



## Protective effect of restorative possibilities on cognitive function and mental health in children and adolescents: A scoping review including the role of physical activity

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### ABSTRACT

#### Background

The exposome approach can be a powerful tool for understanding the intertwining of social, physical, and internal influences that shape mental health and cognitive development throughout childhood. To distil conceptual models for subsequent analyses, the EU-funded project Early Environmental quality and Life-course mental health effects (Equal-Life) has conducted literature reviews on potential mediators linking the exposome to these outcomes. We report on a scoping review and a conceptual model of the role of restorative possibilities and physical activity.

#### Methods

Peer-reviewed studies published since the year 2000 in English, on the association between the exposome and mental health/cognition in children/adolescents, and quantitatively investigating restoration/restorative quality as a mediating variable were considered. Database searches were last updated in December 2022. We used an unstructured expert-driven approach to fill in gaps in the reviewed literature.

#### Results

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Five records of three distinct studies were identified, indicating a scarcity of empirical evidence in this newly developing research area. Not only were these studies few in numbers, but also cross-sectional, lending only tentative support to the idea that perceived restorative quality of adolescent's living environment might mediate the association between greenspace and mental health. Physical activity emerged as a mediator leading to better psychological outcomes in restorative environments. We provide a critical discussion of potential caveats when investigating the restoration mechanism in children and propose a hierarchical model including restoration, physical activity, and relational dynamics between children and their environment, including social context, as well as restorative environments other than nature.

#### Conclusions

It is justified to further explore the role of restoration and physical activity as mediators in the association between early-life exposome and mental health/cognitive development. It is important to consider the child perspective and specific methodological caveats. Given the evolving conceptual definitions/operationalizations, Equal-Life will attempt to fill in a critical gap in the literature.

## 1. Introduction

### 1.1. Exposome perspective on child mental health and cognition

There is increasing evidence that mental health and cognitive functioning are the result of a complex interplay between genetic, psychological, environmental, social, and other factors and experiences (Ventriglio et al., 2021; Barch, 2022; Deguen et al., 2022; Lachmann and Bergström, 2023). Many mental health and cognitive problems in adulthood can be traced back to early developmental stages when the individual is more vulnerable to environmental and social adversities (Mulraney et al., 2021). Some of these early adversities can lead to epigenetic changes which increase the general risk for diseases via age acceleration (de Prado-Bert et al., 2021) or are specifically related to adult mental health problems (Nöthling et al., 2020; Alameda et al., 2022). In general, children with symptoms of mental ill-health have shown poorer academic performance, quality of life, and social and mental functioning in later life (Luby et al., 2017; Copeland et al., 2021), creating a vicious circle, that is still insufficiently understood. Notably, anxiety, attention deficit hyperactivity disorder, conduct and depression disorders are among the most prevalent in children (Barican et al., 2022). Diagnosing these disorders at a young age is challenging and already during late adolescence and adulthood they cause considerable social and economic losses (GBD 2019 Mental Disorders Collaborators, 2022).

The totality of exposures (detrimental or beneficial) over a complete lifetime is best captured by the concept of exposome, initially described by Wild (2005). This umbrella term can be divided into several non-genetic categories, internal and external, which is further subdivided into physical and social specific external, and general external exposomes (van Kamp et al., 2021). The exposome approach can be a powerful tool for conceptualizing and understanding the intertwining and cumulative effect of social, physical, and internal influences (Vineis and Barouki, 2022) that shape mental health and cognitive development across different contexts and microenvironments (e.g., home, public outdoor spaces, school) throughout childhood. Of note, the effects of different exposome components may vary in salience and strength across critical/sensitive developmental windows. However, the exposome effects on mental health and cognition in children and adolescents have been less studied and were predominantly focused on chemical, biological and physical exposures (e.g., Jedynak et al., 2021; Vineis and Barouki, 2022). Furthermore, the observed effects vary substantially, as only selected exposome factors or time windows were included and specific relationships among these factors and the social exposome (Deguen et al., 2022) were rarely explored especially with respect to mental health (cf. Mueller et al., 2019; Maitre et al., 2021) and cognition studies (cf. Julvez et al., 2021; Binter et al., 2022).

The EU-funded project Early Environmental quality and life-course mental health effects (Equal-Life) employs the exposome framework in an integrated study of the broader determinants of children's

development and life course mental health (Van Kamp et al., 2021). Equal-Life is part of the European Human Exposome Network (<http://www.humanexposome.eu/>; Vermeulen & Dillner, 2021). Apart from a non-targeted machine learning approach, Equal-Life relies on a set of theory-based questions formulated based on existing evidence, in order to explore the impact of multi-modal exposures (i.e., exposures interacting or mediating each other) on children's mental health and cognition. To that end, datasets across Europe are used. Equal-Life builds on the original exposome concept (Wild, 2005, 2012) by further stressing the role of social influences, delineating them as a subdomain of the external exposome (Gudi-Mindermann et al., 2023 manuscript submitted to this issue). Central to our research endeavour is the understanding of putative pathways (i.e., mediators) underlying beneficial and harmful mental health effects of the child exposome.

A mediator is an intervening factor, which is influenced by an exposure, which precedes it in time, and in turn leads to an outcome, which follows in time (VanderWeele, 2016). In addition, conceptual time-ordering of these is required (i.e., "the mediator must refer to a causal condition that emerges prior to the criterion outcome but not prior to the predictor"), even when dealing with cross-sectional data (Tate, 2015). The process of mediation then refers to a relationship between exposure, mediator, and outcome, where the mediator accounts for the effect of the exposure on the outcome either in part (partial mediation) or completely (full mediation). Addressing hypotheses about mediating processes is possible using regression-based statistical tools in an exploratory or confirmatory fashion to conduct mediation and moderation analyses. However, in addition to the mathematical and methodological attention, these require serious theoretical and conceptual consideration (Fiedler et al., 2018).

To distil conceptual models that will inform subsequent empirical analyses, Equal-Life has conducted reviews of the literature on selected potential mediators (stress/restoration, sleep, and coping/self-regulation) believed to link the exposome to children's mental health (including well-being and quality of life constructs) and cognition in different developmental phases. Our focus here is on the process of restoration and restorative possibilities, which can be seen as a conceptual focal point in a causal model where multiple pathways starting from the exposome converge to generate childhood health benefits (Dzhambov et al., 2018b).

### 1.2. Concept of restoration

Responding to an excess of demands relative to the resources needed to cope with those demands is taxing and, in turn, depletes adaptive resources, which require periodic restoration (von Lindern et al., 2017). In other words, restoration can be defined as a process through which adaptive capacities diminished in ongoing efforts to meet adaptive demands are renewed, recovered, or re-established (Hartig, 2004). Thus, the restoration perspective necessarily complements and transacts with the stress and coping perspectives in human adaptation processes to the

environment. Importantly, restoration is carried by person-environment transactions and is not an automatic outcome of objective exposure or simply being in a particular environment during time one might have available for restoration (von Lindern et al., 2017). Environment's restorative quality depends on its potential to both permit and promote restoration, depending on contextual factors and individual differences (Hartig, 2004, 2021).

Two influential theories have proposed psychological mechanisms by which nature experience can provide restorative benefits: the Kaplan's (Kaplan and Kaplan, 1989; Kaplan, 1995) attention restoration theory (ART) and Ulrich's psycho-evolutionary theory, usually referred to as stress recovery theory or stress reduction theory (SRT; Ulrich, 1979; Ulrich et al., 1991). Both theories supplement each other – the SRT is more focused on recovery from psycho-physiological stress, while ART deals with recovery from directed attention fatigue (mental fatigue). To be restorative, SRT requires an environment without uncontrollable threat, with moderate levels of complexity, with the perception of natural content or other visual stimuli to reduce psychophysiological arousal and induce positive affect. In ART, the perception of being away from hassles and routines or experienced fascination (e.g., in nature), among other perceptual facets, gives rest to neurocognitive processes involved in sustaining directed attention, and thus improves cognitive abilities (Hartig, 2021). This does not necessarily require the person to be in nature alone (Korpela and Staats, 2020; Hartig, 2021). It can be the experience of social support/cohesion or walking with friends, which Hartig (2021) is framing as “restoration of relational resources” or the psychological distance or feelings of “being away” through physical exercise. A recent theoretical work has emphasized the role of offsetting loneliness through nature contact as a pathway to better health (Astell-Burt et al., 2022).

Regardless of which resource has become depleted, a precondition for its restoration is that the given socio-physical environment will support that restorative process and reduce stress and cognitive load (Hawthorne et al., 2019; Stevenson et al., 2019). Notably, the presence of positive features is the basic requirement of a “restorative environment”, which not only affords opportunities for restoration, but also encourages activities and experiences leading to restoration (Hartig, 2021). Another important aspect is that an environment of high restorative quality can afford opportunities to acquire new adaptive resources (i.e., instoration) and in turn support mental health/directed attention restoration and foster health in general (Markevych et al., 2017). For example, the likelihood of playing, engaging in other outdoor physical activities, or simply hanging out with friends is determined by characteristics of the built environment (Nordbø et al., 2020a). Recent evidence supports a role of restoration in the mechanisms behind mental health and cognitive development of children and adolescents (Berto et al., 2015; Collado and Staats, 2016; Amicone et al., 2018). However, consideration of the child perspective and how child experiences and restoration needs may differ from those of adults is still less well understood (Collado and Staats, 2016).

### 1.3. Aim and scope

We report on a scoping review of the role of restorative possibilities and physical activity as pathways from the exposome to mental health and cognition in children and adolescents. We present a critical appraisal of research gaps in the existing literature that are potentially relevant to Equal-Life. Other scoping reviews in the series, which share the same literature search strategy, are focused on a conceptual framework for the exposome perspective in relation to mental health and cognitive development (Persson Waye et al., 2023a manuscript in preparation/A) and on the pathways – stress (Belke et al., 2023 manuscript in preparation), sleep (Persson Waye et al., 2023b, manuscript in preparation/B), and coping/self-regulation (Leist et al., 2023 manuscript in preparation/A) linking the exposome to mental health and cognitive development.

## 2. Methods

### 2.1. Organization of the review and conceptual model building

The intent of this work was to generate a conceptual model of the relationships between the exposome, restoration, and child/adolescent's mental health/cognition. As building blocks for that model, we leveraged existing empirical evidence and theoretically-indicated pathways that were evaluated as plausible enough to merit investigation in Equal-Life, even if no direct evidence on them was available. In its structure, the present work echoes the structure of other works that start with a systematic review of the literature, which later feeds into a larger conceptual mechanistic model (Astell-Burt et al., 2022).

The model building in the current review went through several stages, where empirical results on the role of restoration as a mediator linking different exposome domains to mental health/cognition served as a foundation. First, we conducted a scoping review of studies that specifically explored pathways from the exposome to restoration and then to mental health/cognition (**1 layer of evidence**). Second, we drew on empirical supporting evidence on partial associations, i.e., studies that examined the constituent pathways in a piecemeal fashion (e.g., from exposome to restoration or from restoration to outcome). Here we looked at single exposures only, still addressing the mechanism via restoration, or instead of restoration explored mediation by instoration (e.g., via physical activity or social interaction in a restorative setting) (**2 layer of evidence**). Thus, while the scoping review followed a systematic and structured approach to evidence retrieval and synthesis, in the 2nd layer we adopted a more unstructured expert-driven approach to fill in gaps in the scoping review literature or add evidence that became available after the completion of the formal literature searches for the scoping review. The final model was developed through an iterative process.

### 2.2. Scoping review protocol

We had no prior information on the extent of the literature on child exposome, restoration, and health, but we anticipated that the body of evidence would be heterogeneous. We were also mindful that the question we aimed to produce an answer to was rather broadly defined: “What is the evidence on restoration acting as a mediator linking the exposome to childhood mental health/cognition?”. Therefore, a systematic review framework was deemed too restrictive. Rather than a systematic review, we employed a scoping review framework, which is suitable for mapping heterogeneous knowledge base on an understudied subject and identifying research gaps, but at the same time shares the principles of transparent and reproducible reporting essential to systematic reviews (Peters et al., 2015). We followed the guidance for conducting scoping reviews outlined by Arksey and O'Malley (2005) and Peters et al. (2015).

#### 2.2.1. Eligibility criteria

We employed strict criteria for studies to be included in the review (Table 1). Study records had to be available in English, study the association between the exposome and child/adolescent mental health/cognition, and quantitatively investigate restoration/restorative quality as a mediating variable. We did not include studies, in which no specific effort was made to evaluate mediation (i.e., studies in which restoration was merely adjusted for and treated as a confounder). Empirical studies of observational or experimental design were eligible, but reviews and ecological studies lacking individual-level data were excluded.

Participants of any gender, nationality, and health status were eligible for inclusion, but they had to be under or equal to the age of 21, within the age range criterion for cohorts in Equal-Life. Studies that included different age groups were also included, if participants' median age was  $\leq 21$  years. Participants could be members of the general population or a specific subgroup.

**Table 1**  
Inclusion and exclusion criteria used to screen study records in the scoping review.

	Inclusion criteria	Exclusion criteria
Population	Humans, children/adolescents (0–21 years) or at least > 50% of participants ≤ 21 years old	Animal studies, < 50% of participants < 21 years old, pregnant women
Study design	Cross-sectional, case-control, cohort, case crossover, (quasi-) experimental, randomized controlled trial	Reviews, ecological/area-level studies
Exposures	Multiple physical exposures or at least two exposures pertaining to different exposome domains, one of which to the physical exposome; objectively measured and/or self-reported	Single exposures or multiple exposures from only social or internal exposome domain
Outcomes	Child/adolescent mental health and/or cognition and/or well-being/quality of life; objectively measured or self-reported (different than above; mental health, positive or negative affect, externalizing or internalizing symptoms, cognitive functioning, and academic performance.	Only maternal outcomes, perceived general health, physical health outcomes
Mediators	Actual or perceived restoration, environmental restorative quality/restorativeness; objectively measured or self-reported	Restoration/restorative quality only treated as a confounder, but not an intermediate variable; no formal test or interpretation of mediation by restoration/restorative quality

Note. For a detailed list of the indicators and search terms, see [Table S1](#).

We considered papers dealing with multiple, cumulative, or combined exposures. We aimed to retrieve both studies that formally stated having used the exposome framework, and studies that considered the effect of multiple exposures in the spirit of the exposome approach, even if they did not specifically use pertinent terminology. At least two physical exposures (e.g., air pollution and traffic noise) or at least one physical exposure in combination with other exposures pertaining to the social (e.g., social support) or the internal exposomes (e.g., biomarkers) were prerequisites for including a study in the scoping review. Our focus on physical exposures was influenced by a knowledge gap regarding the effects and potential mechanisms of cumulative physical exposures on children's and adolescents' mental health and cognition, either in connection to social exposures or as interacting physical exposures ([van Kamp et al., 2021](#)). For further details on this approach, we refer to [Persson Waye et al. \(2023a\)](#) (manuscript in preparation/A).

Outcomes of interest are listed in [Table 1](#) and included measures of mental health, positive or negative affect, externalizing behaviours or internalizing symptoms, cognitive functioning, and academic performance.

### 2.2.2. Information sources and search strategy

Electronic searches of peer-reviewed studies published since the year 2000 were performed in two databases, Scopus and PsycINFO. These searches based on title and abstract were conducted by librarians at the University of Gothenburg on June 17, 2020 and later updated on October 5, 2020. The search strategy was discussed within the research team and with the librarians. Given the time gap between these initial searches and the completion of the evidence synthesis, we updated the searches one last time just prior to submission of this paper. The updated searches were extended from 2020 until December 1, 2022. The search terms in each search block, as well as the keyword strings used in the latest searches are shown in [Table S1](#), Section S1 and Section S2. In addition, we searched papers based on the cohorts and school studies included in Equal-Life (<https://www.equal-life.eu/en>), and reference lists of relevant review papers and articles. To augment the list of

included studies, personal libraries of experts within the consortium and suggested papers from the Equal-Life advisors were screened.

To manage the review at the screening phase, we used Rayyan ([Ouzzani et al., 2016](#)). The first screening was based on title and abstract only. Two reviewers independently assessed each record against the list of inclusion/exclusion criteria. Study records were judged as relevant, not relevant, or potentially relevant. Conflicts between the reviewers were resolved through consensus or by a third reviewer. Papers deemed relevant and potentially relevant were advanced to the eligibility phase, in which a new pair of reviewers assessed each full text. Noteworthy, co-authors of the present review were not involved in screening or assessing the eligibility of their own studies identified in the electronic searches.

### 2.2.3. Data charting

In the eligibility phase, reviewers extracted data on the following study characteristics: study design, location and period, sampling strategy and sample size, exposure definition and assessment, outcome definition and assessment, mediator definition and assessment, and statistical analysis. These data were extracted in a pre-designed form by one reviewer and verified by another reviewer.

### 2.3. Supporting mechanistic evidence

We used further evidence on partial associations between exposome to mediators and/or mediators to outcomes identified at earlier stages of the screening for the scoping review. That is, studies from other sources and those excluded from the scoping review because they did not fulfil all inclusion criteria that were used to support specific associations within our model. For example, if a study only looked at one exposure, such as air pollution, it would be excluded from the scoping review, but could provide useful information for constructing our conceptual model. Further, we performed a non-systematic rapid search for studies in PubMed and Google Scholar of evidence published after the last update of the scoping review. Physical activity-related terms were also used in these searches. We incorporated existing models and theories to construct a conceptual model, which could later inform analyses in Equal-Life. The level of detail at this stage was limited to constructs related to restoration and instoration (i.e., physical activity, social interaction), while more distal constructs that lay closer to other mediators of interest in Equal-Life (stress, sleep, coping and self-regulation) will be covered in the other reviews in this series.

### 2.4. Synthesis of findings

Study characteristics were described in narrative and tabulated. The pathways between exposome, restoration/instoration, and mental health/cognition were graphed.

## 3. Results

### 3.1. Search results

[Fig. 1](#) shows the study selection flow chart. Electronic searches and expert suggestions yielded 3429 hits, of which 2996 were left after removing duplicate records. Following title and abstract screening, we excluded additional 2738 records on relevance. Of the 228 remaining full texts we assessed for eligibility, 223 were excluded. That left us with five (partially overlapping) study records of three distinct studies (i.e., datasets).

### 3.2. Study characteristics

The characteristics of studies included in the narrative synthesis are given in [Table 2](#) ([Dzhambov et al., 2017, 2018a, 2018b, 2018c; Dzhambov, 2018](#)). All five reports were published by the same research

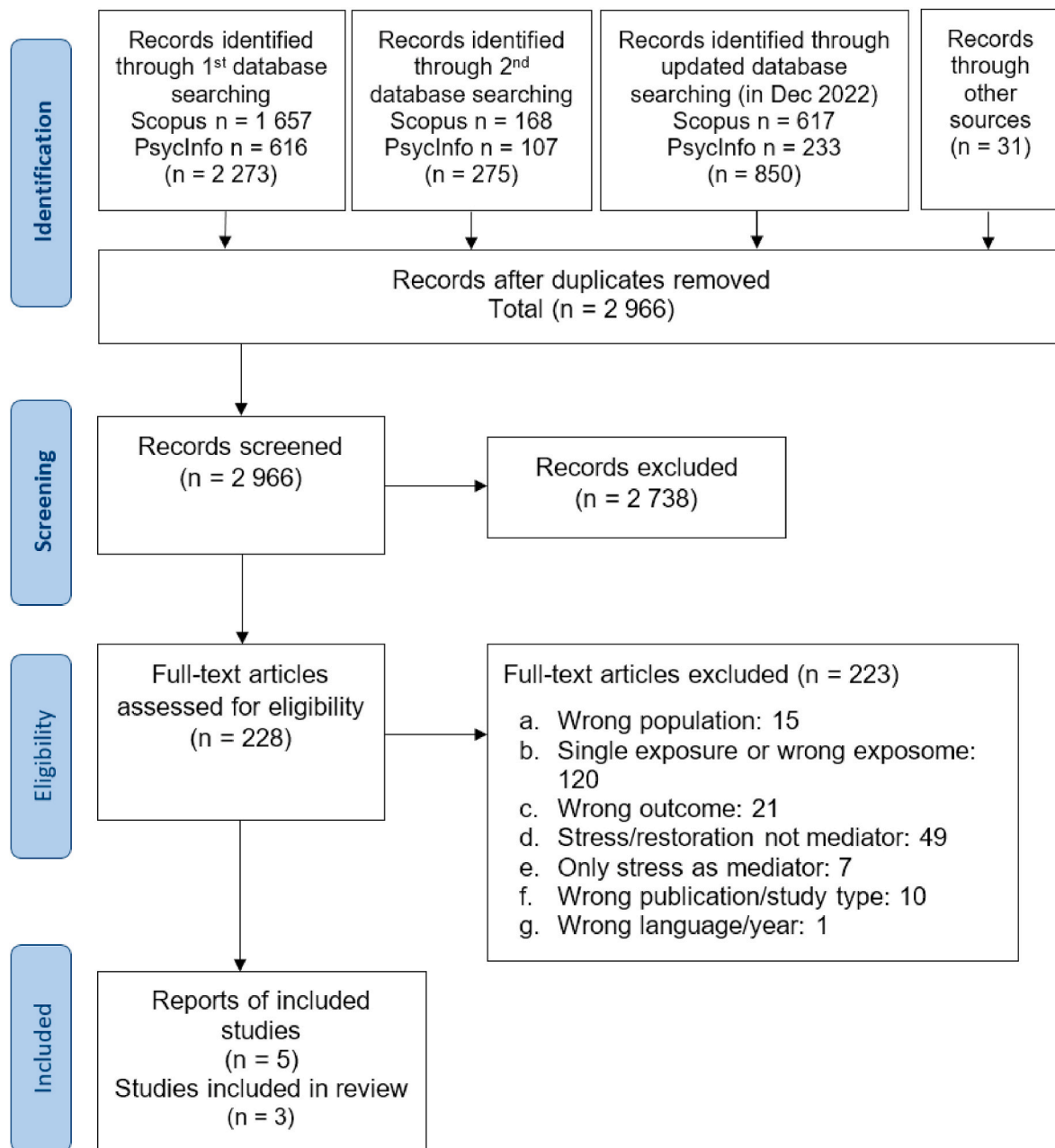


Fig. 1. Flowchart of the paper selection process for the scoping review.

group and some of them shared subjects, leaving us with only three unique datasets. Since they reported on different mechanistic pathways, we retained them in the review but took care not to double count evidence on the same pathway when based on the same sample.

The studies were conducted in the city of Plovdiv, Bulgaria, where convenience samples of university and high school students were surveyed cross-sectionally. Only one study was of panel design and collected data at two time points, the beginning and the end of the academic year (Dzhambov, 2018). The outcome in these studies was a composite of anxiety and depression symptoms measured with the 12-item version of the General Health Questionnaire (Goldberg and Blackwell, 1970). The main physical exposures investigated were natural outdoor environments and traffic emissions. Generally, multiple indicators were used to operationalize greenspace, including satellite-derived vegetation indices, availability of greenspace land use/cover, and distances to green and blue spaces from participants' residential address. Long-term traffic noise and air pollution were

measured more crudely with single indicators (i.e., day-evening-night sound pressure levels and nitrogen dioxide). Three of the studies treated air pollution and noise not simply as co-exposures, but also as mediators that stood on the path from greenspace to mental health (Dzhambov, 2018; Dzhambov et al., 2018a, 2018b). Furthermore, objective measures of these physical exposures were supplemented with perceived measures of green and blue spaces, and annoyance by noise, air pollution and vibration (forming an environmental annoyance scale), which were in turn assumed to operate as intermediate variables leading to mental health. Perceived neighbourhood restorative quality, measured with items from the Perceived Restorativeness Scale (Hartig et al., 1997a, 1997b) that captured feelings of being away and fascination with the neighbourhood environment, emerged as a central mediator. It was associated with more greenspace, higher physical activity and social cohesion, and lower perceived noise and air pollution. In turn, those mediating variables led to better mental health. In one study (Dzhambov et al., 2018a), traffic noise related to mental ill-health via

**Table 2**  
Summary of findings in the scoping review.

Study	Design	Population	Setting	Exposome		Mediator	Outcome	Analysis method	Results
				Physical	Social				
Dzhambov et al. (2018b)	Cross-sectional	Students (N = 720) Median age: 21 (range 18–35 yrs) 64.2% female	Residential (Bulgaria)	Greenness (NDVI, tree cover), Green space land cover, Distance to green space, Perceived greenness scale Distance to bluespace, Perceived bluespace scale Air pollution (NO <sub>2</sub> ) and traffic noise (L <sub>day</sub> ) <u>conceptualised</u> as mediators in the analysis	Perceived neighbourhood social cohesion <u>conceptualised</u> as mediator in the analysis	<u>Restoration</u> Perceived restorative quality of the neighbourhood <u>Instoration</u> Social cohesion, Physical activity <u>Stress</u> Environmental annoyance (noise, air pollution, vibration) <u>Others</u> Perceived neighbourhood green/blue space, noise and air pollution	General mental health (GHQ-12)	Structural equation modelling Other covariates in SEM: sex, age, ethnicity, month, SES, population density, settlement, duration of residence, time spent at home, stressful events	<ul style="list-style-type: none"> <li>- Higher greenness associated with better mental health through higher perceived greenspace, higher restorative quality, and subsequently higher physical activity</li> <li>- Mediation also via lower noise exposure and higher perceived greenspace, and then lower annoyance</li> <li>- Bluespace associated with higher perceived bluespace, restorative quality, and physical activity</li> <li>- Bluespace also associated with higher noise exposure and annoyance</li> </ul>
Dzhambov (2018)	Cross-sectional & 2-wave panel	Students (N = 109) Median age: 21 (range 18–35 yrs) 45% female	Residential (Bulgaria)	Greenness (NDVI) Distance to bluespace Air pollution (NO <sub>2</sub> ) and traffic noise (L <sub>day</sub> ) <u>conceptualised</u> as mediators in the analysis	Perceived neighbourhood social cohesion <u>conceptualised</u> as mediator in the analysis	<u>Restoration</u> Perceived restorative quality of the neighbourhood <u>Instoration</u> Social cohesion, Physical activity <u>Stress</u> Environmental annoyance (noise, air pollution, vibration) <u>Others</u> Air pollution, noise	General mental health (GHQ-12)	Cross-sectional single mediation models; longitudinal mediation using cross-lagged panel single mediation models Other covariates in SEM: sex, age, ethnicity, SES, duration of residence, time spent at home	<ul style="list-style-type: none"> <li>- Cross-sectional analysis: higher residential greenness associated with better mental health only indirectly through higher physical activity and restorative quality. Blue space: mediation by physical activity and restorative quality;</li> <li>- Longitudinal analysis: higher greenness and nearer blue space associated with better mental health, but no mediation.</li> </ul>
Dzhambov et al. (2018a)	Cross-sectional	Students (N = 720) Mean age: 21 yrs (range 18–35 yrs) 66% female	Residential (Bulgaria)	Air pollution NO <sub>2</sub> , Traffic noise LAeq	Perceived neighbourhood social cohesion <u>conceptualised</u> as mediator in the analysis	<u>Restoration</u> Perceived restorative quality of the neighbourhood <u>Instoration</u> Social cohesion, Physical activity <u>Stress</u> Environmental annoyance (noise, air pollution, vibration) <u>Sleep</u> <u>disturbance</u> Difficulty falling	General mental health (reduced GHQ-11)	Structural equation modelling Other covariates in SEM: sex, age, ethnicity, month, income, population density, duration of residence, time spent at home	<ul style="list-style-type: none"> <li>- Association between higher L<sub>Aeq</sub> and GHQ</li> <li>- L<sub>Aeq</sub> associated with higher annoyance, and through it with lower restorative quality, and then with lower physical activity, and thus with higher GHQ.</li> <li>- Higher annoyance associated with higher sleep</li> </ul>

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Table 2 (continued)

Study	Design	Population	Setting	Exposome		Mediator	Outcome	Analysis method	Results
				Physical	Social				
Dzhambov et al. (2017)	Cross-sectional	High school and university students (N = 399) Mean age: 17.89 yrs (range: 15–25 yrs) 32.1% female	Residential (Bulgaria)	Road traffic noise (L <sub>den</sub> )	Perceived neighbourhood social cohesion <u>conceptualised</u> as mediator in the analysis	Restoration Perceived restorative quality of the neighbourhood <u>Instoration</u> Social cohesion, Physical activity <u>Stress</u> Road traffic noise annoyance	asleep + waking up during the night  General mental health (GHQ-12)	Linear regression mediation models (product of coefficients method), structural equation modelling Other covariates in SEM: sex, SES, ethnicity, noise sensitivity	disturbance, and then with higher GHQ. - NO <sub>2</sub> associated with GHQ only indirectly through higher annoyance, lower restorative quality, and lower physical activity - Higher noise exposure associated with worse mental health only indirectly. - Single and parallel mediation models: mediation by annoyance, social cohesion, and physical activity. - SEM: higher annoyance associated with less social cohesion, and in turn with worse mental health - Annoyance also associated with lower restorative quality, then with less social cohesion and physical activity, and in turn with worse mental health
Dzhambov et al., 2018c	Cross-sectional	Students from high schools and universities (N = 399) Mean age: 17.89 yrs (range: 15–25 yrs) 32.1% female	Residential (Bulgaria)	Greenness (NDVI, SAVI, tree cover), Distance to green space, Perceived greenness scale Air pollution (NO <sub>2</sub> ) and Traffic noise (L <sub>day</sub> ) <u>conceptualised</u> as mediators in the analysis	Neighbourhood social cohesion <u>conceptualised</u> as mediator in the analysis	Restoration Perceived restorative quality of the neighbourhood <u>Instoration</u> Social cohesion, Physical activity <u>Stress</u> Road traffic noise annoyance <u>Other</u> Perceived air pollution	General mental health (GHQ-12)	Single mediation models with mediators tested one-at-a-time (product of coefficients method) Parallel mediation model with mediators assumed to act independently Theoretically-indicated serial mediation models Other covariates in SEM: sex, age, ethnicity, SES, population density, duration of residence, time spent at home, school, month	- No direct association between objectively-measured green-space and mental health - Restorative quality mediated the relationship between NDVI and mental health in some single mediation models. - No indirect effects in parallel mediation models - In serial mediation models, higher greenness associated with better mental health via higher restorative quality, and then higher physical activity and

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Table 2 (continued)

Study	Design	Population	Setting	Exposome	Mediator	Outcome	Analysis method	Results
				Physical	Social			higher social cohesion

Note. Abbreviations: GHQ – General Health Questionnaire;  $L_{Aeq}$  – equivalent A-weighted sound pressure level;  $L_{day}$  – daytime sound pressure level;  $L_{den}$  – day-evening-night sound pressure levels; NDVI – normalized difference vegetation index;  $NO_2$  – nitrogen dioxide; SAVI – soil-adjusted vegetation index; SES – socio-economic status; SEM – structural equation modelling.

higher annoyance and sleep disturbance. The social exposome was represented by perceived neighbourhood social cohesion, which was conceptualised as one of the mediators that connected restorative quality to mental health.

Pathways for which evidence of significant mediation was found (i.e., statistically significant indirect effect reported) are shown in Fig. 2. The studies employed formal mediation analyses, comparing single, parallel, and serial mediation models, or fitting complex structural equation models that attempted to model the interrelationships between objective and perceived physical exposures, restorative quality, and the instoration variables social cohesion and physical activity. Physical activity was consistently associated with better mental health, working in serial with higher restorative quality. Of note, the panel study found evidence of mediation by restorative quality and physical activity only at baseline (cross-sectional analysis), but not in the longitudinal analysis (Dzhambov, 2018).

### 3.3. Supporting evidence

Studies that were excluded from the scoping review or that were published after the last update of the searches or that came from personal libraries that reported relevant information on specific pathways of interest, were reviewed at this stage (see Table 3). Seven additional studies supplemented the limited evidence provided by the scoping review. None of these were identified in the searches for the scoping review because they were not addressing exposures in the title/abstracts in an explicit exposome/cumulative approach according to Equal-life’s strategy (Persson Waye et al., 2023a manuscript in preparation/A). The reason for excluding most of these studies from the scoping review was the lack of a second exposome indicator in most of them.

Most studies were of cross-sectional design, but their samples were considerably larger and more diverse than the convenience samples included in the scoping review. Different age groups were covered, including children, teenagers, and university students. One cohort study investigated mental and psychomotor development indicators in infants, followed from birth until the age of two years (Liao et al., 2019).

Most studies focused on the psychological effects of exposure to residential greenspace, measured objectively with a satellite image-

based vegetation index or with perceptual measures of greenness, such as perceived general neighbourhood greenness or green window views from home. One study measured perceived greenspace quality rather than availability (Putra et al., 2021). Other studies did have a second exposome indicator but did not directly measure restoration as a process or the restorative quality of a setting, while two studies looked at perceived restorative quality (Hipp et al., 2016; Gulwadi et al., 2019) but not from an exposome perspective. Besides greenspace, Nordbø et al. (2020a) measured population density, number of facilities/amenities, playgrounds, and schools in the neighbourhood, and Liao et al. (2019) conceptualised fine particulate matter air pollution as a mediator for greenness. Three studies (Wang et al., 2019; Nordbø et al., 2020a; Putra et al., 2021) conceptualised social cohesion/social interaction as a mediator between greenspace and health. Physical activity was also frequently tested as a mediator, with the cohort study by Liao et al. (2019) looking at maternal physical activity during pregnancy. Some studies also considered air pollution and noise (Liao et al., 2019), perceived air pollution and noise levels (Wang et al., 2019), and psychological symptoms as mediators (Putra et al., 2021).

Overall, better psychological wellbeing and less behaviour problems were observed in children/adolescents living or going to school in a greener neighbourhood. Although these studies employed less advanced mediation analysis (tested single mediators) than those included in the scoping review, they could still detect that part of the effect on psychological wellbeing and behaviour problems was mediated by higher perceived restorative quality (Hipp et al., 2016; Gulwadi et al., 2019), higher or more frequent engagement in outdoor physical activity (Wang et al., 2019; Nordbø et al., 2020a; Putra et al., 2021), and more social interaction (Wang et al., 2019; Nordbø et al., 2020a; Putra et al., 2021). Lower air pollution (Liao et al., 2019) and perceived traffic emissions (Wang et al., 2019) also emerged as mediators. Findings were not entirely consistent. For example, Putra et al. (2021) found stronger mediation evidence for child mental health via health-related quality of life than via physical activity and social interaction; this evidence was also more pronounced in late childhood and when the outcome (pro-social behaviour) was caregiver-reported. Another study did not detect mediation by physical activity and only reported an association between distance to greenspace and hyperactivity/inattention in boys, and not

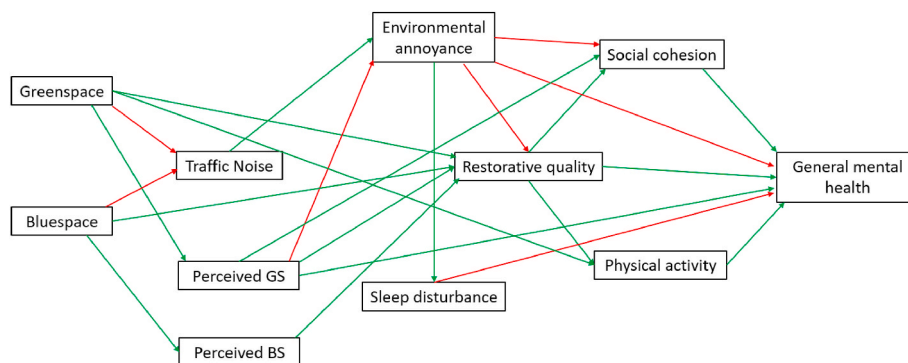


Fig. 2. Pathways for which evidence of mediation (i.e., statistically significant indirect effect) was found in the scoping review. Note. Several studies based on the dataset supplied evidence for construction of the diagram. Green arrows indicate positive associations, and red arrows, negative associations. Abbreviations: GS – greenspace, BS – bluespace.



**Table 3**

Summary of studies providing supporting evidence about pathways from the physical exposome to child mental health/cognition involving restoration/institution.

Study	Design	Population	Setting	Exposome		Mediator	Outcome	Analysis method	Results
				Physical	Social				
Hipp et al., (2016)	Cross-sectional	Students from three universities (N = 441) Mean age: 23.6 yrs. 78.2% female	School campus (USA and Scotland)	Perceived greenness scale	No	<u>Restoration</u> Perceived restorative quality (PRS), subscales: Being away, Fascination, Coherence, Compatibility	<u>Quality of life (WHOQOL-BREF)</u>	Single mediation analysis (product of coefficients method)	- Higher perceived campus greenness associated with greater quality of life via higher perceived campus restorativeness
Liao et al., (2019)	Cohort	New-borns followed for 2 yrs (N = 1312) Age 2	Residential (China)	Greenness (NDVI) Air pollution (PM <sub>2.5</sub> ) <u>conceptualised as mediator in the analysis</u>	No	<u>Instoration</u> Physical activity of mother during pregnancy <u>Other</u> Air pollution	<u>Mental development, Psychomotor development (Bayley Scales of Infant Development) (expert administered)</u>	Single mediation analysis (causal steps approach)	- Reduced levels of traffic-related air pollution explained 13.6%–28.0% of the association between exposure to green space and early childhood psychomotor development
Wang et al., (2019)	Cross-sectional	Teenagers (N = 4538) Mean age: 14.57 yrs. 51% female	Residential (USA)	Greenness (NDVI)	<u>Social cohesion conceptualised as mediator in the analysis</u>	<u>Instoration</u> Social cohesion, Physical activity <u>Stress</u> Self-reported stress <u>Other</u> Perceived air quality and noise in the neighbourhood	<u>Psychological distress (K6)</u>	Single mediation analysis (difference of coefficients method)	- Streetscape greenery and NDVI were positively associated with mental wellbeing. - Significant partial mediators for the streetscape greenery were physical activity, stress, perceived air quality and noise, and social cohesion - For NDVI, only physical activity and social cohesion were significant partial mediators
Markevych et al., (2014)	Cross-sectional	Children (N = 1625) Mean age: 10.1 yrs. 49% female	Residential (Germany)	Distance to green space, Greenness (NDVI)	No	<u>Instoration</u> Physical activity proxies – Time spent outdoors, Time spent in front of a screen	<u>Behavioural problems (SDQ - different subscales and total score)</u>	Parallel mediation analysis (Difference of coefficients method – adjusting for mediator)	- Greater distance between the residence and the nearest green space associated with higher odds of hyperactivity/inattention - This association was only statistically significant among males. - Behavioural problems were not associated with the distance to forests or residential surrounding greenness
Gulwadi et al., (2019)	Cross-sectional	Students (N = 1079) Mean age: 21.5 yrs. 61% female	School campus (Turkey and USA)	Greenness (NDVI)	No	<u>Restoration</u> Perceived restorative quality <u>Other</u> Perceived greenness	<u>Quality of life (WHOQOL-BREF)</u>	Serial mediation analysis (Product of coefficients method)	- Higher greenness directly associated with better overall quality of life - Indirect associations mediated by perceived greenness and

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Table 3 (continued)

Study	Design	Population	Setting	Exposome		Mediator	Outcome	Analysis method	Results
				Physical	Social				
Putra et al., (2021)	Cross-sectional	Children (N = 4983) Age: 4–5 yrs in 1st wave 14–15 yrs in 6th wave 49% female	Residential (Australia)	Greenspace (perceived quality)	Social interaction <u>conceptualised as mediator in the analysis</u>	<u>Instoration</u> Physical activity, Social interaction <u>Other</u> Mental health, HRQOL	<u>Prosocial behaviour (SDQ)</u>	Single mediation analysis (counterfactual approach)	perceived restorative quality <ul style="list-style-type: none"> <li>- Higher greenspace quality associated with prosocial behaviour via physical activity, social interaction and caregiver mental health, but evidence on mediation was weak</li> <li>- Stronger mediation evidence for child mental health and HRQOL</li> <li>- Mediation more pronounced in late childhood</li> <li>- Child-reported outcome (prosocial behaviour) showed weaker mediation compared to caregiver-reported child outcome</li> </ul>
Nordbø et al., (2020a)	Cross-sectional	Children (N = 21019) Age: 8 yrs. 49% female	Residential (Norway)	Green space LULC, Population density, Number of facilities/amenities, playgrounds, schools in neighbourhood	Participation in organized and social <u>conceptualised as mediator in the analysis</u>	<u>Instoration</u> Physical activity, Participation in organized and social	<u>Wellbeing (SMFQ)</u>	Single mediation analysis (counterfactual approach)	<ul style="list-style-type: none"> <li>- Having a park and more playgrounds/sports fields in the neighbourhood, and living in more densely populated areas, associated with more depressive moods and negative feelings.</li> <li>- Participating in physical activity, organized activities and social activity with friends mediated these relations and contributed to counterbalancing some of the negative associations observed</li> </ul>

Note. Abbreviations: HRQOL – health-related quality of life; K6 – Kessler Psychological Distress Scale 6 items; LULC – land use/land cover; NDVI – normalized difference vegetation index; PM<sub>2.5</sub> – fine particulate matter with a diameter ≤2.5 µm; SDQ – Strengths and Difficulties Questionnaire; SMFQ – Short Mood and Feelings Questionnaire; WHOQOL-BREF – WHO Quality of Life-BREF.

with distance to forests or overall residential surrounding greenness (Markevych et al., 2014).

## 4. Discussion

### 4.1. General findings and theoretical framework

In our scoping review, we identified a very small body of evidence, and, moreover, it came only from cross-sectional studies. The results of the identified studies provide some preliminary support for the idea that perceived restorative quality of adolescent's living environment might

mediate the association between greenspace and mental health. It should also be noted that many of the studies were conducted by the same research group and shared participants, even though they tested alternative theoretically-indicated pathways. Still, considering neighbourhood restorative quality as an intermediate link appears justified, as this was supported by additional evidence from two studies on the role of restorativeness on school campuses (Hipp et al., 2016; Gulwadi et al., 2019).

These observations, however limited, are consistent with a long line of theoretical work (Stevenson et al., 2018; Bratman et al., 2019; Hartig, 2021; Marselle et al., 2021) and recent empirical advancements in the

study of mental health and cognitive restoration in natural outdoor spaces (Zijlema et al., 2017; Browning and Rigolon, 2019; Fyfe-Johnson et al., 2021; Hartley et al., 2021). There is growing evidence to suggest that perceived restorative quality of the residential environment may be a central link in several serial causal mediation chains of intertwined capacity-restoring (restoration) and capacity-building (instoration) pathways supporting mental health in children and adolescents (Collado and Staats, 2016; Markevych et al., 2017; Dzhambov et al., 2018b). Restorative environments support behavioural patterns (e.g., outdoor physical activity and social contacts, hobbies like gardening) (Gubbels et al., 2016; Dzhambov et al., 2018b; Bikomeye et al., 2021) and cognitive schemes (e.g., mindfulness) (Dzhambov et al., 2019) associated with better adaptation and coping with stress. Capacities (instoration) may be built through physical activity or social interactions with others (Markevych et al., 2017).

An important observation was that in almost all studies restoration was conceptualised as a mediator for the effect of greenspace or other natural environments. This is understandable but raises concerns about bias in the body of evidence, possibly related to the dominating assumptions in the field. Historically, natural environments have been assumed to enable restorative processes more readily than other environments owing to the relative absence of attentional demands and presence of engaging features which evoke “soft” fascination (Kaplan and Kaplan, 1989; Hartig, 2004). This hypothesis has found support in a number of experimental studies in adults comparing cognitive restoration in natural settings versus other (non-natural or urban) settings (Ohly et al., 2016). Collado and Staats (2016) provide a nice overview of research on children’s restorative experiences in nature. In the broader literature on neighbourhood physical environment and child health and development, better access to greenspace and living in a greener environment are associated with well-being, less emotional and behaviour problems, and better cognition in children (Vanaken and Danckaerts, 2018; Putra et al., 2020; Zare Sakhvidi et al., 2022). Likewise, greenspace in the school surroundings may benefit academic performance (Browning and Rigolon, 2019), but the evidence remains limited (Singh et al., 2022) and of suboptimal quality (van den Bogerd et al., 2020).

However, as suggested by studies in adults, restoration may proceed in natural environments lacking vegetation (Li et al., 2022a), or in environments lacking natural features altogether, such as a company canteen (Bellini et al., 2019) or an artistic/historical setting (Scopelliti et al., 2019), as well as during various experiences unrelated to nature, such as being on vacation (Hartig et al., 2013) or listening to pleasant music (Baldwin and Lewis, 2017). Other people can also facilitate and speed up the process of restoration by providing social support, sense of safety, and sharing our experiences (Staats and Hartig, 2004; Staats et al., 2010). For example, a field experiment showed that teenagers spending time in nature reaped more psychological benefits if they were there with a friend than by themselves (Greenwood and Gatersleben, 2016). Moreover, environmental stressors, such as air pollution and noise, can undermine the restorative potential of a setting for youth (Dzhambov et al., 2018b) and adults (von Lindern et al., 2016), but the review identified no research in children, besides the Plovdiv studies in adolescents. Only recently, we observed an inverse association between traffic noise and children’s perceived neighbourhood quality (Dzhambov & Lercher, 2022). Therefore, we see these gaps as an opportunity for Equal-Life to explore the role of restoration in the causal processes linking different exposome indicators to child mental health and cognition.

#### 4.2. The role of physical activity

Even though we did not specifically use search terms capturing the instoration domain, physical activity did emerge as an important mediator consistently leading to better psychological outcomes in restorative environments. There is a solid theoretical and empirical basis to support this. On the one hand, physical activity in children is shaped

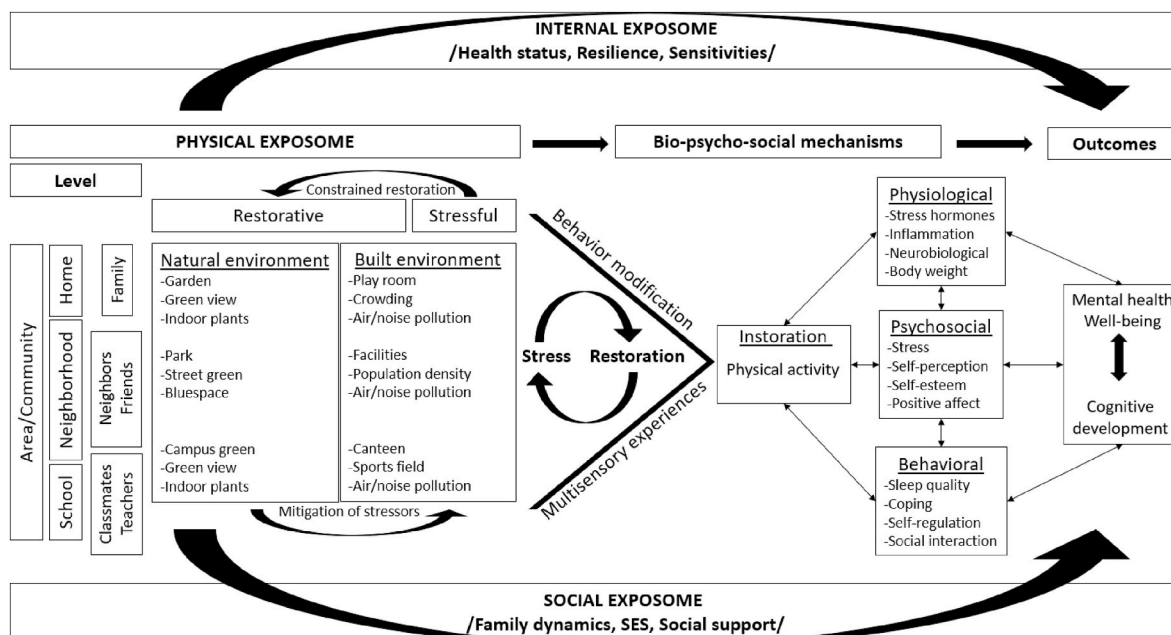
by the surrounding environment. The availability of accessible infrastructure (e.g., parks, playgrounds, sports facilities) is a conduit to outdoor play, engagement in sports, or simply casual walking and commuting (Lambert et al., 2019; Terrón-Pérez et al., 2021; Smith et al., 2022). On the other hand, lack of infrastructure suitable for walking and cycling can discourage outdoor physical activity. Our findings regarding the role of physical activity as a mediator align with the idea that stress reduction and positive sensory engagement with natural environments can promote physiological stress reduction, positive affect, and attention to a greater extent than physical activity performed away from nature (Gladwell et al., 2013; Rogerson et al., 2016; Hsin-Yen Yen et al., 2021, 2021b). The theory about “green exercise” posits that performing physical activity in urban greenspace or in nature confers more health benefits than physical activity with the same parameters performed indoors (Barton et al., 2016). However, the empirical evidence is still heterogeneous and often mixed for both adults (Lahart et al., 2019; Li et al., 2022b) and children (Mnich et al., 2019; Huang et al., 2021). In addition, physical activity is not merely a consequence of being in a particular environment, but itself constitutes a restorative experience that supports childhood health through several neurobiological, psychosocial, and behavioural mechanisms (Lubans et al., 2016). Regardless of context, greater levels of physical activity and more frequent engagement in school sports or recreational physical activity improve mental well-being and cognitive performance (de Greeff et al., 2018; Rodríguez-Ayllon et al., 2019; Hale et al., 2021). Reduction of body weight and physical fitness are one of the major health benefits to children (cf. Jebeile et al., 2022). Physical activity interventions can also improve mental health and cognition through more positive physical self-perceptions, self-esteem, and resilience (Carson et al., 2016; Lubans et al., 2016; Andermo et al., 2020; Hale et al., 2021). An updated systematic review by Biddle et al. (2019) found, with some heterogeneity, positive associations between physical activity and cognitive functioning and partial evidence for reduced depression. Reviews covering physical activity in intervention studies found stronger evidence for improvements in physical self-perception, psychological well-being, and quality of life than in depression (Biddle et al., 2019; Hale et al., 2021). Physical activity can also be conceived as a causal link between the exposome and favourable sleep outcomes, another mediator of interest for Equal-Life (Antczak et al., 2020; Janssen et al., 2020).

#### 4.3. Integrated model

In Fig. 3, we present a conceptual model of the role of restoration and instoration in childhood mental health and cognition. Outright, we want to stress that there is relatively scant literature on these complex pathways in children, with varying degrees of empirical support for different pathways or contingencies outlined in the model.

We start from the classic SRT (Ulrich, 1979) and ART (Kaplan and Kaplan, 1989) and the extension of ART to a more general theory of restoration (von Lindern et al., 2017; Hartig, 2021), where restoration of adaptive resources can be conferred by different settings. We also draw on our scoping review findings and subsequent consideration of the role of physical activity as a prominent affordance of restorative settings leading to better mental health and cognitive outcomes in children and adolescents.

Stress-restoration cycles shape children’s ability to cope with environmental and social demands (Hartig, 2021). Transactions between different exposome components are necessarily hierarchical, organized in various microenvironments (home, neighbourhood, and kindergarten/school) that children occupy and move across, interacting with different key actors, such as parents, teachers, and classmates. It is assumed that direct contact with natural elements through activities like playing in the backyard garden, the park, or in the woods are the main drivers to restoration. However, even brief visual encounters, such as accidental window views or indoor plants, have been shown to elicit stress-dampening responses directly (Ulrich, 1979; Kaplan, 2001) or by



**Fig. 3.** Conceptual model of pathways linking the exposome, restorative possibilities, and childhood mental health and cognitive outcomes (based on Lubans et al., 2016; Markevych et al., 2017; von Lindern et al., 2017; Nordbø et al., 2020b; Hartig, 2021; Bray et al., 2022; Smith et al., 2022).

mitigating environmental stressors (Markevych et al., 2017). At the same time, a number of stressors typically associated with the built environment, such as air pollution, noise, crowding, and poor housing quality (Evans, 2003; Bloemsma et al., 2022), have been shown to undermine the restorative quality of a setting and constrain restorative experiences (Von Lindern et al., 2016). Conversely, facilities, play and sports infrastructure, and gathering places where children can spend time relaxing or socializing, may provide restorative effects (Nordbø et al., 2020a).

In addition, the characteristics of the physical exposome can encourage specific health-relevant behaviours (Frank et al., 2019). Behaviour modification leading to increased physical activity frequency or intensity is facilitated by the presence of physical infrastructure allowing for outdoor or social interaction, such as parks, playgrounds, and sports facilities (Oliveira et al., 2014; Lambert et al., 2019; Nordbø et al., 2020b; Terrón-Pérez et al., 2021; Smith et al., 2022), and promoted by multisensory experiences of pleasantness, safety, and distance from daily hassles (Franco et al., 2017; Bratman et al., 2021; Ratcliffe, 2021). According to a systematic review by Nordbø et al. (2020b), the key built environment facilitators of active travel behaviour in children and adolescents are easier access to facilities and amenities, less traffic exposure, more safety features, and greater walkability. This is also true for younger children (Oliveira et al., 2014; Terrón-Pérez et al., 2021). Other facilitators and barriers can be found across different levels (the child, home, neighbourhood, peers, family) within the broader socio-ecological context (Hesketh et al., 2017a, 2017b).

In turn, physical activity can activate a combination of physiological, psychosocial, and behavioural pathways, which reinforce each other (Dzhambov et al., 2018b; Biddle et al., 2019). For example, doing sports can bring peers together and strengthen their social ties (Jetten et al., 2022) or offset the harmful effects of stress hormones, oxidative stress, and systemic inflammation (cf. Jebeile et al., 2022). We acknowledge that the relationship between other mediators and mental health/cognition also goes both ways. It is conceivable that stress, sleep, coping and self-regulation, which are also of interest as mediators between the exposome and child mental health/cognition in Equal-Life, can be both promoted by physical activity and affect the willingness to engage in physical activity (Kline, 2014; Burg et al., 2017; Boat and Cooper, 2019). Longitudinal studies have shown that physical activity level and mental

health symptoms change together over time without a clear directionality of their relationship (Steinmo et al., 2014). The same issue concerns the observed bidirectionality between sleep quality and mental health in children and adolescents (Quach et al., 2018). Childhood obesity can also form a vicious circle with poor mental health and sleep disturbance (Kansra et al., 2021). Further, physiological changes triggered by engagement with the environment like systemic inflammation and hormonal changes can both contribute to poor sleep and mental health problems and be the result of existing problems (Beurel et al., 2020; LaVoy et al., 2020). Hence, one must appreciate the complex dynamics between different pathways and outcomes, which require both conceptual and analytical consideration in our efforts to understand them.

#### 4.4. Methodological considerations

##### 4.4.1. Operationalization of restoration

According to Han (2003), psychological restoration is the process of reduction in mental fatigue while perceived restorativeness is the potential restorative capacity of a setting. As Hartig noted, confusion about what restoration involves can undermine efforts to understand restorative environments as health resources (Hartig, 2007). We can also distinguish actual from subjective restoration experience (Hartig, 2007). Actual restoration can be operationalized by the recovery of cognitive or other resources following exposure to a taxing environmental stimulus that diminishes, e.g., the capacity for directed attention or one that induces stress (i.e., depletion phase), followed by exposure to a different environmental setting or sensory input (i.e., restoration phase) (Berto, 2005). For example, Jenkin et al. (2017) conducted an experiment where they exposed schoolchildren to videos of natural and urban environments and tested whether changes in selective attention explained changes in self-regulation. On the other hand, self-reported measures of restoration (e.g., the Restoration Outcome Scale; Korpela et al., 2008) can reflect perceptions of the effect of habitual restorative experiences in every-day contexts (Hartig, 2016; Malekinezhad and Bin Lamit, 2018).

In Equal-Life, we will investigate chronic restoration-related pathways, i.e., how environmental settings and experiences “can over time become positively associated with indices of health through pathways that involve the cumulative effects of repeated episodes of adequate restoration” (von Lindern et al., 2017). Exploration of immediate

restoration would require an experimental design and might be a part of the piloting of some interventions. This means that indicators of restoration are not readily available in Equal-Life cohorts and schools study data. However, even if we do not have direct measures of actual/perceived restoration, the restoration perspective can still be tackled implicitly. For example, [Hartig et al. \(2007\)](#) observed a negative correlation between dispensation of antidepressants and monthly mean temperature for the peak vacation period in summer; they suggested that unseasonably cool weather might act as an ecological constraint on restorative activities in outdoor settings, thereby prolonging chronic stress and exacerbating depressive symptoms. Available data on potentially restorative experiences like time spent in nature, playing, listening to music, or hobbies may also be used for investigating the restoration pathway.

As for environmental restorative quality, it can be operationalized by measures of perceived restorativeness, such as the widely used Perceived Restorativeness Scale ([Hartig et al., 1997a, 1997b](#)), the Perceived Restorative Components Scale for Children ([Bagot, 2004; Bagot et al., 2007](#)), or even restorativeness of the sonic environment of a setting (e.g., Perceived Restorativeness Soundscape Scale; [Payne, 2013](#)). For an overview of measures of restoration experience and restorative quality/restorativeness, see [Malekinezhad and Bin Lamit \(2018\)](#) and [Han \(2018\)](#). In Equal-Life, we may have to rely first on relatively crude objective proxies (like the greenness of an area) for restorative quality. These can be refined (e.g., [Grahn and Stigsdotter, 2010; Wheeler et al., 2015; Brindley et al., 2019](#)). We have also planned to enrich the cohorts with objective measures of availability or accessibility to environments (e.g., natural spaces, recreational facilities) or environmental qualities (e.g., presence of amenities, social/cultural features and multisensory qualities like aesthetic beauty and quietness/restorative soundscapes) believed to support restorative experiences. Measures of vegetation visibility from the eye-level can be enriched to better capture perceptual aspects of restorative features and visual patterns ([Labib et al., 2021](#)). Nevertheless, in newly planned field studies data on actual/perceived restoration may also be collected.

#### 4.4.2. Child restorative experiences

Children's restoration might require different environmental qualities and places than those adults would consider restorative ([Collado and Staats, 2016](#)). An uneventful environment, where an adult would feel away from taxing demands and find respite, might generate stress and restoration needs for a child due to understimulation and reduced variation in sensory input (cf. [Bexton et al., 1954; Lewis et al., 1984](#)). It should also be noted that restorative quality is not an invariant characteristic of any environment. For instance, restoration at home or in the neighbourhood may be constrained by introducing air pollution and noise ([von Lindern et al., 2016](#)), which in turn can discourage outdoor physical activity and social interaction ([Dzhambov et al., 2018b](#)). In this vein, [Herzog and Rector \(2009\)](#) observed that perceived danger and uncontrollability of its source could offset the perceived restorative potential of a setting regardless of its naturalness. Lack of restoration opportunities can also ensue from using the environment both for restorative purposes and for activities creating restoration needs like working or studying in the setting ([Dzhambov et al., 2021](#)). Rural children who typically help their parents in agricultural activities may experience less restoration in agricultural areas than their urban counterparts who do not mentally associate this setting with work ([Collado et al., 2016](#)). Having reviewed the available evidence in the exposome field, we fully echo [Collado and Staats's \(2016\)](#) program for expanding future research. Equal-life will aim to go beyond what is already known about children's restorative experiences and consider relevant aspects like the relational dynamics between the child and the environment and circumstances that may inhibit restoration, restorative needs arising from understimulation that may only be relevant for children's restoration, the social context and restoration in relation to interaction with others, as well as restorative environments other than nature.

#### 4.4.3. Statistical considerations

Mechanisms behind the relationship between exposome and mental health can be conceptualised in several ways. The processes that are of central interest in our conceptual models are mediation and moderation, although we recognize that other causal relationships may be conceived. While [Baron and Kenny's \(1986\)](#) conventional logic of causal steps requires that specific criteria must be met for mediation to be established (e.g., an effect of the exposure on the outcome when the mediator is not included in the model), such assumptions can be overly conservative and limit disentanglement of more complex mechanistic relationships. In reality, multiple mediators may work together to generate an indirect effect, so we should carefully consider how these mediators intertwine (operating in isolation, in parallel or in a serial causal sequence). Modern theories posit that a materially important indirect effect through a mediator may be observed, even if the exposure has no total effect on the outcome ([Hayes, 2009; O'Rourke and MacKinnon, 2018](#)).

Another scoping review has indicated that more advanced mediation analyses (i.e., ones that allowed mediators to work in serial causal ordering) were more likely to detect evidence of indirect effects from greenspace to mental health ([Dzhambov et al., 2020](#)). The usefulness of modelling multiple intertwined pathways was further illustrated here in studies that employed structural equation modelling and found presence of indirect effects even in the absence of a total effect of the exposure on mental health (e.g., [Dzhambov et al., 2018b](#)). However, cross-sectional studies may yield spurious indirect associations or ignore reverse causality, which cannot be replicated in a longitudinal design ([Maxwell and Cole, 2007](#)).

Another process of interest, which has not received nearly as much attention in the reviewed studies, is when the effect of one exposure on an outcome is conditional in some way on the presence or absence of another exposure, referred to as moderator (or effect modifier, as it is commonly referred to in epidemiology) ([VanderWeele and Knol, 2014](#)). However, the studies we reviewed exclusively focused on mediation and did not explore instances where an indirect effect could change as a function of the moderator (i.e., moderated mediation) ([Hayes, 2017](#)). It should be noted that a factor may behave in various ways, mediating or moderating the relationship between exposure and outcome, depending on how it has been operationalized, its temporal stability, etc. Moreover, the hierarchical structure of the exposome implies plausible interactions of exposures across different spatial scales and contexts, such as between the family and area-level characteristics, which also deserves consideration in Equal-Life.

#### 4.5. Limitations

Several limitations with our work should be acknowledged. First, the broader exposome concept is relatively new and its operationalization in different papers is still diverse (cf. [Haddad et al., 2019](#)). Some researchers may adopt approaches related to the study of the exposome without using this concept or terminology. Since these studies were still of interest to Equal-life, we attempted to include them regardless of the terminology they used, but we might have omitted potentially relevant papers. Hence, we recognize the need for more structured reporting standards in the exposome and restoration literature in order to facilitate future evidence synthesis.

Second, the initial search terms in relation to all three exposome parts (physical, social, and internal) we derived were not meant to be exhaustive but quite concise (i.e., around 20 search terms) focusing on what was considered most crucial to reach the relevant literature. For instance, for the social part of the exposome, it was proposed to focus on psychosocial aspects. However, adding social and internal exposure terms to the search as alternative search terms would immensely increase the number of papers to screen without contributing much to the combination of exposures while adding them as a constraining search block would limit even more the results not allowing for the inclusion of papers on multiple physical exposures. We strived to include terms

reflecting multiple exposures covering physical exposures already in the search terms and social and internal exposures in the screening phase, fulfilling the Equal-Life goal to apply the exposome concept reflecting inter-relation between physical and social environments while also contributing to the relatively scarce research on multiple physical exposures in relation to children's and adolescent's mental health and cognitive function.

Readers will notice that we only searched peer-reviewed English-language literature in two databases, Scopus and PsychINFO, while systematic reviews in environmental epidemiology tend to cover multiple databases and sometimes grey literature. However, readers will also notice that the level of detail in our keyword search strings considerably exceeded common expectations from a review in the field.

We also acknowledge that the search terms for restoration/restorative quality may not have captured studies where a restorative experience of a process or activity was investigated without specially referring to it with "restoration terminology". Still, cognition/attention-related terms were already included in the "Outcome" search block, therefore we believe they should have captured processes most commonly of interest in the restoration literature. Finally, because this scoping review aimed to map the existing evidence, we did not perform a formal assessment of risk of bias of the included studies (Peters et al., 2015).

## 5. Conclusions

There is a very small body of tentative cross-sectional evidence coming from one research team that perceived restorative quality of adolescent's living environment might mediate the association between greenspace and mental health. In almost all studies, restoration was conceptualised as a mediator for the effect of greenspace or other natural environments. Physical activity emerged as a mediator consistently associated with better psychological outcomes in connection to restorative environments. Based on this, it is justified to further explore the role of restoration and physical activity as mediators in the association between early exposome and mental health and cognitive development up to the age of 21. It is hereby important to consider the child perspective as well as specific methodological caveats. In addition, given the still evolving conceptual definitions and operationalizations reviewed here, Equal-Life will attempt to fill in a critical gap in the literature on exposome and restoration.

## Credit author statement

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

No data was used for the research described in the article.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.envres.2023.116452>.

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