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TITLE

Public open space exposure measures in Australian health research: a critical review of the literature

BRIEF TITLE

Public open space in health research

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Abstract

Numerous studies have shown associations between public open space and a variety of health outcomes. Yet, the extent to which firm conclusions and planning policy recommendations can be drawn from this body of work depends on how public open space availability has been measured and reported. Other researchers have highlighted potential issues with the way that public open space has been measured but have not systematically assessed the extent of this problem. This paper provides a comprehensive critical review of studies of public open space and health conducted in Australia to identify and compare public open space measurement and data treatment. Our analysis showed wide variation in how public open space was measured, as well as a lack of consistency in reporting public open space exposure measures and under-reporting of measurement methods. We find that such tendencies limit how much these studies can be compared and contrasted with each other. The corollary of that finding is that without more detailed reporting of exposure measures it will be difficult to establish an evidence base

that informs planning for healthy, liveable environments. In response, we develop and present a checklist for reporting public open space exposure to address this challenge.

Keywords health geography; public open space; parks; green space; Geographic Information Systems (GIS)

Introduction

Population growth in Australian urban areas and increasing prevalence of chronic diseases have led to an increased focus on the value of public open space (POS) in promoting health. In 2010, the World Health Organization (2010) highlighted the need to consider green space availability in increasingly urbanised areas. In Australia, there are numerous and varying recommendations for public open space (Heart Foundation of Australia, 2018; Western Australian Planning Commission, 2009; Villanueva *et al.*, 2015). In light of the intense focus on urban renewal policies in Australian cities (Government of South Australia, 2017; Victoria State Government, 2017), our study critically reviews how public open space is defined, measured, and reported in Australian public open space and health studies that inform such policies.

Public open spaces have broadly been defined as spaces made available in urban environments mainly for public recreation and amenity (Heart Foundation of Australia, 2018). Since public open spaces offer opportunities for people to connect socially, participate in physical activity,

and to reflect and relax (Lee & Maheswaran, 2011; Maas *et al.*, 2009), considerable health research has focused on assessing their health benefits. These benefits include higher levels of physical activity (Coombes *et al.*, 2010; Gong *et al.*, 2014; Kaczynski *et al.*, 2009), better mental health (Beyer *et al.*, 2014; Nutsford *et al.*, 2013), improved quality of life (Sugiyama *et al.*, 2009), and higher cognitive development (Dadvand *et al.*, 2015). However, while many studies show beneficial health effects of public open space (Barnett *et al.*, 2017; Lee & Maheswaran, 2011), some reveal that the evidence is weak or inadequate (Gascon *et al.*, 2016; de Keijzer *et al.*, 2016).

A common approach in public open space and health research has been to measure the population of interest's potential exposure to public open space by calculating the spatial availability and accessibility of public open spaces using geographic information systems. Then, based on typically residential locations of survey participants, these public open space exposure measures are linked to health data. Finally, statistical models are used to determine whether or not there is a relationship between the public open space measures (that is, the "exposure variables" in epidemiological language) and health (that is, the "outcome variable"). The public open space exposure measures used in this approach need to be adequately defined, measured, and reported to allow for comparability and an assessment of the overall evidence base.

The extent to which existing public open space and health research defines, measures, and reports public open space availability may not be adequate. As noted by others, public open space can be defined in different ways (Koohsari *et al.*, 2015), and is sometimes used

synonymously with green space (Lee & Maheswaran, 2011). The synonymous use of these broad terms and the features that have been used to define them have often been applied without scrutiny. Furthermore, public open space availability has been measured in different ways (for example, calculating the area of public open space within a residential neighbourhood versus the proximity to the nearest public open space). While such difference not a problem in and of itself, the public open space measure chosen is often not problematised and may not be specific enough to draw useful conclusions or inform planning policy (Ekkel & de Vries, 2017). The issue of adequate reporting of public open space measures appears not to have been raised in the literature, yet is essential for assessing and comparing literature, building an evidence base, and informing urban planning policy and practice.

Despite potential issues with public open space definition, measurement, and reporting, the extent of the problem is unknown. Therefore, our study aims to critically review public open space definition, measurement, and reporting in Australian public open space and health studies. In doing so, we highlight important methodological considerations for reporting and assessing public open space exposure measures. The results of this first comprehensive review of public open space definitions, measurements, and reporting, will provide guidance to researchers to ensure that the scientific and policy benefits of future research are maximised. To such ends, we have developed a public open space reporting checklist to prompt thinking about the important public open space components that need to be considered and reported in studies considering associations between public open space and health.

The remainder of the paper describes the methods used to review the literature, and organises the results and discussion by theme, presenting the results and following those with discussions in each theme. Finally, we end with a summary and the presentation of our suggested public open space reporting guidelines. For readability, throughout our paper the term public open space is used to capture all variations of this term (for example, green space, parks) and exposure is used to capture all variations on availability or accessibility measures (for example, proximity, area).

Review of the literature: method

This scoping review was designed to identify and critically evaluate articles using public open space measures in health research in Australia. The key aims of the review were to identify the definition, measurement, and reporting of public open space measures, which were used to set the scene for recommendations for health researchers using public open space measures in Australia. The methodology explains how articles were selected for inclusion.

An electronic search of articles published between January 2005 and October 2015 that referred to public open space was conducted in the PubMed database. PubMed was chosen as one of the primary sources for accessing literature on health and health-related behaviour outcomes.

Search terms for public open space were taken from the extensive list used by Lachowycz and Jones (2011). Health or health-related behaviour outcomes (for example, walking, diabetes) were omitted from the search terms on the basis that the search was conducted in PubMed, and so it

was assumed that the assessment of public open space would relate to health or health-related behaviour outcomes. Detailed search terms are provided in Table 1.

<take in Table 1 here>

The search identified 1,585 articles. Papers were eligible for inclusion in our analysis if they considered (a) an objective measure of public open space as an exposure variable, (b) featured a health or health-related behaviour outcome, and (c) included Australian data. Two investigators independently screened abstracts and then full texts scans with reference to the three inclusion criteria with input from a third investigator in the case of disagreements. The number of articles screened at each stage is shown in Figure 1. Forty articles were included, with 31 identified by screening and a further nine from references found in those articles.

<take in Figure 1 here>

Data were extracted about (a) study location, (b) health outcome, (c) public open space definitions, features, and data sources, (d) exposure/predictor definitions, and (e) treatment of public open space in analysis. Where provided by the authors of papers, justifications for these decisions were recorded. The investigators who carried out the article screening also conducted the data extraction, independently assessing the articles to identify any rationale or reasons provided relating to the exposure measures in the article.

Thematic analysis and discussion

Four themes identified prior to the review were considered in more detail: (1) variations in type of public open space, (2) data source, (3) exposure measure, and (4) statistical treatment. The analysis and discussion were combined in a subsection for each theme.

Variations in type of public open space

Our review revealed variations in public open space definitions, the type of public open space measured and extent of reporting of public open space type. Seventeen different collective terms for public open space were used across the 40 papers, with some studies using more than one term (Table 1). The most common terms used were variations on “public open space” (n=12), “park” or “parklands” (n=12), and “green space” (n=8).

Within the collective overarching term used to define the exposure of interest, a variety of different sub-types were included (Table 1). For example, within the collective term ‘public open space’, stadiums were included in some articles (Paquet *et al.*, 2013, Paquet *et al.*, 2014) but excluded elsewhere (Giles-Corti *et al.*, 2005). Thus, these studies considering public open space were actually capturing different features.

Importantly, the sub-types included were not reported in some papers and/or the distinction between a sub-type and broader term used to capture all public open space (parkland, for example) was not made clear (summarised in Table 1, details in Table 2). Therefore, it was not possible to undertake a full assessment of the sub-types included or excluded in each study.

Some studies incorporated sensitivity analyses, considering multiple types of public open space separately as exposure variables, for example pay-for-use versus free-for-use (McCormack *et al.*, 2007), or parks versus beaches (Edwards *et al.*, 2014); public open space of different sizes (King *et al.*, 2012).

<take in Table 2>

The choice of sub-types included in the public open space definition can substantially alter the assessment of public open space availability; we demonstrate this in Figure 2 using data from the Australian Research Centre for Urban Ecology Open Space 2002 spatial dataset.

<take in Figure 2 here>

Although it has been suggested that a universal definition of public open space is required (Koohsari *et al.*, 2015), this could be problematic because public open space definitions and measures should be tailored to each study's objectives. Instead, there should be greater reporting of sub-types included/excluded. Ideally, this process should be supported by a rationale demonstrating how the public open space sub-types included relate to the outcome being examined. For example, studies with mental health outcomes may encompass a wide variety of sub-types to capture all forms of visible green space in an area, whereas studies examining moderate-to-vigorous physical activity may consider only publicly accessible open spaces above a minimum size. Ekkel and de Vries (2017) also note that different forms of public open space

may be important depending on the geographic location of the study with some features perhaps more important in urban areas than in non-urban areas and vice versa.

Data source

While researchers need to give greater consideration to the public open space sub-types used, based on the objectives of their study, it is important to acknowledge that these choices may be dependent on the data source.

Table 2 shows the broad range of data sources and providers of public open space data used by researchers in the papers reviewed. Public open space data were sourced from the Australian Government (n=15), state governments (n=4), local governments (n=3), private (commercial) suppliers (n=6), and a university research centre (n=12). In some cases, more than one source was used.

Six papers did not provide details of the public open space data source in the article (Francis *et al.*, 2012; Hooper *et al.*, 2014; Hooper *et al.*, 2015; McCormack *et al.*, 2007; Sugiyama *et al.*, 2010; Tseng *et al.*, 2014). However, they all referenced other articles which had used the study data. It is possible that those articles provide source details, however ideally the exposure variables should be explained within each study to aid interpretation and replication. A further eight papers did not provide the year of the data source (Astell-Burt *et al.*, 2014a; Christian *et al.*, 2011; Duncan & Mummery, 2005; King *et al.*, 2012; McCormack *et al.*, 2008; Paquet *et al.*,

2014; Pereira *et al.*, 2012; Sugiyama *et al.*, 2014). This lack makes it impossible to determine if there are any temporal mismatches between the public open space data and the participant data.

Typically, authors did not provide a clear justification for their choice of data source. Where justified, authors stated that the source was used in other studies, sometimes by the same research group (Astell-Burt *et al.*, 2013b; Francis *et al.*, 2012). One paper mentioned ground-truthing, stating that there was moderate to good agreement between the source data and what was on the ground (Knuiman *et al.*, 2014). Another stated that validation was conducted using a combination of GIS software, Google Maps, and Google Street View (Paquet *et al.*, 2013). Some studies supplemented data sources with audits involving direct observations of features within public open space in order to measure aspects such as quality or attractiveness (Francis *et al.*, 2012, Giles-Corti *et al.*, 2005, Sugiyama *et al.*, 2010, Veitch *et al.*, 2011).

It may be that some data sources were chosen because they were freely available and provided coverage of the study area. While this approach is pragmatic, the data were unlikely to have been collected in a manner that matched the researchers' study needs. The source dataset may not contain the public open space sub-types relevant to the health or behaviour outcome being examined, it may have a limited spatial extent (resulting in edge effects), or there may be temporal mismatch to the individual data collected. As an example, the 2006 Australian Bureau of Statistics (ABS) Mesh Block land use classification was used in a number of studies. Yet the original Mesh Block land use categorisation was partly determined by the main planned land use and was not designed to be an authoritative classification of actual land use (Australian Bureau

of Statistics, 2011). Whilst a later version of the Mesh Block land use categorisation has greater representation of actual land use, the use of the 2006 classification could result in public open space being either under- or over-represented as demonstrated in Figure 3.

<take in Figure 3 here>

Each source has strengths and weaknesses that should be assessed relative to the study objectives. For example, government data are often developed for land tax purposes and therefore areas considered low-value land without capital improvement may be assigned broad categories, such as “reserve” or “vacant”. Considering reserve land in public open space classifications (Koohsari *et al.*, 2012, Paquet *et al.*, 2013, Paquet *et al.*, 2014) could result in the inclusion of areas that may not suit a study’s objectives. Further, government data sources are often limited to the boundary of a government area and therefore open space in neighbouring areas would not be represented.

Commercial data sources vary in genesis and researchers should consider both how these data are generated and what they represent. Commercial data sets are typically used for marketing to businesses or other mapping purposes (for example providing a base map for vehicle global positioning system units). These data sources should not be used without first validating their completeness and precision as prior work has demonstrated the lack of quality in commercial data (Hooper *et al.*, 2013).

One study in Adelaide, South Australia, compared three public open space datasets and checked these against a planning standard for public open space supply (Daker *et al.*, 2016). That research highlighted important differences in the estimation of public open space across the study region and demonstrated that the choice of data source has the potential inadvertently to impact on findings and lead to incorrect policy recommendations. Similar research conducted in the United Kingdom has also shown differences in public open space depending on the data source (Mitchell *et al.*, 2011).

This discussion does not endorse a particular source of public open space data. At present there is no single authoritative agreed data source available nationally in Australia, and different jurisdictions have varying data sources available. It is, however, important to recognise that the choice of data source will affect the ability to create different availability measures.

Because public open space data are sourced from many different agencies and organisations it becomes crucial for researchers to provide better descriptions of what was included in the data set they have used. The key features of the data set need to be described in sufficient detail to enable an understanding of what the public open space measure represents and any limitations of the measure.

Public open space exposure measure

Exposure measures using public open space are developed to indicate, for example, how far people live from the nearest public open space (proximity) or the quantity of public open space

near to where they live. Exposure to public open space was generally measured using proximity to the nearest public open space (n=7) or the amount (number, area, or proportion, n = 31) of public open space within an administrative unit or buffer (Table 3). Although studies typically provided clear rationales in their introductions to explain the importance of considering public open space as an exposure, few studies provided clear justification for the choice of a particular public open space exposure measure, such as distance to public open space. However, some did note that different exposure measures may be more important for different health outcomes (Giles-Corti *et al.*, 2005, Koohsari *et al.*, 2012, Paquet *et al.*, 2013, Prins *et al.*, 2011, Sugiyama *et al.*, 2010, Sugiyama *et al.*, 2014).

As mentioned, our review identified seven papers that used proximity to measure exposure to public open space. When calculating proximity, a number of methodological decisions are made that can alter the resulting measure (Thornton *et al.*, 2011). All seven studies reported the use of network distance and origin of proximity measure (Duncan & Mummery, 2005, Edwards *et al.*, 2014, Koohsari *et al.*, 2012, Sugiyama *et al.*, 2010, Sugiyama *et al.*, 2014, Veitch *et al.*, 2011, Wilson *et al.*, 2011). However, other important decisions went unreported. For example, studies rarely reported if the access/destination point to which the distance was measured was the centre point of the public open space, the nearest point along a boundary of the public open space or the nearest entry point. As Koohsari *et al.*, (2015) have highlighted, this access point can substantially influence proximity estimates so it is important to express what was used.

A second approach to measuring public open space exposure was to capture the amount of public open space around participants' homes. These quantity measures varied greatly in terms of:

- (a) the region examined—for example (i) within the boundaries of an administrative unit (Chong *et al.*, 2013; Sanders *et al.*, 2015a; Sanders *et al.*, 2015b; Sanders *et al.*, 2015c; Tseng *et al.*, 2014), (ii) within a buffer around this unit (Astell-Burt *et al.*, 2013a; Astell-Burt *et al.*, 2013b; Astell-Burt *et al.*, 2014a; Astell-Burt *et al.*, 2014b; Astell-Burt *et al.*, 2014c; Astell-Burt *et al.*, 2014d; Kamphuis *et al.*, 2008), or (iii) within a buffer around household location (Carver *et al.*, 2015; Francis *et al.*, 2012; Ghekiere *et al.*, 2015; King *et al.*, 2012; Knuiman *et al.*, 2014; Sugiyama *et al.*, 2014; Timperio *et al.*, 2012);
- (b) the types of buffers used—for example, (i) Euclidean (Ghekiere *et al.*, 2015; Hooper *et al.*, 2015) or (ii) road/pedestrian networks (Carver *et al.*, 2015; Francis *et al.*, 2012; Sugiyama *et al.*, 2014);
- (c) the size of buffers—ranging from 0.4km (McCormack *et al.*, 2007) to 5km (Carver *et al.*, 2015);
- (d) what was measured—for example, (i) number (Carver *et al.*, 2015; Crawford *et al.*, 2010; Francis *et al.*, 2012; Ghekiere *et al.*, 2015; Knuiman *et al.*, 2014; Sugiyama *et al.*, 2014; Timperio *et al.*, 2010; Timperio *et al.*, 2012), (ii) size (Carver *et al.*, 2015; Francis *et al.*, 2012; Kamphuis *et al.*, 2008; King *et al.*, 2012; Sugiyama *et al.*, 2010; Timperio *et al.*, 2012, Tseng *et al.*, 2014; Veitch *et al.*, 2011), (iii) proportion of exposure area covered (Astell-Burt *et al.*,

2013a; Astell-Burt *et al.*, 2013b; Astell-Burt *et al.*, 2014a; Astell-Burt *et al.*, 2014b; Astell-Burt *et al.*, 2014c; Astell-Burt *et al.*, 2014d; Chong *et al.* 2013; Sanders *et al.*, 2015a; Sanders *et al.*, 2015b ; Sanders *et al.*, 2015c), and (iv) greenness (Christian *et al.*, 2011; Pereira *et al.*, 2012).

Studies that used buffer distances to delineate areas often included justification of the distances as being an accessible distance via cycling (Carver *et al.*, 2015) or walking (Astell-Burt *et al.*, 2013a; Carver *et al.*, 2015; Edwards *et al.*, 2014; Ghekiere *et al.*, 2016; King *et al.*, 2012; Koohsari *et al.*, 2012; McCormack *et al.*, 2007; McCormack *et al.*, 2008; Paquet *et al.*, 2014; Paquet *et al.*, 2013; Pereira *et al.*, 2012; Pereira *et al.*, 2013; Sugiyama *et al.*, 2010; Timperio *et al.*, 2010; Wilson *et al.*, 2011). Alternatively, in some studies it was stated that these distances were chosen because they had been used in prior research (Astell-Burt *et al.*, 2013a; Astell-Burt *et al.*, 2014b; Astell-Burt *et al.*, 2014c; Ghekiere *et al.*, 2016) or that associations with health or health-related behaviour outcomes had been established at these distances (Koohsari *et al.*, 2012; Timperio *et al.*, 2012). Where administrative boundaries were used they were the smallest unit available (Chong *et al.*, 2013; Sanders *et al.*, 2015a; Sanders *et al.*, 2015b; Sanders *et al.*, 2015c), although one study stated that individual unit addresses would be preferable (Chong *et al.*, 2013).

Other studies examined accessibility indices that combined measures of distance, attractiveness, and size of public open space, or that considered combinations of public open space measures relating to compliance with policy recommendations regarding public open space. Full details about the measures used in each study are provided in Table 3.

The ability to compare and contrast study findings was limited by the fact that some studies did not report key aspects of their public open space exposure measure. Two rarely reported aspects that have the potential to greatly affect the exposure measure are whether or not the area of public open space was clipped, and whether or not the public open space was intersected by a road. The potential differences which can result from whether or not public open spaces are clipped are illustrated in Figure 4.

<take in Figure 4 here>

Using the clipped measure of availability, Person 1 has 62,933m² of available public open space, while Person 2 has only 13,522m² available and Person 3 has 0m². However, if use is made of the unclipped measure (that is, of the full area of public open space within which each individual's circular buffer intersects), Person 2 is reported to have a much greater public open space availability than Person 1 (108,395m² and 62,936m², respectively). Thus, the use of clipped or unclipped public open space measures has the potential to greatly influence the exposure variable and therefore this aspect of the measure used should be reported.

Figure 5 depicts the implications of paths/roads intersecting public open spaces; this has implications for area measures if, for example, a path traversing the park means that only a portion of the total area of the park is included or the intersected polygon does not meet a minimum size requirement to be counted at all. While it may not be feasible to check, fix and report on this issue, it is important to be aware of this issue as it could influence results.

<take in Figure 5 here>

Some papers used and/or compared multiple public open space exposure measures (Carver *et al.*, 2015; Francis *et al.*, 2012; Koohsari *et al.*, 2012; Paquet *et al.*, 2013; Paquet *et al.*, 2014; Sugiyama *et al.*, 2010; Sugiyama *et al.*, 2014; Veitch *et al.*, 2011) or different buffer sizes (Carver *et al.*, 2015; King *et al.*, 2012; McCormack *et al.*, 2008; Paquet *et al.*, 2013; Prins *et al.*, 2011; Timperio *et al.*, 2010). While sensitivity analyses and the use of different exposure measures in a single study can be useful to examine the robustness of findings, it is important that future studies ensure that the buffer type and scale are justified as appropriate for the relationship being tested (for example, area measures may be more important for moderate-to-vigorous physical activity than proximity), the population being studied (for example, smaller buffers may be more appropriate when the population being studied are children or older adults), and the context in which the study took place—for example, inner city versus rural environments (Cleland *et al.*, 2015a; Cleland *et al.*, 2015b).

Treatment of exposure measure in statistical analyses

The papers reviewed varied in the way in which they treated the exposure variable in the analysis (Table 3). Public open space exposure measures were treated as categorical variables only (n = 19), continuous variables only (n = 16), and both categorical and continuous (n = 5).

Of the studies that treated the exposure measures as categorical, categorisation approaches included percentile categorisation such as median split (Francis *et al.*, 2012; Sugiyama *et al.*,

2010), tertiles (Carver *et al.*, 2015; Francis *et al.*, 2012; King *et al.*, 2012; Pereira *et al.*, 2012; Pereira *et al.*, 2013; Tseng *et al.*, 2014), quartiles (Francis *et al.*, 2012; Giles-Corti *et al.*, 2005) and quintiles (Wilson *et al.*, 2011).

The use of percentile categorisation of exposure variables in epidemiological studies has been criticised (Bennette & Vickers, 2012; Greenland, 1995; Lamb & White, 2015) because of the loss of power to detect associations, the lack of justification for the categorisation, and the difficulty in drawing comparisons across studies since percentile categorisation is sample-specific. Some studies are constrained to the use of percentile categorisation due to data privacy issues relating to participant identifiability, and this should be reported as a limitation. Of the nine papers that used percentile categorisation, only five provided the range of values or cut-points for the split within each category (King *et al.*, 2012; Pereira *et al.*, 2013; Pereira *et al.*, 2012; Sugiyama *et al.*, 2010; Tseng *et al.*, 2014), while one provided cut-points for some but not all of the exposure measures (Carver *et al.*, 2015). This information is required to assess what constitutes, for example, low and high public open space exposure; without this, it is impossible to draw comparisons between studies.

Only 13 of the 23 papers that used categorical exposure measures specified a rationale for the categorisation. Justifications provided for adopting categorisation included skewed or non-normal distribution (King *et al.*, 2012; Sanders *et al.*, 2015b), to identify thresholds (Wilson *et al.*, 2011), or to simplify reporting when non-linearities were identified in associations (Astell-Burt *et al.*; 2014c). Although highly skewed data or data with high numbers of zeros can be

problematic, there are no assumptions about the distribution of the exposure variables in linear regression (Lamb & White; 2015). Instead, the model residuals should be normally distributed.

Common measures such as proximity or area could be treated as continuous variables in statistical analyses: this would aid direct comparisons between different studies, assuming that exposure, outcome, and confounder variables are measured and analysed in the same manner. Treating an exposure as a continuous variable enables an assessment of how the outcome would change with a one unit increase in the exposure measure, noting that the effect size (the coefficient) is dependent on the unit of measurement (for example, one metre or one kilometre and so on).

It is important to acknowledge that the association between the exposure measure and the outcome may not be linear, and may explain the use of categorisation and reference to threshold effects. Koohsari *et al.* (2015) note that it is not clear how large a public open space must be, or how many amenities it should have, for it to be used for physical activity and highlighted the importance of detecting thresholds. Since, the use of percentile categorisation is unlikely to detect a threshold, regression approaches which enable non-linearities and threshold effects to be examined should be used, as discussed elsewhere (McNamee, 2005; Ulm, 1991).

Summary, suggested reporting guidelines, and limitations

This review has highlighted inconsistencies in the use and reporting of public open space in Australia with respect to four key aspects: type of public open space; data source; exposure measure; and statistical analysis. In addition, we have provided examples illustrating how different methodological decisions can influence results.

Perhaps reflecting the fact that many of the reviewed papers may have been undertaken by researchers in a health-based field or have been published in health-based journals, a greater emphasis has been placed on providing details of the outcome measures. However, this choice does not mean that the ways in which public open space has been defined, measured, and treated should be overlooked.

To allow adequate assessment of methodology and enable comparisons between studies, the reporting of public open space needs to be improved. While space restrictions may limit the ability to provide extensive detail, further details could be provided in the appendix to enable full assessment of these measures.

We propose a reporting checklist designed to enhance comparability of public open space study findings akin to the Geo-FERN checklist for reporting of food environment exposure measures has recently been developed (Geographic Information Systems Food Environment Reporting checklist, see Wilkins *et al.*, 2017). The minimum reporting requirements are shown in Table 4, with ticks used to indicate which components should include a justification in the description or in supplementary material since the rationale behind these methodological decisions is important to aid understanding of the appropriateness of these choices to the relationships being examined.

<take in Table 4>

Our reporting checklist seeks to increase the reporting of the key components reviewed in this paper. Sub-type reporting will allow the reader to know what specific aspects of the environment were considered in the definition of public open space and to assess the appropriateness of these relative to the outcome measure. It is important to understand the details of the public open space data source, including the year of the data source and whether the data source is appropriate, comprehensive, and valid, and also to gauge if there are potential temporal mismatches between the data source and health or behaviour outcome data. Detailed reporting of the exposure measure is important as many components included in the reporting tool may seem subtly different but can lead to major differences in the value of the exposure. For interpretation of study findings, the statistical treatment component section of the reporting tool is essential. The checklist will serve both as a useful reference tool for reporting methodological decisions and in some instances may help to provide insight into what should be considered in the development of a public open space exposure measure.

In terms of limits, this review has been restricted to a single country context in an attempt to reduce some of the geographic and cultural differences in public open space types, terms and sources that would be expected in an international comparison. The large body of work undertaken in Australia has provides an ideal opportunity to explore the reporting of public open space measures in a single national context. While the review has comprehensively explored studies examining the associations between health or health-related behaviours and objective

measures of public open space, there are some limitations to it. First, the literature search was limited to a single database (PubMed), and articles that were not indexed in the database are unlikely to have been included. However, the aim of this article has been to provide an overview of reporting practices in studies of this type, rather than to examine the body of evidence relating to associations with health or health-related behaviour outcomes. Therefore, we submit that the articles identified in PubMed provide a fair representation of how public open space exposure measures are presented and described in Australian health literature. Second, although internal features and the quality of public open space are likely to be linked to potential uses and behaviours, they were not considered in this review. Commentaries dedicated to the quality-related aspects of public open space are provided elsewhere (Ekkel & de Vries, 2017; Koohsari *et al.*, 2015). Third, differences in the methods used to create the network distances—for example, service area or sausage buffer (Forsyth *et al.*, 2012)—were not reported on in the reviewed papers and were therefore not discussed in this review. However, authors may consider reporting these details in future studies involving network distance measures.

In conclusion, findings from existing papers should keep in mind the variations in public open space definitions, measures, and treatment. Recall that the aim of this article was not to recommend one approach to the measurement of public open space; public open space measures should remain study specific. Instead, a review of Australian literature has shown that the vast differences existing even within a single-country context make it challenging to draw comparisons between studies. A checklist of reporting guidelines for studies involving public

open space measures has been developed to accompany this paper. It is intended that this checklist be used to improve the reporting of key aspects of public open space measures. Better reporting is important if we are to extract robust, repeatable, and defensible evidence from studies relating public open space to health and health-related behaviours.

Conflicts of interest

The authors have no conflicts of interest to declare.

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FIGURE CAPTIONS

Figure 1: Flow chart summary of articles identified in the literature search and included in the review.

[Figure 1]

Figure 2: Sub-types of public open space (data source: Australian Research Centre for Urban Ecology Open Space 2002 spatial dataset).

[Figure 2]

Figure 3: Comparison of 2011 Mesh Block representation of parkland compared to 2011 Spatial Epidemiology and Evaluation Research Group (Daker *et al.*, 2016), representation of public open space/parkland.

[Figure 3]

Figure 4: Comparison of clipped versus total public open space from 2002 Australian Research Centre for Urban Ecology Open Space spatial dataset.

[Figure 4]

Figure 5: Hypothetical example of count of public open space dependent on split due to paths or roads

[Figure 5]

Table 1. Terminology and type of public open space reported in 40 Australian studies* of public open space and health or health-related behaviours between 2005 and 2015

Term/Type**	n	Not defined	Included sub-terms	n	Excluded sub-terms	n
Greenness	5	0	Normalised Difference Vegetation Index (NDVI)	5		
Green space	8	0	Parks Parkland	1 7	Private gardens Agricultural Farmland	2 5 3
Neighbourhood open spaces	1	0	Parks Sports fields Esplanades Bushland	1 1 1 1	Size < 2 acres	1
Parkland	3	2	Fully accessible, existing open space	1	Restricted and proposed parks Golf courses School playing areas/fields	1 1 1
Parkland: public	2	0	Parks Local parks Neighbourhood parks District parks Regional parks Publicly accessible school grounds	2 2 2 2 2 2		

Parks	8	5	Open space	1	Spaces with restricted access	1
			Reserves/parks	1	Areas not conducive to physical activity (for example, car parks)	1
			Park zoned land	1		
			Municipality parks	1		
			Publicly accessible playing fields	1		
			Formal/informal/natural spaces of all sizes	1		
			Managed reserves	1		
Public open space	9	1	Parks	3	Golf courses	2
			Parks and gardens (including picnicking)	2	Members only golf courses	1
			Parks with and without play equipment	1	Inaccessible recreational areas (for example, sports stadia)	1
			Botanical garden and arboretum	2	Educational institutions/facilities	
			Small gardens	1	Schools	
			Playgrounds	1	Scouting spaces	2
			Outdoor arenas	3	Cemeteries	
			Outdoor stadium/entertainment area	2	Divided road median strips	1
			Sports grounds	1	Sidewalk nature strips	1
			Sports fields	3	Size ≤ 2 acres	1
			Sports ovals	2	Size ≤ 3 acres	2
			Athletics/baseball/cricket/ football/Australian rules/soccer/rugby/hockey/lacrosse/archery/basketball/lawn bowls/croquet/tennis/golf course/golf pitch and putt/golf putt putt/golf driving range/bicycle racing track areas	2	Size $< 700\text{m}^2$	2
			Recreational grounds	2		1
			Recreation not elsewhere classified	2		2
			Commons	2		

		Esplanades	1	
		Beaches	2	
		Wooded area conservation land	1	
		Bushland	1	
		Wilderness	3	
		Reserve(d) lands	2	
		Developed reserve lands	2	
		Undeveloped reserve lands	2	
		Vacant allotment conservation or recreation land	1	
		Buffer strips	1	
		Free or reserved access POS		
Public open spaces: freely accessible	2	0	Public open spaces with no fees or restricted opening hours	2
Public open spaces: reserve/park	1	1		
Public open spaces: sport and recreation	3	0	Public open spaces classified as sport or recreation spaces	3
Recreation-related destinations	1	0	Parks	1
			Sports fields	1
			Beaches	1
Recreational destinations	1	0	Parks	1
			Rivers	1
			Beaches	1

Recreational destinations: free-for-use	1	0	Parks Rivers Beaches	1 1 1	
Recreational destinations: pay-for-use	1	0	Sports complexes Swimming pools Health clubs Recreational centres	1 1 1 1	
Beaches	2	2			
Rivers	1	1			
River or Coast	1	1			

*Some papers considered more than one type. **According to overall name used for the feature in the paper.

Table 2. Data sources used in 40 Australian studies of POS and health or health-related behaviours between 2005 and 2015

Source	Provider	n
Commonwealth Government	Australian Bureau of Statistics 2006 Mesh Block ^a	10
	Landsat TM satellite imagery	5
State government	Western Australian Ministry for Planning	1
	South Australian Land Services Group, Department of Planning, Transport and Infrastructure South Australian, 2001 Digital Cadastral Database (DCDB) and Land Ownership and Tenure System (LOTS) Database	3
Local Government	Rockhampton City Council GIS database	1
	City of Geraldton-Greenough parks dataset	1
	Brisbane City Council, Australia's National Resources and Water, and the main electricity supplier for the Brisbane region ^b	1
Commercial supplier	SENSIS Pty. Ltd.	2
	Yellow Pages Telephone Directory, the White Pages Telephone Directory, the Australian postal service (Australia Post)	1
	Melways ^c	2
	Pitney Bowes Pty. Ltd StreetPro Australia	1
University	Australian Research Centre for Urban Ecology Open Space 2002 spatial dataset	8
Not provided	Not provided	6

^aConsidered Mesh Blocks classified as parkland.

^bDid not explicitly state which source was used for which exposure.

^cStreet directory for Melbourne and Victoria.

Table 3. Public open space availability measures used in 40 Australian studies of public open space and health or health-related behaviours between 2005 and 2015.

Measure	Distance/size	Type	Origin	Definition	Treatment
Administrative unit	i) Postcode ii) SA2	-	-	i) Proportion/percentage ii) Area/size	i) Categorical ii) Tertiles
Buffer	i) 0.4 km ii) 0.8 km iii) 1.0 km iii) 1.2 km iv) 1.5 km v) 1.6 km vi) 2.0 km vii) 5.0 km	i) Euclidean ii) Pedestrian/street network iii) Cycle network iv) Road network v) Network ^a vi) Not defined	i) Home address ii) CCD population-weighted centroid iii) CCD centre point iv) Closest intersection to residence	i) Number ii) Area/size iii) Presence iv) Proportion/percentage v) Distance to nearest in buffer vi) Greenness vii) Quality viii) Attractiveness ix) NDVI ^b	i) Categorical ii) Tertiles iii) Median dichotomy iv) Quintiles v) Continuous
Proximity	-	i) Euclidean ii) Pedestrian/street iii) Road network iv) Network ^a v) Not defined	i) Home address ii) Closest intersection to residence	i) Distance ii) Area of nearest iii) Connectivity iv) Attractiveness	i) Categorical ii) Quintiles iii) Continuous iv) Not reported
Accessibility index	-	i) Road network	i) Home address	i) Index based on distance	i) Quartiles

				ii) Index based on distance and attractiveness iii) Index based on distance, attractiveness and size	
Compliance		i) Road network	i) Residential dwelling points in housing development	i) Compliance score based on area, percentage provision, distance, and size ii) Combination of 43 neighbourhood design features including the amount and type of parks	i) Continuous ii) Categorical (clusters)

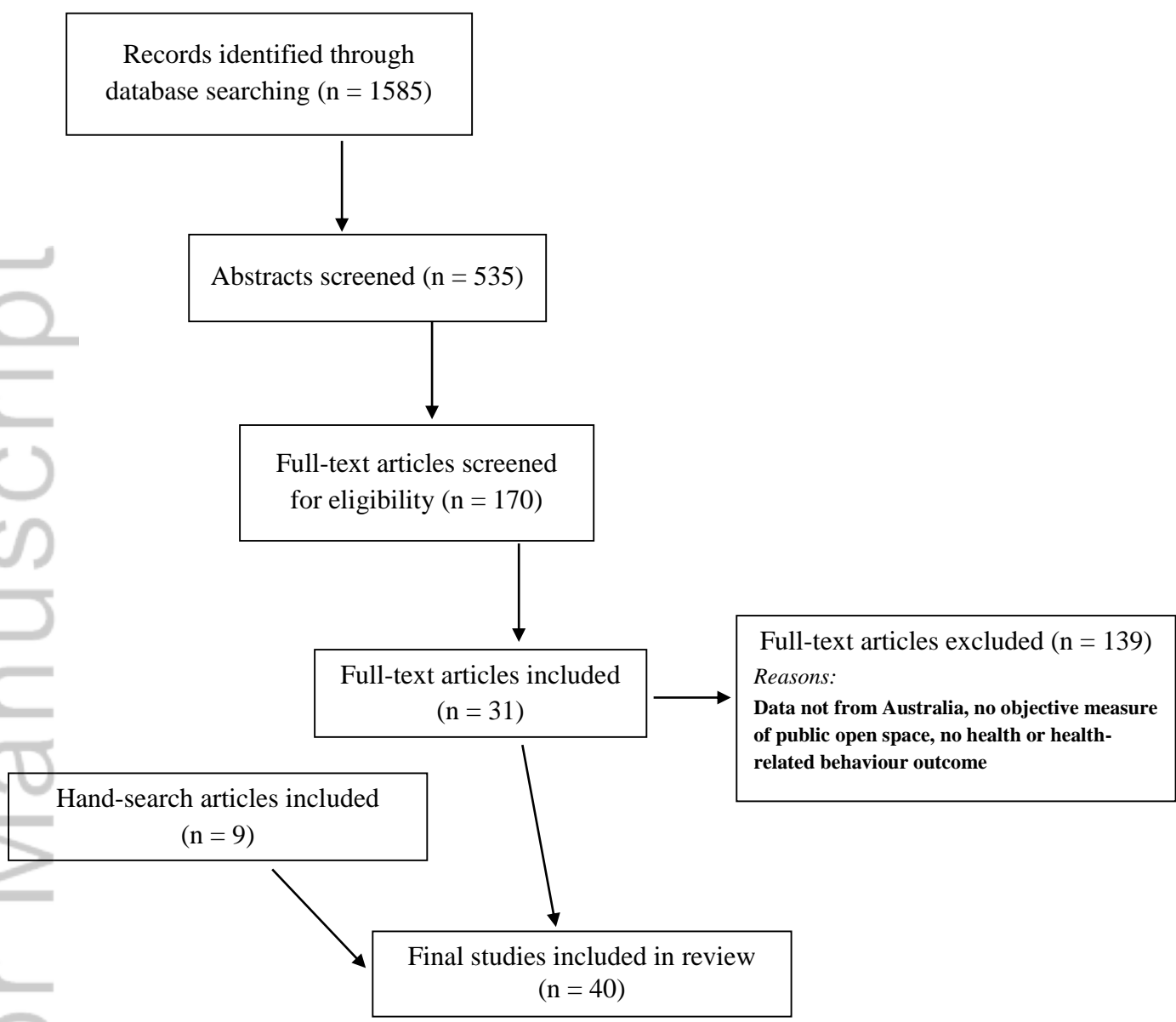
^aType not defined. ^bNDVI: Normalised difference vegetation index

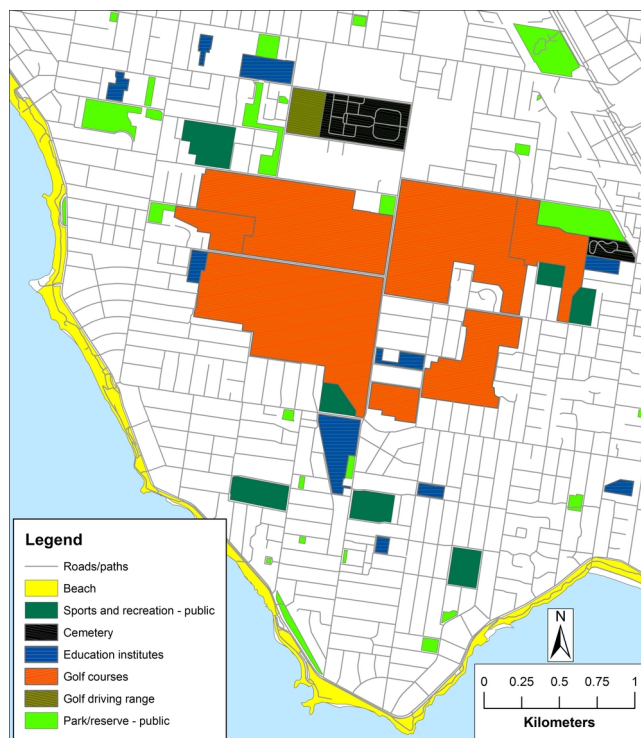
Table 4. Checklist of items to include in publications involving public open space.

	REPORTING COMPONENT	JUSTIFICATION REQUIRED^b
Type		
Sub-types	Sub-types included	✓
	Sub-types excluded	✓
	Minimum POS size if applicable	✓
Source^a		
GIS data source	Provider	
	Why used	
	Date/year	✓
	Cost (for example, free or purchased)	
	Spatial extent (for example, national, local government area)	
	Characteristics of spatial extent (for example, mean/median area and range of area of administrative unit)	
	Ground-truthing	
	Terms of use/limitations (for example, restrictions in editing sub-types; availability measure only provided in deciles)	
Availability		
Proximity	Type of distance (for example, road network, pedestrian network, Euclidean)	✓
	Maximum distance to nearest (if applicable)	✓
	Minimum size of nearest (if applicable)	✓
	Origin point (for example, household, administrative unit centroid)	✓
	Destination/access point (for example, POS centroid, POS boundary)	✓
Amount (area or count)	Buffer type (for example, network, Euclidean)	✓

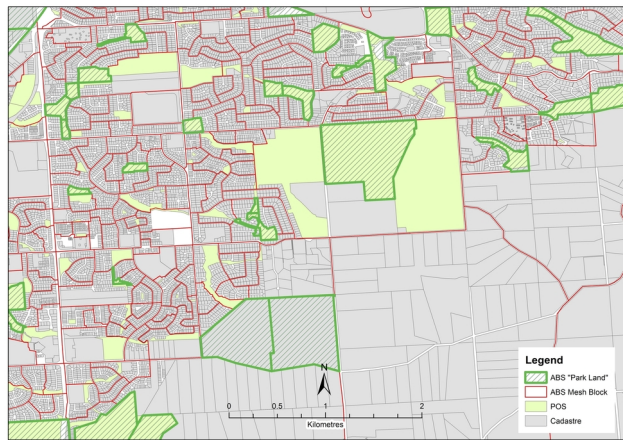
	Buffer size	✓
	Origin point (for example, household, administrative unit centroid)	✓
	POS clipped to buffer/administrative unit (yes/no)	✓
Statistical treatment		
Exposure variable	Descriptive statistics for continuous exposure (for example, mean/median and SD/IQR, if applicable)	
	How categories were chosen (if applicable)	✓
	Category cut-points (if applicable)	✓
	Unit of measurement (for example, metre, kilometre, mile, square metres)	
Sensitivity analysis	Report components of sensitivity analysis where applicable (for example, sub-types, availability measures)	

^a Note that particular source details relevant to satellite imagery data sources have not been detailed. However, some aspects that may be relevant to report for this data source include time of year/season and resolution. ^b The ticks indicate the components that require a justification.

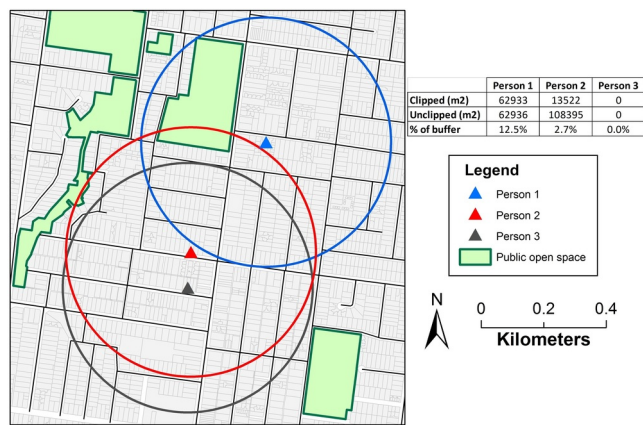




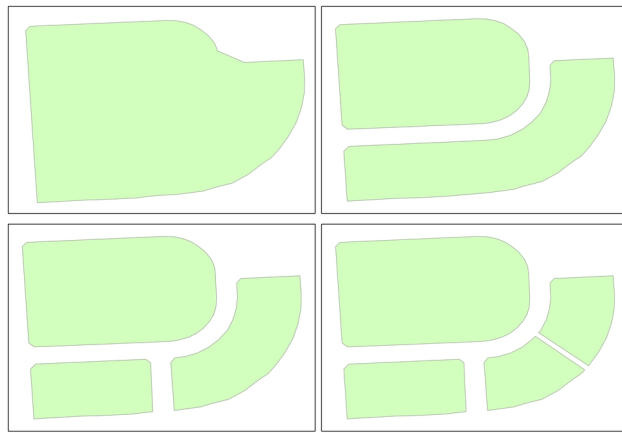
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