Relationship between the neighbourhood built environment and early child development

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Christian, H., Ball, S. J., Zubrick, S. R., Brinkman, S., Turrell, G., Boruff, B. and Foster, S. (2017). Relationship between the neighbourhood built environment and early child development. *Health and Place*, 48, pp. 90-101. https://doi.org/10.1016/j.healthplace.2017.08.010

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Hayley Christian[a,b,c], PhD (hayley.christian@uwa.edu.au)
Stephen J Ball[c,d], PhD (stephen.ball@curtin.edu.au)
Stephen R Zubrick[c,e], PhD (stephen.zubrick@telethonkids.org.au)
Sally Brinkman[c], PhD (sally.brinkman@telethonkids.org.au)
Gavin Turrell[f], PhD (Gavin.Turrell@acu.edu.au)
Bryan Boruff[b], PhD (bryan.boruff@uwa.edu.au)
Sarah Foster[b], PhD (sarah.foster@uwa.edu.au)

[a]School of Population Health, The University of Western Australia, 35 Stirling Highway, Crawley, Western Australia, 6009
[b]Centre for the Built Environment and Health, School of Sport Science, Exercise & Health and School of Earth & Environment, The University of Western Australia, 35 Stirling Highway, Crawley, Western Australia, 6009
[c]Telethon Kids Institute, 100 Roberts Road, Subiaco, Western Australia, 6008
[d]Prehospital, Resuscitation and Emergency Care Research Unit (PRECRU), School of Nursing, Midwifery and Paramedicine, Curtin University, Kent Street, Bentley, Western Australia, 6102
[e]Graduate School of Education, The University of Western Australia, 35 Stirling Highway, Crawley, Western Australia, 6009
[f] Institute for Health and Ageing, Australian Catholic University, 215 Spring Street, Melbourne, Australia, 3000

Author responsible for correspondence:
Asst/Prof Hayley Christian
School of Population Health (M431)
The University of Western Australia
35 Stirling Highway
Crawley WA 6009 Australia
Email: hayley.christian@uwa.edu.au
Telephone: 61-8-6488-8501

Abstract word count: 125
Manuscript word count: 4089
Number of tables: 4
Number of figures: 3

Abstract

The relationship between features of the neighbourhood built environment and early child development was investigated using area-level data from the Australian Early Development Census. Overall 9.0% of children were developmentally vulnerable on the Physical Health and Well-being domain, 8.1% on the Social Competence domain and 8.1% on the Emotional Maturity domain. After adjustment for socio-demographic factors, Local Communities with the highest quintile of home yard space had significantly lower odds of developmental vulnerability on the Emotional Maturity domain. Residing in a Local Community with fewer main roads was associated with a decrease in the proportion of children developmentally vulnerable on the Social Competence domain. Overall, sociodemographic factors were more important than aspects of the neighbourhood physical environment for explaining variation between Local Communities in the developmental vulnerability of children.

Keywords: Built environment, Child, Development, Neighbourhood, Community

Introduction:

The first five years of life are important for the physical, cognitive, social and emotional development of children (Shonkoff and Phillips, 2000). Healthy child development is an enabler of human capability into adulthood (Zubrick et al., 2009). A young child's development is influenced by a number of individual child-level factors (e.g., genetics, physiology), family-level factors (e.g., maternal education, parent-child interaction, parenting practices) and environmental factors (e.g., exposure to pollutants/toxicants, crime and safety, access to schools, childcare, health care and recreational opportunities) (Leventhal and Brooks-Gunn, 2000, Hertzman, 2013, Hertzman and Boyce, 2010, Bronfenbrenner, 1979, Irwin et al., 2007, Shonkoff and Phillips, 2000).

The ecological model proposes that context is an important factor in human development (Bronfenbrenner, 1979). For children, these contexts include family and friends, childcare/school, and the local neighbourhood (Leventhal and Brooks-Gunn, 2000). There is mounting evidence that adults have better health when they live in neighbourhoods with good access to shops and services, high quality parks, connected streets to facilitate walking, sufficient residential densities to support public transport and local businesses, minimal crime, and opportunities for social connectedness (Christian et al., 2013, Müller-Riemenschneider et al., 2013, Foster et al., 2013, Pereira et al., 2013, Giles-Corti et al., 2012a). However, there is little understanding of whether (and how) these attributes influence healthy child development. The specific built environment domains identified as likely potential influences on child development include housing density, access to local services, parks and playgrounds and the outdoor home environment (Christian et al., 2015).

The home is the most proximate environmental influence on child development and where children typically spend most time (Siddiqi et al., 2007). While the impact of poor housing conditions on children's health is well understood (Harker, 2006), the effect of the amount of yard space and its attributes (e.g., play equipment, trees, gardens) on child health and development (Kelty et al., 2008) is under-researched. For instance, a backyard provides children with space to play and be active, yet in countries such as Australia trends towards larger houses on smaller blocks has resulted in less home yard space available for children to play and be active (Hall, 2010).

Outside the home, parks and playgrounds are a preferred setting for children's free play and activity (Muñoz, 2009), however the quantity, quality and proximity of parks and playgrounds varies significantly, with poorer infrastructure in more socio-economically disadvantaged neighbourhoods (Vaughan et al., 2013, Astell-Burt et al., 2014). Moreover, time spent in outdoor play has decreased drastically over recent decades (Gill, 2008). Outdoor play is associated with more physical activity, lower levels of overweight (Kimbro et al., 2011), self-guided exploration and imaginative play (Moore, 1986, Cosco, 2007) and other physical, cognitive and social-emotional benefits (Barnett, 1990). Moreover, numerous studies confirm the importance of proximity to nature (Fjortoft and Sageie, 2000), green public open space (Taylor et al., 1998, Aarts et al., 2010), parks (Roemmich et al., 2006) and playgrounds (Quigg et al., 2011, Sallis et al., 1993) for outdoor play and physical activity in the early years (Christian et al., 2015). There is also evidence that green spaces may positively impact young children's cognitive development (Wells, 2000, Kuo and Taylor, 2004) and motor (Fjortoft, 2004, Fjortoft and Sageie, 2000, Fjørtoft, 2001).

Well-designed neighbourhoods ensure children and families have access to local essential services such as childcare, schools (Trapp et al., 2012) and healthcare. Several studies show a positive relationship between early child development and proximity to child-specific destinations (e.g., recreation centre, library, school) and services (e.g., child care centres) (Kenney, 2012, Fan and Chen, 2012, Rosenberg et al., 2011, Brinkman et al., 2012).While access to child education and health services is clearly important for healthy child development and reducing child health inequality (Hertzman and Power, 2005, Irwin et al., 2007), further clarity is required about how proximity to these services impacts on early child development.

Population-level studies examining the impact of housing density, outdoor space, traffic exposure, the outdoor home environment, nature and parks on early child health and development are required (Christian et al., 2015). The aim of this study was to determine if a child's social, emotional and physical development is associated with the neighbourhood built environment.

Methods

Study design and setting

Population data from the Australian Early Development Census (AEDC) was linked with objective (Geographic Information Systems (GIS)) measures of the natural and built environment (street connectivity, residential density, traffic volumes, proximity to goods, services and child-relevant destinations, green space, home outdoor space). A cross-sectional study of spatial patterns in developmental vulnerability among 149 Local Communities (inclusive of 23,395 children, mean age 5.3 years) in Perth, Western Australia was undertaken.

Spatial units

Area units were Australian Early Development Census (AEDC) Local Communities, whose boundaries are based on the Australian Bureau of Statistics' Statistical Area 2 (SA2) digital boundaries (Australian Bureau of Statistics, 2011). SA2's are based on suburbs and localities with an average population size of 10,000 persons. Of the 171 Local Communities in Perth, 22 were excluded from the analysis because there were no AEDC data for those areas (i.e., zero children).

Developmental vulnerability

Data on developmental vulnerability were sourced from the 2012 AEDC, a population-wide census of all Australian children in their first year of schooling (Brinkman et al., 2014). The 2012 AEDC census includes 96.5% (n = 289,973) of all Australian children enrolled in their first year of full-time school (AEDC, 2013). The AEDC has construct and concurrent validity and predictive ability (Brinkman et al., 2007, Brinkman et al., 2013). The AEDC assigns each child a set of scores on their developmental maturity, as assessed by their teacher, across five domains: Physical Health and Wellbeing, Social Competence, Emotional Maturity, Language and Cognitive Skills, and Communication Skills and General Knowledge (AEDC, 2013). Based on our review (Christian et al., 2015) we focussed on the three domains where there was some preliminary evidence of a relationship between the built environment and child health and development related outcomes: (1) Physical Health and Wellbeing - whether children are healthy, independent, and physically ready for the school day, and their gross and fine motor skills; (2) Social Competence - children's overall social development including how they play, share and get along with other children; and (3) Emotional Maturity

- whether children are able to concentrate during the school day, help others, are patient and not aggressive or angry.

Built environment measures

We used GIS to derive objective area-level measures of the neighbourhood (Local Community) built environment (Table 1).

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Insert Table 1 about here

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Walkability: Neighbourhoods that encourage walking among parents may, in turn, increase children's exposure to, and contact with, features of the local neighbourhood. 'Walkability' variables included street connectivity, residential density, land use mix, traffic exposure and density of public transport stops. Street connectivity measures the inter-connectedness of the street network and is the number of three-(or more)-way intersections per square kilometre. Net residential density is the number of dwellings per square kilometre of residential land. We measured land use mix using an entropy-based method (Christian et al., 2011, Frank et al., 2005) which reflects both the number of different land use categories (e.g., residential; retail; office; health, welfare and community; entertainment, culture and recreation; public open space, sporting infrastructure and primary and rural) within an area, and the evenness of their relative abundance. Traffic exposure was calculated as the percentage of minor roads (i.e., roads carrying less than 3000 vehicles per day) to the total length of roads within a Local Community (Main Roads Western Australia Functional Road Hierarchy, 2007).The density of public transit stops was measured as the number of bus or train stops per square kilometre.

Green space: Variables were derived from a spatial public open space layer developed for the Perth metropolitan area in 2011 (n=3463 parks) (Bull et al., 2013). Population-based median distance to nearest park (of any size), pocket park (<0.3 ha in size), attractive park, nature/conservation area and school grounds were calculated for each Local Community. This was calculated by initially deriving distances to each feature using the smaller spatial scale of SA1 (average population size of 400 persons). The distance from each SA1 centroid to the outer boundary of the nearest feature of interest (e.g., park) was determined, and the median distance (across all SA1s in the Local Community, weighted by SA1 population size) was calculated. This estimates, for each Local Community, how far the average (median) person is from the nearest feature of interest. The advantage of this approach versus an area-based average (e.g., proportion of Local Community area that is park), is that the population-based median captures information about the potentially uneven spatial distribution of people and built environment features within an Local Community, and allows for the measure of exposure to extend across Local Community boundaries (i.e., people could be very close to a park in a neighbouring Local Community). The Park Attractiveness Score was derived from objective measures of park attributes such as the presence of irrigated lawns, walking paths, trees, sporting facilities, amenities, water features, lighting (Giles-Corti et al., 2005). Parks scoring above the median were coded as attractive. Park attributes were determined by remote sensing methods (Google Earth) using the Public Open Space Desktop Auditing Tool (POSTDAT), which has been shown to be a valid and reliable tool for assessing park quality (Edwards et al., 2013).

Child-specific destinations: Proximity to child-specific destinations included population-based median distance to nearest Kindergarten, Child-centre-based-care, Family support service, Child Health Clinic and Playgroup.

Home outdoor space: The home yard for a Local Community was calculated as the percentage of residential land that was not part of a building footprint. The variable was modelled as quintiles, with the highest quintile representing the greatest home yard area.

Area-level socio-demographic variables

Known socio-demographic correlates of child development were created at the Local Community area-level. The 2011 Australian Bureau of Statistics' (ABS) Index of Education and Occupation was used as an area-level index of socio-economic advantage and disadvantage (Pink, 2013). Additionally, area-level data were sourced from the 2011 ABS census and used to create variables representing the percentage of households with 4 year olds in each Local Community that were female, Aboriginal or Torres Strait Islander origin, with one or more siblings, with at least one parent > 24 years, single parent families, at least one parent educated beyond secondary school (year 12), gross family income <$3000 AUD/fortnight and had moved house in the last year. This data were used as an indicator of the children who were in the 2012 AEDC as five year olds. A large set of sociodemographic variables were included to ensure we comprehensively adjusted for sociodemographic variation, rather than examine specific sociodemographic effects.

Statistical Methods

For each child development domain, we used logistic regression to model variation between Local Communities in the odds of developmental vulnerability. As a reference point a null

model (i.e. without covariates) for each developmental domain was run. A set of univariate models were run to separately measure the association between each area-level sociodemographic or built environment variable and developmental vulnerability. A set of adjusted models were then run separately for each built environment variable (i.e. a separate model for each built environment variable) adjusting for all nine socio-demographic factors. A final fully adjusted model including all significant built environment variables from the previous step plus socio-demographic factors was not run because only two to four built environment attributes were significantly associated with developmental vulnerability across each of the three domains of early child development.

For all models, we modelled residual spatial variation in vulnerability using a combination of spatially-correlated and spatially-uncorrelated random effects (Besag et al., 1991). For the spatially-correlated random effect, we used a conditional autoregressive (CAR) term, which was specified following a normal distribution with a mean of zero relative to (conditional on) the mean CAR random effect estimates of neighbouring areas (immediate neighbours only). The uncorrelated random effect was specified as being normally-distributed with a mean of zero, and no constraint of correlation among neighbouring areas. In the context of mixed models (i.e. including fixed effects and random effects), the random effects estimated variation between Local Communities in the odds of developmental vulnerability that was unexplained by socio-demographic and built environment variables. Each model was run as a Bayesian analysis, using WinBUGS 1.4 software (Lunn et al., 2000).

Results

Study area characteristics

Among Local Communities a median 7.7% of children were developmentally vulnerable on the Physical Health and Well-being domain, 7.3% on the Social Competence domain and 7.4% on the Emotional Maturity domain (Table 2). There were high levels of spatial variation in the proportion of children developmentally vulnerable across Local Communities for each of these domains (Figures 1-3).

Insert Figures 1-3 about here

Among Local Communities, a median 48% of young children in Local Communities were female, 2% were of Aboriginal or Torres Strait Islander background, 86% had siblings, 98% had a parent older than 24 years, 14% lived in a single parent household, 47% had a parent educated beyond secondary school, 68% had family income less than $3000 AUD/fortnight and 16% had moved house in the last year (Table 2).

Insert Table 2 about here

Among Local Communities, there was a median distance of 0.2 km to the nearest park (regardless of size) and 0.9 km to the nearest attractive park (Table 2). The median distance to the nearest play group was 0.9 km, child health clinic 1.4 km and family support service 4.6 km. A median of 73% of the road network was classed as minor roads and there were 9 public transit stops per square kilometre. Overall, land use mix and residential density was low, with little variation in levels of land use mix. Street connectivity was on average moderate with variation across Local Communities.

Univariate associations between domains of early child development and socio-demographic and built environment factors

Area-level socio-demographic factors

For all three domains, the odds of developmental vulnerability in a Local Community increased as a function of the proportion of 4 year olds who were of Aboriginal or Torres Strait Islander background, living in a single parent household, having a parent educated less than secondary school or a family income of less than $3000 AUD/fortnight (all $p \leq 0.05$) (Table 3). Higher Local Community scores on the Index of Education and Occupation were associated with decreased odds of developmental vulnerability across all three domains ($p \leq 0.05$). The odds of developmental vulnerability in a Local Community decreased as a function of the proportion of 4 year olds with siblings for the Physical Health and Wellbeing domain ($p \leq 0.05$), but not the other domains. The odds of developmental vulnerability in a Local Community decreased as a function of the proportion of 4 year olds with a parent older than 24 years for the Physical Health and Wellbeing, and Social Competence domains (both $p \leq 0.05$). For all three domains, development vulnerability was not significantly associated with the proportion of 4 year olds in a Local Community who were female or who had moved house in the last year ($p > 0.05$).

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Insert Table 3 about here

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Neighbourhood built environment factors

Children living in communities with intermediate amounts of yard space had the highest odds of being developmentally vulnerable on the Emotional Maturity domain, with the highest

quintile of yard space having a significantly lower risk of vulnerability (OR 0.65; 95% CI 0.48 to 0.86) (Table 3). Each percent increase in the proportion of low traffic roads in a Local Community was associated with a 2% decrease in the odds of developmental vulnerability on the Social Competence domain (OR 0.98; 95% CI: 0.98 to 0.99). The odds of developmental vulnerability was lower for each 100 m increase in the distance to the nearest school grounds (Physical Health and Wellbeing and Emotional Maturity domains) and attractive park (Social Competence domain). The odds of developmental vulnerability was also lower for each 1 km increase in the distance to the nearest child-centre-based-care (Social Competence domain) and family support service (Social Competence domain) (all $p \leq 0.05$). Each unit increase in land use mix was associated with an increase in the odds of developmental vulnerability on the Social Competence domain (OR 1.98; 95% CI 1.02 to 4.20). Distance to the nearest pocket park, nature/conservation area, kindergarten, child health clinic or play group, number of public transport stops or residential density were not significantly associated with any of the domains of early child development ($p > 0.05$).

Multivariate associations between domains of early child development and neighbourhood built environment factors

Most of the significant associations between built environment variables (yard space, low traffic exposure, land use mix and distance to nearest attractive park, school grounds and child-centre-based care) and the odds of developmental vulnerability across domains remained significant even after adjusting for area-level socio-demographic factors (Table 4). One additional variable (distance to nearest park) was significantly negatively associated with the odds of developmental vulnerability across all three domains, after adjustment for area-level socio-demographic factors ($p \leq 0.05$).

Insert Table 4 about here

There were high levels of residual variation in developmental vulnerability between Local Communities after accounting for area-level sociodemographic variables and measures of the built environment (null model of Table 3 vs. socio-demographic model of Table 4). Among the univariate models, the largest decreases in residual variation came from including area-level socio-demographic variables, especially the Index of Education and Occupation, whereas including the measures of the built environment had little effect on levels of residual variation.

Discussion

On each of the early child development domains of Physical Health and Wellbeing, Social Competence and Emotional Maturity, on average 8-9% of Perth metropolitan (Western Australia) children were developmentally vulnerable. These levels are comparable with the national Australian Early Development Census data (Australian Government, 2013). High levels of spatial variation in the proportion of children developmentally vulnerable across Local Communities existed. We sought to determine how much of this variation could be explained by features of the built environment.

Consistent with previous studies (Taylor et al., 2013, Brinkman et al., 2012, Australian Government, 2013), we found strong evidence that area-level socio-demographic factors are associated with child developmental vulnerability across Local Communities. Aboriginal or Torres Strait Islander background, single parent households, low parent education, low family income and lower scores on the Index of Education and Occupation were consistently

associated with increased developmental vulnerability, whereas having siblings and increasing parent age correlated with decreased developmental vulnerability across some domains. Similarly, research using individual-level measures identifies the strongest predictors of poor developmental and academic outcomes to be maternal age (particularly <20 years), smoking during pregnancy, parity, marital status (not married or de facto), and parent occupation (not manager/professional) (Zubrick et al., 2000, Moore et al., 2014, Chittleborough et al., 2016, Brinkman et al., 2013). This highlights the strong influence of socio-economic and demographic circumstances on early developmental capacities.

There was some suggestive evidence that neighbourhood built environment factors may contribute to between Local Community differences in developmental vulnerability. Local Communities which had more home yard space had significantly lower odds of children being developmentally vulnerable on the Emotional Maturity domain. Limited private indoor space and a lack of proximate safe outdoor spaces has the potential to affect child development through restricting play, exploration, social interaction and independent mobility (Frumkin et al., 2004, Giles-Corti et al., 2012b, Whitzman and Mizrachi, 2012, Taylor et al., 2002, Dockery et al., 2010). Further research is required to identify the optimum amount and quality (attributes) of home outdoor spaces required to facilitate outdoor play and optimize early child development.

Children living in high density environments may be exposed to higher levels of traffic noise, contributing to psychological distress, poorer auditory discrimination and lower reading ability (Whitzman and Mizrachi, 2012). Our findings showed that residing in a Local Community with fewer main roads was associated with a decrease in the proportion of children developmentally vulnerable on the Social Competence domain. Similarly, a Swiss

study of 5 year olds, found that living in neighbourhoods with high street traffic was correlated with restrictions in outdoor play, smaller social networks and diminished social and motor skills (Huttenmoser, 1995). Safe roads with lower levels (and speeds) of traffic are required to create safe spaces near home for children to play outdoors and develop their social competence. Low traffic roads may also promote interactions between parents and carers who may stop, linger and interact in spaces with less vehicular traffic and, this may provide a parent-facilitated pathway through which children can increase their social network.

Surprisingly, we found that as the distance to the nearest green space (parks and school grounds) and child-centre-based-care increased, the odds of developmental vulnerability across domains decreased. We hypothesised that proximity to these local destinations would be associated with reduced developmental vulnerability. These unexpected findings indicate the need for further research to understand if proximity to public open space and childcare services influences early child development outcomes. It is possible that it is not simply proximity to relevant child development destinations that may be important but also the quality of these destinations and services. Individual level data on both developmental vulnerability and GIS measures of proximity to local child relevant destinations are needed to confirm these findings.

Even though some significant associations were observed, overall the built environment did not appear to have a strong effect on young children's developmental vulnerability. After accounting for area-level socio-demographic factors, the inclusion of built environment measures in models had a minimal impact on reducing the remaining residual variation in developmental vulnerability among Local Communities. However, although the effect of the

built environment on early child development may appear to be small, even small effects could have significant population impact because of the longer term and lasting effects of the built environment on populations over time. Moreover, socio-demographic factors have the strongest effect on early child development and this is not surprising given the more proximal influence of these factors on child development. It is also plausible that the built environment influences early child development indirectly through its interaction with neighbourhood socio-economic disadvantage. Socially disadvantaged neighbourhoods have a greater concentration of residents of low socio-economic status but also have fewer high quality resources (Bradley and Corwyn, 2002, Leventhal and Brooks-Gunn, 2000, Evans, 2004). It is possible that the effect of the built environment on child development may not be independent of but intertwined with neighbourhood socio-economic disadvantage. More research is required to understand combined neighbourhood effects of the built environment and socio-economic disadvantage on child development.

Research using individual-level data is required to understand the influence of the neighbourhood built environment on early child development. Longitudinal studies are also needed to help understand the role of the neighbourhood built environment on development throughout childhood. It is possible that the built environment's influence on child development is dependent upon a child's level of exposure to that environment with exposure increasing as children get older (or variations in exposure with changing environments e.g., moving house). Future research should also consider the pathways through which the neighbourhood built environment influences early child health and development outcomes. A potential pathway may be via the opportunities (or constraints) that the neighbourhood built environment provides for young children's outdoor play and physical activity through structured sporting programs and facilities.

Study limitations:

We found that a high level of residual variation between Local Communities in developmental vulnerability remained even after accounting for area-level socio-demographic and built environment measures. This suggests that other unmeasured factors (e.g., teacher or school level factors, other parent and child factors) may account for this residual variation and should be considered in future research. This study is limited by its use of an ecologic approach to examine the influence of the neighbourhood built environment on early child development. Home latitude and longitude information would enable more accurate calculation of individual-level built environment measures (e.g., home yard space) and thus there is a call for government departments to release this information for research purposes. Linked data approaches also exist that allow for the capture of small area-level geospatial data without compromising participant privacy and data confidentiality.

The built environment may be important for child development, but more context and behaviour specific measures are needed. Future studies should use a child's home to create GIS-based built environment measures as well as examine finer grain environmental attributes (e.g., yard size, yard attributes, footpaths, street lighting, crime and disorder), the quality and actual use of local destinations and services (e.g., library, recreation centre, swimming pool, early education and care services), type of residence and neighbourhood liveability. Furthermore, research is needed to examine the pathways (e.g., via outdoor play) through which the built environment influences child development. Finally, this study could not explore the role of mediators such as parent perceptions and social–cultural factors on the relationship between the neighbourhood built environment and early child development.

Conclusion

This is one of the first studies to objectively measure attributes of the home outdoor and neighbourhood built environment and the association with early child development. After adjustment for area-level socio-demographic factors a greater amount of home yard space and lower levels of traffic exposure were associated with reduced developmental vulnerability on social-emotional domains of early child development. However, overall, sociodemographic factors had the strongest effect with the built environment having a minimal impact on reducing the variation in developmental vulnerability among Local Communities. Given the long-term cost and health consequences of poor child development, it is vital to identify the qualities and characteristics of neighbourhoods that promote or discourage healthy child development and how changes in neighbourhood environments affect child health and development outcomes over time.

Acknowledgements

HC is supported by an Australian National Health and Medical Research Council (NHMRC)/National Heart Foundation Early Career Fellowship (#1036350) and National Heart Foundation Future Leader Fellowship (#100794). SF is supported by an ARC Discovery Early Career Researcher Award (DE160100140). The authors gratefully acknowledge the contribution from Prof Matthew Knuiman and Dr Tess Gregory, the GIS team (Sharyn Hickey and Bridget Beasley) and Ms Pulan Bai (administrative assistance). This paper used data from the Australian Early Development Census (AEDC). The AEDC is funded by the Australian Government Department of Education and Training. The findings and views reported are those of the authors and should not be attributed to the Department or the Australian Government.

Funding

This work was supported by a University of Western Australia Faculty of Medicine, Dentistry and Health Science Near miss grant (#2013_NHMRC_APP1060123) and a University of Western Australia Near Miss Central Scheme (#2014_NHMRC_APP1080162).

References

AARTS, M.-J., WENDEL-VOS, W., VAN OERS, H., VAN DE GOOR, I. & SCHUIT, A. J. 2010. Environmental determinants of outdoor play in children: A large-scale cross-sectional study. *American Journal of Preventive Medicine,* 39, 212-219.

AEDC 2013. Australian Early Development Census 2012 Summary Report. Canberra, Australia: Commonwealth of Australia.

ASTELL-BURT, T., FENG, X., MAVOA, S., BADLAND, H. M. & GILES-CORTI, B. 2014. Do low-income neighbourhoods have the least green space? A cross-sectional study of Australia's most populous cities. *BMC Public Health,* 14, 1.

AUSTRALIAN BUREAU OF STATISTICS 2011. Australian Statistical Geography Standard (ASGS): Correspondences. Canberra, Australia: ABS.

AUSTRALIAN GOVERNMENT 2013. A Snapshot of Early Childhood Development in Australia 2012: Australian Early Developmental Index (AEDI) National Report. Canberra, Australia: Commonwealth of Australia.

BARNETT, L. A. 1990. Developmental benefits of play for children. *Journal of Leisure Research,* 22, 138.

BESAG, J., YORK, J. & MOLLIÉ, A. 1991. Bayesian image restoration, with two applications in spatial statistics. *Annals of the Institute of Statistical Mathematics,* 43, 1-20.

BRADLEY, R. H. & CORWYN, R. F. 2002. Socioeconomic status and child development. *Annual Review of Psychology,* 53, 371-399.

BRINKMAN, S., GIALAMAS, A., RAHMAN, A., MITTINTY, M., GREGORY, T., SILBURN, S., GOLDFELD, S., ZUBRICK, S., CARR, V. & JANUS, M. 2012. Jurisdictional, socioeconomic and gender inequalities in child health and development: Analysis of a national census of 5-year-olds in Australia. *BMJ Open,* 2.

BRINKMAN, S., GREGORY, T., HARRIS, J., HART, B., BLACKMORE, S. & JANUS, M. 2013. Associations between the early development instrument at age 5, and reading and numeracy skills at ages 8, 10 and 12: a prospective linked data study. *Child Indicators Research,* 6, 695-708.

BRINKMAN, S., SILBURN, S., LAWRENCE, D., GOLDFELD, S., SAYERS, M. & OBERKLAID, F. 2007. Investigating the validity of the Australian early development index. *Early Education and Development,* 18, 427-451.

BRINKMAN, S. A., GREGORY, T. A., GOLDFELD, S., LYNCH, J. W. & HARDY, M. 2014. Data Resource Profile: The Australian Early Development Index (AEDI). *International Journal of Epidemiology,* 43, 1089-1096.

BRONFENBRENNER, U. 1979. *The Ecology of Human Development,* Cambridge, London, Harvard University Press.

BULL, F., BEESLEY, B., HOOPER, P., BORUFF, B. & WOOD, L. 2013. Public Open Space (POS) Tool. Perth, Western Australia: Centre for the Built Environment and Health, School of Population Health, The University of Western Australia.

CHITTLEBOROUGH, C., SEARLE, A., SMITHERS, L., BRINKMAN, S. & LYNCH, J. 2016. How well can AEDI vulnerability be predicted from perinatal characteristics? A whole-of-population data linkage study. *Early Childhood Research Quarterly,* 35, 19-30.

CHRISTIAN, H., BULL, F., MIDDLETON, N., KNUIMAN, M., DIVITINI, M., HOOPER, P., AMARASINGHE, A. & GILES-CORTI, B. 2011. How important is the land use mix measure in understanding walking behaviour? Results from the RESIDE study. *International Journal of Behavioral Nutrition and Physical Activity,* 8, 55.

CHRISTIAN, H., KNUIMAN, M., BULL, F., TIMPERIO, A., FOSTER, S., DIVITINI, M., MIDDLETON, N. & GILES-CORTI, B. 2013. A new urban planning code's impact

on walking: The residential environments project. *American Journal of Public Health,* 103, 1219-1228.

CHRISTIAN, H., ZUBRICK, S., FOSTER, S., GILES-CORTI, B., BULL, F., WOOD, L., KNUIMAN, M., BRINKMAN, S., HOUGHTON, S. & BORUFF, B. 2015. The influence of the neighborhood physical environment on early child health and development: A critical review and call for research. *Health & Place,* 33, 25-36.

COSCO, N. 2007. Developing evidence-based design: Environmental interventions for healthy development of young children in the outdoors. *In:* THOMPSON, C. & TRAVLOU, P. (eds.) *Open Space: People Space.* Abingdon, UK: Taylor & Francis.

DOCKERY, A. M., KENDALL, G., LI, J., MAHENDRAN, A., ONG, R. & STRAZDINS, L. 2010. Housing and children's development and wellbeing: A scoping study. *AHURI Final Report No. 149.* Melbourne: Australian Housing and Urban Research Institute.

EDWARDS, N., HOOPER, P., TRAPP, G. S. A., BULL, F., BORUFF, B. & GILES-CORTI, B. 2013. Development of a Public Open Space Desktop Auditing Tool (POSDAT): A remote sensing approach. *Applied Geography,* 38, 22-30.

EVANS, G. W. 2004. The environment of childhood poverty. *American Psychologist,* 59, 77.

FAN, Y. & CHEN, Q. 2012. Family functioning as a mediator between neighborhood conditions and children's health: Evidence from a national survey in the United States. *Social Science & Medicine,* 74, 1939-1947.

FJORTOFT, I. 2004. Landscape as playscape: The effects of natural environments on children’s play and motor development. *Children, Youth and Environments,* 14, 21-44.

FJØRTOFT, I. 2001. The natural environment as a playground for children: The impact of outdoor play activities in pre-primary school children. *Early Childhood Education Journal,* 29, 111-117.

FJORTOFT, I. & SAGEIE, J. 2000. The natural environment as a playground for children - Landscape description and analyses of a natural playscape. *Landscape Urban Planning,* 48, 83-97.

FOSTER, S., WOOD, L., CHRISTIAN, H., KNUIMAN, M. & GILES-CORTI, B. 2013. Planning safer suburbs: Do changes in the built environment influence residents' perceptions of crime risk? *Social Science and Medicine,* 97, 87-94.

FRANK, L. D., SCHMID, T. L., SALLIS, J. F., CHAPMAN, J. & SAELENS, B. E. 2005. Linking objectively measured physical activity with objectively measured urban form: Findings from SMARTRAQ. *American Journal of Preventive Medicine,* 28, 117-125.

FRUMKIN, H., FRANK, L. & JACKSON, R. 2004. *Urban sprawl and public health: Designing, planning, and building for healthy communities,* Washington DC, USA, Island Press.

GILES-CORTI, B., BROOMHALL, M. H., KNUIMAN, M., COLLINS, C., DOUGLAS, K., NG, K., LANGE, A. & DONOVAN, R. J. 2005. Increasing walking: How important is distance to, attractiveness, and size of public open space? *American Journal of Preventive Medicine,* 28, S169-S176.

GILES-CORTI, B., BULL, F., KNUIMAN, M., MCCORMACK, G., VAN NIEL, K., TIMPERIO, A., CHRISTIAN, H., FOSTER, S., DIVITINI, M. & MIDDLETON, N. 2012a. The influence of urban design on neighbourhood walking following residential relocation: Longitudinal results from the RESIDE study. *Social Science & Medicine,* 77, 20-30.

GILES-CORTI, B., RYAN, K. & FOSTER, S. 2012b. Increasing Density In Australia: Maximising the Health Benefits and Minimising Harm. Report to the National Heart Foundation of Australia. Melbourne, Australia.

GILL, T. 2008. Space oriented children's policy: Creating child friendly communities to improve children's well being. *Children & Society,* 22, 136-142.

HALL, T. 2010. *The life and death of the Australian backyard.* Collingwood, Victoria, Australia, CSIRO Publishing.

HARKER, L. 2006. *Chance of a Lifetime: The Impact of Bad Housing on Children's Lives,* London, UK, Shelter.

HERTZMAN, C. 2013. Commentary on the symposium: Biological embedding, life course development, and the emergence of a new science. *Annual Review of Public Health,* 34, 1-5.

HERTZMAN, C. & BOYCE, T. 2010. How experience gets under the skin to create gradients in developmental health. *Annual Review of Public Health,* 31, 329-347.

HERTZMAN, C. & POWER, C. 2005. A life course approach to health and human development. *In:* JODY HEYMANN ET AL (ed.) *Healthier Societies: From Analysis to Action.* New York, USA: Oxford University Press.

HUTTENMOSER, M. 1995. Children and their living surroundings: Empirical investigations into the significance of living surroundings for the everyday life and development of children. *Childrens Environments,* 12, 403-413.

IRWIN, L. G., SIDDIQI, A. & HERTZMAN, C. 2007. Early child development: A powerful equalizer. *Final report to the WHO Commission on social determinants of health.* Geneva: WHO.

KELTY, S., GILES-CORTI, B. & ZUBRICK, S. 2008. Physical activity and young people: The impact of the built environment in encouraging play, fun and being active.

Physical Activity and Children: New Research, Editor: N.P Neaulieu. New York: Nova Science Publishers.

KENNEY, M. 2012. Child, family, and neighborhood associations with parent and peer interactive play during early childhood. *Maternal and Child Health Journal,* 16, S88-S101.

KIMBRO, R., BROOKS-GUNN, J. & MCLANAHAN, S. 2011. Young children in urban areas: Links among neighborhood characteristics, weight status, outdoor play, and television watching. *Social Science & Medicine,* 72, 668-676.

KUO, F. E. & TAYLOR, A. F. 2004. A potential natural treatment for attention-deficit/hyperactivity disorder: Evidence from a national study. *American Journal of Public Health,* 94, 1580-1586

LEVENTHAL, T. & BROOKS-GUNN, J. 2000. The neighborhoods they live in: The effects of neighborhood residence on child and adolescent outcomes. *Psychological Bulletin,* 126, 309-337.

LUNN, D. J., THOMAS, A., BEST, N. & SPIEGELHALTER, D. 2000. WinBUGS-a Bayesian modelling framework: Concepts, structure, and extensibility. *Statistics and computing,* 10, 325-337.

MAIN ROADS WESTERN AUSTRALIA FUNCTIONAL ROAD HIERARCHY. 2007. *http://www2mainroadswagovau/NR/rdonlyres/7DE6FC8F-A376-49FE-9B99-11BA1F5B3D54/442/frh_criteria3pdf* [Online]. [Accessed 1 Aug 2012].

MOORE, E. A., HARRIS, F., LAURENS, K. R., GREEN, M. J., BRINKMAN, S., LENROOT, R. K. & CARR, V. J. 2014. Birth outcomes and academic achievement in childhood: A population record linkage study. *Journal of Early Childhood Research,* 12, 234-250.

MOORE, R. 1986. *Childhood's domain: Play and place in child development,* London, UK, Taylor & Francis.

MÜLLER-RIEMENSCHNEIDER, F., PEREIRA, G., VILLANUEVA, K., CHRISTIAN, H., KNUIMAN, M., GILES-CORTI, B. & BULL, F. 2013. Neighborhood walkability and cardiometabolic risk factors in Australian adults: an observational study. *BMC Public Health,* 13.

MUÑOZ, S.-A. 2009. Children in the Outdoors: A literature review. *London: Sustainable Development Research Centre*.

PEREIRA, G., CHRISTIAN, H., FOSTER, S., BORUFF, B. J., BULL, F., KNUIMAN, M. & GILES-CORTI, B. 2013. The association between neighborhood greenness and weight status: An observational study in Perth Western Australia. *Environmental Health,* 12, 1-12.

PINK, B. 2013. Technical Paper: Socio-Economic Indexes for Areas (SEIFA). Canberra: Australian Nureau of Statistics, Commonwealth of Australia.

QUIGG, R., REEDER, A. I., GRAY, A., HOLT, A. & WATERS, D. 2011. The effectiveness of a community playground intervention. *Journal of Urban Health,* 89, 171-84.

ROEMMICH, J. N., EPSTEIN, L. H., RAJA, S., YIN, L., ROBINSON, J. & WINIEWICZ, D. 2006. Association of access to parks and recreational facilities with the physical activity of young children. *Preventive Medicine,* 43, 437-441.

ROSENBERG, L., JARUS, T., BART, O. & RATZON, N. 2011. Can personal and environmental factors explain dimensions of child participation? *Child: Care, Health and Development,* 37, 266-275.

SALLIS, J. F., NADER, P. R., BROYLES, S. L., BERRY, C. C., ELDER, J. P., MCKENZIE, T. L. & NELSON, J. A. 1993. Correlates of physical activity at home in

Mexican-American and Anglo-American preschool children. *Health Psychology,* 12, 390-398.

SHONKOFF, J. & PHILLIPS, D. E. 2000. *Committee on integrating the science of early childhood development,* Washington, DC, USA, National Academies Press.

SIDDIQI, A., IRWIN, L. G. & HERTZMAN, C. 2007. Total environment assessment model for early child development. *Evidence Report for the World Health Organization's Commission on the Social Determinants of Health, OMS.* WHO.

TAYLOR, A., KUO, F. & SULLIVAN, W. 2002. Views of nature and self-discipline: Evidence from inner city children. *Journal of Environmental Psychology,* 22, 49-63.

TAYLOR, A. F., WILEY, A., KUO, F. E. & SULLIVAN, W. C. 1998. Growing up in the inner city - Green spaces as places to grow. *Environment & Behavior,* 30, 3-27.

TAYLOR, C. L., CHRISTENSEN, D., LAWRENCE, D., MITROU, F. & ZUBRICK, S. R. 2013. Risk factors for children's receptive vocabulary development from four to eight years in the Longitudinal Study of Australian Children. *PLOS One,* 8, e73046.

TRAPP, G., GILES-CORTI, B., CHRISTIAN, H., BULSARA, M., TIMPERIO, A., MCCORMACK, G. & VILLANEUVA, K. 2012. Increasing children's physical activity individual, social, and environmental factors associated with walking to and from school. *Health Education & Behavior,* 39, 172-182.

VAUGHAN, K., KACZYNSKI, A., WILHELM STANIS, S., BESENYI, G., BERGSTROM, R. & HEINRICH, K. 2013. Exploring the distribution of park availability, features, and quality across Kansas City, Missouri by income and race/ethnicity: An environmental justice investigation. *Annals of Behavioral Medicine,* 45, 28-38.

WELLS, N. 2000. At home with nature - Effects of greenness's on children's cognitive functioning. *Environment & Behavior,* 32, 775-795.

WHITZMAN, C. & MIZRACHI, D. 2012. Creating child-friendly high-rise environments: Beyond wastelands and glasshouses. *Urban Policy Research,* 30, 233-249.

ZUBRICK, S., TAYLOR, C., LAWRENCE, D., MITROU, F., CHRISTENSEN, D. & DALBY, R. 2009. The development of human capability across the lifecourse: Perspectives from childhood. *Australasian Epidemiologist,* 16, 6-10.

ZUBRICK, S. R., KURINCZUK, J. J., MCDERMOTT, B. M. C., MCKELVEY, R. S., SILBURN, S. R. & DAVIES, L. C. 2000. Fetal growth and subsequent mental health problems in children aged 4 to 13 years. *Developmental Medicine and Child Neurology,* 42, 14-20.

Figure 1: Spatial variation in the odds of children being developmentally vulnerable on the Health and wellbeing domain across Local Communities in Perth, Western Australia

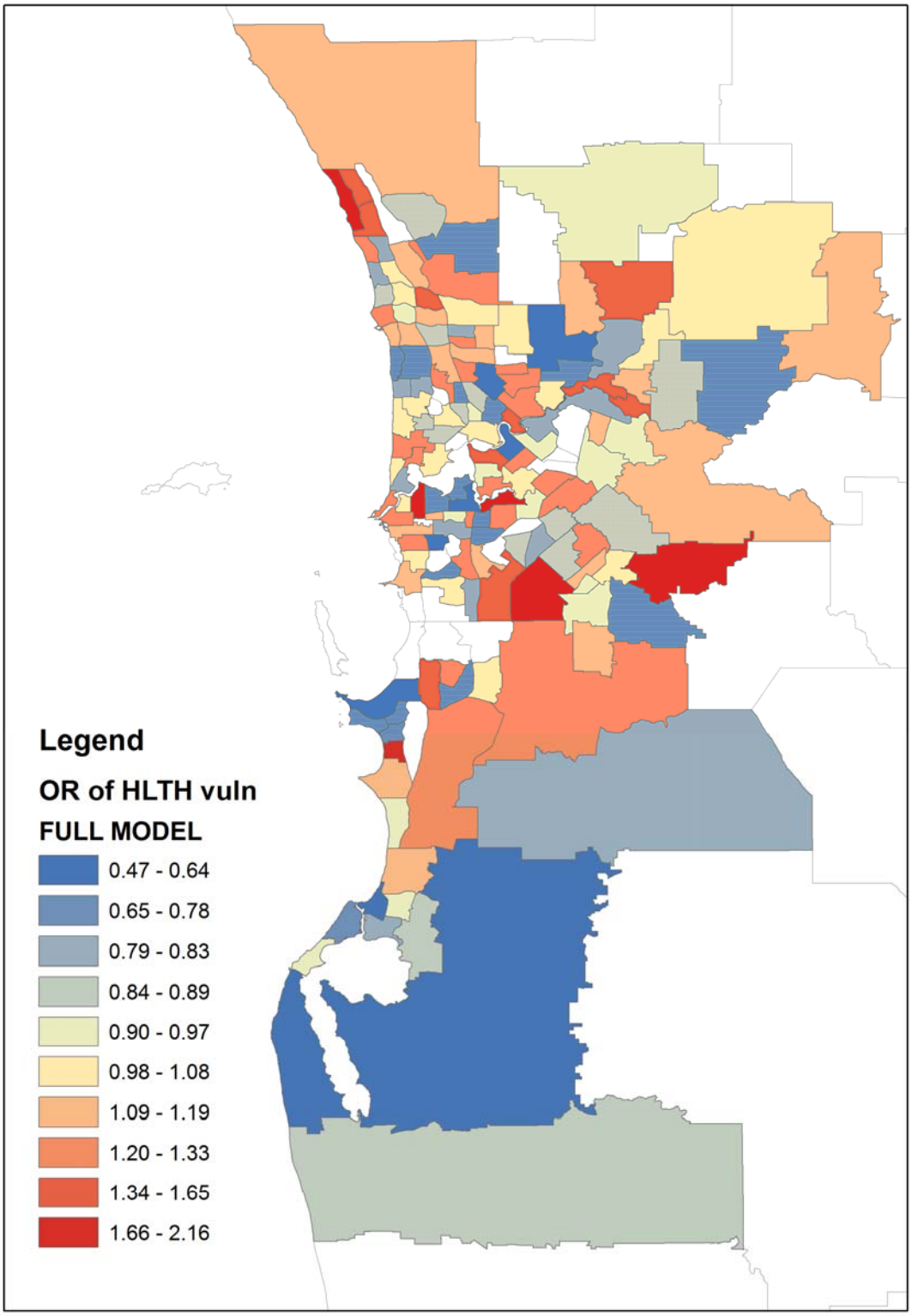

Figure 2: Spatial variation in the odds of children being developmentally vulnerable on the Social competence domain across Local Communities in Perth, Western Australia

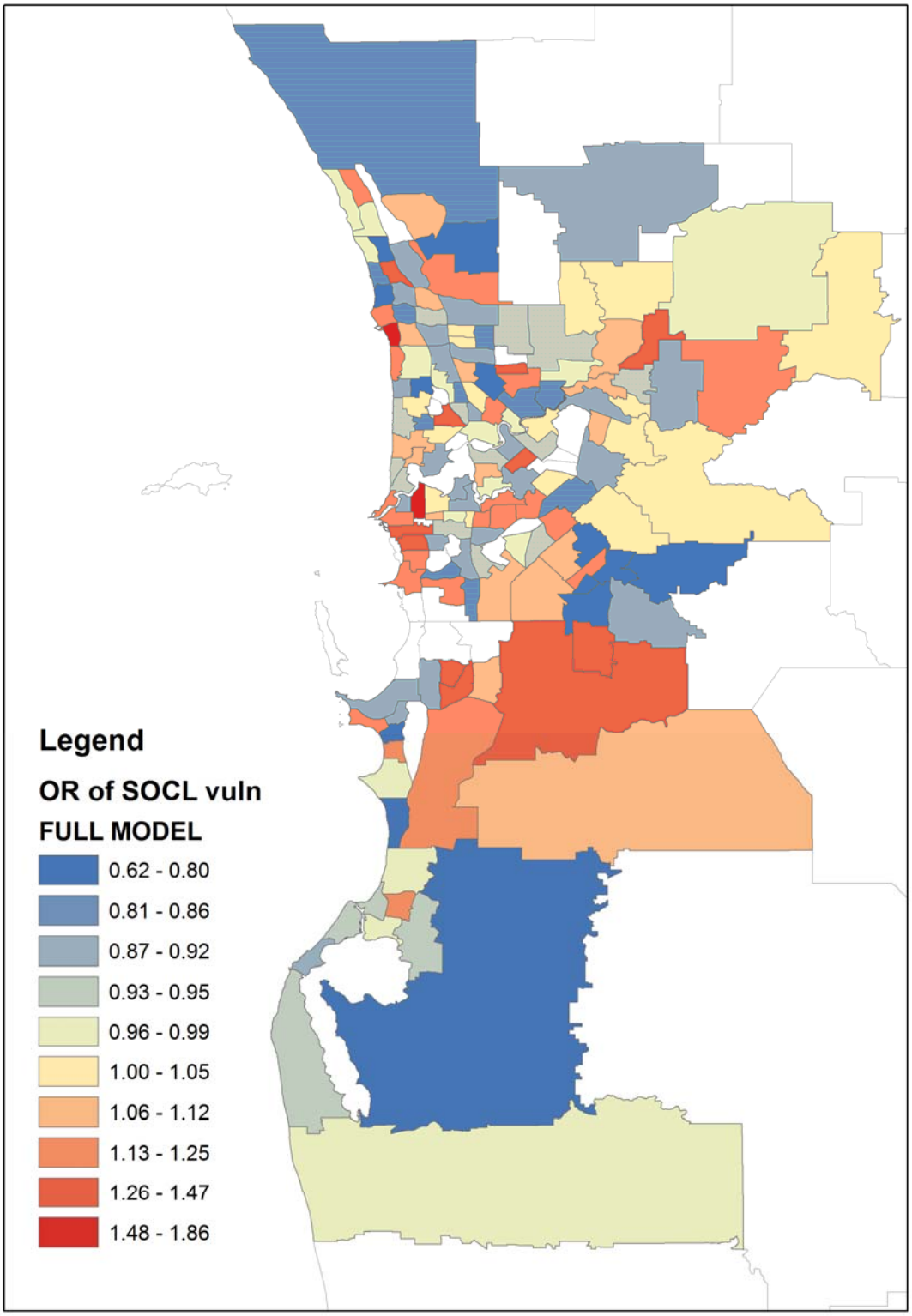

Figure 3: Spatial variation in the odds of children being developmentally vulnerable on the Emotional maturity domain across Local Communities in Perth, Western Australia

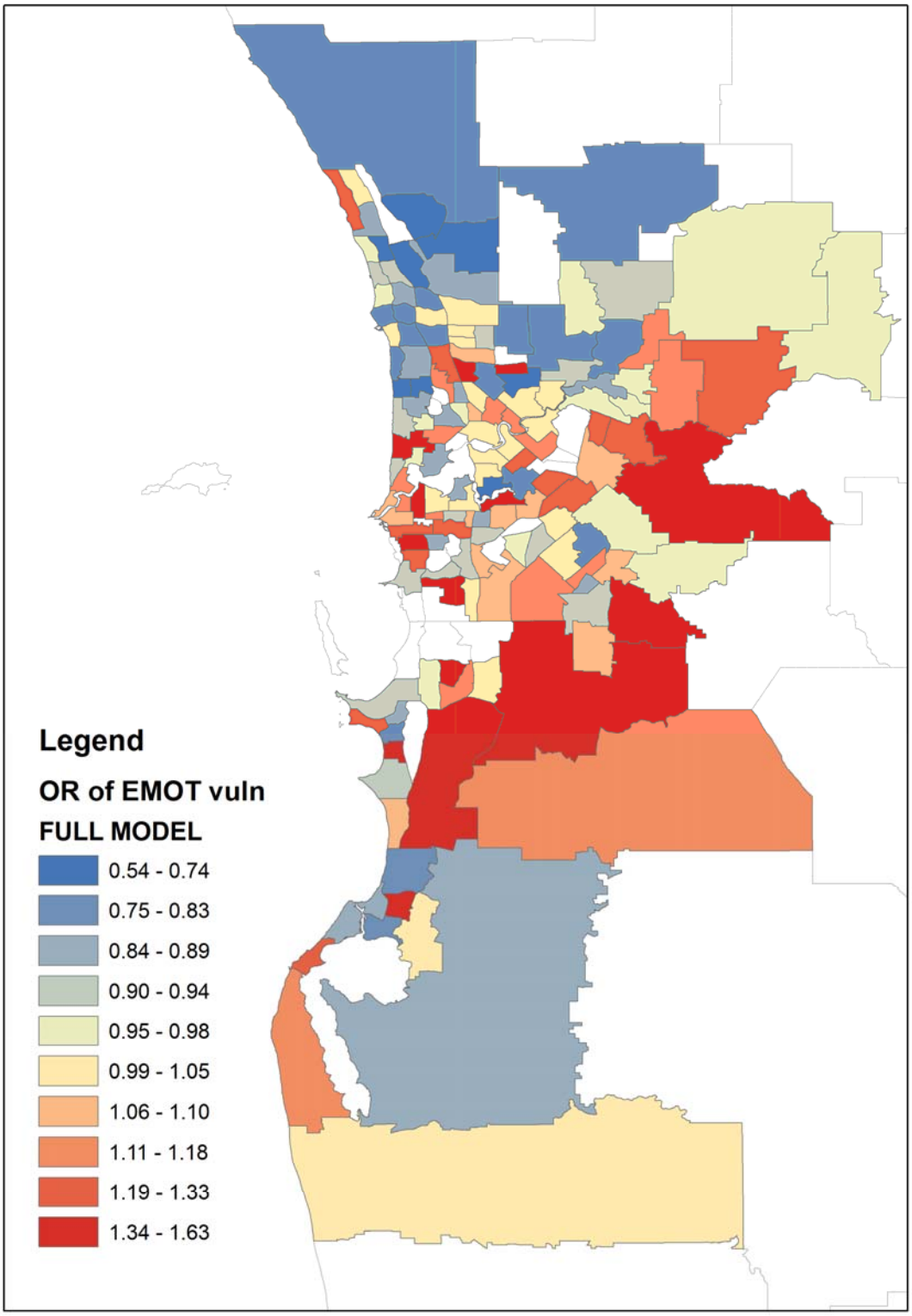

Table 1: Covariate measures

Measure	Description
Socio-demographic factors[1]	
Female	Percentage of 4-yr-olds that are female
Aboriginal or Torres Strait Islander	Percentage of 4-yr-olds that are Aboriginal or Torres Strait Islander
Siblings	Percentage of 4-yr-olds with one or more siblings
Parent >24 years	Percentage of 4-yr-olds with at least one parent older than 24 years
Single parent family	Percentage of 4-yr-olds in single parent families
Parent education >secondary school	Percentage of 4-yr-olds with at least one parent educated beyond Year 12 secondary school
Family income<$3000/fortnight	Percentage of 4-yr-olds whose gross family income is less than $3000 per fortnight
Moved house in last 12 months	Percentage of 4-yr-olds in a different SA2 in 2010
Socio-economic status	Australian Bureau of Statistics - Index of Education and Occupation for SA2
Built environment factors	
Home Environment:	
Home yard area	Mean area of residential blocks that are not building (average yard size) (CBEH derived: Spatial cadastre database from the Western Australian Land Information Authority (Landgate) and Land Use (VGO points) data). Modelled as quintiles with the highest quintile equal to the greatest home yard area (with a separate category for the 4 areas that were null for this variable)
Green Space:[2,3]	
Distance to nearest park	Median distance to nearest park (of any size) (CBEH derived: A land use classification planning and land use codes (PLUC) 51 (Public Open Space), 52 (Sporting Infrastructure) was applied to the VGO information linked with cadastral and Town Planning Scheme (TPS) data)
Distance to nearest attractive park	Median distance to nearest attractive park (Attractiveness Median Score ≥56.04) (CBEH derived: see (Giles-Corti et al., 2005, Edwards et al., 2013)
Distance to nearest pocket park	Median distance to nearest pocket park (size =<0.3 ha) (CBEH derived: A land use classification planning and land use codes (PLUC) 51 (Public Open Space), 52 (Sporting Infrastructure) was applied to the VGO information linked with cadastral and Town Planning Scheme (TPS) data)

Distance to nearest nature/conversation area	Median distance to nearest nature/conservation area (CBEH derived: A land use classification planning and land use code (PLUC) 6 (primary/rural, which includes extractive industries, farming and conservation areas) was applied to the VGO information linked with cadastral and TPS data.)
Distance to nearest school grounds	Median distance to nearest closest school grounds (CBEH derived: Geocoded location of government (public) and non-government (private) schools (all years - primary, secondary, tertiary) from schools data provided by the Department of Education and the Department of Planning)
Child-Relevant Destinations:[3]	
Distance to nearest kindergarten	Median distance to nearest kindergarten (Data source: Schools data from theWestern Australian Government Department of Education and Department of Planning)
Distance to nearest child-centre-based-care	Median distance to nearest child-centre-based-care (Data source: Western Australian Government Department of Local Government and Communities)
Distance to nearest family support service	Median distance to nearest family support service (e.g., early years/parent/family/community support service or centre) (Data source: Western Australian Government Department of Health)
Distance to nearest child health clinic	Median distance to nearest child health clinic (Data source: Western Australian Government Department of Health)
Distance to nearest playgroup venue	Median distance to nearest playgroup venue (Data source: Playgroup WA Inc)
Walkability:	
Street connectivity	Number of 3-way or greater intersections/SA2 area (Data source: road network data from Landgate)
Land use mix	Access to utilitarian and recreational destinations. Evenness of spread different land uses within a SA2 (Christian et al, 2011) (Data source: Spatial cadastre database and vesting reserve report provided by Landgate, VGO points data and land use classification planning and land use codes)
Residential density	Number of residential dwellings/residential land area (km^2) in SA2 (Data source: Spatial cadastre database and vesting reserve report provided by Landgate, VGO points data and land use classification planning and land use code 10)
Low traffic exposure	Percentage of total length of roads within a SA2 that are NOT main roads (Data source: road network data from Landgate and Functional Road Hierarchy information (details

	exposure to number of vehicles/day which was used as a proxy for traffic volume) from Main Roads Western Australia (Main Roads Western Australia Functional Road Hierarchy, 2007)
Public transport stops	Number of public transport stops (bus and rail) per square kilometre of SA2 (Data source: Western Australian Public Transport Authority)

Cadastre, Reserve Vesting Reports, VGO points and Road network data were provided by the Western Australian Land Information Authority.
CBEH=Centre for the Built Environment & Health, The University of Western Australia
VGO=Valuer General's Office
[1] Source: Australian Bureau of Statistics Census 2011
[2] Source: Centre for the Built Environment and Health (CBEH), The University of Western Australia
[3] Population weighted distances (in km) are based on SA1 centroids, and all of population (all ages, both sexes). For example, a suburb with a population-weighted median distance of 2.5km to nearest pocket park means that 50% of the population in that suburb live in SA1s whose centroids are less than 2.5km from the nearest pocket park.

Table 2: Study area characteristics

	Study area population mean	Median among Local Communities	IQR among Local Communities
Early child development domains (% developmentally vulnerable)			
Physical health and wellbeing	8.97	7.69	(4.92, 11.53)
Social competence	8.09	7.33	(5.00, 10.47)
Emotional maturity	8.12	7.35	(5.17, 9.84)
Socio-demographic factors[1]			
Female (%)	48.19	48.36	(45.62, 51.71)
Aboriginal or Torres Strait Islander (%)	2.99	2.08	(0.00, 4.60)
Siblings (%)	85.47	85.71	(81.96, 89.60)
Parent >24 years (%)	97.46	98.30	(96.26, 100.00)
Single parent family (%)	15.29	14.07	(8.66, 20.57)
Parent education >secondary school (%)	47.94	47.18	(36.57, 63.32)
Family income <$3000/fortnight (%)	66.68	67.69	(53.35, 79.36)
Moved house in last 12 months (%)	15.55	15.50	(12.28, 18.49)
Index of Education and Occupation	1012.12	1009.00	(948.50, 1084.00)
Built environment factors			
Home Environment:			
Home yard area (m^2)	1450.35	539.09	(473.91, 1079.51)
Green Space:[2,3]			
Distance to nearest park (km)	0.24	0.17	(0.13, 0.22)
Distance to nearest attractive park (km)	1.29	0.92	(0.62, 1.42)
Distance to nearest pocket park (km)	0.79	0.61	(0.44, 0.91)
Distance to nearest nature/conversation area (km)	0.56	0.42	(0.27, 0.70)
Distance to nearest school grounds (km)	0.63	0.46	(0.40, 0.62)
Child-Relevant Destinations:[3]			
Distance to nearest kindergarten (km)	0.74	0.63	(0.54, 0.78)
Distance to nearest child-centre-based-care (km)	0.77	0.59	(0.47, 0.81)
Distance to nearest family support service (km)	5.34	4.65	(2.94, 6.76)
Distance to nearest child health clinic (km)	1.86	1.41	(1.12, 2.14)
Distance to nearest playgroup venue (km)	1.11	0.93	(0.74, 1.32)
Walkability:			
Street connectivity (number of ≥3-way intersections)	42.43	43.89	(21.84, 52.73)
Land use mix (entropy score)	0.48	0.46	(0.40, 0.54)
Residential density (number residential dwellings/km^2 of residential land area)	13.08	14.03	(6.81, 16.07)
Low traffic exposure (% roads low number of vehicles/day)	73.40	72.94	(65.13, 79.57)
Public transport stops (number per km^2)	8.72	9.08	(3.92, 12.90)

Study area population mean=all-of study area average, regardless of Local Community boundaries
IQR=Inter-Quartile Range
[1] Source: Australian Bureau of Statistics Census 2011
[2] Source: Centre for the Built Environment and Health, The University of Western Australia
[3] Green space measures were calculated as the population-based median distance to nearest feature of interest. This was calculated by initially deriving distances to each feature using the smaller spatial scale of SA1. The distance from each SA1 centroid to the outer boundary of the nearest feature of interest was determined, and the median distance (across all SA1s in the Local Community, weighted by SA1 population size) was calculated.

Table 3: Unadjusted associations between domains of early child development and socio-demographic and built environment factors

	Physical health and wellbeing domain			**Social competence domain**			**Emotional maturity domain**		
	Point estimate	95% CI	Residual Variation	Point estimate	95% CI	Residual Variation	Point estimate	95% CI	Residual Variation
Null model	N/A	N/A	0.568 to 1.834	N/A	N/A	0.630 to 1.613	N/A	N/A	0.656 to 1.599
Socio-demographic factors									
Female[1]	0.985	0.966 to 1.003	0.555 to 1.774	0.992	0.976 to 1.010	0.637 to 1.601	0.986	0.970 to 1.001	0.638 to 1.586
Aboriginal or Torres Strait Islander[1]	**1.059**	**1.027 to 1.091**	0.616 to 1.672	**1.050**	**1.021 to 1.081**	0.668 to 1.513	**1.041**	**1.011 to 1.072**	0.697 to 1.558
Siblings[1]	**0.982**	**0.965 to 0.998**	0.576 to 1.790	0.989	0.974 to 1.005	0.622 to 1.603	0.995	0.982 to 1.012	0.646 to 1.608
Parent >24 years[1]	**0.937**	**0.911 to 0.970**	0.616 to 1.625	**0.939**	**0.905 to 0.967**	0.686 to 1.572	0.971	0.942 to 1.004	0.681 to 1.576
Single parent family[1]	**1.032**	**1.020 to 1.043**	0.634 to 1.558	**1.027**	**1.016 to 1.037**	0.727 to 1.366	**1.024**	**1.013 to 1.034**	0.732 to 1.432
Parent education >secondary school[1]	**0.983**	**0.978 to 0.990**	0.665 to 1.579	**0.984**	**0.979 to 0.989**	0.754 to 1.407	**0.989**	**0.983 to 0.996**	0.699 to 1.513
Family income <$3000/fortnight[1]	**1.019**	**1.014 to 1.024**	0.720 to 1.395	**1.017**	**1.012 to 1.022**	0.798 to 1.322	**1.015**	**1.010 to 1.020**	0.770 to 1.349
Moved house in last 12 months[1]	1.011	0.991 to 1.031	0.562 to 1.759	1.013	0.994 to 1.032	0.614 to 1.599	1.001	0.984 to 1.019	0.648 to 1.633
Index of Education and Occupation[2]	**0.957**	**0.940 to 0.968**	0.693 to 1.423	**0.962**	**0.952 to 0.972**	0.791 to 1.312	**0.966**	**0.955 to 0.977**	0.765 to 1.354
Built environment factors									
Home Environment: Mean home yard area	N/A	N/A	0.565 to 1.780	N/A	N/A	0.631 to 1.526	N/A	N/A	0.634 to 1.621
Null category	0.787	0.327 to 1.860	N/A	0.568	0.234 to 1.259	N/A	0.846	0.380 to 1.805	N/A
1st quintile	0.766	0.581 to 1.028	N/A	0.887	0.671 to 1.145	N/A	0.831	0.638 to 1.080	N/A
2nd quintile	0.880	0.665 to 1.172	N/A	0.789	0.603 to 1.041	N/A	0.809	0.643 to 1.015	N/A
3rd quintile	1.000	N/A	N/A	1.000	N/A	N/A	1.000	N/A	N/A
4th quintile	1.121	0.814 to 1.525	N/A	1.029	0.778 to 1.365	N/A	0.903	0.697 to 1.154	N/A
5th quintile	0.786	0.546 to 1.117	N/A	0.834	0.599 to 1.151	N/A	**0.648**	**0.479 to 0.855**	N/A
Green Space:[3]									
Distance to nearest park	0.990	0.978 to 0.999	0.566 to 1.801	0.990	0.979 to 1.000	0.628 to 1.619	0.992	0.979 to 1.001	0.655 to 1.616
Distance to nearest attractive park	0.998	0.994 to 1.002	0.556 to 1.829	**0.996**	**0.992 to 0.999**	0.605 to 1.616	0.998	0.994 to 1.002	0.647 to 1.632
Distance to nearest pocket park	0.998	0.992 to 1.005	0.560 to 1.820	0.997	0.990 to 1.004	0.628 to 1.627	1.001	0.995 to 1.007	0.647 to 1.616
Distance to nearest nature/conversation area	0.989	0.968 to 1.009	0.578 to 1.812	0.987	0.966 to 1.006	0.650 to 1.606	0.989	0.969 to 1.007	0.647 to 1.577
Distance to nearest school grounds	**0.990**	**0.978 to 0.999**	0.564 to 1.829	0.992	0.983 to 1.000	0.616 to 1.623	**0.989**	**0.978 to 0.998**	0.635 to 1.603
Child- Relevant Destinations:[4]									
Distance to nearest kindergarten	0.998	0.970 to 1.003	0.566 to 1.821	0.993	0.979 to 1.007	0.625 to 1.651	0.990	0.975 to 1.003	0.652 to 1.647

Distance to nearest child-centre-based-care	0.994	0.987 to 1.001	0.576 to 1.783	**0.992**	**0.984 to 0.999**	0.615 to 1.615	0.996	0.990 to 1.002	0.647 to 1.610
Distance to nearest family support service	0.998	0.995 to 1.000	0.560 to 1.784	**0.998**	**0.995 to 0.999**	0.612 to 1.568	0.998	0.995 to 1.000	0.632 to 1.570
Distance to nearest child health clinic	0.998	0.992 to 1.003	0.562 to 1.846	0.997	0.992 to 1.002	0.614 to 1.602	0.999	0.994 to 1.004	0.646 to 1.642
Distance to nearest playgroup venue	0.996	0.987 to 1.004	0.564 to 1.816	0.996	0.986 to 1.003	0.610 to 1.630	0.995	0.986 to 1.003	0.642 to 1.647
Walkability:									
Street connectivity[5]	1.000	0.995 to 1.005	0.553 to 1.820	0.998	0.994 to 1.003	0.641 to 1.611	1.000	0.996 to 1.005	0.656 to 1.614
Land use mix[6]	1.009	0.444 to 2.293	0.558 to 1.836	**1.977**	**1.023 to 4.158**	0.614 to 1.620	1.684	0.864 to 3.219	0.641 to 1.634
Residential density[7]	1.002	0.988 to 1.017	0.563 to 1.846	1.003	0.990 to 1.016	0.613 to 1.644	1.007	0.995 to 1.019	0.619 to 1.692
Low traffic exposure[1]	0.994	0.984 to 1.004	0.583 to 1.806	**0.984**	**0.976 to 0.994**	0.645 to 1.600	0.993	0.984 to 1.003	0.651 to 1.593
Public transport stops[8]	1.016	0.989 to 1.042	0.544 to 1.895	0.998	0.977 to 1.020	0.636 to 1.613	1.007	0.986 to 1.030	0.634 to 1.638

Bold = $p \leq 0.05$

[1] Per percentage point; [2] Per 100 IEO points (approx. 1 std dev of SEIFA); [3] Per 100m of increased distance from nearest green space; [4] Per 1km of increased distance from child-relevant destination; [5] Per increase in number of ≥3-way intersections; [6] Per unit increase in entropy score; [7] Per increase in number of residential dwellings/km^2 of residential land area in SA2; [8] Per each public transport stop per square km

Table 4: Adjusted associations between domains of early child development and built environment factors

	Physical health and wellbeing domain[1]			**Social competence domain[1]**			**Emotional maturity domain[1]**		
	Point estimate	95% CI	Residual Variation	Point estimate	95% CI	Residual Variation	Point estimate	95% CI	Residual Variation
Demographic model			0.750 to 1.377			0.807 to 1.265			0.774 to 1.336
Built environment factors									
Home Environment: Mean home yard area	N/A	N/A	0.744 to 1.387	N/A	N/A	0.802 to 1.299	N/A	N/A	0.799 to 1.311
Null category	0.756	0.305 to 1.666	N/A	0.541	0.227 to 1.200	N/A	0.741	0.365 to 1.489	N/A
1st quintile	0.952	0.705 to 1.252	N/A	1.019	0.816 to 1.285	N/A	0.950	0.758 to 1.196	N/A
2nd quintile	1.022	0.790 to 1.321	N/A	0.861	0.672 to 1.092	N/A	0.841	0.665 to 1.058	N/A
3rd quintile	1.000	N/A	N/A	1.000	N/A	N/A	1.000	N/A	N/A
4th quintile	1.109	0.860 to 1.461	N/A	1.024	0.815 to 1.294	N/A	0.923	0.727 to 1.155	N/A
5th quintile	0.940	0.704 to 1.262	N/A	0.924	0.718 to 1.208	N/A	**0.745**	**0.567 to 0.969**	N/A
Green Space:[2]									
Distance to nearest park	**0.989**	**0.976 to 0.998**	0.739 to 1.377	**0.990**	**0.978 to 0.999**	0.807 to 1.260	**0.989**	**0.977 to 0.998**	0.794 to 1.324
Distance to nearest attractive park	0.998	0.994 to 1.001	0.737 to 1.391	**0.996**	**0.993 to 0.999**	0.810 to 1.278	0.998	0.994 to 1.001	0.782 to 1.321
Distance to nearest pocket park	0.998	0.992 to 1.004	0.725 to 1.382	0.997	0.991 to 1.003	0.800 to 1.263	0.998	0.993 to 1.004	0.783 to 1.312
Distance to nearest nature/conversation area	0.983	0.965 to 1.000	0.736 to 1.385	0.985	0.968 to 1.001	0.808 to 1.297	0.987	0.970 to 1.003	0.782 to 1.313
Distance to nearest school grounds	**0.991**	**0.981 to 0.999**	0.734 to 1.391	0.994	0.985 to 1.001	0.811 to 1.276	**0.990**	**0.981 to 0.998**	0.783 to 1.333
Child-Relevant Destinations:[3]									
Distance to nearest kindergarten	0.994	0.980 to 1.008	0.749 to 1.373	0.997	0.984 to 1.009	0.803 to 1.261	0.991	0.978 to 1.005	0.795 to 1.327
Distance to nearest child-centre-based-care	**0.994**	**0.988 to 0.999**	0.739 to 1.379	**0.993**	**0.986 to 0.999**	0.798 to 1.282	**0.995**	**0.989 to 0.999**	0.790 to 1.324
Distance to nearest family support service	0.999	0.997 to 1.002	0.737 to 1.373	0.999	0.997 to 1.001	0.809 to 1.274	0.998	0.996 to 1.000	0.793 to 1.349
Distance to nearest child health clinic	0.998	0.993 to 1.003	0.737 to 1.373	0.998	0.994 to 1.002	0.809 to 1.274	0.998	0.994 to 1.002	0.793 to 1.349
Distance to nearest playgroup venue	0.993	0.985 to 1.002	0.738 to 1.385	0.995	0.988 to 1.003	0.790 to 1.288	0.993	0.984 to 1.001	0.788 to 1.344
Walkability:									
Street connectivity[4]	1.001	0.996 to 1.005	0.736 to 1.393	0.999	0.995 to 1.003	0.801 to 1.260	1.001	0.997 to 1.005	0.785 to 1.300

Land use mix[5]	1.020	0.465 to 2.184	0.737 to 1.389	**2.413**	**1.257 to 4.614**	0.814 to 1.297	**2.113**	**1.146 to 3.924**	0.791 to 1.346
Residential density[6]	0.998	0.985 to 1.013	0.742 to 1.384	1.003	0.990 to 1.016	0.795 to 1.284	1.011	0.998 to 1.024	0.775 to 1.309
Low traffic exposure[7]	0.997	0.988 to 1.007	0.737 to 1.383	**0.988**	**0.981 to 0.996**	0.829 to 1.264	0.997	0.989 to 1.006	0.773 to 1.305
Public transport stops[8]	1.002	0.979 to 1.023	0.736 to 1.395	0.999	0.981 to 1.019	0.806 to 1.271	1.012	0.990 to 1.032	0.768 to 1.311

Bold = $p \leq 0.05$

[1]All models adjusted for the following socio-demographic area-level factors: child gender, Aboriginal or Torres Strait Islander, siblings, parent>24years, single parent family, parent education>secondary school, family income<$3000/fortnight, moved house in last 12months and Index of Education and Occupation.

[2] Per 100m of increased distance from nearest green space; [3]Per 1km of increased distance from child-relevant destination; [4] Per increase in number of ≥3-way intersections; [5] Per unit increase in entropy score; [6] Per increase in number of residential dwellings/km^2 of residential land area in SA2; [7] Per percentage point; [8] Per each public transport stop per square km