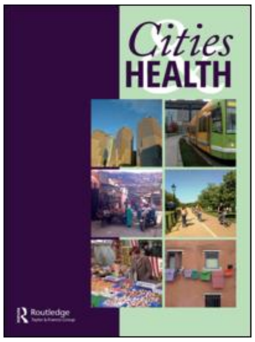

Cities & Health

ISSN: 2374-8834 (Print) 2374-8842 (Online) Journal homepage: https://www.tandfonline.com/loi/rcah20

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To cite this article: Melanie Davern, Lucy Gunn, Carolyn Whitzman, Carl Higgs, Billie Giles-Corti, Koen Simons, Karen Villanueva, Suzanne Mavoa, Rebecca Roberts & Hannah Badland (2017) Using spatial measures to test a conceptual model of social infrastructure that supports health and wellbeing, Cities & Health, 1:2, 194-209, DOI: 10.1080/23748834.2018.1443620

To link to this article: https://doi.org/10.1080/23748834.2018.1443620

CITIES & HEALTH
2017, VOL. 1, NO. 2, 194–209
https://doi.org/10.1080/23748834.2018.1443620

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Using spatial measures to test a conceptual model of social infrastructure that supports health and wellbeing

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ABSTRACT
Social infrastructure requires a consistent and measurable definition and more evidence is needed to demonstrate why it is important to health, wellbeing and the liveability of a community. In this paper, social infrastructure is defined as life-long social service needs related to health, education, early childhood, community support, community development, culture, sport and recreation, parks and emergency services. These services are needed to promote health and wellbeing and underinvestment and poor planning of social infrastructure has been linked to area-based health inequities. Current methods used to plan infrastructure delivery in communities were analysed and a new conceptual framework of social infrastructure developed and empirically tested using geocoded health survey data linked to spatial social infrastructure measures. Both accessibility and mix of social infrastructure were associated with higher Subjective Wellbeing. Residents were most likely to have close access to childcare services, dentists, doctors and sport facilities and least likely to have access to services of culture and leisure including cinemas, theatres, libraries, museums and art galleries. Results provide evidence of direct associations between social infrastructure planning and public health, the need for alternative social infrastructure urban planning methods and policies, and areas for future research.

ARTICLE HISTORY
Received 25 October 2017
Accepted 19 February 2018

KEYWORDS
Social infrastructure; social planning; policy; health; subjective wellbeing

Introduction

Social infrastructure is essential for the creation and ongoing development of healthy communities and must be planned for, to ensure provision of social services across the lifespan. The amenities and services available within a community also influence the liveability of local communities, as well as the health and wellbeing of individuals. Timely and accessible delivery of social infrastructure is an essential domain of liveability in a review of liveability indicators (Badland *et al.* 2014; Lowe *et al.* 2015). The review defined a liveable community as:

> safe, attractive, socially inclusive and cohesive, environmentally sustainable with affordable and diverse housing, linked by convenient public transport, walking and cycling infrastructure to employment, education, local shops and community services, leisure and cultural opportunities and public open space (Lowe *et al.* 2013).

Social infrastructure addresses a number of the social determinants of health and influences avoidable health inequities across society (WHO Commission on Social Determinants of Health and World Health Organization 2008). Socio-spatial inequities have been quantified across Australia (Baum and Gleeson 2010) and growing inequality has been demonstrated (Gleeson 2006). Gentrification, population growth and housing unaffordability have been associated with the displacement of low-income residents in areas well serviced by jobs, transport and social infrastructure (Smith 2002; Smith and Graves 2005; Desmond and Kimbro 2015; Lloyd *et al.* 2016).

Rapid growth in established communities and new urban development requires new approaches to social infrastructure policy, planning and delivery, including clear definition of social infrastructure. Evidence is also required to demonstrate the importance of social infrastructure access to health and wellbeing and how this might influence a community's liveability. There is very little research examining the impact of social infrastructure on the health and wellbeing of residents and this paper seeks to address these gaps. First, it provides a clear and measurable definition of social infrastructure, describes the importance of the construct to health

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and current methods used to plan social infrastructure delivery. Second, it proposes a new conceptual framework of social infrastructure in relation to health and empirically tests some pathways in the model using large scale population health survey data. Finally, it concludes with a discussion of the key findings and implications for future research, public health and urban policy. The development of new social infrastructure indicators are intended to monitor and evaluate local, regional and national social infrastructure planning policies which is long overdue in spatial planning (Ciechocińska and Smith 1984).

What is social infrastructure?

Infrastructure planning is a complex task, requiring a careful balance of current understanding and future predictions of population needs, along with sequencing of infrastructure delivery to meet current and future demands in a timely and equitable way (Seto *et al.* 2014). The most common conceptions of infrastructure focus on 'hard' engineering works such as transportation systems (e.g. highways and railways), communications systems (e.g. telephone and internet), and sewers and water systems (Frischmann 2012). Indeed, McKinsey has estimated that global investment required in physical infrastructure between 2013 and 2030 is $57 trillion, without even addressing existing major backlogs, maintenance budget deficiencies or the needs of emerging economies (McKinsey Global Institute 2013). However, this significantly underestimates infrastructure requirements of rapidly growing cities, because it fails to consider social infrastructure which is often regarded as the 'poor cousin of physical infrastructure' (Whitzman 2001, p. 60). The timely delivery of social infrastructure is critical for communities to address the social service needs of residents across the lifespan.

Despite the importance of social infrastructure it is poorly defined. A summary of services included within social infrastructure is provided in Table 1 below and includes: hospitals and health; education; childcare; community support agencies; sport and recreation; parks and playgrounds, community development services; housing; employment and training, legal and public safety; emergency services; public and community transport; arts and cultural institutions, such as movie theatres, art galleries, senior citizen centres or anywhere that brings people together (Whitzman 2001; Temple and Reynolds 2007). These services are largely government funded and delivery requires expensive investment. However, the timely delivery of social infrastructure is critical because it addresses social service needs across the lifespan – essential services that create the material and cultural living conditions for an area (Gabdrakhmanov and Rubtsov 2013).

The importance of social infrastructure to health

Social infrastructure provides essential societal resources that support individual and community wellbeing (Goe and Green 2005). Satisfaction with place of residence (Bardo and Yamashita 2014) and social infrastructure (Fitz et al. 2015) influences individual satisfaction with their local community and contributes to a community's liveability (Badland *et al.* 2014; Lowe *et al.* 2015). These services provide opportunities for people to interact with destinations within easy walking distance and built environment characteristics have been found to influence social interactions and mental health outcomes (Evans 2003). Access to local services, convenience goods and public open space are associated with increased walking for transport (Giles-Corti *et al.* 2013), and local shops, transport, low-cost recreation facilities, walking and cycling infrastructure associated with increased levels of physical activity in 11 countries (Sallis *et al.* 2009). In comparison, sprawling low density and car dependent suburbs have been shown to produce adverse health outcomes (Griffin *et al.* 2013), and declining social capital (Putnam 2001) which is in turn associated with poor self-rated health (Kawachi *et al.* 1999) and coronary heart disease (Sundquist *et al.* 2006).

Health inequity is defined as systematic differences in health for different groups of people that are avoidable with reasonable action (Marmot *et al.* 2008). Considerable interdisciplinary research has found that neighbourhood characteristics including transport, health care, public open space, crime, social capital, access to food, housing, education and job markets are

Table 1. Services, buildings and infrastructure included in definitions of social infrastructure.

Service	Examples
Health Services	Hospitals, General Practitioners, Mental Health Services, Community Health Centres, Maternal and Child Health Centres and Aged Care Facilities
Education Services	Lifelong learning including Kindergartens, Playgroups, Primary and Secondary Schools, Universities, Vocational and Technical Tertiary Education, University of the 3rd Age, Libraries
Childcare	Long Day Care, Occasional Care and Out of Hours School Care
Community Support Agencies	Community Support Organisations and Centrelink
Arts and Culture	Movie theatres, art galleries, museums and community art centres
Formal sport and recreation	Pools, gyms, indoor and outdoor facilities
Public Open Space	Parks and Playgrounds
Community Development	Community Centres, Neighbourhood Houses, Senior Citizens Centres, Youth Services, Home & Community Care
Social Housing	Public housing, transitional housing and housing diversity to meet the needs of varied demographic profile
Employment	
Legal and Emergency Services	Fire, Police, Ambulance and Judicial Services
Public and Community Transport	Council Community Transport and planning that supports walking and cycling

associated with stark differences in health outcomes (Kawachi and Berkman 2003). Concern about unfair and unjust health inequities were behind the development of the World Health Organisation's Commission on the Social Determinants of Health (hereafter referred to as the Commission) nearly a decade ago (WHO Commission on Social Determinants of Health and World Health Organization 2008). The Commission found that health inequities are strongly influenced by how we plan and deliver the necessary structural determinants and conditions of daily life. Consequently, the social determinants of health describe the conditions where we live, learn work and play. Access to critical services and social infrastructure such as health care, education, conditions of work and recreation, affordable homes and communities are determinants of long term health outcomes and lack of access to these services is influenced by poor public policies, politics and unfair economic arrangements (Marmot *et al.* 2008). Many of these critical services are also identified in our definition of social infrastructure (Table 1) creating the underlying daily living conditions that support health and wellbeing.

Public investment in social infrastructure addresses the social determinants that improve the health outcomes for all members of the community. This is particularly important given the possibility of deprivation amplification (Macintyre 2007) where having a low socio-economic position and living in a deprived area can expose people to double disadvantage. The concept has important policy implications for social infrastructure because it places focus on the environments where people live and the influence of local services as determinants of health outcomes. Applications of multilevel modelling over the last decade have aided better understanding of the importance of area level deprivation and socio-economic position on health (Badland *et al.* 2013). These associations have also been embraced in the systems approach adopted by community development approaches addressing social, economic and environmental influences on health (Pastor and Morello-Frosch 2014).

Early delivery of social infrastructure that is well planned has the ability to encourage social interactions and connections between residents and across communities by facilitating the use of shared spaces and services, and is said to have a 'catalytic effect' (Talen 1999, p. 1372). This describes the indirect effect of the built form on bringing people together and promoting positive or negative perceptions of community connection. It emphasises the importance of neighbourhood design, urban planning and policy on health and wellbeing and the physical development of neighbourhoods in terms of density, street networks, land use and building community (Barton *et al.* 2010). Encouraging social interactions also resonate with Putnam's social capital analyses emphasising the importance of social networks, civic engagement, social trust and reciprocity for societal development.

Different approaches to social planning and its association with health and wellbeing is well documented (Baum *et al.* 2011) and supports the inclusion of citizen representation and empowerment in social planning. For example, a mixed methods natural experiment in the city of Adelaide, Australia, investigated connections between location, health and social capital across four postcodes with lower or higher than average socio-economic status. The areas of lower socio-economic status were outer suburban growth areas built in the 1980s and were the subject of major urban renewal and social planning initiatives with various approaches to social planning. A 10-year community social plan for the area of Seaford developed through multi-agency and community consultation led to an integrated and coordinated social and physical plan with community and commercial partners. Seaford's consultative and participatory community social planning model contributed to improved social capital and mental health outcomes in residents of the area. Despite being significantly more disadvantaged than comparison areas, residents reported higher levels of face-to-face social contact with family and friends, higher levels of trust, perceived neighbourhood cohesion, perceived safety and better mental health as measured by the SF-12 (Baum *et al.* 2011).

Methods used for planning and delivering social infrastructure: a case study of Melbourne, Australia

The importance of location in associations between health, place and activities of daily living make spatial techniques useful for social infrastructure assessment. However, the use of Geographic Information System (GIS) software is not always commonly used in assessments of access to social infrastructure or future social infrastructure planning. More conventional applications of GIS have assessed physical infrastructure access such as roads (Muthama *et al.* 2013), transport (Ray 2007) and utilities (Coppock and Rhind 1991; Liu and Issa 2012). More recent developments have applied GIS in strategic planning of health services (Higgs and Gould 2001; Foley 2002; Murad 2007) and broader social services (Ishfaq and Lodhi 2012).

Accessibility is essential to nearly all models of service planning and encompasses socio-economic, population and spatial perspectives (Curl *et al.* 2011). The most obvious reason for its inclusion in models of social infrastructure planning is to allocate resources fairly (Bisht *et al.* 2010). Accessibility is therefore a key aspect of community planning and particularly relevant for new residential development because social infrastructure delivery should ideally be delivered before the arrival of residents. Accessibility is also commonly linked to principles of social equity and public good that inform planning (Hay 1995). Accessibility has also been linked to other dimensions such as the fit between services and client needs including mobility, transport and travel time (Bigotte and Antunes 2007; Bisht *et al.* 2010), and the ability to accommodate new clients, affordability and acceptability in terms of attitudes and preferences (Penchansky and Thomas 1981). Accessibility models also produce health co-benefits derived with increased physical activity associated with the availability of local community services and neighbourhood facilities (King *et al.* 2003; Pikora *et al.* 2006; Leslie and Cerin 2008; Frank *et al.* 2010; Salvador, Reis, and Florindo, 2010; Jia *et al.* 2014; Koohsari *et al.* 2015).

Accessibility and population density models

There have been two recent approaches to social infrastructure planning in cities. The first is a population-based approach and the alternative an access-based approach. An example of a population-based approach is provided in *Healthy Urban Planning*, published by the World Health Organisation's European Office (Barton and Tsourou 2000) where a list of basic social services are required within 1 km of home for a community of 4000–5000 people. These amenities include playgrounds and other green open space, primary health care services, a primary public school, local shopping area and a public transport stop. In Australia, South-East Queensland's social infrastructure planning guidelines (Queensland Government 2007) was considered an exemplar of integrated strategic planning during the 2000s, winning a national Planning Institute award (Teriman *et al.* 2010). Intended as a tool to promote efficient planning in urban growth areas, it provided a hierarchy of population scales, with appropriate social infrastructure allocations for each level. For instance, a 'neighbourhood' of 1000 homes or 2000–3000 people, would only require parks, bus stops and corner stores, with the possibility of informal community centres through churches or halls. A 'local area' of 5000–10,000 people might require a primary school, a more formalised neighbourhood centre, a sports field and a health care centre. This plan was designed for implementation in both rural and suburban areas with an envisioned catchment area of up to 5–10 km was envisioned (Queensland Government 2007, p. 19). These guidelines were in turn adapted by other Australian states to plan urban growth areas. For instance, the Victorian Growth Areas Authority adopted social infrastructure guidelines in 2008 (Growth Areas Authority 2009b). However, in this adaptation there was an inflation of the population figures required to support basic social infrastructure. For example, a neighbourhood house (or community centre) was recommended for every 20,000 people, one basic open space reserve (park) for every 6000 people and one public primary school for every 8000–10,000 people. There was no indication of maximum distances to these services, or the size of catchment areas. A major problem with this approach is that new suburbs are not serviced with social infrastructure until a residential population is large enough. This is a problem in outer suburban areas that are planned with low population densities. This promotes double disadvantage or deprivation amplification (Macintyre 2007) because these areas often attract lower income households because land is less expensive, yet they often lack of public transport, have long commuting times to employment, and reduced access to education and other social infrastructure services.

An alternate approach to planning these communities is one based on access to social infrastructure, with a priority on walking, cycling and public transport. Sometimes known as 'complete communities' or the '20 Minute City', these communities are planned using strategic planning guidelines that incorporate maximum distances as the basis for social infrastructure provision. For instance, the City of Vancouver's High Density Housing for Families with Children guidelines states that 'family housing development should be within 0.8 km walking distance of an elementary school and its outdoor play area, a daycare centre, an after-school care facility, a community centre and grocery shopping and within 0.4 km walking distance to a playground and a public transit stop' (City of Vancouver 1992, p. 1). However, in lower density communities, longer but still accessible, distances are required.

In the state of Victoria in south-eastern Australia, social infrastructure and land-use planning is managed by state and local government planning authorities in accordance with the *Planning and Environment Act 1987*. The Act ensures that new urban developments are guided by Precinct Structure Plans for new projected populations ranging from 10,000 to 30,000 people and must be incorporated into local planning before development occurs (Metropolitan Planning Authority 2016). Precinct Structure Plans provide long-term strategic planning for site development ensuring that urban areas have good access to services, shopping centres, transport, roads, jobs, housing, public open space and recreation facilities (Department of Environment Land Water and Planning 2015). They provide the masterplan for social infrastructure service provision. Until recently, these plans have been delivered using a minimum population threshold approach for social infrastructure planning. However, in the most recent strategic plan for the metropolitan Melbourne, the Victorian government sets out an aspiration for 20 min neighbourhoods based on a proximity or accessibility approach (Department of Environment Land Water and Planning 2017). These connected social infrastructure services include early childhood centres, primary and secondary schools, public open space and recreation facilities and medical centres. All levels of government including federal, state and local, assist with funding to support access to these services across metropolitan Melbourne. Private providers also operate in social service provision but publicly funded access is common within this case study context and an obvious private vs. public dichotomy is not evident across the city. Education is a service arguably most noted in public discourse to be split between public and private access yet more than two-thirds of all students attend public schools in Victoria and Australia (Australian Bureau of Statistics 2017).

In rapidly growing areas of outer Melbourne the delivery of social infrastructure commonly lags behind the arrival of new residents until local populations grow sufficiently in order to warrant a school or community centre being built. The lack of investment in transport and other infrastructure has raised the concerns of the Victorian Auditor General who estimated that between 2015 and 2030, local and state governments in Victoria would need to expend $A30 billion in order to meet the need of rapidly growing suburban populations (Victoria Auditor General 2013). Using the population-based approach has led to situations of extreme demand pressures on existing facilities. In particular, many growth areas are experiencing delays in construction and availability of primary and secondary schools in these areas, with further delays experienced when existing school reach student capacities and new schools are required.

Methods

Development of a conceptual framework

A conceptual framework of social infrastructure was first developed (Figure 1). It was guided by well-established associations in the literature and used to identify spatial measures of social infrastructure that might be associated with selected behavioural, intermediate and longer-term health and wellbeing outcomes. The conceptual model was developed to reflect hypothesised relationships within a neighbourhood in accordance with modern spatial and planning applications of the term neighbourhood The conceptual framework reflected a social determinants of health perspective of upstream social infrastructure determinants (environmental or neighbourhood factors, e.g. access to social infrastructure) and how they might be plausibly influence and relate to more downstream determinants (i.e. long-term physical and mental health outcomes). The relationships presented in the conceptual framework of social infrastructure, health and wellbeing (Figure 1) are consistent with healthy neighbourhood design principles argued by Barton *et al.* (2010) and Barton (2017) describing how physical development and good spatial planning of neighbourhoods can be used for maximum health gains across communities. Consequently considerable evidence supports Barton's (2017) model that spatial planning decisions, environment, lifestyle and experiences,

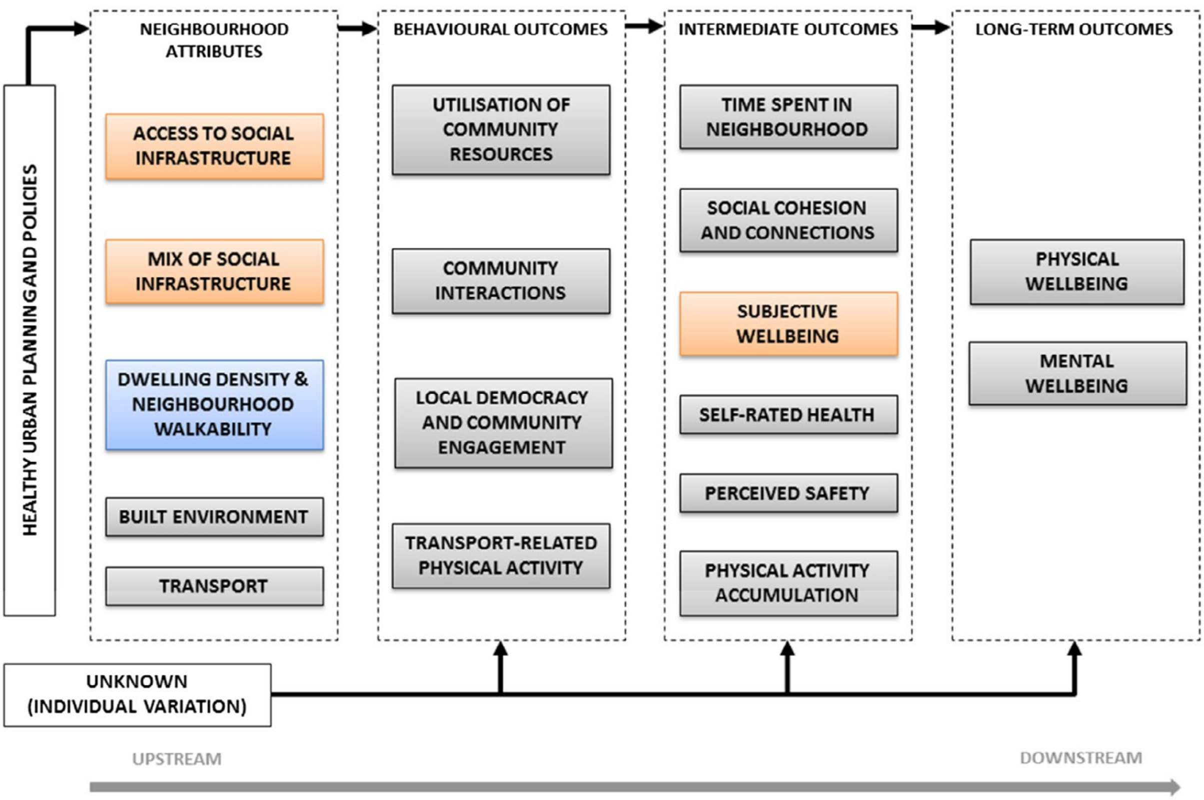

Figure 1. Conceptual model of social infrastructure, health and wellbeing specifying neighbourhood attributes, behavioural outcomes, intermediate outcomes and long-term outcomes for health promoting urban planning and policy.
Note: Coloured variables were included in statistical modelling with built environment covariates depicted in blue and exposures of interest and outcome variables depicted in orange.

influence physical and mental health outcomes. The 'intermediate outcomes' and 'long-term outcomes' presented in the conceptual framework of Figure 1 support these assumptions and were based on indicators that could be measured through routinely collected health surveys. No appropriate data could be sourced for behavioural outcomes and the tested empirical model is represented using coloured variables in Figure 1.

Selection of measures

The primary considerations guiding the inclusion of 'neighbourhood attributes' in the model were that: (i) they aligned to the services included in our social infrastructure definition (Table 1); (ii) the measures were spatially attributable and could be defined by a geographic buffer; and (iii) data on social infrastructure were available at small level geographies (e.g. neighbourhood level). The need for finer grained spatial data has previously been argued by Badland *et al.* (2014) and is required to understand and isolate the influence of the neighbourhood environment on individual health outcomes.

Empirical testing of the proposed conceptual model required sourcing spatial data that approximated the proposed neighbourhood attributes and outcome variables from survey data described in Figure 1. While spatially attributable data could be sourced for most variables, no data could be sourced to adequately represent community interactions and engagement, utilisation of community resources, transport related physical activity, time spent in neighbourhood or physical activity accumulation. Variables depicted in solid colours in Figure 1 were included in the empirical model and are described in detail below.

Neighbourhood attribute data

Geocoded social infrastructure service data were collected from multiple sources. Data for community centres/neighbourhood houses, General Practitioners (GPs), government primary schools and secondary schools, libraries and aged care facilities were sourced from publicly available data and geocoded. Data on childcare and out of school hours childcare were sourced from the Australian Children's Education and Care Quality Authority and geocoded using GIS. Data for cinemas, museums, art galleries, community health centres, dentists, maternal and child health centres, swimming pools and sport and recreation facilities were sourced from a commercial data provider with geocoded locations. Destination distances from geocoded survey data were analysed using Geographic Information System (GIS) software ArcGIS v10.3 and extracted based on street network buffers for distances.

Defining and measuring neighbourhood attributes of social infrastructure was complex and relied on spatial data-sets from a number of sources to test the conceptual model (Figure 1). Access to social infrastructure and mix of social infrastructure were calculated based on four domains: Health and Social Services; Early Years; Culture and Leisure; and Community Centres. These domains were measured by 15 individual service types which were used to calculate the presence of service mix (mix of social infrastructure) and distance to closest service (access to social infrastructure) for each participant (as displayed in Table 3). Police and emergency services were not included in empirical testing because Victorian emergency services have moved to a mobile model of service delivery not based on physical location.

The mix of social infrastructure services was created to account for variation in the number of types of services available within an area. For example, an area might have numerous General Practitioners but no early childhood services or community centres. Binary indicators were used for the presence (=1) or absence (=0) for the 15 types of social infrastructure destinations and a social infrastructure 'mix' score was created by summing the 15 binary indicators for each participant. Consequently, a maximum score of 15 represented the highest mix of social infrastructure with all types present. Access to nearest type of service was also calculated for each participant to investigate the relationship between distances to services and health outcomes. This was predicated on the understanding that neighbourhoods that are better served by social infrastructure tend to have a mix of social infrastructure services more readily available i.e. within closer proximity. Inverse distance was calculated for statistical modelling to invoke a negative effect with increased distance to services. Maximum distance to social infrastructure was also calculated by determining the greatest distance that each survey participant needed to travel to access any particular social infrastructure service. Spatial analyses were calculated using Python 2.7, ArcGIS 10.2 and PostgreSQL 9.6 with PostGIS 2.3.2. Statistical analyses were performed using R 3.3.2.

The conceptual model of social infrastructure and proposed distances were based on previous built environment and health findings (McCormack *et al.* 2008; Nathan *et al.* 2012; Millward *et al.* 2013; Christian *et al.* 2017). Hence, three different buffer distances of 800, 1200 and 1600 m, and a service-specific buffer were applied in all analyses to determine the influence of geographical distance. In general, an able-bodied adult can walk 800 m in about 10 min, and 1600 m in about 20 min, consistent with Australian government policy (Commonwealth of Australia 2013). Distances up to 1600 m from home are also considered walkable or cyclable (Hooper *et al.* 2012), and increases in physical activity are associated with the location of community facilities within 800–1200 m from home in Australia (King *et al.* 2015; Gunn *et al.* 2016). These physical activity findings are based on neighbourhood analyses of large samples of people living in Melbourne, Victoria and were used to inform the development of service specific distances based on the physical capabilities of the populations they served. Distances selected needed to be close enough to support physical activity capabilities but realistic within the policy context of government budgets and service provision funding. This final model tested these theoretically informed accessibility distances for social infrastructure services within communities and referred to as the service-specific buffer model. Using the existing research on walking distances, empirically informed distances were customised according to services types and are presented in Table 3.

The social infrastructure conceptual model was tested according to four different distances from residential location: 800, 1200 and 1600 m; and distance-specific buffers with service specific distances. This is common in the built environment and health research area to overcome possible influences from the Modifiable Areal Unit Problem (MAUP) (Openshaw 1984) and because the best buffer distance to measure the relationship between social infrastructure and health is unknown. The distances chosen are considered to be 'walkable' in that they represent an approximate walk time of between 10 min (800 m) to 20 min (1600 m) which helps match the neighbourhood level exposure measured by road network buffer to SWB. These issues are discussed in greater detail in Brownson *et al.* (2009) and Clark and Scott (2014) who recommend that in the absence of knowledge on the best distance to measure relationships, models be reported at multiple distances. This approach also facilitates comparisons between studies where different GIS measures and buffers may have been used and provides results that are relevant to different age groups and abilities (e.g. older people and children). It is for these reasons that we provide a distance-specific buffer which seeks to include social infrastructure services based on distances found in the literature and an approach to mitigate the MAUP and uncertainty on buffer distances.

Table 2. Sample demographic characteristics (total $N = 7141$).

Sample characteristics	*N*	%
Sex		
Male	2975	41.7
Female	4166	58.3
Age (years)		
Mean (SD)	53.6 (16.5)	
Household Structure		
Sole person	1479	20.7
Couple no children	1994	27.9
Families	2948	41.3
Single parent	447	6.3
Other	273	3.8
Children in ≤18 years in household		
Present	2118	29.7
Not present	5023	70.3
Education		
Some high school or less	1726	24.2
Completed high school	1179	16.5
TAFE/certificate/diploma	1452	20.3
University	2784	39.0
Income (AUD)		
<$40,000	2517	35.2
$40,000–≤$80,000	2014	28.2
$80,000–≤$120,000	1369	19.2
$120,000+	1241	17.4
LOTE		
Speaks English	6400	89.6
Does not speak English	741	10.4
Subjective Wellbeing		
Mean (SD)	76.4 (11.7)	

Notes: AUD = Australian dollars; LOTE = Language other than English; SD = standard deviation.

Survey and outcome data

Geocoded data on adults aged 18 or older ($n = 24,900$) were obtained from the 2011 VicHealth Indicators Survey. The survey used a stratified sampling method across all 79 Local Government Areas (LGAs) within the State of Victoria, Australia and ethics clearance was obtained from the University of Melbourne Human Research Ethics Committee (Project ID 1034347.3). The omnibus survey included items on health, subjective wellbeing, transport issues, arts participation, personal safety, citizen engagement, water conservation, employment, food security and general household demographics. Data were collected using Computer Assisted Telephone Interviews and random digit dialing from May to August in 2011 and only one person per household completed the interviews. Interviewers attempted to make contact with a household by making up to six calls and participant addresses were provided enabling a geocoded data-set. Analyses in this study were based on a sub-sample of 31 LGAs in urban metropolitan Melbourne ($n = 7141$) with demographic characteristics of the sample presented in Table 2. Only participants from the Melbourne metropolitan area were included in analyses because people living in these areas are guided by the same city-based planning policies in terms of social infrastructure service provision and comparable distances to services. Survey data from rural LGAs were not included in empirical testing because of smaller and irregular sampling sizes relative to smaller relative populations.

Subjective wellbeing

Subjective Wellbeing (SWB) was included in the 2011 VicHealth Indicators Survey and used as the outcome measure to test the conceptual model. The inclusion of SWB as an outcome measure is consistent with a strong argument that alternative measures of wellbeing are needed to understand the influence of policy decisions on individuals (Boarini *et al.* 2006). This an approach that has been embraced by the OECD for many years culminating with the release of the Stiglitz–Sen–Fittousi Report (Stiglitz *et al.* 2010), and development of the Better Life Index in 2011 which seeks to understand whether life is getting better for people and identify the drivers of positive and negative change (OECD 2017). Although rarely used as an outcome measure for public policy, the inclusion of SWB in analyses of social infrastructure is consistent with recommendations of

Table 3. Frequencies for access to social infrastructure destination types according to 800, 1200 and 1600 m and distance-specific buffers.

Service	Destinations	800 m buffer	1200 m buffer	1600 m buffer	Service-specific buffer	
		%	%	%	Distance (m)	%
Community Centres	Community Centres	14.76	28.32	40.05	1000	21.48
Culture & Leisure	Cinema / Theatre	9.73	16.51	24.00	3200	50.83
	Libraries (2014)	11.90	25.07	38.43	1000	18.46
	Museums / Art Galleries	4.97	9.10	14.51	3200	38.01
Early years	Childcare	68.46	88.99	95.71	800	68.46
	Childcare (out of school hours)	41.81	70.49	85.17	1600	85.17
Education	State Primary Schools	36.14	65.82	83.10	1600	83.10
	State Secondary Schools	13.26	27.94	45.11	1600	45.11
Health & Social Services	Aged Care (2012)	40.13	61.04	74.42	1000	51.32
	Community Health Centres	21.94	38.30	53.65	1000	30.58
	Dentists	49.46	69.99	81.40	1000	60.80
	General Practitioner Clinics	49.70	72.64	85.81	1000	62.62
	Maternal/Child Health	14.76	28.02	42.45	1000	21.58
Sport & Recreation	Swimming Pools	5.90	13.61	22.34	1200	13.61
	Sport Facilities	49.08	75.38	88.25	1200	75.38

the OECD (2013) the UK's Office for National Statistics (Dolan and Metcalfe 2011; Dolan and Metcalfe 2012) and the need for more efforts to identify the social, economic and political conditions that promote the SWB of populations (White *et al.* 2016). It also builds on existing research linking SWB to policy outcomes linked to community assets including health services (Collicelli 2013; Sims *et al.* 2017), community services in homeless people (Thomas *et al.* 2012), community services in resettled refugee children (McFarlane *et al.* 2011), service availability and social connections in older people (Adams *et al.* 2011), childcare access in East Germany (Schober and Schmitt 2017), and the natural environment (Biedenweg *et al.* 2017), park quality, quantity and accessibility (Larson *et al.* 2016). The importance of needs and services as important influences of wellbeing has a long history in the social sciences with Maslow (1943) theorising that basic economic, physiological and safety needs were required before further human growth and development could proceed. The physical environment of neighbourhoods is also believed to be an influence of health, wellbeing and quality of life (Barton 2017).

SWB was assessed by the Personal Wellbeing Index (PWI) derived from the Australian Unity Wellbeing Index (Cummins *et al.* 2003). The PWI is assessed by asking respondents to rate their satisfaction with the following seven domains of their personal lives: standard of living; health; achievements; personal relationships; community connectedness; safety and future security. All items are rated according to an 11-point satisfaction scale ranging from 0 (*no satisfaction at all*) to 10 (*extremely satisfied*) and the average of these satisfaction ratings is used to form the PWI. These domains can be used separately as domain scores or combined into an average score to create an overall score of SWB. All SWB scores were converted into a standardised scale maximum (%SM) ranging from 0 to 100 prior to analysis. Further information on psychometric properties are available in the PWI Manual (International Wellbeing Group 2013).

SWB has been assessed by the PWI for more than 16 years in Australia through 33 national surveys resulting in a current Australian average score of 76.7 with only 3.1 points in variation in this population level mean over the past 16 years (Capic *et al.* 2016; Davern 2016). The Australian SWB population average has had little variation from April 2011 to April 2016, ranging only 1.3 points from 75.4 to 76.7 over the last 5 years. This small variation is important for understanding SWB results when used as an outcome variable in statistical modelling. The stability in population level means is argued as being homeostatically controlled (Cummins *et al.* 2012) analogous to body temperature control with individual SWB set-point levels ranging between 60 and 90 on a 0–100 scale in a panel study of Household Income and Labour Dynamic Australia (Cummins *et al.* 2014). SWB measured by the PWI is also a useful proxy measure for depression with PWI scores below 60 indicative of depression (Cummins *et al.* 2012) making it a useful, and non-confrontational public health screening tool.

Statistical analysis

The conceptual model presented in Figure 1 was tested using linear regression adjusting for covariates of sex, age, education (some high school or less; completed high school; TAFE/Certificate/Diploma; University) and household income (<$40,000; $40,000– < $80,000; $80,000– < $120,000; ≥$120,000).

Results

Sample demographic characteristics are presented in Table 2 for the sample of 7141 people. Descriptive results and frequencies according to distances to social infrastructure destinations are presented in Table 3 for each of the 4 models tested – i.e. access to social infrastructure within 800, 1200 and 1600 m and service-specific model. Table 3 also presents the sample proportion (%) with access to service types according to distance. The majority of the population (>80%) were located within 1600 m of childcare, sporting facilities, General Practitioners, dentists and primary schools; and around 40% or more had this level of access to other essential services including a community centre, library (38%), a state secondary school, a community health centre and a maternal/child health service. Fewer participants had access to social infrastructure within 800 m. However, 40% or more had this level of access to child care, child care with out of school services, aged care, dentists, General Practitioner clinics and sports facilities. Swimming pools and museums/art galleries were the least accessible social infrastructure services, with only 22% of the sample living within 1600 m of a swimming pool and 15% living within 1600 m of a museum/art gallery Childcare was the most common accessible service, with 95% of participants having access within 1600 m; and 68% within 800 m.

The mean numbers of services available within the different distance models are provided in Table 4. Within the 800 m buffer, participants had on average four social infrastructure destinations, while this increased to seven for the 1200 m buffer and nine for the 1600 m buffer. The average number of social infrastructure destinations was seven when using the distance-specific buffer.

Statistical associations

Although participants could be classified according to municipality-based location across Melbourne, mapping of the geocoded sample revealed that the locations of participants was spatially random within these municipalities. This was validated by calculating Moran I tests and Intra-Class Correlations (ICC) before undertaking multilevel models. Moran I tests on the residuals for the models were close to zero in value and not significant.

ICCs were also used to explore the extent of hierarchy between the municipalities and SWB using a fixed effect null model resulting in an ICC of 1.59% confirming a lack of hierarchical structure in the data (Musca *et al.* 2011). Hence, although municipality based location seemed to support multilevel modelling there was no statistical or spatial evidence to support this and liner regression was applied in analyses.

Table 4. Mean scores and standard deviations for the mix of social infrastructure exposure variables.

Social Infrastructure buffers	Number of Services Available (Mix of Social Infrastructure Score)	
	Mean	SD
Service-specific buffer	7.27	3.38
800 m	4.32	2.87
1200 m	6.91	3.22
1600 m	8.74	3.15

Notes: *m* = metre; SD = Standard deviation.

Table 5 provides linear regression results of SWB when using the social infrastructure mix scores with the distance-specific buffers (Model 1), at 800 m (Model 2), 1200 m (Model 3) and 1600 m (Model 4) as the exposure measure. Social Infrastructure Score is the key variable of interest. All estimates include 95% confidence intervals in parentheses and are notated according to statistical significance levels using asterisks. Confounding variables of socioeconomic and demographic influence are also presented for each model.

Results revealed that access to a mix of social infrastructure services was associated with SWB and there was a strong positive association between SWB and the 800 m model as illustrated through coefficients and associated confidence interval. This relationship was most significant for the 800 m buffer model where the estimate for social infrastructure mix was 0.15 after holding constant the influence of sex, age, education, household structure, the presence of children and household income. These results suggest that holding all else constant, access to all 15 destinations within 800 m increased SWB on average by 2.3 points. However, access to even four additional types of social infrastructure services within 800 m increased SWB by 0.6 points (4 x 0.15), while eight destinations increased SWB by 1.2. Estimating the effects of social infrastructure mix access using the distance-specific model (0.10) suggested that an additional four social infrastructure destinations would increase SWB by 0.4, eight destinations by 0.8, while access to all 15 destinations increased SWB by 1.5.

A second and third set of linear regression models investigated how distance to social infrastructure influenced SWB (see Table 6). Linear regression results of SWB according to the maximum inverse distance a person needed to travel to gain access to social infrastructure services/facilities. Two models were created: Model 5 provides maximum inverse distance (in kilometres) to all social infrastructure types; and Model 6 provides maximum inverse distance for social infrastructure types excluding museums, cinemas and pools that were further away for most people. These three types of services/facilities were excluded because their inclusion skewed the destination distance distribution when distance was calculated based on all social infrastructure types. These were the least frequent and least proximate types of social infrastructure (see Table 3). As part of a sensitivity analysis, museums, cinemas and swimming pools were therefore removed from the score as a refinement of the modelling to investigate if maximum distance influenced SWB outcomes when there was less variation in the distance variable. However, in both models, maximum distance to social infrastructure was not associated with SWB outcomes.

Table 5. Subjective wellbeing linear regression results using social infrastructure mix exposure variables ($n = 7141$).

	Model 1	Model 2	Model 3	Model 4
	Service-specific buffer	800 m	1200 m	1600 m
	$\hat{\beta}$ (95% CI)	$\hat{\beta}$ (95% CI)	$\hat{\beta}$ (95% CI)	$\hat{\beta}$ (95% CI)
Social infrastructure score	0.10 (0.01, 0.20)*	0.15 (0.04, 0.26)**	0.08 (−0.02, 0.18)	0.11 (0.00, 0.21)*
Gender				
Male	Reference	Reference	Reference	Reference
Female	1.50 (0.97, 2.04)***	1.50 (0.96, 2.04)***	1.51 (0.97, 2.05)***	1.51 (0.97, 2.05)***
Age	0.09 (0.07, 0.11)	0.09 (0.07, 0.11)***	0.09 (0.07, 0.11)***	0.09 (0.07, 0.11)***
Household structure				
Sole person	Reference	Reference	Reference	Reference
Couple no children	3.78 (2.99, 4.57)***	3.78 (3.00, 4.57)***	3.77 (2.99, 4.56)***	3.79 (3.00, 4.57)***
Families	2.20 (1.25, 3.16)***	2.20 (1.25, 3.16)***	2.20 (1.25, 3.16)***	2.21 (1.26, 3.17)***
Single parent	−2.50 (−3.78, −1.22)***	−2.50 (−3.79, −1.22)***	−2.50 (−3.78, −1.22)***	−2.50 (−3.78, −1.22)***
Other	0.78 (−0.72, 2.29)	0.77 (−0.73, 2.28)	0.77 (−0.74, 2.27)	0.78 (−0.73, 2.28)
Children ≤18 years in household				
Present	Reference	Reference	Reference	Reference
Not present	−1.42 (−2.23, −0.61)***	−1.43 (−2.24, −0.62)***	−1.41 (−2.22, −0.6)***	−1.42 (−2.23, −0.61)***
Education				
Did not complete high school	Reference	Reference	Reference	Reference
Completed high school	1.52 (0.65, 2.38)***	1.52 (0.66, 2.39)***	1.52 (0.66, 2.38)***	1.52 (0.66, 2.38)***
TAFE/Certificate/Diploma	0.89 (0.08, 1.71)*	0.89 (0.07, 1.70)*	0.89 (0.08, 1.71)*	0.90 (0.09, 1.72)*
University	2.21 (1.45, 2.98)***	2.19 (1.43, 2.96)***	2.23 (1.46, 2.99)***	2.23 (1.47, 3.00)***
Income (AUD)				
≤$40,000	Reference	Reference	Reference	Reference
$40,000–<$80,000	1.53 (0.82, 2.24)***	1.53 (0.82, 2.24)***	1.53 (0.82, 2.24)***	1.54 (0.83, 2.25)***
$80,000–<$120,000	3.13 (2.27, 3.99)***	3.13 (2.27, 3.99)***	3.13 (2.27, 3.99)***	3.13 (2.27, 3.99)***
$120,000+	4.74 (3.81, 5.66)***	4.76 (3.83, 5.68)***	4.74 (3.81, 5.66)***	4.74 (3.81, 5.66)***
Does not speak English	−3.71 (−4.59, −2.83)***	−3.71 (−4.59, −2.83)***	−3.71 (−4.59, −2.83)***	−3.71 (−4.59, −2.83)***
Dwelling density	−0.06 (−0.10, −0.01)*	−0.06 (−0.10, −0.02)**	−0.05 (−0.10, 0.00)*	−0.06 (−0.10, −0.01)*
Fstat	39.05***	39.22***	38.93***	39.02***
Adj R	0.08	0.08	0.08	0.08

Note: CI = Confidence Interval.
***$p < 0.0001$; **$p < 0.001$; *$p < 0.05$.

Discussion

This study tested a limited number of pathways in a new conceptual framework of social infrastructure and found preliminary support for associations between social infrastructure and SWB. We found that closer accessibility to a range of social infrastructure services promoted the SWB of residents. The conceptual framework was tested using spatial neighbourhood attributes and routinely collected population health survey data to demonstrate the importance of both access, and mix of, social infrastructure services as upstream health determinants and their influence on downstream health outcomes. Although the current research is provided as an Australian case study there are many benefits available within a range of international contexts. This includes empirical testing of a conceptual model that has provided a clearer and operationalised definition of social infrastructure that is applicable to international research, planning and policy purposes in the future.

Social infrastructure was defined and assessed through the tested conceptual framework and addressed the major service needs of all age groups and included community centres, culture and leisure, early childhood, educations, health and social services, sport and recreation. They reflect essential services across the lifespan (Gabdrakhmanov and Rubtsov 2013) and are upstream determinants of health that have been assessed at one point in time and could be used to monitor current social infrastructure service provision and measure changes in availability to services across time.

In this study, people were most likely to have spatial access to childcare services, dentists, doctors and sport facilities within 800 m and those with access nearly doubled at 1600 m. However, having access to single services at 1600 m was not most beneficial to health and results suggested that the mix of social infrastructure services available within 800 m was most beneficial to SWB and consistent with existing research demonstrating an association between increased walking and living within a 20 min walk of local facilities (King *et al.* 2003) particularly with a greater mix of facilities (King *et al.* 2015). Access at 1600 m or service-specific distance buffers were also important contributors to the prediction of SWB. Services of culture and leisure including cinemas, theatres, libraries, museums and art galleries were least likely to be available within 1600 m and only half of residents had access to cinemas and theatres within 3200 m. Art galleries and museums were least accessible with only one-third of residents having access to these services within 3200 m.

These findings have potential implications for future policy and planning of new and established communities. They build on the developing evidence base

Table 6. Subjective wellbeing linear regression results using maximum distance to social infrastructure services ($n = 7140$).

	Model 5 (95%CI)[a]	Model 6 (95%CI)
	Maximum inverse distance (in km) [b]	Maximum inverse distance (in km) excluding museums, cinemas, pools [c]
Intercept	67.39 (65.50, 69.28)***	67.51 (65.61, 69.41)***
Inverse distance to social infrastructure (km)	2.43 (−0.29, 5.15)†	−0.98 (−2.62, 0.66)
Gender		
Male		
Female	1.51 (0.97, 2.05)***	1.52 (0.98, 2.05)***
Age	0.09 (0.07, 0.11)***	0.09 (0.07, 0.11)***
Household structure		
Sole person		
Couple no children	3.78 (2.99, 4.57)***	3.75 (2.96, 4.54)***
Families	2.21 (1.25, 3.16)***	2.18 (1.23, 3.14)***
Single parent	−2.49 (−3.78, −1.21)***	−2.47 (−3.76, −1.19)***
Other	0.76 (−0.74, 2.27)	0.76 (−0.75, 2.26)
Children in ≤18 in household		
Present		
Not present	−1.42 (−2.23, −0.61)***	−1.39 (−2.20, −0.58)***
Education		
Did not complete high school		
Completed high school	1.50 (0.64, 2.37)***	1.52 (0.66, 2.38)***
TAFE/Certificate/Diploma	0.88 (0.07, 1.70)*	0.89 (0.08, 1.70)*
University	2.20 (1.43, 2.96)***	2.27 (1.51, 3.03)***
Income		
≤$40,000		
$40,000–<$80,000	1.52 (0.81, 2.24)***	1.50 (0.78, 2.21)***
$80,000–<$120,000	3.10 (2.24, 3.96)***	3.10 (2.24, 3.96)***
$120,000+	4.71 (3.78, 5.63)***	4.72 (3.79, 5.64)***
Do not speak English	−3.69 (−4.57, −2.81)***	−3.70 (−4.58, −2.81)***
Dwelling density	−0.06 (−0.11, −0.01)*	−0.02 (−0.06, 0.03)
Fstat	38.96***	38.85***
Adjusted *R*	0.08	0.08

[a]CI: Confidence intervals.
[b]includes 15 destinations.
[c]includes 12 destinations.
***$p < 0.0001$; **$p < 0.001$; *$p < 0.05$; †$p < 0.1$.

suggesting that destination and service planning in communities has important implications for population health outcomes (McCormack *et al.* 2008; Nathan *et al.* 2012; Millward *et al.* 2013; Christian *et al.* 2017) and active transport behaviours in communities (Hooper *et al.* 2012; King *et al.* 2015; Christiansen *et al.* 2016; Gunn *et al.* 2016). Good neighbourhood design that supports health needs to be available in more cities across the world leading from the examples of Copenhagen in Denmark, Kuopio in Finland, Frieberg in Germany and Portland in the U.S.A. (Barton 2017).

The current results also confirm that reduced access to social infrastructure services is particularly important and has implications for social equity and deprivation amplification (Macintyre and Ellaway 2003). Social equity is supported by the provision of accessible goods and services to all members of the community (Talen 1999). In many cities, housing prices are directly reflective of the amenity provided by local access to services forcing people on lower incomes to live in areas that often less well serviced by both hard (e.g. transport) and social infrastructure, effectively amplifying the impact of the social gradient (Kawachi *et al.* 2002). Distance is a major barrier to social infrastructure service access for people who don't own cars, can't afford to own cars or are unable to drive. The current research emphasises the importance of community planning to SWB, particularly within distances of 1600 m. These findings should be considered within the strategic planning of social infrastructure services in order to produce maximum community benefit – a need that has previously been identified by policy makers (Wear 2016).

In Victoria, social infrastructure planning is developed through Precinct Structure Plans that plan for housing yield, employment provision and location, transport systems, open space, activity centres and community facilities in new housing developments (Growth Areas Authority 2009a). Planning for these services appears to rely too much on population-based methods for planning with most recent planning guidelines still prescribing service provision based on population sizes with highest priority given to primary schools, early childhood services, community centres with limited public open space (Growth Areas Authority 2009b). These guidelines only allude to the need for proximate access to social infrastructure facilities. In order to encourage forms of active transportation, our results suggest a need for these to be further refined with guidelines based on accessibility with a focus on ensuring both social equity and improved health outcomes.

Strengths and limitations

This research provides preliminary evidence that spatial accessibility to social infrastructure services has a positive association with SWB as hypothesised in the conceptual model (Figure 1). However, our current analyses only considered one health-related outcome. Future research should consider examining other health-related outcome measures such as social cohesion, perceived safety, physical activity and physical health outcomes to provide a more comprehensive understanding of the influence of social infrastructure on health and wellbeing. Future research should also seek to identify new sources of data to measure behavioural outcomes in the conceptual model including utilisation of community resources, community interactions, citizen engagement and transport related physical activity such as walkability. These factors are important influences of healthy neighbourhood design. New sources of data are also needed to fully test all relationships in the conceptual model of social infrastructure and health and wellbeing. Ideally this model could also be further exploited through testing and analysis of longitudinal data noting the limitations of cross-sectional data used in the current research.

Future research should also examine the importance and applicability of social infrastructure services and facilities to different demographic groups to assess their relative influence on health and wellbeing. This could also explore the role of weighting service types according to importance or nearest location. For example, schools and childcare services might be more influential to the health and wellbeing of families while community centres and aged care facilities might be more important for middle-aged and older people who are dealing with either their own ageing or the ageing of their parents. Furthermore, approximately 41% of the current sample described their households as a family and these results could change with different population and age focus. The co-location of social infrastructure services in an area also adds complexity to understanding the influence of individual services on SWB. In these circumstances, statistically examining the individual effect of particular services ignores potential confounding (MacKinnon *et al.* 2000). Location-based effects might also have different influence in low, medium and high density urban settings for example within greenfield developments, middle suburb or inner city locations. The current research also did not attempt to measure or account for complex service delivery characteristics including waiting lists, service quality or service capacity. For example, a person could reside within 800 m of numerous medical clinics where doctors have no capacity to accept new patients or use government subsidised fee reduction facilities. This research also did not investigate the influence of service quality or diversity. For example, childcare centres were one of the most geographically accessible social infrastructure services across Melbourne, however they can differ according to service quality, typology (public, private or parent/council run cooperative operation models) and/or service capacity. Future research should explore these broader issues to support the development of more precise social infrastructure planning guidelines in the future.

The inclusion of service-specific buffers was introduced in this study and warrant further investigation. Customised distance buffers were applied in exploration of more refined conceptual framework and to gain insights into the differential effects of services and their delivery at different scales. These service specific buffers show promise with statistical modelling but could be further investigated to refine distances in accordance with current government policy and community needs and expectations and explore thresholds for distances that optimise health and wellbeing. It is possible that universal accessibility distances (i.e. 800 m for all services) produced an average effect on health outcomes while more specific distances (i.e. individualised distance buffers according to service type) could produce greater health benefits. There are likely strengths and benefits to either approach and further research is required, particularly in relation to implementation as planning policy.

A major strength of the current research has been the inclusion of SWB to assess the impact of area-based policy and planning decisions. SWB was useful initial health outcome to explore as it is a variable supported by normative understanding of SWB in the Australian context (Cummins *et al.* 2012; Cummins *et al.* 2014). The small increases in SWB associated with access to social infrastructure services were important when considered with normative national Australian SWB monitoring data that have changed only 1.3 points over the last 5 years (Australian Unity Wellbeing Index Report 2016). Modelling revealed that resident access to social infrastructure services could produce increases in up to 2.3 points in SWB providing a clear example of how service delivery and associated policy could be assessed using SWB as an outcome. The application of SWB in this manner as an outcome measure in public policy evaluation has been argued previously by numerous authors (Stiglitz *et al.* 2010; Dolan and Metcalfe 2011; Dolan and Metcalfe 2012; OECD 2013; Helliwell *et al.* 2014) and should be the primary concern of public policy (Collicelli 2013). An additional benefit of using SWB has been the inclusion of an outcome variable that can be treated as continuous in statistical modelling. Public health research often employs categorical self-reported health measures in outcome measurement limiting statistical modelling and creating challenges for interpretation of results.

Conclusions

Social infrastructure planning in cities requires further attention in both policy and research. It should be considered as important as physical infrastructure given its influence on health and wellbeing – we would not build communities without physical infrastructure and equally we should not be delivering communities or planning neighbourhoods without essential social infrastructure. This research has sought to develop a clear definition of social infrastructure and has developed a conceptual model to understand how the spatial accessibility of social infrastructure influences the wellbeing of residents. We found that having access to social infrastructure positively influences the SWB of residents, potentially providing opportunities for local interactions. Importantly, this research also provides a call for action and new research to increase our understanding of the influence of social infrastructure on health and wellbeing. This includes investigation of the influence of social infrastructure planning, service delivery, service quality, service capacities and demographic needs. Research of this type could aid better decision-making and strategic planning across neighbourhoods that supports and prioritises effective service and facility planning to ensure better health outcomes for all.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the (Australian) National Health and Medical Research Council under the Centre for Research Excellence in Healthy Liveable Communities [grant number 1061404]; BGC is supported by an (Australian) National Health and Medical Research Council Senior Principal Research Fellowship [grant number 1107672]; HB is supported by a RMIT University Vice Chancellor's Fellowship; CW is supported by the Lord Mayor's Charitable Foundation, the Brotherhood of St. Laurence, and Launch Housing; and SM is supported by a (Australian) National Health and Medical Research Council Early Career Fellowship [grant number 1121035].

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