A new approach for measuring space-time-activity-exposure patterns of children

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ABSTRACT

When measuring the effects of noise on health, we often take the noise level at home as a reference value for the exposure response functions. However, how valid is this assumption? Looking specifically at children, exposure to noise not only varies throughout the day, but also depends on their space-time-activity pattern. With increasing age, children's activity space quickly changes and enlarges due to the exploration of new environments. During the day, different locations are used for a variety of activities. The sensitivity to noise exposure is influenced by the type of activities performed. Finally, the activity may be influenced by social circumstances like role expectations. In other words, measuring the noise level at home may not be sufficient to capture the whole picture. In this study, our goal is to describe noise exposure through actual used spaces and explore the social influences on children's space-time-activity-exposure patterns to shed light on the root of health inequalities. This paper presents a new approach for measuring space-time-activity-exposure patterns for children aged 0-21 years old using GPS tracking, activity diaries and a combination of noise measurements.

INTRODUCTION

Socioeconomic inequalities in health are a trending topic both in social sciences and public health research [1]**.** However, most research is aimed at adults, especially regarding mental health [1]**.** More insight is needed into the health inequalities in children and their sources. Looking at the causes of both physical and mental health, a good part of the global burden of disease can be attributed to environmental factors (e.g., air pollution or noise pollution) [2]. Understanding pathways between environmental exposures and health can therefore be of vital importance to reduce health inequalities.

To gain more understanding of these pathways and the influence of the social environment the concept *exposome* has gained more attention in recent years. The exposome concept was coined by Christopher Wild in 2012, he described it as a complementation of the human genome proving a comprehensive description of lifelong exposure history [3]. The exposome concept can be used for a better understanding of the causes and prevention of human disease [3]. In the exposome concept not only the physical exposures such as noise, air quality or green spaces are important but also the social environment such as social networks and social capital.

Where physical exposure (or the physical exposome) is often assessed based on exposure at the home address or on administrative boundaries such as postal code, there is a growing need for methods linking environmental aspects to individual health measures on a more detailed, personal scale [4]. By addressing personal exposures instead of aggregated values, the exposures an individual is facing can be measured better and the individual's exposome can be mapped. A way of mapping personal exposures is through looking at the exposures at the actual used spaces and incorporating a time weighting factor to the exposure based on the length of stay at those spaces. The effect of the duration of the exposure is assumed to be equally important as the intensity [5–7].

Developments of good exposure assessment tools are needed to target environment related health effects in children sooner and better. Children are more vulnerable to the effects of the environment because child development mainly consists of people-place interaction (experiencing (new) activities in (new) places with (new) people) [8]. It is further theorized that the environmental and social experiences in early life shape physiological changes that can have lifelong protective or detrimental effects on children's learning, behavior, health, and wellbeing. This process is called *biological embedding* [9]. However, very little is known about the response and interaction with the places and people children spent most of their time in and with [10].

In this paper, a method is proposed to measure the concept of *settings* to embed time-use, behavior, and people-place interaction into exposure research. The setting concept is used to capture important places of exposure in a child's life combined with the performed activity and the social environment at these places. It deviates from the traditional concept of personal exposure assessment based activity space, which focuses more on the mobility patterns, and it moves to the focus on anchor points, places where individuals spent most of their time [5].

A setting is defined as a place where people engage in social interactions and perform activities. Different settings can give rise to different activity patterns[8, 11]. A setting is therefore a combination of location, activity, and the social environment in which the activity is performed. The pattern in which these settings occur is the activity pattern. This may also vary depending on age and social context. The total space that encompasses all settings and therefore the activity pattern is seen here as the activity space, see Figure 1.

By linking settings to exposure, a detailed overview can be made of the exposure pattern of an individual and the effect it may have on health given the performed activity (e.g., the faster inhalation rate of polluted air when doing physical exercise) resulting in a space-time-activity-exposure pattern (STAEP). This assessment over time will inform us about the life course effects of experiencing exposures (such as noise levels) in a diverse or maybe a limited set of settings.

This paper aims to present the method development for measuring the STAEP of an individual. The focus is on noise exposure; however, the method may be applied to other environmental exposures as well. The method development consists of several steps which will all be addressed below. First, an exploratory survey was done into the leisure time behavior of children to get insight into the used settings. This was followed by the development of a survey to profile the participant based on social background, habitual behavior, sensitivity to noise and (mental) health status. Next, the location and activity tracking method are presented and finally the exposure assessment is addressed.

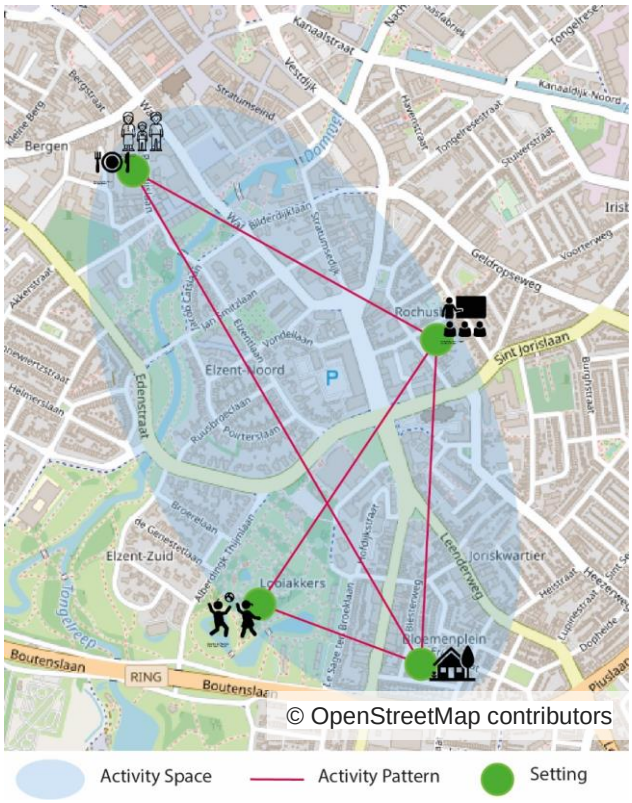

Figure 1: visualization of activity pattern, activity space and settings

METHOD DEVELOPMENT

Preliminary selection of settings

To get insight into the relevant settings of children and to make a preliminary selection for further research a survey study was conducted concerning the time-use of Dutch children in the age range of 0-21 years old. The parents were asked to fill in the survey when the child was between 0 and 12 years old; from the age of 12 the children filled in the survey themselves. In total 588 parents and children participated in the study, of which 459 parents filled in the survey for their child, and 129 children filled in the survey independently (only applicable for children age 12-21). The participants were recruited from primary schools in the Eindhoven area, students from Avans University of Applied Sciences and a representative online panel. Data were collected between October and December 2020. The Ethical Review Board of Eindhoven University of Technology approved the study and all participating parents and children (>16 years) provided digital informed consent for their own and/or child's participation.

The focus was on settings for leisure time activities outside the school and home environment. A set of the 12 most frequented activities in the Dutch national time allocation study (TBO) [12] was used to assess leisure-time time allocation. The set included playing outside, sports activities, other non-sport related out of school activities such as music lessons, dining out, cultural activities, religious activities, hiking or biking for fun, shopping for fun, shopping for necessities, social activities and resting/relaxing. Participants were asked to indicate how often the activities within the predefined set occurred in the past week (normal school week), what the duration of this activity was, where it was conducted (location type: green space, other outdoor space, home, at other people's home, other indoor space, utility spaces), with

whom the activity took place, how far the location was located from the home and the mode of transportation in the form of a multiple-choice style diary format.

Using a TwoStep clustering procedure on the data regarding the total time spent on the predefined activities, the time spent on the individual activities and time spent at location types, four groups were revealed in the data whose members participated in similar settings. The silhouette score, a measure of goodness-of-fit between -1 and +1 [13], was 0.2 which suggests a fair cluster solution. Cluster 1 contained 42.5% of the population with a mean time of 5.58 hours spent on leisure time activities during a week. Cluster 2 contained 14.9% of the population with 14.9 hours leisure activities, cluster 3 16.3% with 16.8 hours and cluster 4 7.7% and 23.3 hours. The total time spent on the pre-defined list of leisure time activities differed significantly between clusters at $p<0.00$ level [$F(3,584) = 184.675$, $p = 0.000$]. Post hoc comparison using the Tamhane test indicated that the mean number of hours in cluster 1 ($M=5.58$, $SD=3.75$) was significantly different from cluster 2 ($M=14.92$, $SD=5.63$), cluster 3 ($M=16.81$, $SD=9.29$) and cluster 4 ($M=23.33$, $SD=8.42$). Only clusters 2 and 3 did not differ significantly on total time spent on the predefined set of leisure activities.

Within the clusters there are variations in participation rate in an activity and the duration of an activity. Therefore, to indicate the differences between the clusters, activity and location profiles were made based on the most and least used activities and locations per cluster. When >50% of the cluster participated in an activity or visited a location type these types were deemed relevant for the cluster, when the participation was below 10% this variable was deemed as irrelevant. Settings are based on relevant (>50% participation) location-activity pairs and the most frequented activity partners within that location-activity pair. The found relevant settings per cluster are given in Table 1.

Cluster 1 only had one relevant setting. It can be that the predefined list of activities did not accurately reflect the interests of this cluster or they indeed only have one relevant setting. Based on these observations in the data, cluster 1 is labeled as “outdoor players”.

Cluster 2 is a socially and physically active cluster with high participation rates in the activities *social, sports, hiking and biking for fun* and *playing outdoors*. Due to the physically active nature of the relevant activities and the diverse number of location types that is used for the activities, cluster 2 is labeled as “social active explorers”.

Cluster 3 has the second-highest overall time spend on leisure activities but has a more limited set of relevant activities. This cluster has a less pronounced nature in activity participation, there are only three activities in which the majority participates but there is also only one with fewer than 10% participation. This indicates that the activities are more diverse in this cluster than in other clusters. Due to the less pronounced nature of activity-location combinations in this cluster and the relatively low means for activities, this cluster is labeled as “the hoppers”.

Cluster 4 has high means for social activities and other relevant activities are mainly performed alone. Due to the extremely high average time spent on social activities at home in relation to the other activities and the very high participation rates in them as well, this cluster is labeled “the social homebodies”.

The social profiles of the clusters were assessed based on significant differences in socio-demographic variables. Clusters differed significantly based on age ($p=0.000$), work status of the caretaker ($p=0.008$), whether or not they slept at multiple locations (e.g. other caretaker) ($p=0.002$), the number of caretakers ($p=0.021$) and borderline significantly on education level of caretaker ($p=0.052$). The profiles are summarized in Table 2.

Table 1: relevant settings per cluster

Cluster	Represented age	Relevant settings			
		Activity	Location	Activity partner	
				1	2
Outdoor players	-	Playing outdoor	Outdoor - other	Parent	Peers
Social active explorers	4-11	Social activities	Other people's homes	Peers	Parent
		Sport	Indoor - other	Peers	
		Sport	Outdoor - other	Peers	
		Hiking and Biking for fun	Green spaces	Parent	
		Hiking and Biking for fun	Outdoor - other	Parent	Sibling
		Playing outdoor	Outdoor - other	Peers	Sibling
Hoppers	4-7	Playing outdoor	Outdoor - other	Peers	Parent
		Sport	Indoor - other	Peers	Parent
		Sport	Outdoor - other	Peers	Parent
		Grocery shopping	Retail	Parent	
			Green spaces	Parent	
			Indoor - other	Peers	Sibling
			Home	Parent	
Social homebodies	12-21	Social activities	Other people's homes	Peers	
		Resting	Home	Alone	
		Grocery shopping	Retail	Alone	
		Hiking and Biking for fun	Green spaces	Alone	Parent
		Hiking and Biking for fun	Outdoor - other	Peers	Alone
		Sport	Indoor - other	Alone	Peers
		Sport	Outdoor - other	Peers	

Although no clear age group could be assigned to the first cluster of the *outdoor players* the other clusters clearly reflected an age effect on activity pattern. Clusters 2, 3 and 4 represent the ages 4-11, 4-7 and 12-21 respectively. The expectation already exists that children of different ages behave in different ways. The found settings relevant to the clusters were also

in line with the expectations one would have of the represented age groups: younger children spent more time playing outdoors under the supervision of parents and as children grow older the activities become more independent and focused on interaction with others (as can be seen by comparing for example cluster 2 and 4, social active explorers vs. the social homebodies).

Table 2: Social profiles per cluster

Cluster	Social profile
Outdoor players	Children of diverse ages with two caretakers. At least one caretaker has medium to high level education and works fulltime or parttime. These children sleep in their own homes and visit on average one other home in the week
Social active explorers	Children of the primary school age 4-11 with two caretakers. At least one caretaker has medium or high education, where a high education is more likely. At least one parent is fulltime or parttime employed. These children sleep in their own homes and visit on average two other homes in the week
Hoppers	Children of the younger primary school age (4-7) with two caretakers. At least one caretaker has medium or high education, where a medium education is more likely. At least one parent is fulltime employed. These children sleep in their own homes and visit on average one other home in the week
Social homebodies	Adolescents and young adults (12-21 years) with two caretakers. At least one caretaker has medium or high education, where a high education is more likely. At least one parent is fulltime. These children occasionally sleep at someone else's home and visit on average two (rounded from 1.5) other homes in the week

Based on the social profiles of the clusters differences in settings and therefore STAEP may be explained by parental education level, parental employment status, the number of caretakers and the number of social interactions (in the form of different home environments visited per week). Taking clusters 2 and 3 (*social active explorers* and *hoppers*) as an example of comparable, primary school, age groups differences can be seen in the presence of social activities and the differences in location use.

The *social active explorers* have the social activity setting as their main setting, most time is spent here (Mean = 2.93 hours per week). The *hoppers* lack a setting with a social activity, in this cluster the main setting is playing outdoor in non-green spaces (Mean = 2.05 hours per week). The use of the same location types also differs between the clusters. Green spaces cannot be attributed a specific activity in the *hoppers* cluster because it is used for a diverse set of activities, there was no majority reached for a specific activity. Lastly, the *hoppers* have their own home included in the relevant settings for leisure activities, the *social active explorers* do not. Combining this with the social profiles of the clusters it may be speculated that children of parents with a higher education level (cluster 2) are more likely to participate in social activities and are more physically active compared to children from parents with a medium education level (cluster 3).

To conclude, in addition to the age effect the cluster analysis does reveal that there are other factors at play. The question remains on how these differences can be further explained. Due to the limited set of variables we have in this study, relevant factors may have been missed. The physical exposome is not captured in this study and the social exposome only to a limited extent. The differences in relevant settings may be explained by factors of the social exposome other than SES indicators (e.g. income, education level) or by environmental factors such as access to facilities or environmental exposures. However, it is clear that in the next phase the measurements should be age targeted and should ensure a good distribution of social backgrounds within the age groups to get more insight into the effects of the social exposome. With the addition of a more detailed location assessment, the exposures during the activities can either be measured or modeled. Finally, when data on mental health is collected the prevalence of mental health problems can be related to the STAEP.

Survey development

From the exploratory survey study it was found that a more detailed personal profile is needed to better explain the mechanisms behind the clustering of participants in a certain set of relevant settings. We focus on three aspects: the social exposome, the physical exposome and mental health. The goal is to explore possible mechanisms resulting from the social environment or social background, the physical environment and underlying health conditions that may influence location use and activity choice and therefore affect exposure. Although the proposed study is of cross-sectional nature and no causal pathways can be determined, the grouping of participants within certain STAEP clusters may reveal similarities in other aspects as well that can serve as a point of further investigation in the future.

The social exposome is captured by socio-demographic variables (such as age, household income, parental education etc.), household composition and social relationships. In the Netherlands, 20% of the children below the age of 16 have divorced parents, 27% of which spent an equal amount of time at both parents' homes [14]. This is important to take into account not only for the social exposome but also for the physical exposome. Since time is spent in multiple home environments and the activity space is presumably wider, a greater number of exposure variations may occur.

The social relationships, as part of the social exposome, are incorporated in the health-related quality of life scale of children (KINDL) developed by Ravens-Sieberer and Bullinger, which also measures the functional capacity in everyday life, psychological well-being and physical state to determine a level of quality of life [15]. It has a varying number of items depending on the child age with a maximum of 40 and a high internal consistency (Cronbach's α = 0.69-0.89) [15].

Besides the KINDL questionnaire, mental health status is also measured by the strengths and difficulties questionnaire (SDQ) developed by Goodman and Scott [16]. The SDQ is a 25-item questionnaire relating to conduct problems, inattention and hyperactivity, emotional symptoms, peer problems and prosocial behavior. It is an established method for measuring mental health in children from ages 4 to 18.

The physical exposome is addressed in the survey by the sensitivity to noise measured using the child friendly INCH questionnaire developed by Persson-Waye [17]. It shows the prevalence of noise perception, emotional reaction, and coping strategies. The questionnaire has a good internal validity with a Cronbach's α varying from 0.52-0.65. In addition, noise annoyance by noise source and sleep disturbance by noise source is assessed using a scale from 0-10 based on the past 12 months. As a reference general sleep quality is assessed using the Groningse sleep quality scale [18].

Finally, to accommodate infrequent behavior or neighborhood characteristics that may influence activity choice, a section in the survey is dedicated to habitual behavior. Participants are asked to indicate for a set of activities similar to the ones mentioned in the exploratory survey, how often they occur (yearly, monthly, bi-weekly, weekly, or daily). In addition, attention is paid to the perceived accessibility of various facilities. The latter is of importance because the lack of a specific setting in an individuals' life may not only be due to preference but also due to the lack of facility to conduct a specific activity, i.e. sports location.

The survey is developed to use validated scales for measuring constructs when possible. In other cases, e.g. when addressing habits and neighborhood perception, scales are used which are accommodated in municipal health research in the Netherlands or have been used in environmental health cohorts such as RANCH, NORAH or ALSPAC [19–21]. An overview of the validated scales used in the survey is given in Table 3.

Table 3: Overview of used validated scales

Name of scale	Abbreviation	Measured constructs	Cronbach's α
Questionnaire for Measuring Health-Related Quality of Life in Children and Adolescents	KINDL^R	physical well-being, emotional well-being, self-esteem, family, friends and everyday functioning	0.67-0.89 [15]
Strengths and Difficulties Questionnaire	SDQ	conduct problems, inattention and hyperactivity, emotional symptoms, peer problems and prosocial behavior	0.53-0.86 [22]
Inventory of Noise and Children's Health	INCH	prevalence of noise perception, emotional reaction, and coping strategies	0.52-0.65 [17]
Groningse Sleep Quality Scale	GSKS	Sleep quality	0.86 [18]

When conducting the surveys, a division is made between parental and child/adolescent surveys. When the child is between the ages of 0 and 11, the parent is fully responsible for filling out the survey. Proxy report versions of the standardized scales (KINDL and SDQ) are used for this. From the ages 12 to 21 the child/adolescent themselves are responsible for filling in the major part of the survey. Information on parental background and housing conditions are provided by the parent for a higher reliability. All questions are adapted to fit the age of the child when the questionnaire method requires doing so (in the case of KINDL and SDQ).

At the end of the research period a closing survey is sent to the participants to confirm that the week they participated in the study they were not sick and nothing out of the ordinary occurred in their activity or exposure pattern (e.g. staying home due to illness or construction works in the neighbor's home).

Location and activity assessment

A vital part in the measurement of STAEP is the tracking of location and activities of the individual. For this a number of methods are considered: diaries, smart devices, GPS-loggers, and the combination of these measures. The goal was to find a common method for all of the targeted ages (0-21 years).

A combination of a diary and a GPS-logger was chosen over the use of smart devices. One could argue that the use of an activity diary alone would be enough to collect relevant settings when a question is added on where the activity is conducted. However, collecting GPS information allows for a detailed exposure assessment that would not be possible based on diary data alone and provides continuous location data even when the diary is not filled in. The choice of a standalone device over smart devices for GPS logging was made for two reasons. The first was to ensure better data protection. When using commercial smart devices, the collected data may also be used by third parties. Because the target group is children, the location information is too sensitive. Therefore, stand-alone devices were chosen to collect and protect data in a more controlled way. The second reason was that the standalone GPS-loggers can be used by all ages and require no interaction with the device, and it is not required to wear the device on the body. The logger can be carried in a backpack belonging to the child.

The GPS-logger is carried by the participant (the caretaker when the child is 0-3 years old or the child) for seven consecutive days. In parallel, an activity diary is kept in an open, online format. Participants are asked to log in to a secure website at least once a day to record their activities of that day (when recording is done in the evening) or the day before (when recording is done in the morning). The activities can be recorded in a free format, meaning that participants can add an activity to a day and attribute a starting time and duration to the activity, they do not have to fill in specific time slots.

The diary entries consist of: the activity, start time, duration, location type (e.g., park, at home), with whom the activity took place (e.g., alone, with friends), the mode of transport to the location and the emotional state during the activity indicated by emojis.

Noise exposure assessment

The noise exposure assessment is divided into two measurement periods, one during the 7-day tracking period and one after the tracking period. During the tracking period participants will receive five requests randomly during the day on their smartphone (the parents will receive this when the child does not have a phone) for the momentary assessment of the sound environment. The questions are based on the soundscape data collection questionnaire (ISO 12913-1 method B) and are intended to inventory the perceived sound sources, the sound – environment fit and the annoyance level due to the sound of the individual. When parents receive an assessment alert when they are not with the child, they are instructed to ignore the request.

It was chosen not to let participants carry a personal noise measurement device due to the increased burden for the participant and the possible unreliability of the measurements due to undocumented circumstances (wind, clothes moving, people standing close by).

During the tracking period sound loggers are installed in the participants' homes in the living room and the child’s bedroom and in the child’s classroom. The sound levels are recorded every 1/125 second in 1/3 octave bands. By frequently logging the sound levels the indoor sound environment can be recorded in more detail without invading the privacy of the

participants. The indoor sound levels can be matched to indoor activities with more accuracy than an Lden measured on the façade would do.

The added value of the STAEP lies with the exposure assessment at the relevant settings besides the home and school environment. A set of representative measurements for settings will be done after the tracking period by the researcher. The activity diaries and GPS patterns will be assessed to find a set of relevant settings per age group, at these settings noise levels will be measured at a representative time. When the sample is not clustered in the same area the measurement locations can be divided into setting types, i.e. green locations for sports near roads. Based on an average of multiple measurements at different locations of the same setting type, the setting type can be attributed a noise level category in the range of 5 dB(A).

STAEP creation

With the acquired sound level measurements, the child's space-time-activity pattern can be enriched with exposure data to look for patterns in exposure levels, activity pattern, social background and mental health prevalence. The total method is summarized in Figure 2.

A TwoStep clustering procedure will be run to cluster participants based on their STAEP. By assessing differences between clusters based on the social exposome, physical exposome and mental health status, the relation between activity pattern and mental health will be explored.

NEXT STEPS

Pilots for the validation of this method are planned in May 2021. For the recruitment of the pilot we will work together with local primary schools, high schools, and universities to find a select group with a minimum of 5 people per age group (0-3, 4-7, 8-11, 12-17, and 18-21) to participate. The results from the pilot measurements will be presented at the 13th ICBEN congress in June 2021.

Figure 2: summary of the STAEP measurement method

DISCUSSION

The aim of this paper was to propose a method for a new approach to measuring exposure patterns of children using space-time-activity-exposure patterns (STAEP). The concept of *settings* in this new approach embeds the time-use, behavior, and the people-place interaction into exposure research. In the first phase, the explorative survey study was performed to get insight into the relevant settings for children and possible factors that may be of influence on them. As stated before, the data was collected in between October and December 2020. During this time period, the COVID-19 pandemic was still holding a tight grip on our daily lives.

The representativeness of the findings in this phase is therefore under the influence of two things the selected list of activities and the COVID-19 pandemic. The predefined set of activities is based on the TBO study, an open diary as proposed in the next phase of this study, will most likely result in a more diverse set of activities and can therefore also result in different clusters and a different composition of relevant settings. Although there was an option to add an additional type of activity in an open format, not all participants may have done this. The pandemic may give a set of relevant settings which is different from what it would have been pre-COVID times. During the time period of data collection, the Netherlands was in a semi-lockdown. Primary schools were open and children until the age of 12 went to school but high schools and higher education facilities were closed and conducted online education. The practice of both indoor and outdoor sports was restricted for the ages 18 and up and finally public buildings such as libraries, museums and theaters were closed to the public for a two-week period within the time of data collection. The general prevention message of “stay home, keep distance, avoid crowded places, stay home when ill and work from home when possible” remains valid throughout the data collection period.

The strength of this new approach to exposure assessment lies in the unique approach of combining location, local exposure, activity, and activity partner to define clusters in space-time-activity-exposure patterns. By doing this a connection can be created between the physical and social exposome in a manner that has not been done before. The limitation of this study is that it is planned to be of a cross-sectional nature, meaning that a causal relationship between health and the environment cannot be made. However, insight into the prevalence of mental health issues in children can be gained, not only in relation to social background or exposure but in the combination of both with the unique addition of the performed activity, which may be of influence on the sensitivity to the exposure.

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REFERENCES

1. Reiss, F. (2013). Socioeconomic inequalities and mental health problems in children and adolescents: A systematic review. *Social Science and Medicine*, *90*, 24–31. https://doi.org/10.1016/j.socscimed.2013.04.026
2. Prüss-Üstün, A., Wolf, J., Corvalán, C. F., Bos, R., & Neira, M. P. (2016). *Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks*. World Health Organization.
3. Wild, C. P. (2012). The exposome: from concept to utility. *International Journal of Epidemiology*, *41*(1), 24–32. https://doi.org/10.1093/ije/dyr236
4. Kamp, I. Van, Loon, J. Van, Droomers, M., & Hollander, A. De. (2004). Residential Environment and Health : A Review of Methodological and Conceptual Issues. *Reviews on environmental health*, *19*(3), 1–

21.

5. Yi, L., Wilson, J. P., Mason, T. B., Habre, R., Wang, S., & Dunton, G. F. (2019, November 1). Methodologies for assessing contextual exposure to the built environment in physical activity studies: A systematic review. *Health and Place*. Elsevier Ltd. https://doi.org/10.1016/j.healthplace.2019.102226
6. Perchoux, C., Chaix, B., & Kestens, Y. (2019). Activity spaces in place and health research: Novel exposure measures, data collection tools, and designs. *Health & Place*, *58*, 102130. https://doi.org/10.1016/j.healthplace.2019.05.008
7. Rollings, K. A., Wells, N. M., Evans, G. W., Bednarz, A., & Yang, Y. (2017). Housing and neighborhood physical quality: Children's mental health and motivation. *Journal of Environmental Psychology*, *50*(1), 17–23. https://doi.org/10.1016/j.jenvp.2017.01.004
8. Bronfenbrenner, U. (1979). *The Ecology of Human Development*. Cambridge: Harvard University Press.
9. Minh, A., Muhajarine, N., Janus, M., Brownell, M., & Guhn, M. (2017). A review of neighborhood effects and early child development: How, where, and for whom, do neighborhoods matter? *Health and Place*, *46*(November 2016), 155–174. https://doi.org/10.1016/j.healthplace.2017.04.012
10. Rollings, K. A., Wells, N. M., Evans, G. W., Bednarz, A., & Yang, Y. (2017). Housing and neighborhood physical quality: Children's mental health and motivation. *Journal of Environmental Psychology*, *50*, 17–23. https://doi.org/10.1016/j.jenvp.2017.01.004
11. World Health Organization. (1998). *Health Promotion Glossary*.
12. Sociaal en Cultureel Planbureau (SCP). (2017). *Tijdsbestedingsonderzoek 2016 -TBO 2016.* https://doi.org/10.17026/dans-x9b-s7tw
13. Rousseeuw, P. J. (1987). Silhouettes: A graphical aid to the interpretation and validation of cluster analysis. *Journal of Computational and Applied Mathematics*, *20*(C), 53–65. https://doi.org/10.1016/0377-0427(87)90125-7
14. Central Statistics Bureau. (2017). Ruim kwart gescheiden ouders kiest voor co-ouderschap. Retrieved April 6, 2021, from https://www.cbs.nl/nl-nl/nieuws/2017/51/ruim-kwart-gescheiden-ouders-kiest-voor-co-ouderschap
15. Ravens-Sieberer, U., & Bullinger, M. (1998). Assessing health-related quality of life in chronically ill children with the German KINDL: First psychometric and content analytical results. *Quality of Life Research*, *7*(5), 399–407. https://doi.org/10.1023/A:1008853819715
16. Goodman, R., & Scott, S. (1999). Comparing the Strengths and Difficulties Questionnaire and the child behavior checklist: Is small beautiful? *Journal of Abnormal Child Psychology*, *27*(1), 17–24. https://doi.org/10.1023/A:1022658222914
17. Waye, K. P., Van Kamp, I., & Dellve, L. (2013). Validation of a questionnaire measuring preschool children's reactions to and coping with noise in a repeated measurement design. *BMJ Open*, *3*(5), 1–8. https://doi.org/10.1136/bmjopen-2012-002408
18. Meijman, T., De Vries-Griever, A., De Vries, G., & Kamperman, R. (1985). *The construction and evaluation of an onedimensional scale measuring subjective sleep quality*. Groningen, The Netherlands.
19. Stansfeld, S., Berglund, B., Clark, C., Lopez-Barrio, I., Fischer, P., Öhrström, E., … Berry, B. (2005). Aircraft and road traffic noise and children's cognition and health: a cross-national study. *The Lancet*, *365*(9475), 1942–1949. https://doi.org/10.1016/S0140-6736(05)66660-3
20. Timpson, N., & Smith, G. D. (n.d.). About | Avon Longitudinal Study of Parents and Children | University of Bristol. Retrieved April 13, 2021, from http://www.bristol.ac.uk/alspac/about/
21. Guski, R., & Schreckenberg, D. (n.d.). NORAH - NORAH Website. Retrieved April 13, 2021, from http://www.laermstudie.de/en/
22. Maurice-Stam, H., Haverman, L., Splinter, A., van Oers, H. A., Schepers, S. A., & Grootenhuis, M. A. (2018). Dutch norms for the Strengths and Difficulties Questionnaire (SDQ) - parent form for children aged 2-18years. *Health and Quality of Life Outcomes*, *16*(1), 123. https://doi.org/10.1186/s12955-018-0948-1