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A framework for understanding school based physical environmental influences on childhood obesity

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Abstract

Schools are inviting settings for the promotion of healthy behaviours in children, and a number of interventions have been trialled to improve diet or increase physical activity levels with the ultimate aim of reducing the prevalence of obesity. However, these have seen mixed results and there is suggestion that consideration needs to be given to a broader definition of the school environment in order to encourage sustainable behaviour changes. This review considers evidence for associations between the physical school environment and diet, physical activity and adiposity. School environment covers the neighbourhood around the school as well as the school grounds, buildings and facilities. Reviewed evidence is used to construct a conceptual framework for understanding associations between the physical school environment and adiposity and related behaviours. The framework highlights how school environments may be modified to promote behaviour changes, and how they may limit or enhance the success of other school-based interventions. Consideration is also given to where future work may best be directed.

Keywords

Obesity; school; physical environment; conceptual framework; child; neighborhood

Introduction

The prevalence of childhood obesity increased dramatically during the later part of the 20th century (Wang and Lobstein, 2006). Due to the health consequences of obesity (Dietz, 1998, Maffeis and Tato, 2001, Reilly, 2005), and its potential to track from childhood into adulthood (Freedman et al., 2005), there is great interest in preventing the acquisition of excess body fat in children (Department of Health, 2010). Schools have been identified as important vehicles for health promotion due to the significant role they play in most children's lives. The provision of meals, the availability of physical activity facilities, and the design of the learning environment give schools unequalled opportunities to promote good weight management (Peterson and Fox, 2007, Story, 1999).

In their review of school-based obesity prevention programs, Zenzen and Kridli (2009) identify four intervention modalities: diet, physical activity, healthy lifestyle education, and parental involvement. These intervention types were typically used in combination; over half the interventions they reviewed used all four and all used at least two. Components of

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the interventions included targeted lessons to reduce TV viewing or increase participation in moderate to vigorous physical activity (MVPA), reducing the consumption of high-fat foods, and including additional physical education (PE) lessons into the timetable. A curriculum focus is common amongst programs informed by behavioural choice and social-cognitive theory as they are designed to provide pupils with the cognitive and behavioural skills required to change behaviour (Gortmaker et al., 1999). However, the success of interventions is mixed. Whilst some behavioural changes have been observed, only one of the interventions reviewed by Zenzen and Kridli saw a reduction in obesity prevalence.

Many reviewers have noted that curriculum based interventions are dependent on the motivation, quality and training of school staff, and their ability to deliver programs consistently. Programs must find space in already full curricula, and time and financial concerns may limit their success and sustainability (Doak et al., 2006, Lissau, 2006, Peterson and Fox, 2007, Sharma, 2006, Thomas, 2006). A criticism directed at many school-based interventions is the lack of attention paid to the role of the school environment. While this 'environment' in its broadest sense may certainly include lesson content, reviewers have stressed the importance of taking a more ambitious scope. In their review of obesity prevention interventions and programs, Doak et al (2006: 128) highlight the difference between teaching children that they should be more active and eat more fruit and vegetables, and actually giving them the opportunity in terms of time, space and facilities to do so, recommending that interventions should "directly alter the physical or social environment".

An ecological approach to public health assumes that an individual's good health requires a supportive environment; one that provides the conditions to create and maintain good health, and which supports communities and individuals in making healthy choices (Kickbusch, 1989). This model has been developed with respect to obesity. Egger and Swinburn (1997) coined the term "obesogenic environments" and propose that the environment and individual biology influence behaviour and therefore intake and expenditure of energy.

We hypothesise that by adopting a broader environmental approach, rooted in ecological theory, school-based interventions for the prevention of obesity may be more successful. Yet to our knowledge, no framework exists within which associations between the physical school environment and adiposity may be studied, and this may be a reason why such approaches are not often considered. This paper presents a new evidence-based framework describing the associations that have been observed between specific elements of the physical school environment and diet, physical activity and adiposity outcomes. Where possible it emphasises the strength of associations reported and the mechanisms by which they are thought to operate. It is hoped that this may help improve future school-based interventions and also aid decision making in terms of the siting and design of new schools.

Methods

We began with a review of the literature investigating the influence of schools' physical environments (encompassing neighbourhoods, grounds, building design, available facilities and equipment) on adiposity, diet and physical activity outcomes. Our review included a range of study types, from cross sectional comparisons to controlled intervention trials.

Studies were identified via searches in PubMed, Scopus, and Medline. Searches were undertaken in August 2010 and search terms included: obesity, fat mass, adiposity, weight, BMI, physical activity, walk, cycle, sport, exercise, physical education, sedentary, diet, nutrient, fat, food, drink with either "school neighbourhood/neighborhood", "school grounds", facilities, sports facilities, sports equipment, play facilities, play equipment, playground markings, "canteen layout", "canteen design", "vending machine". We only

included studies in which participants were 18 years old or younger, and which considered the environments of pre-school, primary, and secondary educational establishments. Papers were excluded if their exposure measures related only to the social or policy environments of schools, or to the home environment. Evidence from identified papers was used to inform the construction of a conceptual framework with the aim of illustrating which associations have been observed, which have been hypothesised, and where gaps in knowledge exist.

Results

Initial searches identified 456 papers. Thirty seven papers remained after exclusions and through their reference lists we identified a further six, giving a final total of 43 papers to inform the framework. Their details are given in Table 1. Over half the studies were undertaken in the USA (n=22) with the rest being located in Western Europe (n=16), Canada (n=3), and Australia (n=2). Twenty one studies were cross-sectional in nature whilst 17 papers reported interventions. Longitudinal studies (n=2), qualitative research (n=2) and retrospective surveys (n=1) were also included. Only one paper was based in a pre-school setting while 15 looked at primary schools (or other establishments for children aged 5-11 years), 20 were in secondary schools (for ages 11-18 years) and seven included both primary and secondary establishments.

Nineteen papers had a physical activity outcome of which 12 used an electronic device (accelerometer, pedometer, or heart-rate monitor). Other methods used to measure physical activity were participant self-report (n=3) and teacher or researcher observation (n=4). Only one paper looked at physical activity outside the school environment as an outcome, with the rest measuring activity during all or part of the school day. Physical activity was typically classified by its intensity, with a majority of studies considering time spent in activity of at least moderate intensity. Eleven studies looked at moderate-to-vigorous physical activity (MVPA) of which three separately considered associations with vigorous physical activity (VPA). Four studies looked at a range of physical activity intensities including sedentary time, light physical activity (LPA), moderate physical activity (MPA) and VPA and three used a measure of overall activity (steps per minute and accelerometer measured mean vector magnitude). One study simply asked children what types of activities they took part in. Three studies were included that looked at the participant-reported use of active modes of travel to school.

Dietary outcomes were considered in 13 of the papers. Five assessed diet via a recall (24-hour recall, and 5-day school lunch recall), four used a form of food frequency questionnaire (FFQ), three assessed participant knowledge and preferences via a questionnaire and one used researcher observation of school lunchtime intake. In contrast to the work on physical activity, the over half of the papers (n=7) with a diet outcome considered consumption outside of the school as well as within it. Three papers measuring the food environment did not include a dietary outcome, instead looking at food sales figures, reported purchasing of foods, and student and teacher perceptions of food environments. All of the papers considering anthropometric outcomes used BMI (n=6). In three papers it was based on self-reported heights and weights, while participants were measured in the other three. BMI was also used to define overweight and obese status in three papers (using different cut-points) and change in BMI z-score and change in BMI trajectory (change in centile) were each used once.

In terms of exposure measures, the papers covered three different domains of the school environment:

- School neighbourhoods: Facilities and properties of the environment beyond but around the school.

- School grounds and design: The design of the school building and its grounds.
- School facilities: Both larger-scale, more permanent facilities such as obstacle courses and vegetable gardens, and smaller-scale, less permanent features such as games equipment, playground markings and vending machines.

Within these domains consideration was given to potential drivers of either food or physical activity related behaviours, although no papers were found that investigated food environment aspects of the school grounds.

A new conceptual framework

The papers identified were used to create a new conceptual framework illustrating the links between the physical school environment and adiposity and its behavioural determinants. The framework, which is graphically depicted in Figure 1, shows the components of the three environmental domains identified, and how they are linked to physical activity, diet and adiposity. Included in the framework are external factors, not investigated in the included papers directly, but which are thought to influence and moderate both the school environment, and its associations with behaviour and body composition. The links in the framework indicate the strength of evidence found for associations; bold lines indicate statistically significant intervention effects, thin lines show where cross-sectional evidence of a statistically significant association exists, and dashed lines demonstrate where associations are hypothesised, but have either not been investigated or have not previously exhibited statistically significant associations.

The framework does not attempt to model the whole school environment by including social and policy domains, but instead emphasises the physical school environment. However, we do include some aspects of the social and policy environments of schools which may modify associations between the physical environment and health behaviours in addition to having their own direct impacts.

We have not considered evidence for the factors that may actually shape school environments in this review, but we hypothesise that planning and transport policy, topography and schools legislation may all effect the siting of a school. A school's location may in turn impact on its grounds and the facilities it is able to accommodate. The framework also recognises that, just as social and policy environments may impact the relationships between the school physical environment and health behaviours, the physical environment itself may also drive policy decisions and the social environment. Similarly individual and home factors are included in the framework as they may modify school environment associations, and directly impact physical activity, diet and adiposity. Indeed many of the associations reviewed between the school physical environment and physical activity and diet outcomes were seen to vary by age and gender.

Outcomes

Outcomes in the framework are based around the energy balance equation. Diet outcomes link through to 'energy in', while physical activity links to 'energy out'. The balance between these two parameters thus determines body composition, specifically the laying down of fat tissue marked on the framework as 'adiposity'. Where papers investigated an anthropometric outcome, our framework shows a link directly to 'adiposity' which we consider to encompass the variety of direct and proxy measures used to describe body composition. The majority of included papers considered a behavioural rather than an anthropometric outcome and, where outcomes were anthropometric, for ease and simplicity of interpretation the framework does not specify exactly which anthropometric measure was used in each individual analysis.

A diverse range of diet and physical activity measures were considered in the included papers. For physical activity measures, a key divide was between the consideration of behaviour only in the school or at other times as well. A large number of papers considered only physical activity during the school day which was further split according to commuting, recess and class-time periods. The framework encompasses these distinctions, linking environmental factors with the specific outcome they were seen to be associated with, and it shows hypothetical links between activity in school and energy balance. While many of the included papers used time spent in activity of different intensities as their outcome, for clarity of illustration these distinctions are not depicted in the framework. Use of an active mode of travel to school is specifically depicted in the framework as a physical activity outcome as it has been shown to be an important contributor to children's overall physical activity levels (van Sluijs et al., 2009)

In terms of dietary outcomes, our framework suggests that school food environments may influence the availability ("are foods present?") and accessibility ("how easily can children get them?") of foods and therefore the consumption of foods within the school environment. Some aspects of the school food environment may also impact children's knowledge and perceptions of food, which may then affect food purchases and intakes made outside the school. Few of the included studies attempted to follow through this potential pathway from the school to consumption patterns and finally weight status. However, the framework attempts to combine evidence from different studies to consider what is known about the various components of the pathway.

School neighbourhoods: Physical activity environment

The literature investigating the role of the school neighbourhood as a potential determinant of physical activity focused on associations with walking and cycling to school, behaviours which can make a significant contribution to overall physical activity levels (van Sluijs et al., 2009). The characteristics of the school neighbourhood and the routes to school taken within it that are most studied are related to the road network, encompassing elements of both safety and connectivity. The presence of a main road on the route to school has been seen to reduce the likelihood of active travel (Panter et al., 2010, Timperio et al., 2006) as have less connective routes with fewer intersections (Schlossberg et al (2006). In addition the topography of a neighbourhood may effect active travel behaviour, with lower odds of walking and cycling seen where steep roads are present (Timperio et al., 2006). These associations are included in the framework, along with the presence of physical activity facilities, the diversity of neighbourhood landuses, and neighbourhood aesthetics; measures that we hypothesise may be relevant, but which have not shown statistically significant associations in the literature.

Only one study looked at school neighbourhood characteristics and their associations with physical activity rather than travel mode. Focussing on the immediate surroundings of the school, Jones et al (2010) found that children attending schools with the best nearby provision for walking and cycling (e.g. cycle lanes, traffic calming) spent more time in MVPA during commuting times to and from school compared to those at schools with the worst provision. The framework therefore links characteristics of the road network and safety to more general physical activity as well as specifically travel mode.

School neighbourhoods: Food environment

Somewhat limited evidence exists for the influence of the food environment of school neighbourhoods on diet and adiposity. The presence of fast-food restaurants near schools, which theoretically increase the accessibility of fast-foodstuffs, has been associated with less healthy food intakes (more soda, less fruit and vegetables) and with increased likelihood of

overweight or obesity (Davis and Carpenter, 2009). However, another study found no relationship between obesity and the presence specific food outlet types, although that work did find a counterintuitive association whereby children at schools with generally more food outlets nearby were less likely to be obese (Seliske et al., 2009). A further determinant of the accessibility of food in the school neighbourhood is the means by which children travel to school as it may be expected that those who walk and cycle would be more exposed to outlets around the school. Indeed, greater confectionery consumption has been seen among secondary school children who walked or cycled to school compared to those travelling by car (New and Livingstone, 2003), so a link between active travel and food accessibility and intake is made in the framework

School grounds and design: Physical activity environment

School grounds are typically described by their size, the types of surfaces they include, and the types of spaces (e.g. courts, playing fields) they provide. The provision of greater outdoor space per child has been associated with increases in break-time physical activity measured in both pre-school children (Cardon et al., 2008) and adolescents (Cradock et al., 2007). Similarly, building area per child has also been associated with increased movement (Cradock et al., 2007) and time spent in MVPA (Cohen et al., 2008). While these associations have been replicated cross-sectionally, we found no studies looking at an intervention or natural experiment based around expansion of school grounds or buildings

Beyond the size of a school grounds, the types of surfaces present may have an impact on their suitability for physical activity. The presence of vegetation, or 'greened' areas such as woodland, wildlife gardens, or vegetable plots, has been hypothesised to be a potential stimulus for physical activity. A study by Dymont and Bell (2008), found teachers reported that, while vigorous activity was more likely to occur in the turf and asphalt areas of their grounds, 'greened' areas supported more moderate and light activity, and they had the impression that the physical activity levels of their pupils had increased as a result of school ground greening. However, this has not been empirically tested, and some cross-sectional work has shown no association between the presence of vegetation and step counts in pre-school children (Cardon et al., 2008).

Traditional surfaces in school grounds are grass fields and hard courts/playgrounds, both of which may have markings for games and sports. Qualitative work has suggested that children have a preference for grass surfaces over hard ones, but has also identified bitumen with court or line markings or fixed equipment as particularly suitable for active play (Willenberg et al., 2010). Better designed grounds (based on a composite measure including the slope of the grounds, their suitability for sports, informal games and general play, and the presence of hard playgrounds) have been associated with increased recess MVPA (Jones et al., 2010), as has the presence of individual features including marked, hard-surface courts (Sallis et al., 2001), playing fields (Nichol et al., 2009) and indoor gymnasias (Nichol et al., 2009). These components of the school grounds may provide the space children need in which to be active, but may also provide support for activity-promoting curricula; schools with gymnasias have been found to provided significantly more physical education (PE) time than those without (Fernandes and Sturm, 2009).

Evidence that the design of school grounds can influence physical activity also comes from an intervention study. Ridgers et al (2007) found that when playgrounds were re-developed to include differently-coloured zones designed for sports, multi-activity, and quiet play, pupils were seen to participate in significantly more recess time MVPA and VPA than children at control schools. The effect of the intervention on MVPA was greater among younger children, and at schools with longer recess periods, while the effect of increased VPA strengthened with time, being greater six months post-intervention than six weeks.

Relationships between grounds components and physical activity are seen to vary by gender (Jones et al., 2010, Nichol et al., 2009, Sallis et al., 2001), and age (Nichol et al., 2009) and to be influenced by the quality of the grounds (Nichol et al., 2009, Sallis et al., 2001) and the supervision provided (Sallis et al., 2001). These factors are included in the framework as external forces which may moderate associations between school environments and health-related behaviours.

School facilities: Physical activity environments

Several studies have looked at associations between the facilities present at a school and physical activity outcomes. Qualitative work has suggested that lack of playground equipment is a barrier to participation in physical activity in the school setting (Thompson et al., 2001). This observation is supported by several cross-sectional studies which have seen a positive association between the number of facilities and amount of equipment available and physical activity at school (Haug et al., 2010, Haug et al., 2008, Jones et al., 2010, van Sluijs et al., 2010). This relationship has been reported in girls (Haug et al., 2010) and boys (Jones et al., 2010) and at both primary (Haug et al., 2010, Jones et al., 2010, van Sluijs et al., 2010) and secondary (Haug et al., 2008) schools. We note however that studies vary greatly in what they define as a physical activity facility; there is some overlap with school grounds components (e.g. playing fields), and some facilities are region and season specific (e.g. sledding hills).

The provision of games equipment for use at break has seen some success in interventions to increase physical activity. Two studies reported significant intervention effects of increased time spent in MVPA at recess after the introduction of additional games equipment (Haerens et al., 2007a, Verstraete et al., 2006). Haerens et al (2007a), further found that a group receiving the intervention plus parental support showed more MVPA and a smaller increase in BMI z-score than either the control group receiving nothing, or those receiving the intervention without parental support. Another physical activity facility which has been trialled in an intervention setting is the painting of bright markings on hard-surface playgrounds. Two studies (one a development from the other) have shown increases compared to control schools in the time spent in recess MVPA and VPA after playgrounds were painted with multi-coloured markings (Stratton, 2000, Stratton and Mullan, 2005).

We identified one study which considered impact of teaching facilities on physical activity. Lanningham-Foster et al (2008) devised a new, active-permissive classroom environment ('the Neighbourhood') which included standing desks, wireless laptops, portable video display units, and mobile whiteboards to allow for active lessons, and activity promoting games. Children were allowed to move throughout the Neighbourhood during lessons. Physical activity recorded in the Neighbourhood (mean activity 115m/s²) was comparable to that observed during free-living measurements in the school holiday (113 m/s²), and significantly higher than that seen in a traditional classroom (71 m/s²).

School facilities: Food environment

We identified two areas of research concerning the role of food environment facilities in schools. The first investigates the impact of school fruit and vegetable gardens as aids in teaching children about nutrition and healthy eating. The use of school gardens has been associated with increases in fruit and vegetable recognition, willingness to taste and preference (Cason, 1999, Morris et al., 2001). In intervention studies, the provision of nutritional education coupled with practical gardening lessons in a school garden was seen to significantly increase children's preferences for vegetables (Morris and Zidenberg-Cherr, 2002) as well as their fruit and vegetable intakes compared to both control and nutrition education only groups (McAleese and Rankin, 2007).

By far the larger area of study is that concerning the availability and accessibility of food from school canteens and vending machines. Different foods may be made available from these sources, and their prices, promotion, location within the school and opening times in turn influence accessibility. In qualitative research, children have identified availability, choice, cost, and time and effort (accessibility) involved in obtaining food as barriers to eating a healthful diet (McKinley et al., 2005). This suggests that changing these parameters may in turn influence diet and ultimately weight status.

Vending machines offer children easy, unsupervised access to food and drinks. Their use has been associated with increased consumption of sugary drinks (Wiecha et al., 2006), while their presence in schools has been associated with lower consumptions of fruit (Kubik et al., 2003) and increased snack food purchasing (Neumark-Sztainer et al., 2005). Vending machines selling low nutrient, energy dense foods near canteens have been associated with greater odds of obesity in middle school children (Fox et al., 2009). However, vending machines also offer opportunities to influence diet. The costing of snacks available from them has been seen to influence purchasing patterns outside schools (French et al., 1997), and changing the contents of vending machines from snacks higher in sugar and fat to healthier options (e.g. dried fruit) is seen as viable option for schools, and as an acceptable change to both staff and students (Davee et al., 2005). Children at schools where soft-drink vending machines are turned off at lunchtime have also been seen to purchase fewer soft drinks than those at schools where machines are left on (Neumark-Sztainer et al., 2005), and French et al (2001) saw sale of low-fat snacks from vending machines in secondary schools and workplaces increase from 25.7% to 45.8% as a percentage of all snack sales when their price was reduced.

Food provision in school canteens has been associated with a variety of dietary outcomes. Kubik et al (2003) report poorer diets in pupils at schools with la carte lunch programs, and an inverse relationship between the serving of fried potatoes and the consumption of fruit and vegetables. In elementary school children the odds of obesity have been seen to be higher at schools where fried potatoes and/or desserts are offered more than once a week (Fox et al., 2009). Changes in the availability of foods at school lunch time have also been associated with diet quality. Cullen and Zakeri (2004) followed a group of children as they moved from an elementary school serving a fixed lunch menu to a middle school where an a la carte menu and snack bar allowed a greater range of meal choices. They reported significant reductions in the consumption of fruits, vegetables and milk and increases in intake of sweetened beverages and high-fat vegetables in the pupils in the first year of middle school.

The impact of altering food availability and accessibility in schools has been tested in several interventions to improve diet and reduce obesity. The CATCH study, which modified food provided by schools as well as implementing additional health curriculum, saw significantly greater decreases in percentage energy intake from fat in the diet of pupils at intervention schools than at control schools (Luepker et al., 1996), an outcome similar to the Pathways intervention (Caballero et al., 2003). In interventions focused on the intake of specific food types, Prell et al (2005) saw an increase in fish consumption at intervention schools where relevant changes were made to both home economics curriculum and school meal provision, but Haerens et al (2007b) saw no change in the consumption of fruit, soft drinks or water following an intervention specifically targeting the provision and cost of these items. It is noteworthy that these interventions, and others which have included a food service component (Coleman et al., 2005, Sahota et al., 2001), have also provided additional health and nutrition education to pupils, and in some cases have also involved parents and families (Caballero et al., 2003, Haerens et al., 2007b), making it difficult to determine the contribution of food service changes to intervention outcomes.

Discussion

The evidence presented in this review shows that the physical environment of schools is important in influencing pupil behaviours. The framework we present sets out current evidence for associations between the physical environment of schools and adiposity and related behaviours. It is hoped that this presentation will enable a clearer understanding of how the physical environment may be adapted to promote healthy behaviours, or where elements may modify or even act against other health promotion interventions. The framework also highlights areas requiring further investigation.

Our conceptual framework includes some well-informed elements showing promise as interventions but others merely hinting at potential associations and requiring further work. Much of the evidence reviewed was from cross-sectional studies, and more robust study designs are needed to shed further light on the specific impacts of the school environment on diet, physical activity and adiposity. Interventions may be developed for implementation within schools but different approaches may be required in the study of school neighbourhoods.

Within the school grounds, providing additional play equipment and altering food provision appear to be successful intervention components. The redesigning of school grounds has also shown promise in improving physical activity levels, although more longitudinal and controlled intervention studies in this area may help better define which specific aspects of the school grounds may best promote physical activity. It appears that providing a range of play spaces, with room for competitive games, informal play, and lighter intensity activity may prove most effective in increasing activity levels across age and sex groups.

Schools' social and policy environments must also be considered when planning interventions. Staff supervision has been seen to improve physical activity levels (Sallis et al., 2001) and most of the school food environment interventions we reviewed included changes to both food provision and additions to the curriculum. Associations between school grounds and facilities and health behaviours have been seen to vary by age and gender, and it may be that impact of neighbourhood factors may be similarly moderated by individual factors. Future work should investigate these differences, in order to best determine which interventions may be most appropriate for different settings and aims.

Neighbourhood factors do not necessarily provide easy opportunities for planned interventions, but longitudinal work following children as they move schools may help clarify associations, and natural experiments (such as the building of new schools, or significant developments in the food or physical activity environment around existing schools) could be exploited. Future work should also consider measurement of both neighbourhood food and physical activity environments, including factors such as crime, landuse mix, access to greenspace, and physical activity facilities, which have all been studied in relation to the home neighbourhood, but not that of the school (De Vet et al., 2011). While causality cannot be determined through cross-sectional comparisons, consideration of diet, physical activity and adiposity outcomes may throw light on potential causal pathways.

Changes to school neighbourhoods may require input from a national or local policy level, which may, for example, limit the siting of unhealthy food outlet near schools, or improve road safety. While individual schools themselves may not have a great impact on their physical neighbourhood, an awareness of the barriers and enablers of healthy behaviours in their neighbourhoods may aid schools in developing policies and curricular to improve health outcomes. For example, secondary school pupils who are allowed to leave the school grounds at lunch time have been seen to be more likely to eat at fast-food restaurants, than those kept at school (Neumark-Sztainer et al., 2005).

This review has a number of strengths and weaknesses. In terms of strengths we conducted a wide-ranging, thorough review of available literature, and united the evidence found in a new conceptual framework, which we hope will be of use to others. However, we also faced a number of limitations. We considered only evidence published in English, and did not make a formal assessment of the quality of papers included. As research in this area is fairly limited the inclusion of a range of study types was required in order to provide as broad a picture of associations as possible, however, this may have diminished our ability to compare the relative strength and importance of associations, and the large number of cross-sectional work included means that the direction of causality cannot be determined.

Conclusions

The evidence presented in this review suggests that the physical environment of schools can impact children's diet and physical activity. However, more work is needed to determine how the associations observed operate among different age and gender groups, and how best associations may be adapted into interventions or influence policy. Just as changes to the curriculum alone are unlikely to support sustainable behaviour changes (Doak et al., 2006), modifications to the physical environment are likely to be most effective when coupled with supportive social and educational changes. Awareness of the physical environment of and around schools may help develop more successful interventions, and aid planning of healthier schools to improve diet and physical activity levels among children. This may in turn improve weight status. It is hoped that the evidence and conceptual framework presented in this review will aid this awareness.

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Figure 1.

Conceptual framework for associations between the physical environments of schools and diet, physical activity and adiposity

Table 1

Summary of included papers

Reference	Study type	Setting	N ^o Children (schools)	Age	Environmental measures ^a	Outcome	Results
<i>School Neighbourhood: Physical activity</i>							
Dalton et al 2011	CS	US	1552 (45)	7 th -11 th Grades (12-17y)	Residential density, land use mix and network measures of school buffer	AT (SR)	Sidewalks, residential density, and building continuity increased the odds of AT and (for latter two) frequency of AT. Frequency also positively related to intersection density, food outlets, curbs, on-street parking, small setbacks and building height
Jones (2010)	CS	UK	1868 (92)	Year 5 (9-10y)	AT/PA provision around school	PA (M)	Comparing best and worst, girls and boys both spent more commuting time in MVPA at schools with best walking and cycling provision. Boys did more MVPA at lunchtime at schools with the best sports/play facilities scores, and girls were more active with better designed grounds
Panter (2010)	CS	UK	2012 (92)	Year 5 (9-10y)	Route measures, policies and facilities	AT (SR)	Odds of both cycling and walking to school were decreased by route length >1km, lower route directness, and having a main road on the route
Schlossberg (2006)	CS	USA	287 (4)	6th-8th Grades (11-14y)	Route measures	AT (SR)	Greater route length decreased odds of AT to and from school. Lower intersection density decreased odds of AT to school while higher dead-end density decreased odds
Timperio (2006)	CS	Australia	912 (19)	5-6y and 10-12y	Route measures	AT (SR)	Odds of AT increased by shorter (both), direct (older) route and decreased by a main road (both) and a steep road (younger)
Trilk et al 2011	CS	US	1394 (22)	12 th Grade (17-18y)	PA facilities near schools	PA (SR)	Girls with 5 facilities near their school were more active than those with <5. Significant interaction between facilities and urban/rural location. Girls in rural areas with 5 facilities did 12%

Reference	Study type	Setting	N ^o Children (schools)	Age	Environmental measures ^a	Outcome	Results
							more PA than those in rural areas with <5.
<i>School Neighbourhood: Food</i>							
Davis (2009)	CS	USA	500000 (ng)	Grades 6-10 (11-16y)	Fast food restaurants around schools	Adiposity, diet (SR)	Students with fast-food restaurants within 0.5 mile of their schools consumed fewer servings of fruits and vegetables, were more likely to drink soda, and be OW or obs
Laska et al 2010	CS	USA	349 (ng)	10-17y	Food outlets around homes and schools	Adiposity (M) Diet (SR)	Few, inconsistent, associations between school neighbourhood measures and diet and adiposity measures. Of the 105 test, 3 showed significant associations.
New (2003)	CS	UK	504 (3)	11-15y	Mode of travel to school	Diet (SR)	Average rank of confectionary consumption of children travelling to school by car was 185. Walking = 217, cycling = 216
Seliske (2009)	CS	Canada	7987 (178)	Grades 6-10 (11-16y)	Food retailers around schools	Adiposity (SR)	At 1km having any food retailer associated with decreased OR of OW, and at 5km access to any retailer decreased odds of OW
<i>School Grounds: Physical activity</i>							
Cardon (2008)	CS	Belgium	783 (39)	4-5y	Grounds size and facilities	PA (M)	Fewer children per m ² was associated with increased step counts in boys and girls. Presence of hard surface play areas increase step counts for boys
Cohen (2008)	CS	USA	1566 (36)	6th Grade (11-12y) Girls	Grounds size and facilities	PA (M)	More facilities associated with increased MVPA - an average increase of 3.88 minutes per additional facility
Cradock (2007)	CS	USA	248 (10)	7th-8th Grade (12-14y)	Grounds size	PA (M)	Campus area, playground area and building area (all per child) associated with increase in vector magnitude equated to 20-30% over range of data
Dyment (2008)	CS	Canada	na (59)	Elementary schools (5-14y)	"greening" of grounds	PA (SR)	Highest proportion of children engaged in VPA in turf and asphalt areas. Greened areas supported more LPA. Teacher perception

Reference	Study type	Setting	N ^o Children (schools)	Age	Environmental measures ^a	Outcome	Results
Fernandes (2009)	L	USA	8935 (ng)	5th Grade (10-11y)	Grounds components	PA (M)	that PA levels increased after greening. Having a gymnasium associated with 8.29 minutes more PE per week. No associations between school facilities and BMI trajectory
Fjørtoft et al 2010	CS	Norway	81 (2)	14y	Landscape elements/areas	PA (M)	GPS showed most break-time movement (of generally low intensity PA) close to school buildings. Highest intensity PA clustered around the ball game areas
Lanningham-Foster (2008)	I	USA	40 (1)	4th Grade (9-10y)	Class-room design	PA (M)	Mean activity significantly higher in The Neighbourhood than in either traditional classroom (mean activity = 115 (neighborhood), and 71 in both traditional classrooms.
Nichol (2009)	CS	Canada	7638 (154)	Grades 6-10 (11-16y)	Grounds components	PA (SR)	Odds of being active increased at school with a playing field (boys), a poor quality gym (junior schools), poor or good quality gym (boys), poor or good quality field (girls), and good quality field (elementary schools).
Ridgers (2007)	I	UK	470 (26)	Elementary schools (5-11)	Intervention: grounds re-design	PA (M)	Post-intervention increase seen in MVPA and MPA at intervention schools - increasing by 4.5% and 2.3% respectively. Intervention effect was larger among younger children
Sallis (2001)	CS	USA	ng (24)	Middle schools (11-14y)	Grounds components	PA (OB)	Environmental characteristics explained 59% (boys) and 42% (girls) of the variation in proportion engaging in MVPA. Most boys active in courts with high supervision, higher proportion of girls active were high levels of equipment and supervision
Willenberg (2010)	MM	Australia	3006 (23)	Primary schools (5-12y)	Grounds components	PA (OB)	More VPA observed in areas with loose equipment and teacher supervision. MPA highest in areas with fixed play

Reference	Study type	Setting	N ^o Children (schools)	Age	Environmental measures ^a	Outcome	Results
<i>School Facilities: Physical activity</i>							equipment. Children identified soft surfaces as most suitable for more intense PA due to safety concerns
Durrant (2009)	CS	USA	165 (ng)	12-18y	PA facilities	PA, Adiposity (SR)	No associations between school factors and TV viewing nor BMI. School equipment index not associated with overall PA nor school-based PA
Haerens (2006)	I	Belgium	2287 (15)	11-15y		Adiposity (M)	Significant intervention effect seen for girls in intervention plus parental support group only; BMI and BMI z-score increased less in this group than control or intervention alone. No effect seen for boys.
Haerens (2007)	I	Belgium	258 (15)	11-15y	PA facilities added	PA (M)	Significant intervention effect seen for intervention plus parental support group only.
Haug (2008)	CS	Norway	1347 (68)	Grade 8 (12-13y)	PA facilities	PA (SR)	Odds of daily activity increased at schools with more facilities, and by having open field, Outdoor obstacle course, playground equipment and a cardio/weight equipment room
Haug (2010)	CS	Norway	16471 (130)	Grades 4-10 (8-15y)	PA facilities	PA (SR)	For older boys odds of PA were increased by presence of: soccer field, areas for hopscotch/skipping, playground equipment, a sledding hill and more facilities generally. Last two significant for older girls
McKenzie et al 2010	CS	USA	ng (13)	Elementary schools (4-11y)	PA facilities	PA (OB)	Odds of engaging in MVPA were higher in areas with loose play equipment. Greater participation in MVPA was also observed in unsupervised areas compared to supervised ones.
Nielsen et al 2010	CS	New Zealand	417 (7)	5-12y	Playground area and PA facilities	PA (M)	School-time and overall PA (average cpm) increased with increasing number of

Reference	Study type	Setting	N ^o Children (schools)	Age	Environmental measures ^a	Outcome	Results
Stratton (2000)	I	UK	60 (2)	5-7y	playground markings added	PA (M)	facilities. No relationship seen with grounds size after adjustment for number of facilities. % recess time in MVPA increased in the intervention group and decreased in the control group. Intervention effect significant for MVPA and VPA, but no main effect differences
Stratton (2005)	I	UK	99 (8)	4-11y	playground markings added	PA (M)	MVPA and VPA increased significantly at intervention schools. No significant age or gender interactions with the intervention
Taylor et al 2011	CS	New Zealand	441 (16)	Years 2 and 4 (6-9y)	PA facilities	PA (M)	Positive association between number of facilities and both total PA (cpm) and MVPA
Thompson (2001)	Q	USA	180 (9)	3rd-5th grades (8-11y)	PA facilities	PA (OB)	Staff identify lack of facilities as a barrier to children's PA.
van Sluijs (2010)	CS	UK	1908 (92)	Year 5 (9-10y)	PA facilities and policies	PA (M)	Less SA at schools with 'Park & Stride', more MPA at schools with lollypop person and better walking provision. More VPA at schools with more medium/good quality PA facilities and pedestrian training, lower VPA at schools with policy promoting PA
Verstraete (2006)	I	Belgium	235 (7)	5th-6th grades (10-12y)	PA facilities added	PA (M)	Significant increases seen in intervention group in % time spent in MPA, but not in VPA nor LPA. Interactions showed intervention effect only significant among girls.
School Facilities: Food							
Caballero (2003)	I	USA	1409 (41)	2nd Grade (7-8y)	Food service (and policy/ed) changes	Adiposity, diet (M)	No intervention effects observed in adiposity measures. Observer-measured % energy from fat decreased significantly in the intervention, and not control schools.
Carson (1999)	I	USA	ng (1)	Kindergarten (5-6y)	Veg garden with/without nutrition ed	Diet (M)	Increase in willingness to taste and identification of fruit and veg as 'best

Reference	Study type	Setting	N ^o Children (schools)	Age	Environmental measures ^a	Outcome	Results
Cullen (2004)	L	USA	581 (5)	4th-5th Grades (9-11y)	Move from elementary to middle school	Diet (SR)	snacks', and increases in fruit and veg recognition. For those moving to middle school consumption of fruit, veg and milk decreased, and high fat veg and sweetened drinks increased. For those at middle school throughout high-fat veg and milk consumption increased and veg and sweetened drinks decreased
Davee (2005)	I	USA	na (7)	High schools (14-18y)	n/a	Diet (OB)	Changes to VM contents widely accepted, but resistance from staff and students to changes in ALC programs. No results reported on adiposity nor diet measures
Fox (2009)	CS	USA	2228 (287)	1st-12th Grades (6-18y)	Food availability and outlets	Adiposity (SR)	No significant associations with BMI/weight status in high schools. In middle schools LNEF foods in ALC associated with lower BMI but LNEF from VMs associated with higher BMI. In elementary schools serving french fries and desserts once a week associated with higher odds of obesity.
French (2001)	I	USA	na (20)	High schools (14-18y)	VM promotion and pricing changes	Diet (OB)	Increase in price reductions of low-fat snacks associated with increases in sales. Promotional signage was weakly associated with increases in low-fat snack sales.
Haerens (2007)	I	Belgium	2840 (15)	11-15y	Increased fruit accessibility (plus ed)	Diet (SR)	For girls only fat intake and % energy from fat decreased in all three groups, but significantly more in the intervention plus parent input group.
Kubik (2003)	CS	USA	598 (16)	7th -8th Grades (12-14y)	Food availability and outlets	Diet (SR)	At schools with ALC programs, pupils ate fewer servings of fruit and fruit and veg, and had higher percentage energy intake from total fat and saturated fat. Increasing numbers of VMs were

Reference	Study type	Setting	N ^o Children (schools)	Age	Environmental measures ^a	Outcome	Results
Luepker (1996)	I	USA	5106 (96)	3rd Grade (8-9y)	Food service (and policy/ed) changes	Adiposity, diet (OB)	associated with decreased fruit consumption Greater increase in energy consumption among control schools. Energy from fat decreased at intervention schools, but not at control schools. Dietary cholesterol decreased at interventions and increased at controls. No intervention effects seen for adiposity measures.
McAleese (2007)	I	USA	122 (3)	10-13y	Veg garden with/without nutrition ed	Diet (SR)	Significant intervention effect seen for ed plus gardening group. This group saw greatest increase in fruit and vegetable consumption (increasing by over one portion of each a day) as well as vitamin A and Fibre.
McKinley (2005)	Q	UK	106 (11)	Year 7 (11-12y)		Diet (SR)	Cost, time and effort, and choice/availability all identified as barriers to healthy eating. Foods identified as 'healthy' seen to be not as filling, tasty or good value as 'unhealthy' foods
Morris (2002)	I	USA	213 (3)	4th Grade (9-10y)	Veg garden with/without nutrition ed	Diet (M)	Significant intervention effect for nutritional knowledge and veg preference scores. Veg preference scores varied by type of vegetable
Morris (2001)	I	USA	97 (2)	1st Grade (6-7y)	Veg garden with nutrition ed	Diet (M)	No significant intervention effect on nutritional knowledge nor vegetable preference, but students at intervention school more likely to be willing to taste different veg after intervention
Neumark-Sztainer (2005)	CS	USA	1088 (20)	9th-12th Grades (14-18)	Food availability and outlets	Diet (SR)	Children allowed off site at lunch time ate significantly more at fast food restaurants and snack food consumption increased with increasing numbers of snack VMs

Reference	Study type	Setting	N ^o Children (schools)	Age	Environmental measures ^a	Outcome	Results
Prell (2005)	I	Sweden	228 (3)	8th Grade (14-15y)	Food service (with/without ed) changes	Diet (OB)	The % of children eating fish at lunchtime increased in both intervention groups, and decreased in the control, however the effect was only significant among the SL + HE group.
Wiecha (2006)	CS	USA	1684 (10)	6th -7th Grades (11-13)	Food availability and outlets	Diet (SR)	Children reporting using VMs reported consuming more sugar sweetened beverages.

Abbreviations: ALC = a la carte program, AT = active travel, CS = cross-sectional, ed = education, I = Intervention, L = Longitudinal, LNED = Low nutrient energy dense (food), M = Measured, MM = Mixed-methods, MPA = Moderate physical activity, MVPA = moderate-to-vigorous physical activity, na = not applicable, ng = not given, OB = Observed, Obs = obese, OR = odds ratio, OW = overweight, PA = physical activity, Q = Qualitative, SA = sedentary activity, SES = socio-economic status, SR = self-reported, VM = Vending machine, VPA = vigorous physical activity

^a Measures of the school environment. Some papers also investigated home environments, which are not included here.