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Outdoor learning in urban schools: Effects on 4–5 year old children's noise and physiological stress

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ABSTRACT

Natural outdoor environments reduce physiological stress. But in an urban school context, does outdoor learning still have beneficial effects even where nature exposure is more limited? The current, pre-registered study used wearable devices including heart rate monitors and actigraphs to examine physiological stress in 4–5 year old children across 8 matched indoor and outdoor sessions (N = 76 children, N = 601 sessions in total). Results revealed that children's resting heart rates while seated and listening to a teacher were significantly lower when outside compared to indoors ($p < 0.001$, d = 0.512). Children also moved more while seated during indoor sessions (p < 0.001, d = 0.546). Despite activities and resources being matched across conditions, outdoor learning sessions were significantly quieter than indoor ones, both when children were seated, listening to a teacher (p = 0.004, d = −0.455) and when actively engaged in play and learning activities ($p < 0.001$, d = 1.064). There was a significant positive correlation between noise levels and resting heart rate in the indoor condition ($r(97) = 0.364$, $p < 0.001$) but not in the outdoor condition. These findings suggest that learning outdoors, even in urban settings, associates with lower physiological stress in children and that this effect may partly be due to reduced noise. The fact that noise associates with resting heart rate indoors but not outdoors may indicate that being outside buffers children against the stressful effects of excess noise.

1. Introduction

Children's mental wellbeing is declining. Over the past 3 years, the risk of a child aged 5–16 having a mental health problem has increased by 50% (National Health Service, 2022) and children's happiness with their lives is significantly lower now than 10 years ago, largely driven by unhappiness with school (The Children's Society, 2023). In many ways this is unsurprising. Today, 29% of children in the UK live in poverty (Child Poverty Action Group, 2023), and the proportion of children growing up in cities has increased from 7% 200 years ago to over 55% today (UNICEF, 2019). Urban living has been associated with higher risk of mental health disorders (Engemann et al., 2019; Kovess-Masféty et al., 2005; Peen et al., 2010) and changes in stress processing in adults (Lederbogen et al., 2011) and increased physiological stress and stress reactivity in infants (Wass et al., 2019). Urban lifestyles have also seen a shift away from time outdoors in nature. Only 10% of children play in natural settings compared to 40% of the previous generation (Natural England, 2019), and they spend less time in unsupervised outdoor play (Dodd et al., 2021). Economically disadvantaged children tend to have less nature contact (Mears et al., 2019; Natural England, 2019) and are more likely to report low wellbeing and to be unhappy at school (The Children's Society, 2023). Children from disadvantaged backgrounds are also thought to be disproportionately affected by swapping 'green time' for 'screen time' (Oswald et al., 2020).

Therefore, providing outdoor time within the school day could be an important way of ensuring equality of access and reducing existing mental health disparities. Yet time spent outdoors at school has decreased, too (Baines & Blatchford, 2019). Currently less than a quarter of children engage in outdoor activities at school that are not physical education (Natural England, 2022).

In this study, we investigate how learning outdoors affects children's physiological stress. It is well documented that stress has effects on children's learning (Arnsten, 2009; Whiting et al., 2021), long term health, and wellbeing (Brietzke et al., 2012; Shonkoff et al., 2012) yet little attention has been paid to how the physical learning environment influences physiological stress in children.

Potential sources of stress and discomfort shown to negatively impact children in school environments include excess noise (Klatte

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et al., 2013; Massonnié et al., 2020), poor lighting (Winterbottom & Wilkins, 2009), lack of windows (Vásquez et al., 2019) and excess visual clutter (Fisher et al., 2014; Godwin et al., 2022). These effects may be particularly acute for the 26% of children estimated to have sensory processing difficulties (Galiana et al., 2022).

Environments with intermediate levels of colour and complexity have been shown to be most conducive to learning, with natural factors such as light, air quality and temperature, all playing a role in student success (Barrett et al., 2015). In one study, children with plants in their classroom experienced stronger positive feelings about their environment and had lower absences from school than a control group (Han, 2009).

Natural environments have been associated with decreased salivary cortisol, anxiety, self-reported stress and blood pressure, and improved heart rate variability (Yao et al., 2021). Population studies also suggest higher levels of neighbourhood green space associate with significantly lower levels of symptomology for stress in adults (Beyer et al., 2014) and early life exposure to greenspace was associated with blood pressure even years later in adulthood (Bijnens et al., 2017).

However, the majority of research on physiological stress and nature has been conducted with adults and school-based research is scarce. Existing physiological evidence suggests that learning outdoors in natural outdoor settings may impact children's diurnal cortisol rhythms (Dettweiler et al., 2017), which have been shown to associate with children's emotion regulation and behaviour (Oberle et al., 2017). Learning outdoors has also been linked to improved vagal tone (Mygind et al., 2018) and even views of nature from classroom windows effectively supported stress recovery (Jiang et al., 2016). Furthermore, studies suggest that proximity to nature may buffer the impact of stressful events on children's psychological stress (Corraliza et al., 2012; Wells & Evans, 2003) or act as a protective factor against artificial light and traffic-related air pollution which were found to be significantly associated with children's perceived stress (Franklin et al., 2020).

As yet, though, the exact reasons why natural outdoor settings affect physiological stress in children remain largely unknown. Natural environments may trigger positive affect and reduce physiological stress due to an innate, adaptive response (Ulrich et al., 1991). Alternatively, being outside in green space could reduce stress due to reduced air pollution (Mann et al., 2021), increased physical activity (Rodriguez-Ayllon et al., 2019), increased exposure to natural light (Wirz-Justice et al., 2021) and improved sleep (Matricciani et al., 2019).

One further likely but under-investigated potential mediator is noise. Environmental noise exposure associates with increased physiological stress in children, (Bremmer et al., 2003; Evans et al., 2001), and negatively impacts cognition and school performance (Connolly et al., 2019; Howard et al., 2010, pp. 1–5; Hygge, 2003; Klatte et al., 2013; Norlander et al., 2007; Shield & Dockrell, 2003; Woolner & Hall, 2010, pp. 3255–3269). Studies which use causal mediation analyses provide support for noise as a factor in nature's positive effects. For example, one study found that reductions in noise mediated 35.2% of the observed associations between lifetime exposure to greenspace and early cognitive development (Jarvis et al., 2021).

Several components of noise have been shown to impact preschoolers' perception of soundscapes (Dellve et al., 2013; McAllister et al., 2019), with levels of 'pleasantness' and 'peacefulness' significantly affecting which soundscapes young children prefer (Ma et al., 2022). Outdoor environments may be quieter, as without walls and ceilings they have less reverberation than an indoor classroom, allowing noise to dissipate more quickly. Therefore lower noise levels in outdoor spaces could be the mechanism mediating nature's stress reducing effect. However, existing research (McAllister et al., 2019) suggests that children's opinions differ regarding whether it is noisier indoors or outside at preschool. To our knowledge, no existing studies have measured noise levels across matched indoor and outdoor preschool sessions to make this comparison objectively.

Understanding the mechanisms that explain why natural outdoor environments impact children's stress is practically important because outdoor environments differ from one another in many ways. Outdoor areas in urban schools are commonly dominated by concrete or tarmac and may not contain many natural features such as grass, shrubs and trees. They may also be situated close to road noise. Would these outdoor areas still be beneficial for stress and noise reduction? Existing research on urban outdoor environments is mixed. One systematic review suggests that urban outdoor spaces have a positive effect on wellbeing and stress (Jabbar et al., 2021). Other research concludes that natural environments are more restorative (Menardo et al., 2021) and therefore likely to be more beneficial for psychological outcomes (Wicks et al., 2022). Central to the problem comparing 'natural' to 'urban outdoor' spaces is a lack of clarity in the existing literature regarding what constitutes a 'natural' or 'green' space, and how much nature is present in urban outdoor areas. In addition, the majority of this research has been conducted with adults and there is a paucity of research involving younger children.

Therefore, our goal in the present study was to address the following research questions. First, how does physiological stress differ between urban indoor and outdoor environments? Second, how does noise differ between urban indoor and outdoor environments? Third, to what extent are these two findings related? And finally, are particular groups of children - such as children from lower income families and children who speak English as an additional language - more likely to experience positive effects of an urban outdoor environment than others?

To test this, we conducted 8 matched indoor and outdoor sessions with an ethnically diverse sample of 4–5 year old children attending urban state schools in the London Borough of Newham. We used wearable devices to investigate how physiological stress differed between settings, and whether these effects were mediated by noise. 4–5 year old children were chosen as the participant sample for 3 reasons: 1) there is currently a lack of research evidence regarding whether time outdoors reduces physiological stress for this age group; 2) if learning outdoors does confer benefits for children, it makes sense to begin this at the start of children's school career so that benefits can be reaped for as long as possible? and 3) for practical reasons, namely that most reception classes in primary schools in the UK have access to a specific outdoor area exclusively for their use, and the timetable tends to be more flexible for this age group.

Newham was chosen as the location for this study because existing research suggests that urban dwellers (Anabitarte et al., 2021; Markevych et al., 2014; Mygind et al., 2021), those from ethnic minorities (Natural England, 2019; Robinson et al., 2022) and those from low SES backgrounds (James et al., 2015; Sivarajah et al., 2018) are likely to have less contact with natural outdoor spaces and might be the people who benefit most from increased outdoor time. Newham is one of the three most deprived areas of London (Office of National Statistics [ONS], 2022) and is highly ethnically diverse (London Borough of Newham, 2023a) with low levels of green space compared to the rest of London (London Borough of Newham, 2023b). Outdoor access during school hours could therefore be particularly important for children attending school in Newham, as it may help tackle stress related to socio-economic challenges, and address the lack of nature contact they have outside of school.

To measure childrens' physiological stress we recorded heart rate and movements both while they were seated and while free-flowing between learning activities (which were matched between indoors and outdoors). Previous research from our group (Wass et al., 2015, 2016) and others (Calderon et al., 2016) suggests that these measures covary with other peripheral physiological markers (eg pupil size, electrodermal activity), and accurately track central nervous system arousal (Aston-Jones & Cohen, 2005; Calderon et al., 2016; Pfaff & Banavar, 2007). Decreased resting heart rate and reduced micro-level movements while seated indicate decreased stress (McCall et al., 2015; Tanaka et al., 2000; Wass et al., 2015). Based on the previous literature, we predicted that children would have significantly lower heart rates and decreased movement during carpet time outdoors, and that noise levels would be lower outdoors during both carpet time and choosing time. We also predicted that we would observe associations between noise levels and physiological stress in both contexts. Finally, we expected differential effects on heart rate, with children from underprivileged socioeconomic backgrounds experiencing stronger beneficial effects from outdoor learning compared with others.

2. Method

2.1. Participants

This research was conducted in the Reception year (equivalent to US PreSchool) classrooms of 4 state-funded primary schools in the London Borough of Newham, UK (see Table 1).

Although geographically located within the same London borough, the samples from the four participating schools varied in size and student demographics as detailed in Table 1. Further school characteristic information can be found in the supplementary materials.

Sample Characteristics. From across the 4 schools, a total of 76 participants aged 4–5 were enrolled to take part in this study and a total of 1216 observational sessions were conducted (up to 8 indoor/8 outdoor per child). In order to be included in the analyses examining heart rate, children needed to have completed a minimum of 2 indoor and 2 outdoor sessions. 32 children did not meet this criteria therefore the sample size for the heart rate analyses was N = 45 children who completed 350 total observational sessions. The drop out rate was high due to resistance to wearing the ECG monitor which was attached to the skin. For the analyses based on actigraphy, useable data were available from N = 51 children, who completed 601 total observational sessions. Further detail of drop-out statistics per school and missing data rates per participant can be found in the supplementary materials.

A literature search revealed few papers in this field, none of which had implemented the same measures in a comparable way. Therefore an estimated minimum sample size of 74 was calculated to be large enough to detect a small to medium effect size of 0.3, with statistical power of 80%.

2.2. Procedure

Ethics. This study met the requirements to gain ethical approval from The University of East London Research Ethics Committee. In addition, written approval was gained from the headteachers of each participating school. Following this, teachers and parents signed consent forms before the study began. Children were asked for their verbal consent on each data collection day and could opt out at any stage if they were unwilling to participate. The study was designed to fit within the children's usual learning activities and timetable so that it did not detract from their planned curriculum and caused minimal disruption.

Recruitment and Piloting. Children were first read a social story (see supplementary materials) about the project and participation in the experiment. A piloting session in each condition followed, during which children assimilated to wearing the equipment and learning in the outdoor environment before the recording started.

Indoor And Outdoor Environments. In each participating class, approximately 35–40 min of data was collected each day, for 4 days per week, for a period of 4 weeks. Of these data collection sessions, half took place outside and half indoors in the children's usual classroom (see Fig. 1).

At each school, an outdoor classroom was created on-site to use as the treatment condition (images of indoor and outdoor classrooms are provided in Fig. 2). To minimise extraneous variables, furniture and resources were taken from the indoor classroom and repositioned outside and activities and resources were matched across each condition. The outdoor area was also demarcated to replicate the same size as the indoor classroom.

Data was collected throughout the school year, with different classes taking part in different seasons. The time of year that each school was visited for data collection can be found in Fig. 2. Tarpaulins and individual circular mats were used for conducting carpet times outdoors when the ground was wet or cold, and the temperature and weather was logged daily so that any conditions could be considered when analysing outliers in the data.

Activities. All data collection sessions consisted of two segments - 'carpet time' and 'choosing time' (see Fig. 1).

'Carpet time' lasted on average 12 min and 17 s. During this period, children were seated throughout the session and listened to their usual teacher who either read a story or taught a maths lesson. Carpet time stories were taken from a pre-selected series which were matched in terms of difficulty, length and theme. For maths sessions, teachers followed their usual curriculum, matching resources and themes across conditions. As carpet time lengths ranged from 5 min to 25 min, to ensure consistency in the volume of data analysed across sessions, heart rate and actigraphy data were analysed and averaged from the first 5 min of each carpet time only.

'Choosing time' lasted for 30 min during which children were able to choose between a range of floor-based and table-top learning- and play-based activities such as phonics games, puzzles, play doh and drawing. These activities were chosen by the class teacher and followed the usual school curriculum and approach for this age group. All activities and resources made available in the control condition were also made available in the treatment condition. The interactive whiteboard was not used for indoor sessions as it could not be replicated outside. Similarly, large outdoor play equipment such as climbing apparatus and slides were not used during outdoor sessions as they could not be replicated inside.

Table 1
Demographic breakdown of participating sample.

School	1	2	3	4	Average
N	**8**	**17**	**38**	**13**	**19** (11.40)
Class groups recruited	1	2	3	1	**1.75**
Sessions Recorded	98	165	317	177	**189.25** (79.70)
Female (%)	87.5	70.6	42.1	46.2	**53.2** (18.50)
Age (years)	4.99 (0.35)	5.02 (0.22)	4.90 (0.38)	5.33 (0.35)	**4.97**(0.36)
SEN (%)	12.5	11.8	2.6	0	**6.7**(5.51)
EAL (%)	100	35.3	60.5	46.2	**60.5**(24.5)
FSM-6 (%)	25	17.6	10.5	7.7	**15.2**(6.71)
SDQ	7.9(7.1)	4.5(3.4)	8.3(5.1)	6(6.3)	**6.2**(5.2)

Note. N/M(SD)/%. $N = 76$. Sessions Recorded = number of observable testing sessions run in each school. SEN = Special Educational Needs, EAL = English as Additional Language, FSM-6 = eligibility for Free School Meals currently or in the past six years, SDQ = Strengths and Difficulties Questionnaire total score.

2.3. Equipment and measures

Wearable Devices. Each participant wore a specially designed device made by Harkwood industries consisting of: a heart rate (electrocardiogram) monitor with 3 Ag–Cl electrodes attached in a modified lead II position; a microphone attached to the child's lapel; an actigraph; GPS; and a battery (please find accuracy assurance for raw data in the SM). This was contained within a rectangular plastic box measuring approximately 7 cm × 5 cm. The device also had GPS connectivity which allowed recorded data and events to be linked to real time. These devices were worn underneath clothing in an elasticated belt around the child's middle, half-way between the waist and chest (see Fig. 3). The belts were made by a seamstress according to a specific design created by the BabyDevLab at the University of East London. The strap was made from thick elastic material with Velcro to fasten and incorporated a cotton

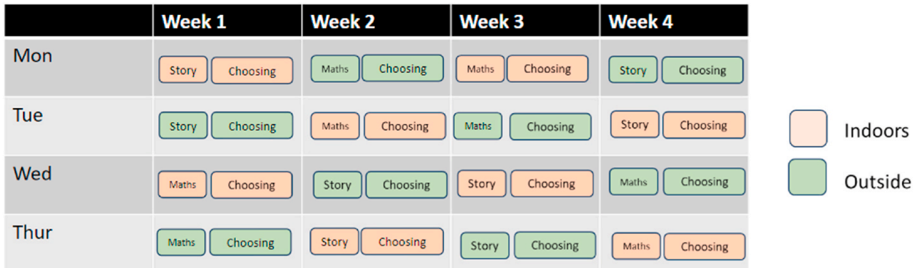


Fig. 1. Example of data collection schedule. Note. Procedure was repeated across 7 classes of children. Occasionally scheduling was adjusted due to rain or cancelled sessions due to school timetabling issues. However, 8 sessions were always completed in each condition, with 4 of the sessions consisting of a story for carpet time and 4 having maths.

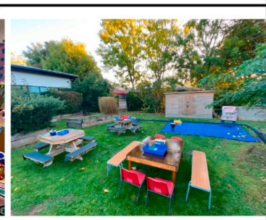
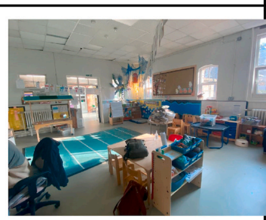
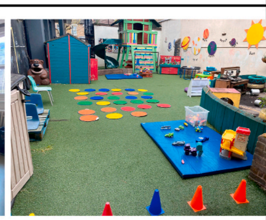
School	Indoor classroom	Outdoor classroom	Data Collection Period
1			February 2022 - April 2022
2			April 2022 - July 2022
3			October 2022 - March 2023
4			April 2023 - July 2023

Fig. 2. Examples of indoor and outdoor classrooms at each participating school and the time of data collection.

pouch with a press stud to close, which the device could slip into and would be held securely in place.

Decibel Meter. Noise levels were monitored using a sound level meter from RS components (model RS PRO RS-95). This is a handheld instrument with a microphone, the diaphragm of which responds to changes in air pressure caused by sound waves. It is recommended for measuring ambient sound levels. The sound level meter was positioned at the middle point of the indoor and outdoor classrooms and 9 instant readings were taken each during carpet time and choosing time. These 9 readings were comprised of 3 readings taken at equally spaced intervals during the beginning, middle and end of each carpet time and choosing time session (further detailed in supplementary materials). These noise readings were collapsed to a single average per session for analyses.

Individual Differences Data. Schools were asked to provide the following information about each participant: whether they had a pre-existing preference for being inside or outdoors at school; the child's Special Educational Needs (SEN) status and type; entitlement for Free School Meals currently or in the past six years (FSM-6), a measure of socio-economic status in the UK which is based on a household receiving any of the following government benefits: income support, income-based Jobseeker's Allowance, income-related Employment or Support Allowance; indication of English as an additional language (EAL);

Fig. 3. Image of a participating child fitted with the wearable device.

admission date to the school and prior school/childcare experience; age; previous and current level of academic attainment in relation to national expectations. This data was anonymised and stored with the child's participant number.

Strengths and Difficulties Questionnaire (SDQ). The Strengths and Difficulties Questionnaire (Goodman, 1997) was completed by the participants' usual class teacher. This is a 25-item emotional and behavioural screening tool comprising 5 subscales (emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems, prosocial behaviour), and designed for use with children aged 3–17.

2.4. Data processing

ECG Data. To pre-process the ECG data, the signal was first detrended before performing R peak identification using the in-built MATLAB function 'findpeaks'. The minimum peak height was defined as a simple amplitude threshold. Minimum peak distance was set at 270ms (corresponding to a maximum heart rate of 130 BPM for children aged 4–5) and used to improve the performance of 'findpeaks'. Following this, automatic artefact rejection was performed. A maximum temporal threshold was applied to exclude those R peaks occurring within more than 1200ms since the previous R peak (corresponding to a minimum heart rate of 75 BPM for children aged 4–5). Data sets where more than 50% of ECG data was unusable after filtering or incomplete cable connection were not included in analysis.

Actigraphy Data. Actigraphy data was recorded at 37Hz. Absolute values of each data point across the three axes of movement (i.e X, Y, Z axes) were summed to produce a total activity vector for a carpet time session. Activity data was then downsampled to 1Hz by calculating the average from all the readings within each second. These activity vectors for every recorded session were then compared by condition.

The participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research, supporting data is not available.

This study's design and hypotheses were preregistered via OSF prior to data analysis; see https://osf.io/fy3jx/?view_only=af6f43fc166e4ea8a3dd39dcc1c9d7c2.

2.5. Overview of analyses

The results below are presented based on six analyses.

Analysis 1 examined whether participants' resting heart rates differed between indoor and outdoor conditions by conducting a linear mixed effects model with a fixed effect of condition and random effect of participant. A mixed ANOVA was then run to analyse the variance in resting heart rate between conditions to examine any effect of school on resting heart rate compared to condition.

Analysis 2 examined whether movement levels when seated during carpet time differed between indoor and outdoor conditions. A linear mixed effects model was conducted with a fixed effect of condition and random effect of participant.

Analysis 3 examined differences in carpet time noise levels between the indoor and outdoor conditions using a paired samples *t*-test. A mixed ANOVA was run to analyse the variance in noise levels between conditions to examine any effect of school on noise level compared to condition.

Analysis 4 examined differences in choosing time noise levels between the indoor and outdoor conditions using the same procedure as Analysis 3.

Analysis 5 examined the relationship between noise levels and resting heart rate during carpet time by running a Spearman's rank-order correlation in each condition.

Analysis 6 examined whether specific groups of children were more likely to have a lower resting heart rate when outdoors. Binomial logistic regressions were performed to ascertain whether EAL, FSM, SEN, SDQ or Gender significantly predicted changes in heart rate.

3. Results

See supplementary materials for full breakdown of sample sizes for each cell in the following experimental designs.

3.1. Effect of indoor/outdoor condition on heart rate during carpet time

Assumption testing through visual inspection of residual and predicted value plots confirmed homogeneity of variance within each of the following linear mixed effect model (LME) datasets. Q-Q plots confirmed normality in random effect variables. Linearity was not tested as fixed effects tested in each model fit were categorical (i.e fixed effect of condition or test session number).

A LME was run using the fitlme function in Matlab to analyse the main fixed effect of condition (indoor/outdoor) on resting heart rate with a random effect of participant. A significant main effect of condition (beta = −1.79, $t = -2.58$, $p = 0.010$) was observed, such that heart rate was lower during outdoor carpet times ($M = 103.0$, $SD = 7.82$) than indoor ones ($M = 105.8$,$SD = 8.99$), 95%CI[1.12, 4.31],$t(44) = 3.345$, $p < 0.001$, $d = 0.512$ (see Fig. 4).

Further, mixed-ANOVA did not yield significant interactions between condition and school, $F(3,41) = 0.830$, $p = 0.485$, 95%CI[-9.874, 14.598], partial $\eta^2 = 0.057$ or condition and class group, $F(6,38) = 1.008$, $p = 0.435$, 95%CI[-32.008, 16.416], partial $\eta^2 = 0.137$ on resting heart rate. This indicated that during carpet time, condition alone significantly affected resting heart rate, despite the data being collected across different seasons, different class groups of children and from different participating schools' where their indoor and outdoor classrooms varied.

3.2. Difference in movement levels during indoor and outdoor carpet time

Despite our analyses (described above) indicating that children remained seated during carpet time, we also wished to examine childrens' micro-level movements (levels of fidgeting) during carpet time as an additional measure of autonomic arousal (Calderon et al., 2016). To do this, we conducted an identical analysis as described above to examine the main fixed effect of condition (indoor/outdoor) on movement with a random effect of participant. A significant main effect of condition (beta = −23.35, $t = -2.99$, $p = 0.003$) was observed, such that total movement during carpet times in the indoor condition ($M = 122.0$

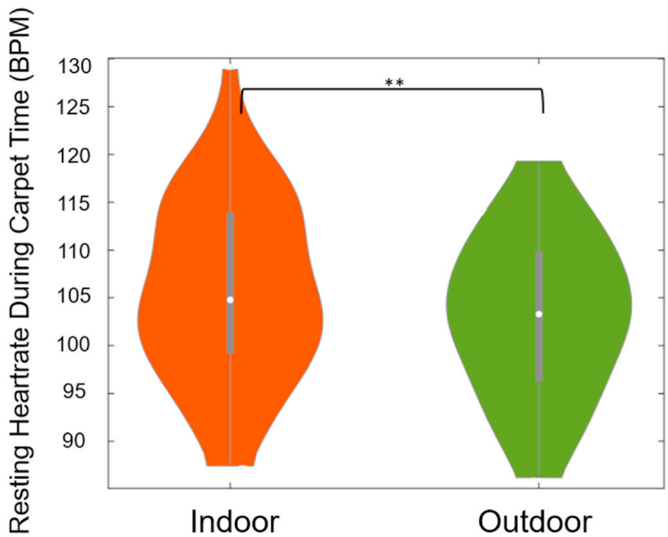


Fig. 4. Violin plot comparing the whole sample of children's heart rate during indoor and outdoor carpet times. Median denoted by white marker.

m s^{-2}, SD = 82.31 m s^{-2}) was significantly greater compared to the outdoor condition (M = 83.8 m s^{-2}, SD = 52.18 m s^{-2}), 95%CI[26.93, 49.35],$t(599) = 6.684$, $p < 0.001$, $d = 0.546$ (see Fig. 5).

3.3. Difference in noise levels during indoor and outdoor carpet time

Unlike the heart rate and movement data, where one datapoint was available per child per session, for noise levels only one reading was available per session. Therefore, parametric t-tests were used to determine whether there was a statistically significant mean difference between noise levels across each condition during both carpet and choosing times. Prior to conducting these, exploratory analyses were carried out to test assumptions for each statistical test including normality, outliers, sphericity, homogeneity of variance and covariance and linearity in the session level noise data. The assumption of normality was not violated for either carpet or choosing time as assessed by Shaprio-Wilk's test ($p > 0.05$) and inspection of studentized residuals. A paired samples t-test confirmed that there was a significant difference between noise levels recorded during indoor carpet times (M = 62.3, SD = 4.7) compared to outdoor carpet times (M = 59.5, SD = 4.2),95%CI [-4.58, −0.707],$t(36) = -2.770$, $p = 0.004$, d = -0.455, such that higher

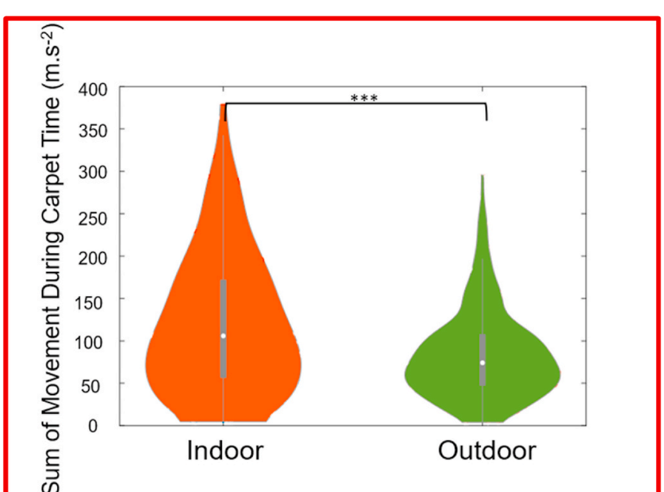


Fig. 5. Violin plot comparing sum of movement levels during indoor and outdoor carpet times. Median denoted by white marker.

noise levels were observed indoors (see Fig. 6).

Mixed ANOVA did not yield significant interactions between condition and school, $F(2,34) = 0.171$, $p = 0.844$, 95%CI[-6.407, 1.584], partial $\eta^2 = 0.010$ or condition and class group, $F(5,31) = 0.200$, $p = 0.960$, 95%CI[-8.577, 2.516], partial $\eta^2 = 0.031$. This indicated that during carpet time, condition alone significantly affected noise levels despite noise level readings being taken across different class groups of children in different participating schools' indoor and outdoor classrooms.

3.4. Difference in noise levels during indoor and outdoor choosing time

A paired samples t-test also confirmed there was a significant difference between noise levels recorded during indoor choosing times (M = 72.0, SD = 3.7) compared to outdoor choosing times (M = 68.2., SD = 3.4), 95%CI[2.2, 5.3],$t(37) = 4.818$, $p < 0.001$, $d = 1.064$, such that higher noise levels were observed indoors (see Fig. 6).

Further analyses using mixed ANOVAs also indicated there were no significant interactions between condition and the class group $F(5, 32) = 1.782$, $p = 0.145$, 95%CI[-0.80,789, 6.67873], partial $\eta^2 = 0.218$, or school, $F(2, 35) = 1.846$, $p = 0.173$, 95%CI[-1.0917, 3.8947], partial $\eta^2 = 0.095$ on choosing time noise levels. This indicates that outdoor sessions were consistently quieter than indoor sessions, even when participant groups changed and features of the outdoor area differed e.g. more traffic noise/fewer natural features) (see supplementary materials for descriptive statistics and figures).

3.5. Relationship between heart rate and noise during carpet time

A non-normal distribution of noise level data paired with heart rate data at a participant level violated the assumptions for a parametric correlation, and so a Spearman's rank-order correlation was run to assess the relationship between noise and heart rate during carpet time. A significant positive correlation was observed $r(210) = 0.198$, $p = 0.002$. To explore whether the same relationship between noise and resting heart rate was observed in the indoor and outdoor conditions considered separately, two separate Spearman rank correlations were conducted (see Fig. 7). Indoors, there was a significant positive correlation between noise during carpet time and resting heart rate, $r(98) = 0.364$, $p < 0.001$. Outdoors, no significant relationship between noise and resting heart rate, $r(112) = 0.048$, $p = 0.309$ was observed.

3.6. Differential effects of indoor/outdoor condition on specific groups of children

Heterogenous effects were observed on children's resting heart rates as demonstrated in Fig. 8 below.

To identify whether specific groups of children were more likely to experience a decrease in heart rate outdoors, a binomial logistic regression was performed to ascertain the effect of: Special Educational Needs; Free School Meals; English as an Additional Language; scores on the Strengths and Difficulties Questionnaire; and Gender. The dependent variable was whether the participant experienced a decrease or increase in average resting heart rate during carpet time while outdoors compared with indoors. Linearity of SDQ score, (as the only continuous variable) was assessed via the Box-Tidwell (1962)procedure. The logistic regression model was statistically significant, ($\chi^2(5) = 16.315$, $p = 0.006$. The model explained 41.4% (Nagelkerke R Square) of the variance in which condition decreases in resting heart rate were observed among the sample and correctly classified 66.7% of cases. Sensitivity was 75.0%, specificity was 52.9%, positive predictive value was 72.4% and negative predictive value was 56.3%. Of the 5 predictor variables, only two were statistically significant: gender and FSM (as shown in Table 2).

Girls were significantly more likely than boys to present with lower heart rates outdoors, which may relate to the fact that girls' mean indoor

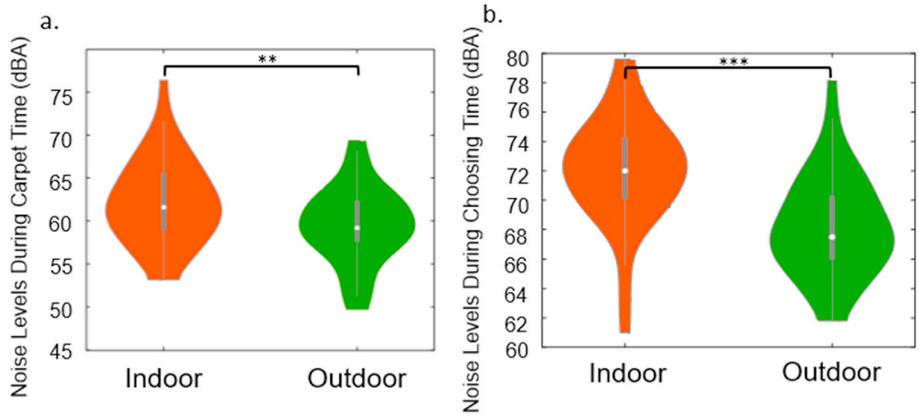


Fig. 6. Violin plot comparing noise levels during indoor and outdoor carpet (a) and choosing (b) times. Median denoted by white marker.

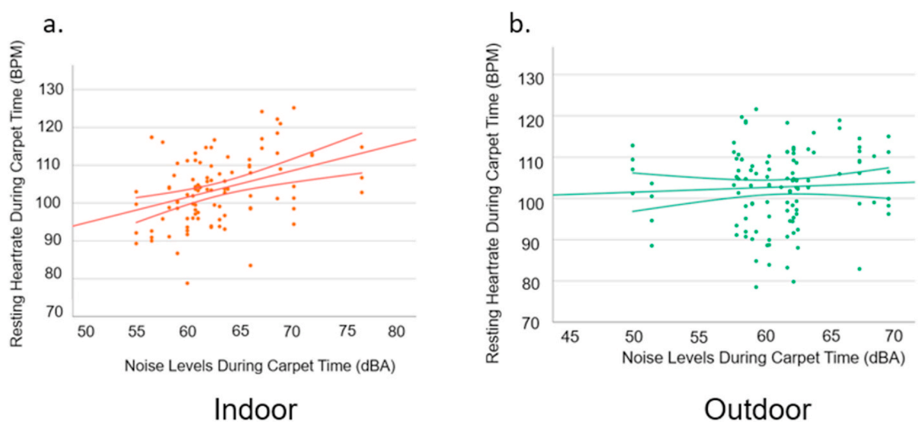


Fig. 7. a) Scatter plot showing the relationship between resting heart rate and noise levels during indoor carpet times. b) scatter plot showing the relationship between resting heart rate and noise levels during outdoor carpet times.

heart rates ($M = 106.3$, $SD = 9.6$) were higher than boys' ($M = 105.2$, $SD = 8.5$) providing greater capacity for decrease. Girls were 9.4 times more likely to present with lower heart rates outdoors than boys. Contrary to our expectations, children eligible for free school meals (FSM) were *less* likely to show lower heart rates outdoors than their non-FSM peers. All other variables (EAL, SDQ and SEN) did not significantly predict in which condition participants would experience a decrease in resting heart rate.

As can be seen in Fig. 9a, a paired samples *t*-test confirmed that there was a significant difference between resting heart rates indoors ($M = 106.3$, $SD = 9.6$), and outdoors ($M = 102.4$), $SD = 7.8$) for girls 95%CI [1.43695,6.10545],$t(24) = 3.334$, $p < 0.001$, $d = 0.667$. However, boys resting heart rates indoors ($M = 105.2$, $SD = 8.5$) and outdoors ($M = 103.9$, $SD = 8.0$)) were not significantly different 95%CI [-0.77,250,3.57150],$t(19) = 1.349$, $p = 0.097$, $d = 0.302$.

A paired samples *t*-test also confirmed that there was a significant difference between resting heart rates indoors ($M = 107.0$, $SD = 8.8$), and outdoors ($M = 103.6$, $SD = 7.7$) for children who were not eligible for FSM 95%CI[1.53812, 5.20891],$t(36) = 3.728$, $p < 0.001$, $d = 0.613$. However, children who were eligible for FSM did not show significant differences in resting heart rates indoors ($M = 100.1$, $SD = 8.0$) and outdoors ($M = 100.4$, $SD = 8.3$) 95%CI[-2.73802, 2.10052],$t(7) = -0.321$ $p = 0.381$, $d = -0.110$. This is demonstrated in Fig. 9b.

4. Discussion

The primary findings of this study were as follows: First, when we matched indoor and outdoor settings within an urban school setting (by providing similar activities, spread over a similar area) we found that, both during carpet time and choosing time, noise levels were significantly lower outdoors. As increased noise in educational settings has been associated with a range of negative effects on children, particularly influencing language and literacy outcomes (Bremmer et al., 2003; Connolly et al., 2019; Evans et al., 2001; Howard et al., 2010, pp. 1–5; Klatte et al., 2013; Shield & Dockrell, 2003; Wålinder et al., 2007; Woolner & Hall, 2010, pp. 3255–3269), our results confirming that noise levels are reduced significantly outdoors may have important implications for improving learning outcomes. These results provide a rationale for offering a range of learning activities outdoors, and not viewing the outdoor environment as exclusively for play or physical education.

Second, we found that, during carpet time (when children were seated listening to a teacher), both heart rate and movement levels were significantly lower outdoors compared with inside. These findings suggest that children experienced lower levels of physiological stress when outdoors. As short-term physiological stress has well-documented short- and medium-term effects on childrens' learning (Whiting et al., 2021), and research evidences relationships between short-term physiological stress and long-term physiological stress (Evans et al., 2001, 2005), with associated adverse mental health (Conway et al., 2018) and cognitive outcomes (Evans & Schamberg, 2009), identifying learning environments which reduce physiological stress is of practical importance. Our finding that resting heart rates reduce during just a 5 min period of sitting outdoors suggests that even short periods of time outside can be beneficial. However, further research needs to ascertain how long stress reducing effects last for, whether there is a dose-response relationship

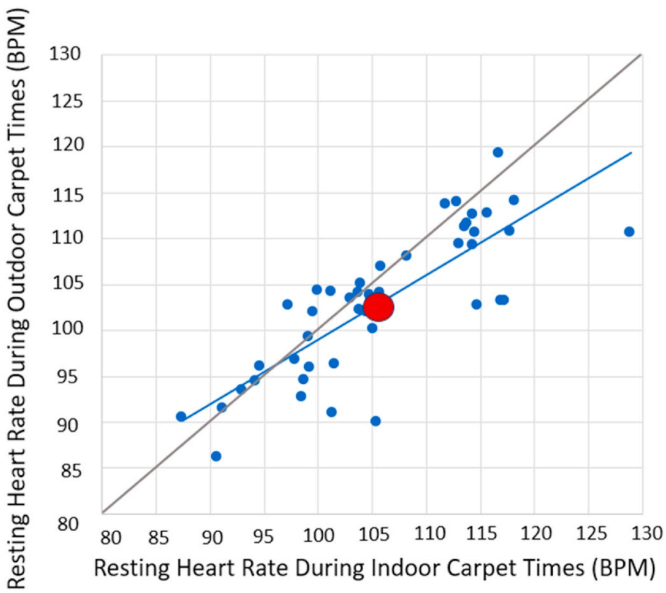


Fig. 8. Scatter plot showing the effect of condition on resting heart rate during carpet time, comparing each child's average heart rate across the indoor sessions (x axis) with each child's average heart rate across the outdoor sessions (y axis) The 1:1 equivalence is drawn in grey. If the data point is below this line, this indicates that average heart rate for that child was lower outdoors than indoors. The large red dot shows average heart rate across all children. In addition, a linear best fit line is drawn in blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

and whether this effect increases or attenuates as children get older (Whiting et al., 2021).

Third, we found that, whereas noise and heart rate were significantly associated indoors, no significant relationship was observed between noise and heart rate in outdoor environments, suggesting that being outdoors may have buffered children from the stressful effects of excess noise. This indicates that time outdoors may help reduce stress after particularly noisy or stimulating parts of the school day, or may help protect children against some of the negative effects of urban living.

Existing evidence suggests that children experience environments differently (Aykan et al., 2020) and that learning outdoors may have heterogeneous effects. The results of the present study confirmed this partially. Although differential effects on heart rate were observed, within the binomial logistic regression model, only 2 out of 5 of the individual differences variables (Gender and Free School Meals) were found to significantly predict childrens' change in heart rate between indoor and outdoor settings. Contrary to our expectations, children eligible for free school meals (FSM) were not more likely to show lower heart rates outdoors. However, this finding may have been due to using FSM eligibility as a proxy for SES (Gorard, 2012; Hobbs & Vignoles, 2007). This was chosen as FSM data was readily available from the schools recruited. However this was problematic as in Newham all children are eligible for Free school meals due to a Mayoral policy. Therefore many low SES families do not complete the FSM paperwork required to identify them as a low-income family. As a result, many low SES children will have been missing from the FSM-eligible sample and the number of qualifying children was low (N = 8). The other measures we examined - Special Educational Needs, English as an Additional Language and scores on the Strengths and Difficulties Questionnaire - were not found to be significant predictors of childrens' change in resting heart rate between indoors and outside. This may be because our experimental design, with a relatively small number of children who each took part in up to 16 sessions, was not well set up to detect individual differences.

In addition, although our sample contained high proportions of students who spoke English as an additional language (51%), this number was slightly below the average levels in the schools recruited (69%), indicating some small sampling bias. Similarly, the proportion of children in our sample with Special Educational Needs (6.7%) was lower than across the schools we studied (12.5%). This was likely because this study was conducted during the first year of primary school, whereas many diagnoses do not take place until later in the child's school years. Children with SEND may also be less likely to consent to being fitted with the wearable equipment due to sensory sensitivities or difficulties in understanding the study aims and instructions.

To our knowledge, this is the first study to compare children's physiological stress in outdoor vs indoor learning environments, whilst controlling for extraneous variables such as activity type, resources and the size of space available, and examining the potential mediating effects of noise. Strengths of this study include its ecological validity (achieved by utilising the children's usual classrooms, teachers and outdoor environments and keeping resources and activities consistent with the school's usual curriculum and timetable), within-subjects design which controlled for child characteristics, repeated sessions in each condition, and its use of objective measures for noise, stress and movement.

With these strengths naturally come limitations. It was not possible for us to reliably separate sound that was caused by the children in the space from ambient/background noise. Thus, it may be that increased noise levels caused increased physiological stress, or that children first experienced physiological stress, which made them increase the noise they were making. Or, it may be a combination of the two. Of note, however, increased noise and physiological stress were both observed during carpet time, when the teacher was speaking and the pupils were quietly listening for the majority of the time, indicating that the noise was not entirely self-generated by the children. In future, it would be informative to take noise readings in each environment when it was unpopulated, to measure background noise levels, and also to track changes in physiological stress and noise continuously, in order to examine Granger-predictive relationships between these variables over time.

In addition, although all classed as 'urban outdoor areas' because of their location in Newham, the outdoor areas used in this study did vary across schools. Whilst 3 out of the 4 areas had tarmac, concrete or artificial grass underfoot, 1 area had lawn. Similarly, 2 outdoor areas

Table 2
Logistic Regression Predicting Likelihood of Decrease in Heart Rate in Indoor or Outdoor Condition based on EAL, FSM, SEN, SDQ and Gender.

	N	*B*	SE	Wald	*df*	*p*	Odds Ratio	95%CI of Odds Ratio	
								Lower	Upper
a. EAL	23	0.239	0.773	0.096	1	0.757	1.271	0.279	5.785
b. FSM	8	−3.543	1.378	6.605	1	0.010	0.029	0.002	0.431
c. SEN	3	2.937	1.992	2.175	1	0.140	18.860	0.380	935.053
d. SDQ	–	−0.038	0.070	0.299	1	0.584	0.963	0.839	1.104
e. Gender	25	2.241	0.902	6.180	1	0.013	9.400	1.607	55.002
Constant		0.063	0.819	0.006	1	0.939	1.065		

Note: Gender is for females compared to males.

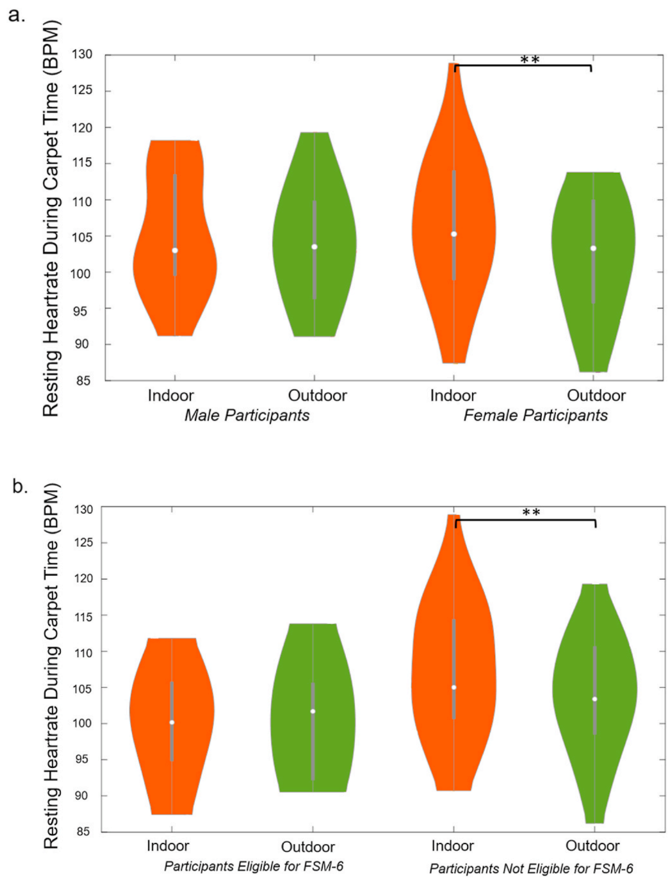


Fig. 9. Violin plot comparing resting heart rates of male and female participating children during carpet time in the indoor and outdoor condition (a) and violin plot comparing resting heart rates of those children eligible for free school meals (FSM) and those not eligible (b) during carpet time in the indoor and outdoor condition.

contained trees on-site whereas 2 did not. Thus, they varied regarding the amount of natural features they contained and this was not something we were able to control. When we examined how the strength of the effects we observed varied between schools (as reported in the mixed ANOVAS), we found that effects were consistent across schools. Based on a limited sample we found no evidence that children from schools with more natural elements in their outdoor areas had significantly greater reductions in physiological stress than their counterparts in less natural outdoor settings. This suggests that noise, rather than exposure to nature *per se*, may be an important mediating pathway.

However, in order to verify these findings, future research should aim to objectively measure and/or control the amount of nature in outdoor conditions and to compare across multiple schools, in order to isolate the effects of different natural features and proportions of nature. This has already begun in research that uses virtual reality (Wang et al., 2019) to assess the stress relieving effects of different types of natural environments. However, this could be replicated more ecologically in school settings, for example by adding potted trees or shrubs to urban spaces with no natural features.

This study was designed to address criticisms of existing outdoor learning research including methodological issues such as subjective measures, a lack of control groups, and reflecting 'special' teaching situations rather than 'everyday teaching'. Previous reviews have recommended conducting more quasi-experimental studies with a strong focus on higher methodological quality (Becker et al., 2017; Jucker & von Au, 2022, p. 386; Tillmann et al., 2018). To build on our attempts at this, future research should continue using empirical methods and objective, reproducible measures, not only to measure outcomes but also to explore which aspects of outdoor learning environments mediate effects, replicating the noise and movement measures used in this study and also building on our understanding by incorporating additional environmental variables such as air quality and visual complexity.

5. Conclusion

In conclusion, this study examined the impact of outdoor learning in urban settings and with diverse and disadvantaged populations and found significantly lower levels of physiological stress in outdoor environments. These results support the existing body of literature suggesting a link between outdoor time in nature and reduced physiological stress (Dettweiler et al., 2017; Mygind et al., 2018; Yao et al., 2021) but add important new dimensions by studying younger children, evidencing measurable benefits in urban outdoor environments and identifying noise as a potential mediating pathway.

Comprising over 600 individual sessions of data, this is one of the most empirical studies of outdoor learning to date and the first school-based study to objectively measure noise and stress levels indoors and outside. No prior research has controlled for confounding variables to this degree, allowing us to begin identifying which specific types of outdoor learning and outdoor spaces are effective.

Given children's decreasing connection with the outdoors, and rises in children's unhappiness with school and mental health problems, spending more time outdoors at school may help alleviate some of the stressful effects of urban living and could support children's learning and mental health. We encourage educators to make more use of outdoor environments for curriculum learning including for short activities such as storytime and circle times. School policies which remove outdoor access as a punishment for challenging behaviour or unfinished class work should be reconsidered.

Teacher training programmes should raise awareness of the ways in which the physical learning environment can impact children's learning and wellbeing, drawing attention to the potential of outdoor environments in reducing noise and stress. Moving everyday learning activities outdoors costs nothing, requires minimal additional training and resources and does not create substantial additional workload for teachers. In fact, many teachers have reported increased wellbeing and job satisfaction when spending time teaching outdoors (Deschamps et al., 2022; Marchant et al., 2019; Waite et al., 2016). Thus, we consider it an avenue worthy of more exploration and attention.

Author note

We have no known conflict of interest to disclose.

The participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research supporting data is not available.

This study complies with institutional research ethics guidelines and was granted ethical approval from the University of East London ethics committee.

This study's design and hypotheses were preregistered via OSF prior to data analysis; see https://osf.io/fy3jx/?view_only=af6f43fc166e4ea8a3dd39dcc1c9d7c2.

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CRediT authorship contribution statement

Gemma Goldenberg: Writing – original draft, Visualization, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Molly Atkinson:** Writing – original draft, Visualization, Project administration, Investigation, Formal analysis, Data curation. **Jan Dubiel:** Supervision. **Sam Wass:** Writing – review & editing, Supervision, Funding acquisition.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2024.102362.

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