interactions. Interestingly, such parent-child interactions may in fact modify children's gene expression without altering the nucleotide sequence, as recent work in epigenetics has demonstrated (Meaney, 2010).

Phase 3: Identifying and addressing key inequalities and opportunities

As we have discussed above, the final step involves interdisciplinary, international research teams both filling in the gaps in the research literature in understudied contexts and implementing interventions to improve children's developmental functioning. One key leverage point for both cognitive and socioemotional development that might be further studied and then addressed is chaos. Implementing interventions within children's home, school and neighborhood environments that reduce chaos and/or moderate its impacts on children may be a particularly effective way to improve children's developmental outcomes. Interventions could include building sound barriers to block out aircraft and traffic noise, relocating homes and schools further from busy highways and airports, and redesigning open plan homes and classrooms to include quiet, secluded spaces for children.

One of the ways in which chaos has a particularly insidious effect is in its interruption of play, a key proximal process for young children's cognitive and socioemotional development (Bartlett, 1999; Milteer et al., 2012). Unsafe housing, school and neighborhood settings also disrupt play, as was coherently argued by the children living in as diverse contexts as Argentina, India, South Africa, Australia, the United Kingdom, the United States, Norway and Poland involved in UNESCO's *Growing Up in Cities* project (Chawla, 2002). Low-income urban children may be at particular risk for interruption of play processes (Chawla, 2002; Milteer et al., 2012), and these same children frequently encounter multiple environmental risk factors in their home, school and neighborhood environments (Bartlett et al., 1999; Evans, 2004). Thus building safe, green play spaces for low-income and other children across the global North and South will likely have a particularly positive impact on their cognitive and socioemotional development. In addition, the implementation of Community Adventure Play Experiences (CDI, 2012), that is, temporary play spaces within children's own communities that engage them in interactive play with recycled materials, may be a particularly low-cost and sustainable approach to increasing opportunities for child play in low-resource settings. In low-income and highly mobile communities, these may provide a good alternative to constructing new playgrounds, and have the added advantage that they can take place both indoors and outdoors. Such spaces may also provide common ground for community members to have greater social interaction, forming networks of relationships.

The physical environments experienced by children have important impacts on their cognitive and socioemotional development. Yet the work to date documenting these impacts in the global South is limited. We thus call for the development of a holistic, multidisciplinary and multilevel approach, based on Bronfenbrenner's bioecological model, to the investigation of the impacts of the physical environment on child and adolescent development. Such work should be led by an interdisciplinary, international team of researchers in collaboration with local and national government agencies and community members, including the children themselves. This approach will allow us to more effectively intervene in the actual lived environments of both high- and low-income children across the globe.

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