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ORIGINAL ARTICLE

Shade coverage, ultraviolet radiation and children's physical activity in early childhood education and care

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Abstract

Objective To investigate the association between shade coverage in early childhood education and care (ECEC) centres and pre-school children's physical activity, outdoor time and ultraviolet radiation (UVR) exposure.

Methods A total of 48 ECEC centres (678 children) in the Western Australian Play Spaces and Environments for Children's Physical Activity (PLAYCE) study took part. Physical activity at ECEC was measured using 7-day accelerometry. UVR exposure was measured using polysulphone film attached to children's shoulders. Educators reported time spent outdoors. The Shade Factor and remote sensing imagery captured shade coverage.

Results Centre vegetation but not Shade Factor was significantly negatively associated with children's UVR exposure ($p < 0.001$). Higher levels of vegetation were associated with increased time outdoors, but higher levels of the Shade Factor were associated with decreased time outdoors (all $p < 0.001$). Neither shade measure was significantly associated with physical activity. Outdoor time moderated the relationships between shade measures, physical activity and UVR exposure.

Conclusions The provision of shade, particularly through natural forms such as tree canopy, is an important sun protection strategy and enabler of outdoor time in children attending ECEC.

Keywords Shade · Physical activity · Childcare · Sun exposure · Methods · UVR

Introduction

Physical activity in young children is associated with a number of health and developmental benefits such as healthy weight status, cardiovascular fitness, physical literacy, bone development, social–emotional development and academic achievement (Carson et al. 2017). Whilst international public health guidelines emphasise the benefits of physical activity from a young age, many pre-school age children do not meet physical activity

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recommendations (Active Healthy Kids Global Alliance 2017). Objective measures of physical activity show less than a third of 2–5-year-olds achieve the recommended 3 h of physical activity per day required for health and development (Christian et al. 2018; Hnatiuk et al. 2014). One of the most significant determinants of children's physical activity levels is time spent outdoors (Hinkley et al. 2008).

However, the amount of time spent outdoors is also positively associated with increased exposure to ultraviolet radiation (UVR) (Chodick et al. 2008). Too much UVR exposure in young children can increase the risk of skin and other cancers later in life (Whiteman et al. 2001). Nevertheless, UVR exposure from the sun is important for helping the body to produce vitamin D which is essential for children's healthy bone development and eye health (Paxton et al. 2013). UVR exposure varies considerably by place and time of year with cities located closer to the equator experiencing higher UVR levels (WHO 2018). This is particularly important for countries such as Australia which has on average higher levels of UVR. Approximately, two in three Australians will be diagnosed with skin cancer by the time they are 70 with the majority of skin cancers caused by exposure to the sun (Cancer Council Australia 2018). Careful management of UVR exposure during childhood is necessary to avoid an increased risk of skin cancer from excessive sun exposure whilst achieving enough sun exposure to maintain adequate vitamin D levels.

The early childhood education and care setting is a key behaviour setting for promoting physical activity and safe sun exposure in young children. Over a half of all 2–3-year-olds in Australia attend an early childhood education and care (ECEC) centre (AIHW 2017). In the UK, 93% of young children are enrolled in formal care (Janta 2011) and 26% of children under the age of six attend centre-based care in the USA (Child Care Aware of America 2012). Attributes of the ECEC physical environment are associated with increased pre-schooler physical activity (Tonge et al. 2016; Trost et al. 2010). For example, outdoor ECEC environments provide increased opportunities for active play through activity promoting play equipment, natural features and varying surfaces when compared with indoor environments (Tandon et al. 2015; Tonge et al. 2016). Natural environments facilitate greater risk-taking in play allowing children to test their limits, try new skills, build confidence and develop their fundamental movement skills which supports physical activity participation (Little and Sweller 2015). Compared with traditional ECEC playgrounds, natural environments encourage young children's physical and mental development and physical activity (Christian et al. 2015).

Along with individual-level child-based sun protection strategies (e.g. sun cream, hats, clothing), shade provision in ECEC outdoor physical environments helps minimise children's overexposure to the sun. Shade provision in ECEC provides a practical means for ensuring children have safe levels of sun exposure whilst maximising their opportunity to spend time outdoors and be active. However, it is unclear whether shade is a potential moderator of the relationship between time spent outdoors and physical activity, and time spent outdoors and UVR exposure. Alternatively, shade coverage could be directly associated with time spent outdoors, and the time outdoors then influencing children's physical activity. Finally, it is plausible that shade coverage could potentially be directly associated with children's physical activity. To date, a single objective measure of shade coverage in ECEC (the Sky View Factor) has been used (Boldemann et al. 2006, 2011); however, more sophisticated and sensitive measures of shade can be obtained by using data from remote sensing imagery. To date, no studies have investigated the interplay between centre-level shade provision and children's physical activity and UVR exposure.

Thus, the aim of this study was to examine the association between ECEC shade coverage and pre-school children's physical activity and UVR exposure, using two different approaches to measuring shade. We hypothesised that higher levels of centre shade coverage would be associated with higher levels of children's physical activity and time spent outdoors and lower levels of UVR exposure.

Methods

Study design and sample

This study formed part of the Play Spaces and Environments for Children's Physical Activity (PLAYCE) study (Christian et al. 2016). PLAYCE was a cross-sectional observational study of 1596 pre-school children, clustered by long day care centre ($n = 104$) across the Perth Metropolitan area, Western Australia. Centres were recruited based on size (small and large based on the number of approved places) and across low, medium and high socio-economic status. Centre directors first provided their informed consent, and through consultation with centre staff, parents of children aged 2–5 years were invited to participate. Further details about the PLAYCE study protocol have been published elsewhere (Christian et al. 2016). A total of 48 ECEC centres and 678 children took part in the current study (328 had matched physical activity and shade data). Data were collected from November 2015 to April 2016. Ethics approval was granted by The University of Western Australia Human Research Ethics Committee (RA/4/1/7417).

Measures

Socio-demographic factors

Child age and gender were collected by parent survey. The socio-economic status (low, medium, high) of the suburb in which each ECEC centre was located was derived from the Australian Bureau of Statistics Socio-Economic Index for Areas (SEIFA). Centre size was based on the number of approved places at each centre in the metropolitan area (quartiles) (Christian et al. 2016).

Physical activity

ActiGraph GT3X+ accelerometers assessed frequency, duration and intensity of physical activity. Devices were worn on an elastic belt on the right hip (Pate et al. 2010) during waking hours for 7 days. Valid data included at least 1 day at ECEC with 75% wear time (Christian et al. 2016; Rice and Trost 2014). Accelerometer data were processed to determine amount and intensity of physical activity pre-schoolers undertook at ECEC using the Pate and colleagues cut points to distinguish between sedentary (SED), light (LPA) and moderate to vigorous (MVPA) intensity physical activity (Janssen et al. 2013; Pate et al. 2006). Parents completed an accelerometer diary to record the start and finish time for each day their child attended ECEC and to identify when their child didn't wear the device (e.g. swimming). For children who attended ECEC for more than 1 day during the 7-day monitoring period, their data were averaged. Average minutes of MVPA and total physical (sum of LPA and MVPA) per average day at ECEC were used in analyses.

UVR exposure

Children's UVR exposure was objectively measured using polysulphone film mounted cardboard holders (UV badge) attached to a child's left shoulder (Glanz et al. 2010). A new UV badge was worn each day whilst at ECEC for up to 3 days. The pre- and post-exposure UVR absorbance of the UV badges was measured using a spectrophotometer (model: CARY 3 UV/Vis). The absolute difference in film absorbance (dA) was calculated and converted to an Effective Erythermal Dose (EED) (in Joules/m^2) by calibrating with the Commission Internationale d'Eclairage (CIE) Erythemal Response (Gies and Wright 2003). An EED of 200 J/m^2 is the standard threshold limit for sunburn in fair, untanned skin (Boldemann et al. 2011). The outcome variable was average UVR exposure per average day (EED/day) of ECEC.

An atmospheric measure of the average UV Index across the days children wore a UV badge was calculated. The daily UV Index was calculated by taking the median UV Index value over the time period per day each child wore their UV badge. The daily UV Index data were provided by the nearest Cancer Council Western Australia UV Index metre ($n = 21$) to the centre each child attended. The UV Index is an international standard measure of the strength of sunburn producing UVR with values 0–2 'low', 3–5 'moderate', 8–10 'very high' and 11 + 'extreme' (WHO 2018).

Time spent outdoors

Time spent outdoors was estimated using the PLAYCE Childcare Daily Schedule (Christian et al. 2016). On an hourly basis, educators documented the main activity types in which children were engaged. Each type of activity which included reference to outdoors (e.g. outdoor play, free play outdoors) was coded and added together to give an estimate of time spent outdoors for that day. In most instances, educators recorded activities for 1 day only. Where there was more than 1 day recorded, daily outdoor time was averaged.

Shade coverage

Two different measures to capture ECEC shade coverage were used to determine how an existing measure (Sky View Factor) compared with more sensitive and comprehensive data captured through remote sensing imagery.

Shade Factor

The Sky View Factor (SVF) (Boldemann et al. 2011) was used to measure built (e.g. shade sails) and natural (e.g. tree canopy) forms of shade coverage in centre outdoor play spaces. The SVF is the fraction of visible free sky. The Shade Factor was calculated as the proportion of free sky that was shaded, i.e. 1-SVF. A fisheye lens was attached to an iPad placed one metre above the ground on a tripod using a spirit level (Fig. 1) (Boldemann et al. 2011). Photographs were taken at 'Open Area' locations in childcare centre outdoor spaces between 10.00 and 11.00 am. 'Open Areas' were defined as larger spaces free from obstruction and equipment (Cosco et al. 2010). For centres that had more than one 'Open Area', the image from the 'Open Area' utilised by the majority of the children in the study was chosen. The Shade Factor was calculated using the SkyViewFactorCalculator version 1.1, a free open-source executable developed for MATLAB (Holmer et al. 2001; Lindberg and Holmer 2010). The calculation involves

Fig. 1 Example of fish eye images from 'Open Area' in an early childhood education and care (ECEC) centre (Play Spaces and Environments for Children's Physical Activity Study, Western Australia, 2015–2018). Image 1—ECEC 'Open Area'; Image 2—image from ECEC 'Open Area' taken vertically using a fisheye lens 1 m above the ground; Image 3—image used to calculate the Shade Factor (1-Sky View Factor)

dividing the total number of free sky pixels by the total number of circular image pixels.

Remote sensing imagery

High-resolution (50 cm pixel) airborne multispectral 4-band (blue, green, red, near-infrared) imagery was acquired over the region covering the extent of the ECEC centres from a custom-built sensor mounted in a fixed-wing aircraft (Evans et al. 2012). Imagery was acquired during cloud-free conditions and processed to derive a 3D Vegetation Feature Height Model (VFHM) (Westoby et al. 2012). A Height-Stratified Vegetation Cover (HSVC) raster layer was produced, classifying land cover into three categories: non-vegetated, vegetation < 3 m in height and vegetation > 3 m in height.

A Geographic Information System (GIS) was used to identify the location, shape and size (polygon) of ECEC outdoor play spaces through an onscreen digitising process using 10–15-cm colour orthorectified aerial imagery flown by Landgate in the summer of 2016 (Landgate 2016). Boundaries of each ECEC centre were loaded into the GIS software system QGIS version 2.12 Lyon (Open Source Geospatial Foundation (OSGeo) 2018), and these were used to clip the HSVC within each ECEC centre and the area calculated for no vegetation, vegetation < 3 m in height and vegetation > 3 m in height.

Statistical analysis

Nonparametric Wilcoxon and Mann–Whitney tests were used to test for differences between socio-demographic variables and physical activity, outdoor time, UVR exposure and shade variables. Spearman rank correlations were used to test for associations between the two shade measures and between children's outdoor time, physical activity and UVR exposure. Multilevel linear regression models were used to determine associations between shade and vegetation measures with average daily physical activity, outdoor time and UVR exposure of children at ECEC. All models considered data at the centre (fixed effects) and child (random effects) level and adjusted for child age, gender, and centre SES and size. Physical activity models also took into account accelerometer wear time, and UVR exposure models adjusted for badge wear time. All models were run separately for both measures of shade coverage (Shade Factor and amount of vegetation different height classes) to inform which may be more important for children's outdoor time, physical activity and UVR exposure whilst attending ECEC. Analyses were also conducted to assess the moderating effect of outdoor time on the relationship between centre-level shade and physical activity and UVR exposure.

Results

Characteristics of sample

On average children were 3.4 years (SD 0.8) and 53% male. Of the 48 ECEC centres that took part, 32% were from low SES, 34% from medium SES and 34% from high SES suburbs. Overall, 58% of centres were in the largest size quartile, 27% were in the smallest, and 15% were in the middle quartiles of size.

Physical activity, sun exposure, outdoor time and centre shade characteristics

On average, children did 132 adjusted min/day of total physical activity and 64 adjusted min/day of MVPA whilst at ECEC (Table 1). Across centres, children spent on average 3.1 h outside per day. Children's mean UVR exposure (EED) per day was 128 J/m^2. The mean shade coverage for centre outdoor 'Open Areas' was 42%. Approximately 30% of centres' outdoor play space had vegetation with 23% of this being < 3 m in height and the remaining 7% > 3 m high.

Correlation between different measures of centre shade coverage

A significant negative correlation was found between the Shade Factor and the proportion of vegetation < 3 m in height ($\rho = -0.161$, $p = 0.004$), whereas a significant positive correlation was found between the Shade Factor and the proportion of vegetation > 3 m in height ($\rho = 0.116$, $p = 0.039$). No significant correlation was found between the Shade Factor and the proportion of total vegetation at centres ($\rho = 0.103$, $p = 0.066$).

Relationships between centre-level shade and physical activity, outdoor time and UVR exposure

Centre-level outdoor time was not correlated with children's total physical activity or MVPA but was significantly positively correlated with UVR exposure ($\rho = 0.29$, $p = 0.000$).

After adjustment, shade-related variables were significantly associated with time spent outdoors but not minutes/day of total physical activity or MVPA (Table 2). Higher levels of shade as measured by the Shade Factor were associated with decreased time outdoors; however, higher levels of vegetation (total and < 3 m in height) were associated with increased time outdoors (all $p < 0.001$).

Centre vegetation but not Shade Factor was significantly negatively associated with children's UVR exposure (Table 2). For every 1% increase in centre vegetation, children's UVR exposure decreased by 2.3 J/m^2 per day at ECEC ($p < 0.001$).

Further analyses examined the moderating effect of outdoor time on the relationship between shade variables and physical activity and UVR exposure (Table 3). Outdoor time moderated the relationship between Shade Factor and children's UVR exposure as well as the relationship between the amount of vegetation < 3 m in height and physical activity (total PA and MVPA) (all $p < 0.05$). No moderating effects of outdoor time on the relationship between the amount of vegetation > 3 m in height or overall vegetation levels and physical activity or UVR exposure were observed.

Discussion

Higher levels of ECEC centre vegetation were associated with children spending more time outdoors but not with children's physical activity whilst attending care. These findings are in contrast to a 2006 Swedish study of 11 preschools (197 children 4–6 years) in Stockholm (Boldemann et al. 2006) which found that high quality environments with more trees, shrubbery and broken ground were associated with increased physical activity (pedometer counts) in children, compared with low-quality environments. However, the study did not specifically examine centre vegetation and instead used a subjectively derived categorical measure of high- and low-quality environments

Table 1 Physical activity, ultraviolet radiation exposure, outdoor time and early childhood education and care shade characteristics (Play Spaces and Environments for Children's Physical Activity Study, Western Australia, 2015–2018)

	n	Mean or %	SD	Range
Physical activity at ECEC (min/day)				
Total physical activity[a]	595	131.6	38.7	7.2–305.2
Moderate–vigorous physical activity (MVPA)[a]	595	64.3	27.7	4.0–224.2
Accelerometer wear time	595	424.0	77.0	140.0–630.0
Time spent outdoors at ECEC (min/day)[b]	689	187.6	50.5	78.0–281.0
UV exposure per day at ECEC				
Erythemal dose/day (J/m^2)[a]	144	152.1	135.0	0–788.2
UV badge wear time (min/day)	144	404.8	72.3	223.0–580.0
Average daily UV Index[c]	122	6.1	1.8	1.7–9.0
Shade at ECEC				
Shade Factor (%)	674	41.8	29.6	40.0–99.9
Proportion vegetation (%)	329	30.5	22.1	0–82.3
Proportion of vegetation < 3 m height (%)	329	22.7	20.5	0–78.6
Proportion of vegetation > 3 m height (%)	329	7.8	13.7	0–58.6

Mean and SD calculated at the child level

[a]Adjusted for wear time based on a standard 8 h day of attendance at ECEC

[b]Calculated at the centre level

[c]Average UV Index per child across days UV badge was worn

Table 2 Associations between centre-level shade and physical activity, outdoor time and ultraviolet radiation exposure (Play Spaces and Environments for Children's Physical Activity Study, Western Australia, 2015–2018)

	Total PA (min/day at ECEC)			MVPA (min/day at ECEC)			Outdoor time (min/day at ECEC)			UVR exposure (J/m^2 per day at ECEC)		
	β	95% CI	p value	β	95% CI	p value	β	95% CI	p value	β	95% CI	p value
Shade Factor (%)[a]	0.03	− 0.10, 0.17	0.63	0.04	− 0.05, 0.13	0.41	− 0.64	− 0.82, − 0.47	< **0.01**	− 0.83	− 2.68, 1.02	0.38
% Total vegetation[b]	< 0.01	− 0.19, 0.19	0.97	0.02	− 0.13, 0.17	0.77	0.73	0.51, 0.96	< **0.01**	− 2.31	− 3.08, − 1.53	< **0.01**
% < 3 m vegetation[b]	< − 0.01	− 0.22, 0.21	0.96	− 0.01	− 0.18, 0.16	0.91	0.74	0.49, 0.98	< **0.01**	− 2.26	− 3.03, − 1.49	< **0.01**
% > 3 m vegetation[b]	0.02	− 0.28, 0.32	0.89	0.08	− 0.16, 0.32	0.52	0.92	− 0.28, 2.11	0.13	0.91	− 12.46, 14.28	0.89

Bolded p values significant at $p \leq 0.05$

All models controlled for gender, age, centre SES and size and clustering at the centre level; TPA and MVPA models also adjusted for accelerometer wear time; UVR exposure model also adjusted for UV badge wear time

[a]N = 562 total PA and MVPA; N = 650 outdoor time; N = 140 UVR exposure

[b]N = 283 total PA and MVPA; N = 322 outdoor time; N = 67 UVR exposure

Table 3 Moderating effect of outdoor time on the relationship between centre-level shade and physical activity and ultraviolet radiation exposure (Play Spaces and Environments for Children's Physical Activity Study, Western Australia, 2015–2018)

	Total pa (min/day at ECEC)			MVPA (min/day at ECEC)			UVR exposure (J/m^2 per day at ECEC)		
	β	95% CI	p value	β	95% CI	p value	β	95% CI	p value
Shade Factor models[a]									
Outdoor time	− 0.07	− 0.21, 0.07	0.32	− 0.07	− 0.17, 0.02	0.13	− 1.42	− 3.11, 0.27	0.10
Shade Factor	− 0.22	− 0.74, 0.30	0.41	− 0.19	− 0.54, 0.16	0.29	− 9.23	− 16.38, − 2.09	**0.01**
Outdoor time × Shade Factor	0.001	− 0.001, 0.004	0.32	0.001	− 0.001, 0.003	0.18	0.04	0.01, 0.08	**0.03**
%≤ 3 m vegetation models[b]									
Outdoor time	0.10	− 0.06, 0.26	0.24	0.07	− 0.04, 0.19	0.21	− 2.80	− 4.10, − 1.50	< **0.01**
%< 3 m vegetation	0.78	0.002, 1.55	**0.05**	0.68	0.13, 1.22	**0.02**	− 11.22	− 18.95, − 3.49	< **0.01**
Outdoor time × %< 3 m vegetation	− 0.005	− 0.01, − 0.0004	**0.03**	− 0.005	− 0.008, − 0.001	< **0.01**	0.04	− 0.02, 0.09	0.18

Bolded p values significant at $p \leq 0.05$

All models controlled for gender, age, centre SES and size and clustering at the centre level; TPA and MVPA models also adjusted for accelerometer wear time; UVR exposure model also adjusted for UV badge wear time

[a]N = 562 total PA and MVPA; N = 140 UVR exposure

[b]N = 283 total PA and MVPA; N = 67 UVR exposure

that included total outdoor area, overgrown surfaces (trees and shrubbery) and broken ground, and the integration of play structures and areas with vegetation (Boldemann et al. 2006). Whilst higher amounts of vegetation in ECEC facilitate children spending more time outdoors, it is possible that the location of vegetation and its integration with other outdoor play space features (e.g. play structures) is what encourages more physical activity. Future research should investigate the interaction between vegetation and other attributes of ECEC outdoor play spaces to determine the impact on children's physical activity.

Contact with nature provides children with numerous health and developmental benefits. Nature contact is associated with children developing a sense of identity, autonomy, psychological resilience, cognitive function (Wells 2000), gross motor skills (Fjortoft 2004) and learning healthy behaviours. Our findings show that children spend more time outdoors in ECEC centres with greater amounts of vegetation. For every 1% increase in the total amount of vegetation as well as vegetation < 3 m in height, children spent approximately one additional minute per day outside. Furthermore, we observed that outdoor time moderated the relationship between vegetation < 3 m in height and physical activity, such that more vegetation < 3 m in height facilitated less time spent outdoors and less physical activity. It is possible that the presence of greater amounts of low-level vegetation in relatively small ECEC outdoor play spaces reduces the amount of unobstructed running space which is important for facilitating higher intensity MVPA. Further studies using longitudinal designs are required to confirm these relationships. Natural experiments of renovations to ECEC outdoor play spaces may provide a feasible method of evaluating the effect of an increase or decrease in vegetation levels on children's time spent outdoors and physically active.

A number of studies have shown outdoor time is a significant determinant of children's physical activity whilst attending care (Ferreira et al. 2007; Hinkley et al. 2008). However, our study did not find that outdoor time was associated with children's physical activity. It is possible that our centre-level educator reported measure of daily outdoor time was not sensitive enough in comparison to our accelerometer-derived measure of individual child physical activity levels. Objective individual measures of children's time spent outdoors at ECEC (e.g. Global Positioning Systems) should be considered in future studies (Christian et al. 2016).

Our findings showed that children's UVR exposure was positively associated with time spent outdoors and negatively associated with vegetation. For every 1% increase in the total amount of vegetation as well as vegetation less than 3 m in height, children had 2.3 J/m^2 effective erythemal (EED) dose equivalent less UVR exposure per day whilst attending care. These findings are similar to those found by Boldemann et al. (2006) who observed that free sky was associated with increased individual child UV exposure in a group of Swedish pre-school children. Both our study and Boldemann's used the same methodology to measure free sky; however, our study calculated the proportion of fish eye photography images that were not free sky (i.e. 1-% free sky = Shade Factor). Our study also found that outdoor time moderated the relationship between the Shade Factor and UVR exposure, such that more shade (> 55%) facilitated more time spent outdoors (once above 175 min/day) and thus more UVR exposure. Whilst the provision of shade within ECEC whether natural (vegetation – tree canopy) or built (shade sail, pergola, veranda) form provides important protection for children against overexposure to harmful UVR (Lane et al. 2015), it also facilitates more opportunity for children to be outdoors and active.

In contrast to centre vegetation, we found that measuring shade using the Shade Factor was not associated with children's accelerometer-derived physical activity and was associated with decreased time spent outdoors. It is possible that this is due to the Shade Factor and vegetation measures capturing different aspects of the ECEC physical environment. For example, the Shade Factor captures both natural and built forms of shade whilst the vegetation measures were derived from remote sensing imagery and only capture natural shade (tree canopy: > 3 m in height and grass/shrubs, < 3 m in height). In addition, the Shade Factor only captured shade for a particular outdoor area (Open Area) and may not represent levels of shade in other areas of the ECEC outdoor space. Provision of built and natural forms of shade within ECEC centres is important for minimising children's overexposure to UVR; however, natural forms of shade (tree canopy) as well as other lower heights of vegetation may have a number of developmental benefits for children by exposing them to nature (Kuo and Taylor 2004; Wells 2000). Furthermore, the cooling effect provided from natural vegetation through evapotranspiration may provide added benefit for those ECEC services located in warmer climates (Qiu et al. 2013).

Study limitations and strengths

This study was limited by the smaller number of centres with remote sensing imagery data and fewer children with UVR exposure data. The cross-sectional design could not determine whether more vegetation in centres causes children to spend more time outdoors because they are engaging with their environment in a more fulfilling way, or if those children who spend more time outdoors happen to attend centres with greater levels of vegetation. Due to the busy nature of most ECEC centres, educators may not have been able to place the badges immediately on (or take off) children once they arrived at the centre which would have impacted the badge wear time and exposure time. Furthermore, although UV badges were placed on children's shoulders, they may have been wearing hats and sunscreen which could have reduced the actual UV exposure dose. Future measures of UVR exposure should take into account the time of day and for how long each child is outdoors and consider using the UVR exposure ratio to take into account the effect of ground irradiance over time and location at ECEC. Whilst a strength of this study was the use of accelerometry to measure children's physical activity at ECEC, it could not differentiate between physical activity accumulated indoors compared with outdoors. A more context specific measure of physical activity (i.e. time spent in outdoor physical activity whilst in care) would provide a better match between behaviour and the ECEC outdoor physical environment.

The Shade Factor was calculated from images taken from 'Open Areas' of ECEC outdoor play spaces and thus may not be representative of the amount of free sky and shade in other areas such as above play structures. The Shade Factor was also limited because it could not differentiate between shade provided from natural (tree canopy) and built form. However, a strength was that the Shade Factor was specific to the outdoor area/s a child could access and was exposed to. In contrast, centre vegetation measures were based on the whole outdoor area for a centre and may not represent the vegetation children were exposed to if they were restricted to certain outdoor play areas. Finally, the measure of outdoor time used was at a centre level. Future studies should consider objective measures of individual child time spent outdoors whilst at ECEC.

Conclusions

The ECEC physical environment influences child health-related behaviours in different ways. The provision of shade, particularly through natural forms such as tree canopy, is an important sun protection strategy and enabler of outdoor time in children attending ECEC. Our findings showed that more vegetation within centre outdoor areas was associated with reduced UVR exposure and increased time spent outdoors. These findings can be used to advocate for increased natural forms of shade and vegetation in ECEC to promote children's sun protection and outdoor play.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethics standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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