Healthy development during preschool:
Examining the roles of outdoor time, light exposure and popularity.

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General Summary

Over the past century, developmental and prevention science has been concerned with finding the causes of poor health outcomes. Numerous studies have linked early experiences and life events with lifelong health and prosperity, and efforts across several scientific fields have started to disentangle protective and pathogenic pathways. This has led to new approaches to population-based interventions that have the potential to prevent diseases and optimize health.

Contemporary models highlight the importance of understanding health as a developmental process that continues throughout life and can be modified during developmental windows or by crucial events. Within this perspective, health is viewed as unfolding and resulting from multilevel, adaptive and bidirectional interactions between children and their physical and social environments. Healthy development occurs when there is harmony between biological, cultural, and psychological processes, and evolution has made health phenotypes malleable to enhance adaptability to the various environments that children may encounter.

Based on this framework, the present thesis examines protective factors in the physical and social environment of preschool, as well as how they relate to children's health status and development. In Papers I and II, we report our findings that exposure to daylight and the outdoor environment is associated with positive short- and long-term cognitive and behavioural outcomes. Paper III presents our results that children's social environments may play a role in the risk of attracting infectious diseases. We find that the associations between environmental protective factors and developmental outcomes are of a complex nature, with non-linear, dose-response influences operating on multiple levels.

List of Papers

- I. Ulset, V. S., Vitaro, F., Brendgen, M., Bekkhus, M., & Borge, A. I. H. (2017). Time spent outdoors during preschool: Links with children's cognitive and behavioral development. *Journal of Environmental Psychology*, 52, 69-80.
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Definitions

Table 1.

Operationalizations and definitions used in this thesis

Term	Definition
Behavioral development	* Teacher- and parent-reported symptoms of inattention and hyperactivity over time.
Circadian rhythm	One or several endogenous oscillators following a 24-hour cycle that regulates the sleep-wake cycle and a range of other biological functions.
Cognitive development	* Scores on the digit span test across time.
Daycare (centre)	A place for non-parental care of young children, typically while parents are at work. Also known as kindergarten and preschool.
Early childhood	The developmental period spanning from age 3 through 7 years.
Executive function	Children's ability to pay attention, maintain focus on tasks, self-monitor, regulate emotions, and inhibit impulses.
Hyperactivity symptoms	Excessive movement, restlessness, and fidgeting.
Inattention symptoms	A style of behavior that involves little organization and low persistence.

Interdaily stability	A measure of stability of children's activity rhythms over the course of 14 days. Used in this thesis as a proxy for circadian rhythms.
Light exposure	* The duration, dosage, and intensity of light (lux) to which children are exposed during the day and night.
Outdoor time	In this thesis, outdoor time refers to the number of hours that children spend outdoors in preschool daily.
Physical environment	* The outdoor versus indoor environments of the day care centres in our studies, including environmental light exposure and nature-based versus conventional daycare.
Popularity	Children who are influential and accepted by their peers.
Preschool children	Children who attend daycare, typically between 1 and 6 years of age.
Protective (factor)	A developmental event or characteristic in the child or the environment that decreases (i.e., moderates) or compensates for the risk of an unwanted outcome.
Risk (factor)	A developmental event or characteristic in the child or the environment that increases the likelihood of an unwanted outcome.
Social environment	* This encompasses peer-perceived popularity status, family functioning, and socioeconomic status.
Working memory	* A child's score on the digit span test is a measure of working memory.

* Aspects of the concept that are dealt with in this thesis.

Introduction

More than 90% of Norwegian children commence daycare in early childhood as their parents return to the labor market (Bell, Donkin, & Marmot, 2013). The effects of daycare have been extensively demonstrated and play an important role in establishing trajectories of lifelong health, as well as in preparing children for formal school (Burger, 2010; Vermeer & van IJzendoorn, 2006). Universally available daycare may also help compensate for socioeconomic risk factors (Zachrisson & Dearing, 2015). There is a rapid growth and development in early childhood that makes children more susceptible to influences in their social and physical environment (Rose, 2001). Thus, there is an increasing understanding that efforts to promote health and development should target children universally in early childhood, be cost-effective, and be implemented where people live their daily life rather than in health care institutions (Halfon, Forrest, Lerner, & Faustman, 2018; Holte, 2012). As such, universally available daycare offers an important setting for identifying risk and protective pathways that may have implications for parents, teachers, prevention scientists, and policymakers.

In the traditional biomedical and biopsychosocial model of health that has dominated the field over the previous century, risk factors' influence on health outcomes has been assumed to operate in a simple, mechanistic, and linear manner. However, successful health development is a consequence of multiple genetic, molecular, behavioral, evolutionary, social, and biological circumstances (Halfon & Hochstein, 2002). Recently, health development has become understood as a complex adaptive process that emerges from the interaction between living systems and events in their environments (Halfon & Forrest, 2018), meaning also that the developmental timing (Kuzawa & Thayer, 2011) of environmental influences should be taken into account.

Both the timing and rhythm of developmental events may be important for health and development. Biobehavioral regulatory systems may be especially susceptible to programming by exposure to risk and protective factors during developmental windows or sensitive periods (Halfon & Hochstein, 2002), and disturbances in biological rhythms are associated with a range of mental and somatic health problems and diseases (Wulff, Gatti, Wettstein, & Foster, 2010), including attention deficit hyperactivity disorder (ADHD; Bijlenga, Vollebregt, Kooij, & Arns, 2019). New advancements in statistical analysis now make it possible to take these temporal rhythms into account (Blume, Santhi, & Schabus, 2016). The associations between risk and protective factors and developmental outcomes may also be bidirectional, operating across multiple levels (i.e., from molecular to historical). For example, popular children may receive more support from their teachers, which in turn predicts higher levels of popularity (De Laet et al., 2014). There may also be dose-response or threshold associations. For example, there is a radical improvement in health and mortality that occurs when socioeconomic risk and protective factors surpass a certain quantitative limit (i.e., the limit of poverty; Wolf, Feinglass, Thompson, & Baker, 2010). However, a dose-response association may also occur between higher levels of socioeconomic status. For example, those at the highest level are typically more healthy than those just below (Adler et al., 1994).

Since cognitive, behavioral, and social skills, as well as immune functioning, are under particularly rapid reorganization and increases in complexity during the preschool years, they may be especially susceptible to influences in the environment (Scott, 1986). The three papers in this dissertation examine protective factors (i.e., something that reduces the effects of risk or illness) in the everyday physical and social environment. We use a variety of novel methodological and statistical approaches to examine the complexity of associations between

potential protective factors and indicators of mental and somatic health development. The three papers consider the complexity of relationships between variables, such as timing effects, biological rhythmicity, dose-response links, multiple levels of influence, bidirectional relations and social network structures. Within this framework, the scope of this thesis is to examine environmental protective factors in the context of preschool, focusing on the time children spend outdoors, exposure to environmental light, and children's popularity among their peers.

The Nordic daycare context

Nordic daycare centers place a larger emphasis on the outdoor natural environment than those in other countries. In their paper, Borge, Nordhagen, and Lie (2003) suggest that Norwegians in particular have a strong attachment to nature and a preference for outdoor activities. The typical Norwegian parent seems to have a strong belief that healthy and happy children play outside in green and natural environments. The outdoors offers children opportunities for new friendships, collaborative play, physical activity, and learning how to thrive and “survive” in the rough Nordic weather and seasons. There is also a widespread egalitarian belief that nature is for everyone. For example, the traditional right of access to all forests, mountains and beaches is regulated by law, independent of land ownership. These beliefs have led to a practice in Norwegian daycare centers where children spend at least a few hours outdoors each day, irrespective of weather and season. Some centers even spend the whole day outdoors throughout the whole year, only using primitive traditional shelters to have lunch and stay warm when the weather is too rough. Thus, Norwegian daycare centers reflect the belief that the social and outdoor environment is important for children's health and well-being. However, little quantitative empirical data exists regarding how this unique

social and environmental context may affect children's social, cognitive, and behavioral development.

The natural environment

Time spent outdoors in nature

Empirical evidence suggests that the time children and adults spend outdoors in nature is beneficial for their short-term well-being and buffers against mental health problems (Cameron-Faulkner, Melville, & Gattis, 2018; Chawla & Nasar, 2015). For example, there is experimental evidence showing that exposure to natural outdoor environments improves verbal communication (lexical and grammatical complexity) between parents and their preschool children (Cameron-Faulkner et al., 2018). Exposure to natural environments is associated with enhanced psychological well-being (Wells & Evans, 2003), improved attachment relationships in high-risk adolescents (Bettmann & Tucker, 2011), and enhanced cognitive performance (Berman, Jonides, & Kaplan, 2008a). The influences of the outdoor natural environment on children's cognitive and behavioral functioning seems to be highly multifactorial, and several mechanisms have been proposed (Chawla & Nasar, 2015). For example, the outdoor environment offers opportunities for unrestricted play and physical activity (Copeland, Khoury, & Kalkwarf, 2016), fresh air, learning experiences (Maynard & Waters, 2007), attention restoration (Ohly et al., 2016), and daylight exposure (Ancoli-Israel et al., 1997). In turn, exposure to these elements may protect against a host of health problems (Pate et al., 1995; Pattinson, Allan, Staton, Thorpe, & Smith, 2015).

Daylight exposure

The light that children are exposed to in outdoor environments (i.e., sunlight) is up to 200 times stronger than indoor lighting (Dharani et al., 2012). Experimental animal studies have demonstrated that high levels of daylight during sensitive periods in early life decreases

the risk of inattentive-hyperactivity-like symptoms in adulthood (Koshiha et al., 2015). A similar link has been observed in humans, since the prevalence of attention-deficit/hyperactivity-disorder (ADHD) is lower in geographical areas with high levels of sunlight exposure (Arns, van der Heijden, Arnold, & Kenemans, 2013). Daylight is the principal cue for biological rhythms entrainment in all species (Cao et al., 2015) and is implicated in endocrine (Middleton, Arendt, & Stone, 1997; Scheer & Buijs, 1999), metabolic (Pattinson et al., 2015; Reid et al., 2014), circadian (LeGates, Fernandez, & Hattar, 2014), and cognitive functioning (Cajochen, 2007; Vandewalle, Maquet, & Dijk, 2009).

For example, light exposure has effects on attention and alertness that are similar to those of pharmacological stimulants used in the treatment of ADHD (Cajochen, 2007). Environmental light is also the principal cue for biological and circadian rhythms entrainment (Cao et al., 2015), and of those children who struggle with inattention and hyperactivity symptoms, up to 80% suffer from delayed circadian phase and delayed melatonin peak (Van der Heijden, Smits, Someren, & Boudewijn Gunning, 2005; Van Veen, Kooij, Boonstra, Gordijn, & Van Someren, 2010). Taken together, these findings suggest that exposure to light and outdoor environments may be beneficial for biological rhythms, cognitive functioning, and symptoms of inattention and hyperactivity. However, very little is currently known about these links in the context of preschool or whether there are long-term connections with children's development.

The social environment

Social determinants are a major source of health inequalities (Marmot, 2005). The literature has focused heavily on social risks such as socioeconomic status (Adler et al., 1994; Demakakos, Nazroo, Breeze, & Marmot, 2008; Dowd, Zajacova, & Aiello, 2009), social

support (Holt-Lunstad, Smith, & Layton, 2010), access to health services (Lu et al., 2004), and environmental hazards (Adler & Newman, 2002). However, animal studies suggest that there may also be more direct bidirectional influences between the immune system, social status, and health (Cole, 2014; Irwin & Cole, 2011; Sapolsky, 2005). The social dynamics of non-human primates, such as the chimpanzee, are characterized by a social hierarchy in which some individuals behave as subordinate to higher-ranking individuals (Shively & Wilson, 2016). These dominance-subordination relationships are often maintained by aggression from the dominant party, and the stress related to being “subordinate” or unpopular can become chronic, leading to a range of health problems, including increased susceptibility for infection (Snyder-Mackler et al., 2016).

In parallel to the social dynamics of nonhuman primates, social exclusion is extremely common among children attending preschool (Fanger, Frankel, & Hazen, 2012). Physical aggression occurs frequently, especially when dominance relationships are established at times of transition (e.g., start of preschool, transition to school, rearrangement of groups; Roseth, Pellegrini, Bohn, Van Ryzin, & Vance, 2007). Preschool attendance is associated with increased cortisol (Vermeer & van IJzendoorn, 2006), especially at times of transition (Groeneveld et al., 2013; Parent et al., 2018) and among children who are perceived by their peers as unpopular (Gunnar, Sebanc, Tout, Donzella, & van Dulmen, 2003). Analogous to the findings from animal studies, it is possible that strong social hierarchies among children attending preschool can lead to similar health problems. Infectious diseases are among the most common health issues in preschool (Côté et al., 2010), and the development of the immune system is especially influenced by disease ecology during this time (McDade, 2005). Despite the importance of early childhood for children’s immunological and social

development, little attention has been paid to the potential associations between children's popularity and health status during preschool.

Theoretical perspectives

Complex systems theory

Over the previous century, mechanical models were used to understand health. The body was viewed as a machine that may break down and cause sickness. This led to a reductionist ontology to research and practice, where the goal was to identify the smallest observable parts that constitute an illness. The reductionist conception has led to unifactorial notions such as the idea that depression is caused by a chemical imbalance in the brain (Leo & Lacasse, 2008), that biological mechanisms have a one-way deterministic influence on psychological processes, or that single genes are responsible for causing complicated diseases (Huang, 2012). Such beliefs are heavily rooted in what has been dubbed the Cartesian-split-mechanistic scientific research paradigm (Overton, 2015), which posits a supernatural split between the natural world and the mind.

Over the past few decades, developmental science and other fields such as physics, biology and psychology have shifted from a Cartesian ontology to a complex systems ontology (Lerner, 2012). From this perspective, health is considered a consequence of multiple genetic, molecular, behavioral, evolutionary, social, and psychological circumstances (Halfon & Hochstein, 2002). Recent developmental theories emphasise process and complexity, viewing organisms as having agency and being self-organizing and self-regulating. Secondly, responses to environmental influences are nonlinear, complex, and adaptive (Overton, 2015). Thirdly, multiple levels of influence (molecular, cell, psychology, family, society, culture, history, and evolution) interact to produce health and development.

Thus, health is not merely the presence or absence of symptoms, but a developmental process involving multiple layers of bidirectional influences.

Adaptive mismatch between historical and modern contexts

The evolutionary perspective assumes that natural selection has shaped the cognitive and behavioral mechanisms of our species, and that these adaptations enhance survival and reproduction (Darwin, 1859). In light of this, health problems may be viewed as an adaptive response to harmful environments (such as exposure to pathogens or experiences of hostility) or a specialization of the mind to some types of environments, at the cost of a greater mismatch with another type of environment (Jensen et al., 1997). Over the previous 10 millennia, there have been striking changes in human society and culture. Anthropologists have proposed that the cultural advancements in humanity have happened so quickly that evolution has been unable to keep up, resulting in several mismatches between the hard-wiring of human physiology and the environment (Jensen et al., 1997).

For example, in contrast to modern humans, our ancestors spent more time in the natural outdoor environment, foraging for food. Some health issues, including inattention and hyperactivity symptoms, sleep problems, and the social gradient in infectious diseases may result from a mismatch between environmental demands of modernity and the more “primal” historical context in which our minds developed. For example, some children have a strong propensity for rough and tumble play (Pellis & Pellis, 2007). These explorative and hypervigilant behaviors in children may be propensities selected for during the evolution of childhood to facilitate learning and development in a more rugged environment. However, the demands of childhood have changed in modern times, and other skills such as sustained attention and self-regulation are required to cope with the formal school setting. In such

constrained settings, some children's propensities for rough and tumble play may come across as inattention and hyperactivity symptoms (Jensen et al., 1997).

Another mismatch that pertains to childhood exists between the invention of artificial light and the strong coupling of light exposure to circadian processes (Wyse, Biello, & Gill, 2014). Ironically, the availability of artificial light has led humans to do more work, school, and leisure activities indoors, meaning that modernity has caused a reduction in exposure to outdoor daylight (Wright Jr. et al., 2013). Outdoor daylight is up to 200 times stronger in intensity (lux) compared to typical artificial indoor lighting. The intensity, timing and regularity of daylight exposure has acute effects on cognitive functioning (Rautkylä, Puolakka, & Halonen, 2012) and is important for the entrainment of the human circadian clock. In turn, irregular circadian timing is associated with a range of diseases and increased risk of mortality (Zuurbier et al., 2014).

A third possible mismatch lies between the safety of the modern educational context and the tendency of the immune system to down-regulate immune functioning in the face of social threats (Cole, 2014). Children have historically faced a high risk of being attacked by predators when they are excluded or separated from their herd. The conserved transcriptional response to social adversity hypothesis posits that the immune system therefore reacts to social exclusion with a down-regulation of the antiviral defense and an up-regulation of pro-inflammatory gene expression (Irwin & Cole, 2011). The up-regulation of inflammation prepares the body for the possible tissue damage that may result from being attacked and injured by predators or enemies. In modern daycare centers, children are at high risk of both contracting infections (Côté et al., 2010) and experiencing social exclusion (Bonica, Arnold, Fisher, Zeljo, & Yershova, 2003). However, the risk of being attacked and wounded by predators is extremely low, meaning that an immune response that prepares the body for

tissue damage may not be necessary. Instead, when chronically elevated, pro-inflammatory responses may instead cause serious health problems (Eaton et al., 2002).

Attention restoration theory

Another theory that draws attention to the matches and mismatches between children and their surroundings is attention restoration theory (Kaplan, 1995). The theory posits that an experience of compatibility arises when there is a good match between the activities encouraged by an environment and the inclinations and developmental drives of the child. For example, there may be a good match between a child's propensity for rough and tumble play and the unrestricted natural outdoor environment, as it welcomes highly active behavior. According to attention restoration theory, environments that allow the child to take on primal roles such as hunting and fishing, hiking, and making bonfires, are a good match for our deep-rooted inclinations for learning how to survive.

Specifically, Kaplan suggested that when there is a good fit between the inclinations of a person and the environment, attention operates with little effort, and the shared repository for executive attention and self-regulation is allowed to rest and "recharge" from use (Kaplan & Kaplan, 1989). One hypothesis derived from this theory is that children who spend most of their daily time outdoors in nature will benefit from attention restoration such that their attention skills and self-regulatory skills are enhanced, and inattention and hyperactivity symptoms may even be alleviated. There may also be long-term links between exposure to nature and cognitive development, because executive attention is a prerequisite for higher-level cognitive functions such as learning and reasoning (McCabe, Roediger III, McDaniel, Balota, & Hambrick, 2010).

Developmental switches

Environmental risk and protective factors would have an enhanced influence on health and development if they targeted endocrine or immunological mechanisms that have the power to shift between developmental trajectories. Evolutionary theories of development predict the existence of developmental switches that can trigger the development of a certain phenotype (West-Eberhard, 2003). Based on input from the body and the external environment, developmental switches may shift development along alternative pathways, resulting in multiple phenotypes (Del Giudice, Gangestad, & Kaplan, 2015). Certain phenotypes may increase the likelihood of survival and reproduction in particular environments. For example, the development of aggressive or submissive traits may be adaptive in an environment with high risk for being physically assaulted (Kaplan & Gangestad, 2005). Within a developmental switch perspective, early experiences of a hostile environment would trigger the development of a latent aggressive phenotype in the individual, mediated by the activation of a coordinated expression of different genes (DelGiudice, 2018).

It has been proposed that the endocrine systems (e.g., cortisol) play a key role in triggering the development of phenotypes, because the HPA-axis integrates and interprets crucial survival information from environmental factors such as threatening social and non-social situations (Del Giudice et al., 2015). Daycare attendance may be such a social situation, and it has consistently been linked with increases in children's cortisol levels (Groeneveld et al., 2013; Vermeer & van IJzendoorn, 2006). Studies of humans and animals suggest that these elevations in cortisol may be explained by the separation from primary caregivers (Feng et al., 2011). However, researchers have also found higher cortisol levels for those children who often experience social exclusion and dominance by peers in daycare (Gunnar et al., 2003). From an evolutionary perspective, early experiences of social rejection and dominance

may trigger the development of phenotypes that would increase fitness in a strongly hierarchical society or in a society with high risk of being attacked and injured by enemies or predators. In that regard, the conserved transcriptional response to adversity may operate as a developmental switch by allocating developmental resources to either growth or immunological defense towards infectious agents (McDade, 2005).

Empirical findings on health development in the preschool context

Symptoms of inattention and hyperactivity

Inattention and hyperactivity symptoms are among the most common psychosocial problems during preschool (Wichstrøm et al., 2012). Inattention and hyperactivity symptoms are the core symptoms of ADHD, which is a highly heterogeneous condition involving multiple levels of etiology, including genetic, perinatal, postnatal and environmental influences (E. Taylor & Sonuga-Barke, 2008). ADHD has a particularly strong genetic component, with a heritability of approximately 74% (Faraone & Larsson, 2019). The heritability that is observed for ADHD may be the result of both additive and interaction effects involving multiple genetic and environmental causes (Neale et al., 2008). ADHD is also associated with early emerging alterations in cortical development (Shaw et al., 2006), in the right frontal-striatal circuitry, and the cerebellum (Bush, 2011).

This dissertation focuses on inattention and hyperactivity symptoms on a dimensional scale, and the terms *symptoms* and *disorder* are used cautiously. Inattention and hyperactivity symptoms are common in young children, and the stability of these symptoms in the youngest children is low (Gardner & Shaw, 2008). Thus, symptoms of inattention and hyperactivity may or may not be manifestations of ADHD. Since there is a rapid pace of maturation and

cognitive development starting at birth and continuing throughout the preschool years, it is challenging to distinguish normal from abnormal behavior. Approximately half of children who exhibit behavioral problems in early childhood will outgrow these problems (Borge, 2018; Campbell, Shaw, & Gilliom, 2000). Moreover, approximately half of the children who exhibit inattention and hyperactivity symptoms also exhibit comorbid symptoms of some other disorder (Egger & Angold, 2006). Accordingly, the etiology of behavioral problems may be similar to the etiology of ADHD. Arguably, however, the high rates of comorbidity may be seen as a reason for caution in using a diagnostic approach in studies of developmental psychopathology in preschool-aged children (Gardner & Shaw, 2008).

The phrase “symptoms of inattention” refers not to the mental processes that are assessed by tests of attention (such as the digit span test) but rather a style of behavior that involves little organization and short persistence (Taylor & Sonuga-Barke, 2008). In early childhood, inattention manifests as a tendency to engage in short sequences of play, not completing activities, and not listening to caregivers. Clinically, the symptoms of inattention continue to persist with age, while those of hyperactivity and impulsivity often become less pronounced. Hyperactivity symptoms are usually the most salient of the two problems during the preschool years. These symptoms include excessive movement, restlessness, and fidgeting.

Since inattention and hyperactivity symptoms are common, and have substantial implications for self-regulation, and are often associated with a range of health outcomes in adulthood, inattention and hyperactivity symptoms are also an important part of children’s normal health development. Problems with inattention and hyperactivity typically emerge in early childhood. These difficulties may continue throughout childhood and into adulthood, through academic underachievement, conduct problems, anxiety, depression, and marital

problems (Biederman, 2005; Masten et al., 2005). Those children who go on to develop ADHD are at greater risk of morbidity and mortality from several adverse health outcomes, including drug abuse and smoking (Charach, Yeung, Climans, & Lillie, 2011), accidental injuries (Merrill, Lyon, Baker, & Gren, 2009), sleep problems (Van Veen et al., 2010), obesity (Cortese & Peñalver, 2010), hypertension (Fuemmeler, Østbye, Yang, McClernon, & Kollins, 2011), diabetes (Levitt Katz et al., 2005), and suicidal behavior (Birmaher, Brent, & Benson, 1998). Some studies have found that ADHD is associated with a doubling of medical costs (Guevara, Lozano, Wickizer, Mell, & Gephart, 2001; Leibson & Long, 2003).

Executive functions

Theories of cognition and cognitive development typically involve an executive module that is in charge of organizing goal-directed behavior (Baddeley & Hitch, 1974; Best & Miller, 2010; Posner & DiGirolamo, 1998). Two different concepts have been used interchangeably in the literature, namely working memory and executive function. The tasks of working memory and executive function involve directing, sustaining, and shifting attention, as well as inhibiting automatic responses or impulses (Wongupparaj, Kumari, & Morris, 2015). Tests of working memory and executive function are strongly correlated. Both tap into an underlying attention capacity that is crucial for cognition (McCabe et al., 2010). In Baddeley's conceptualization, working memory is divided into the subcomponents of a central executive and its two "slave" components: the visuospatial sketch pad and the phonological loop (A. Baddeley, 1992). The digit span test is commonly used to assess the capacity of the phonological loop to retain auditory information (Lezak, Howieson, Loring, & Fischer, 2004), while the forward digit span task taps into the efficiency of attention (i.e., undistracted attention), rather than short-term memory (Kaufman, McLean, & Reynolds, 1991).

The development of executive function accelerates rapidly during early childhood (Doman, 2008; Sattler, 2008). Around the age of 4 years, the working memory system typically enters into a spurt of development that lasts until the age of 7, which is accompanied by a corresponding growth of the prefrontal cortex (Tsujimoto, 2008). The development of executive functions lies at the core of cognitive development, involving cognitive processes such as attention, inhibitory control, and working memory (Lezak et al., 2004). These skills are crucial for children's ability to think, concentrate, inhibit their impulses, and control their emotions. In other words, executive functions are crucial for self-regulation (Hofmann, Schmeichel, & Baddeley, 2012). In turn, self-regulation is strongly associated with health development, social functioning, and academic and occupational achievement across the life span (Baumeister & Vohs, 2004; Moffitt et al., 2011). Due to being bidirectionally associated with health-promoting behaviors, such as physical activity, and avoidance of health risk behaviors, such as smoking (Allan, McMinn, & Daly, 2016), executive functioning is interdependent with disease processes. The development of executive functions during the preschool years plays an important role in preparing children for school, and high-quality preschool care is linked with positive outcomes in children's cognitive development (NICHD Early Child Care Research Network, 2000).

Children's popularity

Popularity typically refers to a child's sociometric status within their group of peers, sociometric status being a type of measurement that asks children to nominate who they like and dislike (Perren & Alsaker, 2006). Theoretically, children's social competence and cognition emerges at 3 years of age (Bartsch & Estes, 1996). Thus, preschool is the period when most children make their first friends, establish a social reputation, and have their first experiences with social inclusion and rejection (Black & Hazen, 1990; Dunn & Cutting, 1999;

Lippitt, 1941; Roseth et al., 2007), all of which are important for children's level of popularity (Rubin, Bukowski, & Bowker, 2015). However, the literature agrees that while friendships are characterized by a reciprocal affection and regard for one another, as well as a mutually beneficial cooperation and negotiation (Bukowski, Newcomb, & Hartup, 1996), popularity is a separate construct describing children who are highly impactful and accepted by their peers (Siegler, DeLoache, & Eisenberg, 2003). Those children who are rated as popular by their peers seem to remain so over the course of months (Walker, 2009). However, as years go by, popularity status is highly likely to change by regressing towards the mean (Newcomb & Bukowski, 1984). There seems to be an exception for those children low in popularity who are also rejected by their peers, as the stability for this status is higher, and the rate of rejection may also increase over time (Rubin, Bukowski, & Parker, 1998).

There is a strong social gradient in the morbidity and mortality of almost all health problems (Adler et al., 1994; Adler & Newman, 2002). In fact, the quality of social relationships is a stronger predictor of mortality than smoking, alcohol consumption, and physical activity (Holt-Lunstad et al., 2010). In adults, subjective social status is associated with an increased risk of depression, hypertension, diabetes, obesity, and high cholesterol (Demakakos et al., 2008). However, very little is known about the consequences of childhood sociometric status for children's health development. Since social status may operate via immunological processes to influence infection susceptibility (Eisenberger, Moieni, Inagaki, Muscatell, & Irwin, 2016), and children are more likely to acquire infections when they attend daycare centers (Côté et al., 2010), sociometric popularity may also affect children's health, particularly during preschool.

General aim

The general aim of this dissertation was to examine protective factors in the physical and social environment that have the potential for promoting children's healthy development and preventing health problems. Using data from Norway and Australia, the three papers in the thesis examine a variety of potential protective factors and their relationship to important indicators of health development during preschool, such as behavioral, cognitive, and social development. These outcomes have the potential to affect developmental switches via endocrine or immunological pathways (Del Giudice et al., 2015) and are linked with health development throughout the lifespan (Cowan, 2014; Dowd et al., 2009; Kinge, Sælensminde, Dieleman, Vollset, & Norheim, 2017; Masten et al., 2005; E. Taylor & Sonuga-Barke, 2008). In accordance with a life-course health-development framework (see Figure 1), we consider health as a consequence of a complex interplay between multiple behavioral, evolutionary, social, and biological circumstances (Halfon et al., 2018). The current dissertation contemplates multiple levels of children's circumstances and the complex links among them, such as linear and nonlinear dose-response relations, timing effects, rhythmicity, interactions, network structures, developmental trajectories, and bidirectional influences between multiple levels (i.e., from micro to macro level).

Figure 1.

Simplified conceptual figure of health development, illustrating the concepts in the thesis.

P1 (Paper 1), P2 (Paper 3), P3 (Paper 3) refer to the paper in which the variables were used.

Aims of the Study

Using a variety of study designs, samples, measures, and statistical approaches, the aim of the present dissertation was to examine links between socioenvironmental predictors in preschool and indicators of children's health and psychosocial development in early childhood. We used prospectively collected data from two longitudinal studies from Norway and Australia that are well suited to explore how social experiences and exposure to different natural and physical environments in preschool may be linked with children's health and development. The target population is children aged 3 to 7 years who attend non-parental day care in a variety of preschool centres. A multi-informant approach was applied, using parent reports, teacher reports, cognitive testing, and objectively measured light exposure. We analyse this data using social network analysis, time series analysis, multivariate regression, autoregressive cross lagged analysis, and multi-level mixed model analysis. The specific aims for each paper are discussed in the next section.

Paper 1

The first paper determined whether the time devoted by 28 daycare centres to outdoor activities was associated with children's concurrent and prospective working memory and symptoms of inattention-hyperactivity. There is growing evidence supporting a positive link between exposure to natural outdoor environments and children's attention skills. However, most studies use cross-sectional designs and small samples, do not control for possible confounding variables, and no studies have reported whether the link between outdoor time and children's cognitive and behavioural development is linear or nonlinear, takes the form of a dose-response relation, or if the benefits of outdoor time diminish when the children commence school. Thus, the aim of this study was to ascertain if there is a dose-response relation between the time that children spend outdoors and their development of inattention-

hyperactivity symptoms and working memory between 3 to 7 years, net of a host of possible confounding factors.

Paper II

The first paper suggested that children who spend long durations of time outdoors in early childhood may have better working memory and be at decreased risk of developing symptoms of inattention and hyperactivity. Children who are outdoors for long periods are exposed to higher intensities of daylight for longer durations of time than children who stay indoors, since the intensity of outdoor light exposure is up to 20 times stronger than indoor lighting. Light exposure has alerting and timing effects on circadian rhythms, which in turn are strongly associated with ADHD. However, children's physical activity levels, sleep quality, or circadian rhythmicity may also affect inattention-hyperactivity symptoms over and beyond the impact of light-exposure. Thus, the aim of the second paper was to examine whether the timing, duration, and intensity of objectively measured light exposure was linked with parental reports of children's inattention and hyperactivity symptoms, both concurrently and prospectively, while controlling for children's sleep habits and physical activity levels.

Paper III

Lastly, the third paper explored whether social experiences in preschool may be linked with children's physical health. Animal studies and studies in human adult populations indicate that social stress and the immune system are strong regulators of one another. Low social status increases the risk of contracting an infectious disease, while infection is associated with a number of subsequent mental, somatic, and social outcomes. Children who attend daycare centres are at a twofold risk of contracting infections. This is also a time when children have their first social experiences of peer rejection and inclusion. However, no research exists regarding links between social dynamics and infectious diseases in early

childhood. There may be self-reinforcing cycles between social status and health causing upwards and downwards “spirals” in children’s development. Thus, this study intended to determine if there are bidirectional dose-response associations between children’s popularity as perceived by their peers and the frequency of six infectious diseases that commonly occur in preschool.

Methods

Design

Paper I and III

In paper I and III we used data from the *The Matter of The First Friendship Study* (Eivers, Brendgen, Vitaro, & Borge, 2012), which is a large, prospective, multi-informant study investigating the importance of peer relations in preschool for subsequent health and psychosocial adjustment. *The Matter of The First Friendship Study* gathered information from children’s families, from teachers in preschool and school, and from children themselves. At each of the four annual assessments, children were tested and interviewed, while teachers and parents responded via mailed questionnaires. The study was funded by a grant from the Norwegian Research Council (grant 142592, 170560/V50), while ethical approval was obtained from the Norwegian Data Inspectorate and the Norwegian Regional Ethics Committee.

Paper II

The data that was used in paper II was obtained from *The Sleep in Daycare Study* (Pattinson et al., 2015; Pattinson, Staton, Smith, Sinclair, & Thorpe, 2014), which is a two-wave prospective study carried out in Brisbane, Australia, in 2012 and 2013. The original purpose of this study was to investigate whether compulsory sleep in preschool had any

adverse or positive effects on children's night time sleep, behavior, health and well-being. This study was part of a larger study (E4Kids Study) that comprised a total of 300 preschool centers. *The Sleep in Daycare Study* comprise objective information about children's sleep, activity and environmental light exposure using two weeks continuous actigraphy recordings at baseline. Concurrently and at 12 months follow up, parents completed sleep diaries and questionnaires about children's health and behavior. At baseline and follow up, the researchers visited each of the seven daycare centers to measure the children's height and weight, and to observe the daily routine and environment. Parents were mailed a 14-day sleep diary, an Actiwatch 2 (MiniMitter Phillips) device, and the parent survey. The study was funded by a grant from the Financial Markets Foundation for Children in Australia (grant 2012-213). Ethical clearance was obtained from the Queensland University of Technology's Human Research Ethics Committee.

Table 1.

Longitudinal design

Year	Source	Informants	Age
2006	Daycare center	Child, parents, teachers	2 - 6
2007	Primary school or day care center	Child, parents, teachers	3 - 7
2008	Primary school or day care center	Child, parents, teachers	4 - 8
2009	Primary school or day care center	Child, parents, teachers	5 - 9
2011	Daycare center	Managers	

Participants

Paper I and III

The recruitment for *The Matter of the First Friendship* study began in 2006, and the 562 participating children attended one of the 33 day-care centres in two semi-rural municipalities just outside Oslo, Norway. Out of the 1507 children residing in one of the two municipalities that were born between 2000 and 2005, a total of 996 children (63 %) were eligible to participate since they attended one of the day-care centres. The parents of 619 children (62 %) agreed to participate by giving their active, informed and written consent. At baseline, 47 % of the sample consisted of boys, while children's age ranged from 11 to 77 months ($M = 52.45$, $SD = 15.96$). We did not keep track of the racial or ethnic background of the participating families, meaning that this statistic is unavailable. Following the first assessment in 2006, participants were followed annually for a period of four years (see Table 1). At the second assessment, a total of 128 (22.8 %) of the participating children had attended one of the 13 schools for 1 year. At the third assessment, 278 (49.5%) of the children had commenced school, while at the fourth and final assessment, a total of 396 (70.4%) had commenced school.

Due to variation in daycare center size (ranging from four to 100 children) there was considerable variation in the maximum number of nominations that each child could potentially receive. To account for this confound, we standardized popularity scores based on the sizes of their social networks. As illustrated in Figure 1, we used community detection (Clauset, Newman, & Moore, 2004) to identify group sizes. This is similar to the procedure used by in similar studies where the size of social networks are not given by structural indicators such as classroom size (Perren & Alsaker, 2006).

Table 2.

Overview of participation in Study I and II

Assessment	Year	n	P	T	C	Study I		Study II	
						<i>Base</i>	<i>Used</i>	<i>Base</i>	<i>Used</i>
First wave	2006	610	583	509	478	555	509	-	-
Second wave	2007	561	462	529	522	532	524	549	386
Third wave	2008	550	417	472	524	533	405	543	404
Fourth wave	2009	523	339	471	491	516	253	507	330

Note. n = any participation, P = parent participation; T = teacher participation; C = child participation; Base = participants with response on any study variable; Used = participants that were included in analysis.

Norway and the other Nordic countries offer extensive paid parental leave, enabling parents to stay at home with their child for up to one year (Henrik Daae Zachrisson, Janson, & Nærde, 2013). Daycare is subsidized in Norway and high quality care is universally available for all families (Adamson, 2008; Henrik Daae Zachrisson et al., 2013). Consequently, there is a high proportion of children attending daycare in the Nordic countries.

Figure 2.

Result of community detection at Time 1.

Paper II

The recruitment for *The Sleep in Daycare* study began in early 2012, while data were collected during the Australian spring and summer (October – December), ending on the 14th of December, 2012. Participating daycare centers were recruited from a pool of 118 centers that were participating in the Effective Early Educational Experiences for Children (E4Kids) Study in Queensland, Australia (Tayler, Ishimine, Cloney, Cleveland, & Thorpe, 2013). Within each daycare center, one room caring for children within the preschool age range (3 – 5 years) was recruited. The managers of 7 daycare centers, all located in high socio-economic status areas, and the parents of 62 children agreed to participate by providing their active,

informed written consent. The children gave their assent to participate in the study. At baseline, complete data was obtained from 49 (79.0%) children. At baseline, 48 % of the sample consisted of boys, while children's age ranged from 45 – 64 months ($M = 56.49$, $SD = 4.89$). At the second assessment, data was obtained from 43 children (22 boys), giving an attainment rate of 88 %.

Measures

Paper I

Inattention and hyperactivity

At each assessment, teachers completed the Strengths and Difficulties Questionnaire (Goodman, 2001; Heiervang, Goodman, & Goodman, 2008). While the children were in preschool (ages 3 – 6), the questionnaires were completed by preschool teachers, while at age 7 the questionnaires were completed by the elementary school teachers who had then known the children for at least one year. The Strengths and Difficulties Questionnaire is a brief behavioral screening tool that measures ADHD-symptoms, emotional problems, conduct problems, prosocial behavior and peer problems in children. Teachers reported about the child's behavior over the previous few months. Inattention symptoms were assessed by the two items 1) *easily inattentive and has poor concentration*, and 2) *completes tasks, has good concentration*, while hyperactivity symptoms were assessed by the three items 1) *restless, overactive, cannot keep still*, 2) *squirmy, fidgety*, and 3) *quickly changes from one activity to the other*.

Digit span

Children's working memory was assessed at each data collection, using the digit span test, which is a subtest of the Weschler Intelligence Scale for Children (WISC-IC). During the

child interview, that took place in a separate and quite room, children were asked to repeat number sequences that were read out loud by the trained interviewers. The digit span test consists of two subtasks, one in which the children are asked to repeat the numbers in the same order as read by the interviewer (forward digit span), and one in which the children are asked to repeat the numbers in backwards order (backwards digit span). Only the forward digit span was used in the present study, since the youngest children consistently failed at the more difficult digit span backwards task, yielding to little variance.

Background variables

In order to account for the possibility of confounding by third variables of the associations between outdoor time and the outcomes, we controlled for a host of different background variables concerning child, family and daycare center characteristics.

Child characteristics

Children's temperament was reported by parents at the second assessment, using the Toddler Temperament Scale (Carey & McDevitt, 1978). Children's gender and age in months were reported by parents at each assessment.

Family characteristics

Socioeconomic status (SES) comprised parent reports at the first assessment about the income levels and education of both mothers and fathers. Education levels ranged from junior high school to higher university degree, while income levels ranged from no income to more than NOK 500 000 (approximately USD 77 000). The mean of the four variables were calculated to provide a composite SES score. Information about *parent's recent psychological health* was reported by parents themselves at the first assessment, using an eight-item version of the Hopkin Symptom Checklist (Strand, Dalgard, Tambs, & Rognerud, 2003). *Family*

harmony was measured at the first assessment, using the Family Harmony scale from the Ontario Child Health Study (Côté, Borge, Geoffroy, Rutter, & Tremblay, 2008). The questionnaire was completed by parents, and probed for interpersonal support, emotional climate and conflict resolution in the family. *Parent's own inattention-hyperactivity symptoms as a child* comprise the same items measuring inattention-hyperactivity symptoms in children, however parents were instructed to give their answers based on their own behavior when they were a child. This information was obtained at the fourth and final assessment. Information about *family use of nature* was gathered at the first assessment from the parent questionnaires. Parents were asked how often they spend time in the forest, park or mountains with the child, and how often they spend time in nature by themselves.

Day care center characteristics

Staff education level reflects the overall education level of the staff, separating between employees without relevant education, those with at least two years of some vocational training after high schools, and those with at least three years of formal teacher education in college or university. *Employment stability* was assessed by asking the managers if they would rate employment stability as unstable, relatively stable or stable. *Child-caregiver ratio* was calculated based on the number of children in each daycare center divided by the number of full-time employee positions. *Child group size* reflects the number of children in each group, ranging from 4 to 24. *Sensitivity towards children* is a crude binary measure, based on whether the managers mentioned sensitivity to children during the interview, when asked about values of the daycare center. In order to reduce the number of parameters in the analyses, the staff education level, employment stability, child-caregiver ratio, child group size and sensitivity towards children variables were first standardized and then summarized before they were entered into the analyses. *Nature based daycare center* indicates whether the

daycare center is a purely nature-based center, meaning they only have basic indoor facilities and spend the full day outdoors, irrespective of weather and season.

Paper II

Inattention and hyperactivity

To assess children's inattention and hyperactivity, parents completed the Strengths and Difficulties Questionnaire (Goodman, 2001), that is previously validated in an Australian sample (Mellor, 2005). Parents were asked to provide their responses based on the child's behavior during the previous six months. The items that were used to measure hyperactivity were 1) *restless, overactive, cannot keep still*, 2) *squirmy, fidgety*, and 3) *quickly changes from one activity to the other*, while the items used to measure inattention were 1) *easily inattentive and has poor concentration*, and 2) *completes tasks, has good concentration*. The levels of inattention and hyperactivity in this sample were slightly higher than Scandinavian samples, including Paper I (Elberling, Linneberg, Olsen, Goodman, & Skovgaard, 2010; Ulset et al., 2017) However, they were similar to an Australian, UK and US samples (Bloom, Cohen, & Freeman, 2010; Mellor, 2005; H. Meltzer, Gatward, Goodman, & Ford, 2000).

Actigraphy measures

Light exposure, sleep duration, activity levels and circadian stability were assessed with actigraphy. In this paper we used wearable devices (Actiwatch 2, MiniMitter Phillips) with sensors that measure light (lux) and movement (accelerometer). The devices were worn on the children's dominant wrist. Periods where the parent reported that the device was removed from the child's wrist, or inactive periods for more than 5 minutes were excluded from the analyses. Data were cleaned using the Actiware 5.2 software.

Light exposure

We calculated the light variables to reflect the duration, timing and intensity of light exposure. To determine the duration of light exposure, we computed the Time above threshold (TAT) variables, that reflect the average daily number of minutes that the children spend above a certain light threshold. TAT was computed for a range of threshold between 10 and 3000 lux. The procedure was first described by (Reid et al., 2014), and carried out for the data used in the present study by (Pattinson et al., 2015). In order to determine the timing of light exposure, the Mean light timing above threshold (MLiT) variables was computed, that integrates information about the duration (minutes above threshold), timing (clock time of each minute above threshold), and intensity (lux threshold). MLiT was computed as follows:

$$MLiT^T = \frac{\sum_{j=1}^{1440} \sum_{k=1}^7 (Y_j * I_{jk}^T)}{\sum_{j=1}^{1440} \sum_{k=1}^7 I_{jk}^T}$$

Y_j denotes the j^{th} epoch (ranging from 1 to 1440), while I_{jk}^T is coded as 1 if the lux value is larger than T (threshold). j refers to each one minute epoch ranging from 1 to 1440, while k refers to day, ranging from 1 to 14. For example, an MLiT1000 score of 780 minutes would indicate that the child's light exposure greater than the threshold of 1000 lux, is on average centered at 13.00 (780 minutes after the start of the period at 24.00).

Circadian stability

Children's activity levels were used to compute interdaily stability, which is a non-parametric evaluation of the stability of children's rest-activity rhythm from day to day across the 14 day assessment period. Other studies have used interdaily stability as a proxy for circadian rhythm stability (McGowan & Coogan, 2018). We used the nparACT package for R studio (Blume et al., 2016). Interdaily stability ranges from 0 (on par with gaussian noise), to

1 which indicates a strong coupling to a zeitgeber, such as light exposure. Interdaily stability is computed as follows:

$$\text{Interdaily stability} = \frac{n \sum_{h=1}^p (\bar{x}_h - \bar{x})^2}{p \sum_{i=1}^n (x_i - \bar{x})^2}$$

Note. p is the number of sampling points per day, n is the total number of sampling points, $\bar{x}_h$ is the average of all data, and x_i denotes the activity value from each 1-minute epoch.

Control variables

Physical activity levels were computed as the mean of all epochs of activity over the 14 days of recording. Sleep onset and waking time were assessed by a combination of parent reported sleep diaries and wrist actigraphy. The onset of sleep was determined by using the time of sleep onset as indicated by parents, unless the time indicated by the parents fell on a time that was determined as sleep by the actigraphy, in which sleep onset was defined as the last wake epoch. Waking time was determined by using the diary time indicated by the parent, unless the time indicated fell on an epoch that was determined by the Actigraph as sleep, then the time was extended to the first wake epoch. Total sleep duration was calculated using the mean duration of all sleep periods during the 14-days of recording. Night time sleep duration was computed as the mean duration of sleep that occurred between sleep onset and waking time, and daytime sleep duration was computed as the mean duration of sleep occurring between waking and night time sleeping over the 14 days of recording. Children's age and gender were reported by parents. Information about children's body mass index was gathered at both baseline and follow up by the researchers, in accordance with WHO guidelines.

Paper III

Children's infections

Time 1 and Time 2 in this paper comprised data from the third and fourth data collection of *The Matter of the First Friendship Study*. Parents were asked to provide information about the occurrence and frequency of six infectious diseases that are commonly contracted by children attending preschool. The six types of infections were 1) eye infection, 2) ear infection, 3) throat infection, 4) lung infection, 5) gastrointestinal tract infection, and 6) the common cold. At the third assessment of *The Matter of the First Friendship Study*, analogous to the first assessment used in *Paper II*, parents were asked to complete the same list of questions retrospectively, thinking about the time that their child had recently enrolled in day care. As in similar studies of infectious diseases in preschool (Côté et al., 2010; Nordlie & Andersen, 2002), the frequencies of infections were stratified as 0, 1, 2, 3 or “4 or more”. Composite scores for three developmental periods were computed. Baseline was based on parent's retrospective accounts of the child's infection the year of preschool enrollment. Time 2 was based on data collected when the children were between 4 and 8 years, while Time 3 was based on data from when the children were 5 to 9 years.

Children's popularity

Social network analysis (Freeman, 1978) and the peer method (Perren & Alsaker, 2006) was used to assess children's popularity as reported by peers. During the child interviews, children were asked to nominate up to five classmates that they would like to bring on an imaginary bus trip. These peers may or may not be the same as their friends. Photographs of all the children in their group and a cardboard bus was presented as illustration. The children were asked to put their own picture behind the bus driver, and then select up to five other photos of children that they would like to bring on the bus trip. Children

who had transitioned to elementary school were asked to nominate who they wanted to bring on the bus trip by saying their names. The children could also nominate friends from other classes or from their daycare group. Popularity was operationalized as standardized indegree centrality (Freeman, 1978), meaning that the score assigned to each child equaled the number of nominations that they received from other children in their network (see Figure 3).

In network analysis and graph theory, various indicators of centrality are used to identify the most important nodes in a graph (Freeman, 1978). For example by identifying spreaders of infectious agents (Christley et al., 2005; Dekker, 2013), or the most influential or popular children in a social network (De Laet et al., 2014). The most commonly used centrality measures are degree, closeness, betweenness and eigenvalue centrality (Freeman, 1978). We use degree centrality since it is equivalent to the conceptualization of popularity that is used with the peer method (Perren & Alsaker, 2006), and has been shown in simulation studies to be the best centrality measure (i.e., strongest predictor) to identify individuals who are at high risk of attracting an infectious disease (Christley et al., 2005; Dekker, 2013).

Degree centrality can be considered as directional or undirected. In an undirected graph, the direction of nominations is not accounted for and can be represented by a rectangular adjacency matrix where the presence of a nomination is coded as 1 or 2 (when there are reciprocal nominations). In a directed graph the adjacency matrix can be nonsymmetric, and the in-degree of a node is calculated by summing the entries of the corresponding column, while the out-degree is calculated by summing the entries of the corresponding row (see Figure 3). Thus, while degree centrality is the sum of all incoming and outgoing nominations (edges) to a node (child), we use *in-degree centrality*, which is the sum of incoming nominations only. We only use incoming nominations because we first and foremost want to measure how influential the child is as perceived by their peers, while also

considering the risk of attracting infectious diseases that comes from being centrally located in the social network (i.e., exposed to many people).

Figure 3.

Illustration of popularity nominations from the “Bus Trip” assessment

Note. Each node (i.e., circle) depicts a child in the social network. The edges (i.e., arrows) depict directed popularity nominations. The numbers inside nodes are fictional ID numbers.

Statistical methods

The statistical analyses for the papers in this study were conducted using R (version no 3.6.2) (R Core Team, 2018), SPSS Statistics [version 25] (IBM, 2017), and Mplus [version 7] (Muthén & Muthén, 2019).

Paper I

In this paper we used multilevel (linear mixed) modeling to test whether the growth curves of digit span and inattention-hyperactivity were predicted by the number of hours spent outdoors in preschool. The longitudinal design made the data from *The Matter of the First Friendship Study* suitable for using multilevel mixed model, which helps us to tackle 1) the issues of hierarchically structured data, 2) the missing data pattern, and 3) estimating growth curves, while 4) controlling for possible confounding influences, and 5) investigating interactions across levels.

We use a multilevel variant of mixed model since our data structure was a hierarchically organized, in which lower-level observations (i.e., repeated measures of digit span and inattention-hyperactivity), were nested within contextual observations (children and daycare centers). The problem with contextual variables is that they may introduce dependency in the data. One of the assumptions that is made when conducting regression analysis, is that there is homogeneity of regression slopes across the different groups or units in the data set (e.g., between daycare centers). Since the equation for the standard error is valid only when observations are independent, and the standard error is used to compute *p*-values and confidence intervals, breaching this assumption may lead to invalid significance tests. In multilevel models this variation between groups can be modelled by estimating the variances in intercepts (i.e., random intercept) and slopes (i.e., random slopes) at the different contextual levels.

Level-one model
$Y_{IJK} = \beta_{0JK} + \beta_{1JK}x_1 + \varepsilon_{IJK}$
Level-two model
$\beta_{0JK} = \beta_{00K} + u_{0JK}$
$\beta_{1JK} = \beta_{10K} + u_{1JK}$
Level-three model
$\beta_{00K} = Y_{000} + u_{00K}$
$\beta_{10K} = Y_{100} + u_{10K}$
Full model
$Y_{IJK} = Y_{000} + Y_{100} + u_{00K} + u_{0JK} + u_{10K} * x_1 + u_{1JK} * x_1 + \varepsilon_{IJK}$

Note. Illustration of a multilevel model with three levels, and a predictor variable (x_1) at level 1. In a model where level 1 is the repeated measures level, level 2 is the child level, and level 3 is the daycare center level, “I” refers to a specific measurement wave, for a specific child (J), in a specific daycare center (K). The random intercept is denoted by a beta coefficient β_{0JK} . The subscript indicates that the value of the intercept is the same value across all measured occasions (0), for child J attending daycare center K. Thus, β_{0JK} is the mean score of all measurement occasions for child J attending daycare center K. Similarly, the random slope of the level 1 predictor is denoted by β_{1JK} , where 1 refers to a specific level 1 predictor (if there were more predictors they would be labeled 1, 2, 3 etc). Thus, β_{1JK} is the effect of the predictor on the dependent (Y) for a measurement occasion for child J located in daycare centre K. On level 2, β_{00K} refers to the common value of the child level random intercept β_{0JK} for each measurement occasion (0) for each child (J) in each daycare center (K), thus representing the child level effect for the intercept. Child specific variation around this value is denoted by u_{0JK} . β_{10K} denotes the value of the child level random slope β_{1JK} . Thus, β_{10K} is the child level effect for the slope. u_{1JK} refers to the child specific variation around this value. In the three-level model, Y_{000} is the common value of the random intercept for each measurement occasion (0), for each child (0) in each daycare center (0). Since there are three zeroes, this show that Y_{000} is the grand mean for the dependent variable. Daycare center specific variation around this value is denoted by u_{00K} . Similarly, Y_{100} denotes the common value of the random slope, where u_{10K} is the variation around this value for the specific daycare centers. This is a simplified example adapted from Bickel (2007). There are variations in the notional conventions between sources. For example, some authors have used beta for level 1, gamma for level 2, and sigma for level 3.

There were at least three sources of missing data in this paper. First, at each data collection some participants were purposefully missing due to the accelerated design. Second, as is normal in longitudinal studies there was the issue of attrition. Also, some children were too young to participate at the first data collection resulting in some participants entering the study at one of the follow-up assessments. Third, some data were missing due to incomplete responses (N= 20.9%). Missing data was handled by full information maximum-likelihood (FIML) estimation in SPSS. Using this method, missing data are not replaced or imputed, but rather handled within the statistical model, by estimating the population parameters that would most likely produce the estimates from the sample data. Using full information maximum likelihood provides similar results as multiple imputation methods (Collins, Schafer, & Kam, 2001). Growth curves were estimated by adding a Time term as a fixed effect to the model, that corresponded to the children's age. Non-linear development was modelled by adding a quadratic time term (Time²). Covariates were included in the analyses if they were correlated with either the main predictor or any of the dependent variables.

Paper II

In Paper II, analyses were carried out in three steps. First, we conducted sensitivity analyses to examine whether a range of lux thresholds (i.e., ranging from 10 to 3000 lux) were associated with children's hyperactivity and inattention. Second, we examined Pearson's Bivariate Correlations between the predictor variables, outcome variables and number of possible control variables. The control variables that were correlated with either a predictor or outcome variable were included as control variables in the next step. Third, we used multiple regression analysis to examine whether light exposure and circadian rhythm were linked with hyperactivity, and if there were any significant interactions between circadian stability and

light exposure in predicting hyperactivity. Multiple regression is a well suited statistical approach for examining and comparing the contribution of several continuous or categorical independent variables in predicting a continuous dependent variable (Cohen, West, & Aiken, 2014). The model for a simple linear multiple regression with two independent variables is:

$$Y = b_0 + b_1x_1 + b_2x_2 + \varepsilon$$

Multiple regression analysis is well suited for modelling moderation, or in other words to examine if the relationship between the independent variable and the dependent variable depends on a third variable. Finally, multiple regression can accommodate longitudinal designs with two measurement waves, by including the autoregressive effect of the dependent variable (i.e., the effect of the independent variable at Time 1 on itself at Time 2). The model for a simple slope regression including an autoregressive effect is:

$$Y^{(2)} = b_0 + b_1x_1 + b_2x_2 + b_3Y^1 + \varepsilon$$

Paper III

In the third paper we used an autoregressive cross panel model to examine the bidirectional links between infectious diseases and popularity as assessed by peers. This type of analysis fall under the larger heading of structural equation models (SEM), which is commonly used to model longitudinal data in psychology (Selig & Little, 2012). In autoregressive cross lagged panel models, several regression equations are assembled to model longitudinal bidirectional associations between two or more constructs that are measured on several occasions. Another strength is that cross-lagged models rule out the possibility that longitudinal links between two different constructs (such as popularity at Time 1 being associated with infection at Time 2) is caused by the two constructs being correlated at Time 1.

$$X^{(2)} = \alpha_1 + \beta_1 X_1 + \beta_2 Y_1 + \varepsilon_X$$

$$Y^{(2)} = \alpha_2 + \beta_3 Y_1 + \beta_4 X_1 + \varepsilon_X$$

$$X^{(3)} = \alpha_3 + \beta_5 X_2 + \beta_6 Y_2 + \varepsilon_X$$

$$Y^{(3)} = \alpha_4 + \beta_7 Y_2 + \beta_8 X_3 + \varepsilon_X$$

The two variables (X and Y) were measured at three occasions, and are denoted with subscripts indicating time of assessment. The linear regression coefficients $\beta_1, \beta_3, \beta_5$ and β_7 represent the autoregressive effects (i.e., a variable that is regressed on itself measured at an earlier time), where large autoregressive coefficients refer to high stability in a variable over time.

The linear regression coefficients $\beta_2, \beta_4, \beta_6$ and β_8 represent the cross lagged-effects (i.e., a variable that is regressed on another variable at an earlier time). The fit of the model between the SEM model and the observed data was evaluated using the Chi-square value, the Tucker Lewis Index (TLI), and the Root Mean Squared Estimate of Approximation (RMSEA).

	Paper I	Paper II	Paper III
Title	Time spent outdoors during preschool: Links with children's cognitive and behavioral development	Environmental light exposure is associated with fewer symptoms of hyperactivity in preschool children	Are unpopular children more likely to get sick? Longitudinal links between popularity and infectious diseases in early childhood.
Participating sample	n = 562	n = 49	n = 579
Data source	The matter of the first friendship study (Norway).	The Sleep in Daycare Study (Australia)	The matter of the first friendship study (Norway)
Age and time	12 – 78 months (M = 52.45, SD = 15.96) at baseline. Accelerated design with five time points corresponding to age in years.	45 – 64 months (M = 56.49, SD = 4.89) at baseline. Follow-up after 12 months.	24– 90 months (M = 64.14, SD = 15.96) at baseline. Three time points encompassing all cohorts at each time.
Dependent variables	<ul style="list-style-type: none"> - Teacher reported inattention and hyperactivity symptoms (SDQ). - Working memory (Digit span forward). 	Parent reported inattention-hyperactivity (SDQ)	<ul style="list-style-type: none"> - Infectious diseases (parent reports) - Peer popularity (sociometric status)
Independent variables (control)	Outdoor time (gender, age, SES, temperament, family harmony, parent's inattention-hyperactivity as a child, nature based DCC, DCC _{quality})	Timing, duration and intensity of light exposure, circadian stability (gender, age, BMI, sleep onset, sleep offset, sleep duration).	(Age, gender, serious illness)
Analysis	Multilevel mixed model analysis	Time series analysis, multiple regression analysis.	Autoregressive cross lagged analysis, network analysis.

Results

Summary of paper I

The study reported in Paper I examined links between the duration of time spent outdoors in preschool and children's development of working memory and inattention-hyperactivity symptoms. In Scandinavia it is considered common sense that outdoor time promotes health and development, and a growing literature supports this notion. However, most studies are cross sectional, have small sample sizes, undertake a binary approach to outdoor exposure and fail to control for possible confounding influences of third variables. Therefore, we used a longitudinal design and a large sample of children and day-care centres allowing us to examine both short-term and long-term associations, within a dose-response perspective, while controlling for a host of possible confounding variables. We found a positive dose-response association between outdoor hours and children's working memory, and an inverse association between outdoor hours and inattention and hyperactivity symptoms. The findings suggest that outdoor time in preschool may be a universal, cheap and accessible way of preventing the development of inattention-hyperactivity symptoms, and to promote children's working memory skills.

Summary of paper II

The study reported in Paper II examined whether the timing, duration and intensity of environmental light exposure was associated with children's concurrent and long-term inattention and hyperactivity symptoms, and if these links were moderated by the stability of children's circadian rhythms. Of those children who are diagnosed with attention deficit hyperactivity disorder (ADHD), up to 78% also exhibit a disturbance in circadian stability. In

fact, a growing body of research suggests a causative role of circadian stability in ADHD. Light exposure is the strongest environmental stimuli that influence the circadian clock. Findings from animal studies show that marmoset monkeys who are exposed to high levels of daylight during specific developmental windows in early childhood, are less likely to develop inattention and hyperactivity-like behaviour. In the outdoor environment, the intensity of light exposure can reach 100 000 lux, compared to the approximately 500 lux of indoor light intensity. In Paper I, we found that the time that children spend outdoors in early childhood is inversely associated with inattention and hyperactivity, namely the core symptoms of ADHD. Some studies also suggest that light enhance attention and self-regulation in a fashion that is similar to pharmaceutical stimulants, via a noradrenergic pathway. We found that the duration, but not timing, of light exposure was strongly and negatively associated with hyperactivity symptoms, however this association was not moderated by circadian stability. We did not find an association between light exposure and inattention symptoms. Thus, it may be that naturally occurring light exposure in preschool can prevent or alleviate hyperactivity symptoms in young children. However, studies are needed that are better suited to examine the direction of causation.

Summary of paper III

In the third paper, we examined if there were bidirectional influences between children's social status as perceived by peers and the frequency to which they contracted six infectious diseases that commonly occur during preschool. There is a strong social gradient in the risk of attracting almost any type of disease. This link between low social status and poor health outcomes is explained by differences in access to health care and resources, or from exposure to environmental hazards. However, findings from animal studies and adult populations suggest that social status may affect the risk of contracting infectious diseases

more directly through immunological and endocrine pathways. In particular, the stress that is associated with social rejection and with repeatedly losing dominance interactions may weaken the immune system's capability of dealing with infectious agents. Some evidence also shows that individuals with high sociometric status are more likely to contract infections because they are centrally located in their social networks. A third possibility is that infectious diseases may negatively affect social behaviour by inducing sickness behaviours, which in turn activate the behavioural immune system of peers. To our knowledge, now previous studies have examined if there are bidirectional influences between infectious diseases and peer status in early childhood. The findings revealed negative dose-response associations between popularity as perceived by peers with the frequency of infectious diseases the following, but not concurrent, year. The results suggest that unpopular children may be at increased risk of contracting an infectious disease.

Discussion

Main findings

The physical environment

There is compelling theoretical and empirical evidence that short-term exposure to outdoor natural environments can enhance directed attention and self-regulation (Berman et al., 2008a; S. Kaplan, 1995), ultimately alleviating symptoms of inattention and hyperactivity (Faber Taylor & Kuo, 2011; Kuo & Faber Taylor, 2004; A. F. Taylor & Kuo, 2008; Van den Berg & Van den Berg, 2011). However, it has not been known whether exposure to outdoor environments during preschool could be connected to the short- and long-term development of working memory and ADHD symptoms. We found that the amount of time spent in

outdoor environments (i.e., physical and natural environment) during preschool was related to children's trajectories of inattention-hyperactivity and working memory from 3 to 7 years of age, after controlling for a host of multilevel confounding influences. Children who spent more time outdoors exhibited lower levels of inattention-hyperactivity and better working memory compared to children spending less time outdoors. There was a non-linear dose-response relationship between outdoor time and these outcomes that was strongest when the children were 5 and 6 years old. However, the associations decreased in strength again after children had commenced school.

The associations were not moderated by gender, suggesting that outdoor time was not a protective factor in the sense of reducing risk of ADHD symptoms in boys. Rather, outdoor time seemed to be independently associated with cognitive-behavioral development, and thereby can be viewed as a compensation for risk factors. The strength of the association between outdoor time and the outcomes became weaker after children enrolled in school. This suggests that potential effects of exposure to the outdoor environment on cognitive and behavioral development is of a concurrent nature. However, children's early symptoms and skills may affect long-term academic achievement and health through developmental cascades (Lewin-Bizan, Bowers, & Lerner, 2010; Masten et al., 2005), meaning that there may be a discontinuous development of a trait or skill that manifests differently at later ages. For example, other influences may come into play after the transition to school, such as struggles to adapt to the indoor setting of formal school after being accustomed to spending most of the time outdoors. Yet, outdoor time might have an effect on cognitive skills that becomes more salient during later developmental periods. For example, differences in self-regulation or cognitive control may become more apparent in adolescence because of new types of demands (e.g., secondary school). The use of growth curves and the finding that the children

did not differ at baseline support the hypothesis that outdoor time plays a causal role in children's cognitive-behavioral development. However, as in any study without randomized allocation into groups, the finding could also be a result of a selection effect.

The first paper did not assess any of the many proposed mechanisms explaining the observed links between nature exposure and child outcomes (Chawla & Nasar, 2015), such as increased physical activity (Copeland et al., 2016; Erickson, Leckie, & Weinstein, 2014; Gapin & Etnier, 2010; Gray et al., 2015), exposure to specific natural elements (Ohly et al., 2016), environmental light exposure (i.e., sunlight), or improved sleep and regulation of biological rhythms (Ancoli-Israel et al., 1997; Cajochen, 2007; Coogan, Baird, Popa-Wagner, & Thome, 2016; Van Veen et al., 2010).

In Paper II, we examined whether exposure to environmental light, which is of radically greater intensity in the outdoor environment compared to the indoor environment (Dharani et al., 2012), may protect against inattention and hyperactivity symptoms in preschool children. Related to his work on probabilistic epigenesis, Gottlieb (1998) noted that certain patterns of light exposure may trigger epigenetic changes in small animals. Findings from epidemiological studies and animal studies show that the prevalence of ADHD is lower in sunny geographical areas (Arns et al., 2013), and exposure to high levels of daylight during sensitive periods of development is linked with fewer inattention-hyperactivity-like symptoms in marmosets (Koshihara et al., 2015).

We were unable to determine whether daylight exposure, sleep, and physical activity levels mediated the associations between outdoor time and cognitive-behavioral development that were found in the first paper. Therefore, using an Australian sample of children attending preschool, we explored whether environmental daylight exposure may be associated with

concurrent and intermediate-term development of inattention and hyperactivity. We found a strong inverse association between the duration of environmental light exposure and children's hyperactivity symptoms, but not inattention. Additionally, the timing of light exposure was associated with children's circadian stability, but not with inattention or hyperactivity.

The finding that light exposure was linked with hyperactivity, but not inattention, invites the possibility that endocrine functioning and associated circadian processes are involved in a mechanistic pathway. Light exposure has been found to affect melatonin onset and reduce hyperactivity symptoms, although the study found it did not appear to influence inattention symptoms (Fargason et al., 2017). Moreover, children with the hyperactive, but not inattentive, subtype of ADHD, exhibit weakened HPA-axis reactivity (i.e., low cortisol levels) in response to stress (Hong, Shin, Lee, Oh, & Noh, 2003). The HPA-axis is also implicated in the circadian clock, and cortisol is amplified by morning environmental light exposure (Scheer & Buijs, 1999). These findings taken together, and in parallel with findings from animal studies showing that light has the potential to trigger epigenetic switches (Gottlieb, 1998) and that there are sensitive windows in early development for the effects of light (Koshihara et al., 2015), imply that light exposure may have the potential to also influence developmental switches in humans. Light exposure could potentially partially explain the observed association between outdoor time in preschool and positive child outcomes. Further research could examine whether the link between light exposure and hyperactivity symptoms is mediated by endocrine and epigenetic processes (Del Giudice et al., 2015), using methods that can clarify the direction of causation.

The social environment

There is a gradient in the association between social status (including socioeconomic status) and the risk of contracting almost any disease (Dowd et al., 2009). Several authors have suggested that early environments are important determinants for the development of immune functioning and health over the life course (McDade, 2005). In preschool, most children make their first encounters with social groups and friends (Wu, Hart, Draper, & Olsen, 2001), as well as being frequently exposed to infectious diseases (Côté et al., 2010). Thus, the interplay between infections and social dynamics during this time may pose consequences for children's long-term health development. We found that children who received many popularity nominations from their peers (i.e., high social status) were less likely to incur infectious diseases during the following, but not concurrent, year. This connection was significant above and beyond the simultaneous influence of popularity and the level of infections at the previous assessment. When the associations were stratified by the number of popularity nominations, we observed a dose-response relation in which for each increase of a popularity nomination, there was a decrease in infections, with the largest average difference being between 0 and 1 popularity nominations. We did not find any prospective links between infectious diseases and subsequent popularity. The finding that popularity is associated with an increased risk of attaining infectious diseases may be understood in light of extensive evidence from animal studies showing that social status can change inflammatory processes and increase the risk of infection (Shively & Day, 2015).

The bidirectional approach and the finding of a dose-response relation provides an indication of the direction of causation, suggesting that social hierarchies can act as a predecessor of health development. However, there are limitations to the methods used, as this study was observational and exploratory in nature, as well as the statistical analysis used

in this thesis (Hamaker, Kuiper, & Grasman, 2015). As such, the findings of the study should only be viewed as hypothesis-generating. For instance, it may be that promotion of social inclusion at this crucial time of development can have long-term benefits for children's health development. The dose-response relation between social status and infections invites the idea that efforts to promote social environments in preschool that are characterized by acceptance and inclusion may be beneficial for children irrespective of their level of popularity at baseline.

Limitations and methodological considerations

Measurement and validity

Parent, teacher and manager-reported data

We used a combination of preschool manager interviews, child interviews and objective measures to collect information about children's natural, physical, and social environment and their health development. In the first paper, daycare centre managers were asked to retrospectively account for the daily number of hours that the centre on average spent outdoors during winter and summer. This is not an optimal operationalization of outdoor time, because there may be changes in outdoor time across the four years of measurement that were not incorporated into this estimation. Moreover, it is a crude measure. Outdoor time can substantially vary from day to day depending on weather or staff preferences, and this may not have been taken into account. There may also be variations in outdoor time depending on children's age. That being said, criterion validity of the construct is strengthened by previous findings that outdoor time is strongly and positively associated with other outdoor and nature-related constructs such as use of nature and exposure to forests, primitive shelters, open space, and wilderness (Jølsett, 2019; Sandsaunet, 2012).

In Papers I and II, we relied on parent and teacher reports of inattention and hyperactivity symptoms. We also used parent reports of the control variables, including children's temperament, family harmony, parental symptoms when they were a child, parent's own use of nature, use of nature with child, outdoor time, and indicators of socioeconomic status. Overall, the internal consistency of the scales was good, with the exception of children's temperament, which yielded a Cronbach's alpha of only 0.5. One possible explanation is that the scale was originally developed and standardized for children under the age of 1 year, while the age range in the current study when parents reported the data was 2 – 6 years. Thus, there may be issues with the reliability of the temperament questionnaire as used in the present study. In the first paper, we relied on teacher reports of children's inattention and hyperactivity symptoms, using the Strengths and Difficulties Questionnaire (Goodman, 2001). Internal consistency was good, but some issues related to validity should be mentioned. First, preschool teachers' perceptions of children's inattentive and hyperactive behaviour may be obscured by the outdoor context. For instance, inattentive and hyperactive behaviour may not appear problematic in the outdoor context because it is not perceived as disruptive. Second, teachers may themselves be affected by the outdoor context (e.g., by attention restoration) such that they become more patient and perceive behaviour as less problematic. A study that directly observes children's behaviour in the outdoor context could bring more clarity to these issues.

Sociometric data

One of the strengths of the research summarized in this dissertation is that we were able to draw upon a large database of information from interviews with young children, soliciting the peer perspective on social status, which may differ substantially from adult perceptions (Eivers, Brendgen, & Borge, 2010; Wu et al., 2001). Even though the stability in

peer-reported social status has been shown to be moderately strong and less reliable than teacher reports (Wu et al., 2001), we found that stability in popularity was low between the three measurement waves. For instance, popularity at Time 1 was not at all associated with popularity at T3. A possible explanation for this low stability may be the long duration of time between measurements in combination with the young age of the participants. Sociometric studies of popularity have typically involved school-aged participants (De Laet et al., 2014), and weeks rather than years separated the assessments (Wu et al., 2001). Hence, the low stability may reflect rapid fluctuations in social dynamics at this young age. Also, many previous sociometric studies have been carried out in classrooms where all or most of the pupils were participating in the study, and the classrooms consisted of the same children across measurements. In the current study, there were 28 daycare centres, while community detection revealed that there were 41 social clusters at T1, 40 clusters at T2 and 48 clusters at T3. The increase in social clusters (i.e., connected social networks) might reflect the reorganization into new groups when children transition from preschool to one of the 13 schools in the two municipalities.

Actigraphy

A considerable strength of the current dissertation is the use of objectively measured physical activity, sleep-wake patterns, and environmental light exposure. However, comparisons between different types of measurement devices show poor inter-device reliability, highlighting a need for caution when comparing findings from studies using different types of actigraph devices (L. J. Meltzer, Walsh, Traylor, & Westin, 2012). Actigraphy has been found to be a valid and reliable measure of physical activity (Rothney, Schaefer, Neumann, Choi, & Chen, 2008), as well as light exposure and sleep in normal individuals with good sleep patterns, and to identify sleep patterns that are associated with

neurobehavioral disorders (Sadeh, 2011). The most problematic validity issue of actigraphy for sleep measurement is low specificity in detecting wake episodes during sleep. The complementary use of parent-reported sleep diaries in the current study strengthens the validity of the sleep measures. We used interdaily stability as a non-parametric estimate of children's circadian rhythmicity, based on rest-activity data from actigraphy. Rest-activity rhythms are one of the core behaviours controlled by the biological clock, and they serve as a good proxy for circadian functioning (Blume et al., 2016). However, other operationalizations of circadian rhythmicity often comprise measures of the circadian hormone melatonin.

Working memory

We used the digit span test as a measure of working memory. Due to insufficient variability in the digit span backwards test scores for the youngest participants (age 3, 4 and 5), we used only the digit span forward test for the purpose of this study. With respect to Baddeley's operationalization of working memory (A. Baddeley, 1992), the digit span forward task is a test of the phonological loop, which is one of three components of working memory. However, by other definitions of working memory or executive functioning, the digit span forward test is more closely related to attention efficiency, or, in other words, the ability to not be distracted (Lezak et al., 2004), rather than to what is often thought of as memory (Kaufman et al., 1991).

Sample and generalisability

For the purpose of the current dissertation, we used samples from Norway and Australia. Both samples were relatively homogenous in terms of ethnicity. The samples used in Papers I and III were from a semi-rural area in Norway, while the urban sample used in Paper II was from a large Australian city. The Australian sample purposefully targeted preschool centres located in high socioeconomic status areas. The Norwegian sample

consisted of mainly cohabitating or married respondents (93 %) with an employment rate of 84% for mothers and 96% for fathers, and the average income was higher than the regional average. Thus, the samples used may represent a population with higher socioeconomic status than many communities outside of Norway and wealthy parts of Australian cities. This should be considered when applying findings to other community contexts. Moreover, both samples consisted only of participants that attended preschool, and as such, the findings may not be representative for children who are cared for at home during early childhood.

Attrition and response rates

As is common in longitudinal and cohort studies, we were not able to recruit all of the eligible children in the two municipalities, and some participants dropped out from the study during the four years. In Papers I and III, approximately 63% of the children belonging to the cohorts born between year 2000 and 2005, and who attended preschool, were eligible for participation. Of these, 62% of parents agreed to participate, while 83% of consenting participants remained when the study concluded after the fourth assessment. In Paper II, a total of 62 children were invited to participate, out of which the parents of 49 (79.03%) of the children agreed to participate. In this study, 43 had complete data at follow up, reflecting a retention rate of 87.8 %. Thus, in both the Norwegian and Australian samples there is a possibility of self-selection bias that may threaten the validity of our findings (Shadish, Cook, & Campbell, 2002). As an attempt to rule out attrition bias, independent *t*-tests were used to determine if children who participated in all data collections differed from those who dropped out on any of the study variables. We did not find any significant differences. However, there may still be differences in the study outcomes between those who decided to participate in the study and those who did not. For example, other comparable studies have found that those living alone, with more than three children, or who are mothers younger than 25 years are less

likely to volunteer as participants in research (Nilsen et al., 2009). This may constitute a threat to validity if, for instance, the associations between the study variables differ for those living alone. However, Nilsen and colleagues (2009) reported that when they used data from a national health registry for comparison, this type of self-selection did not bias the associations between exposure and outcome variables. Thus, it is possible but unlikely that self-selection effects from systematic attrition have affected the findings of our study.

Implications

The focus on popularity, light exposure, and outdoor time as protective factors in preschool was selected because of the strong implications for cost-effective universal prevention and health promotion. Almost all children in Norway attend preschool. Outdoor time is associated with a number of health-promoting activities, and the outdoor environment is free and readily available. It is feasible to give large quantities of exposure to outdoor time during several crucial years of health development. Likewise, preschool is a place where children can make friends and experience social inclusion and support, providing a sense of acceptance.

The findings that there were dose-response relationships between outdoor time and cognitive-behavioral development, between light exposure and hyperactivity symptoms, and between the popularity and infection risk, lends some support to causal inference. Moreover, the findings are consistent with experimental studies in animals and humans showing short-term effects of exposure to nature and light on attention and ADHD symptoms (Berman, Jonides, & Kaplan, 2008b; Koshiba et al., 2015; Van den Berg & Van den Berg, 2011), as well as experimental animal studies showing increased infection risk following a reduction of social status (e.g., Snyder-Mackler et al., 2016). However, some limitations should be mentioned. The effects did not seem to be specific for at-risk children. We examined whether

gender moderated the link between outdoor time and cognitive-behavioral development, which it did not.

We also found that the link between light exposure and hyperactivity symptoms was not moderated by circadian rhythm. Thus, we cannot say that these potential protective factors target specific pathogenic processes. The finding in Paper II that exposure to light was linked with lower levels of hyperactivity offers a hypothetical explanation for the link between outdoor time and positive outcomes of children's cognitive-behavioral development in Paper I. However, we did not examine mediator effects in any of the studies in this thesis. As a result, we know very little about the protective process and the mechanisms underlying the findings. This weakens the case for causal inference.

In Paper III, we used an autoregressive cross-lagged model to examine the bidirectional links between infection and popularity. Recently, the autoregressive cross-lagged model (CLPM) has been criticised for often leading to spurious results since the model is not able to separate within- and between-subjects effects (Hamaker et al., 2015), especially when the constructs have a strong time invariant and trait-like structure. The use of CLPM implies the assumption that the variation over time for all participants in a study varies around the same means. This does not mean that the two variables in a CLPM are unrelated, but that the lack of separating between within and between effects can lead to inaccurate conclusions about the strength and directionality of the relations between variables. One way of controlling for the stability and trait-like nature of constructs is to use a random intercepts cross-lagged panel model (RI-CLPM; Hamaker et al., 2015). Our finding that popularity is prospectively associated with infection should therefore be interpreted with care and be replicated in a study using a larger sample size and controlling for time-invariant differences.

We chose to examine potential protective factors that theoretically may influence developmental switches via endocrine or immunological processes. We still do not know if the effects of the protective factors examined in this study continue into middle childhood, adolescence, and adulthood. Thus, the findings do not paint a complete picture of this story, and they should be viewed as hypothesis-generating and possible foundations for prevention research that may strengthen or discredit the findings of these three studies.

Future longitudinal research may further strengthen the case for causal inference and implications for policy, intervention, and prevention by replicating the findings in a variety of other samples. Experimental pilot studies may be carried out over the short term to examine the effects of social acceptance, light exposure, and outdoor time on children's immunological and neuroendocrinological functioning. Also, the potential role of genetic switches should be explored. To examine non-continuous effects or potential developmental cascades (Masten et al., 2005), researchers may investigate whether the amount of time that children spend outdoors in early childhood is linked with BMI, inattention-hyperactivity symptoms, and math and reading skills in adolescence, as measured by national standardized test scores.

Moreover, it may be prudent to examine if exposure to outdoor environments enhances children's short-term attention and learning and whether these increases are mediated by physical activity levels, environmental light exposure, parasympathetic activity and stress, social influences, or the timing, dosage and duration of outdoor time, and to examine if benefits of outdoor time are specific for children with certain risk factors (such as boys or at-risk children). This will help to identify protective pathways and allow for higher specificity of a potential intervention. For example, girls and boys may benefit differentially from specific outdoor-based activities or from interventions that aim to create social cohesion in the child group.

Conclusions

There is a need for new approaches to universal prevention and intervention. This thesis examined associations between protective factors in the social, physical, and natural environment of preschool, as well as their connections to several indicators of health development. Within a health development perspective, we used a variety of methodological and statistical approaches to generate new hypotheses about protective factors in preschool that may have important implications for prevention, intervention, and policy in early childhood. The findings could provide new avenues for early prevention research. Future research may consider using longitudinal studies to examine long-term outcomes and developmental cascades. Also, to strengthen causal inference, experimental studies can examine whether manipulation of the protective factors changes child and adolescent outcomes. Subsequent studies can explore whether these associations are specific for certain groups (moderator effects) and identify protective pathways by considering mediators on the molecular and societal level, and all levels in between.

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Papers I - III

Time spent outdoors during preschool: Links with children's cognitive and behavioral development

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ABSTRACT

This study examined the concurrent and long-term relations between the amount of time children attending daycare spend outdoors and their cognitive and behavioral development during preschool and first grade. We applied a multi-informant design using cognitive testing and ratings from parents and teachers to follow 562 Norwegian preschoolers (298 girls; mean age at first assessment = 52.45 months, $SD = 15.96$) over a period of four years. Children's attention skills were tested with the digit span test while teachers rated their behavior. Growth curve analyses showed a positive relation between outdoor hours and children's digit span scores, and an inverse relation between outdoor hours and inattention-hyperactivity symptoms, controlling for a host of possible confounds. Results indicate that outdoor time in preschool may support children's development of attention skills and protect against inattention-hyperactivity symptoms.

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1. Introduction

In Western countries, the proportion of mothers returning to the labor market shortly after having a child has grown over the past decade. Several indicators suggest that this growth has not yet peaked (Bell, Donkin, & Marmot, 2013; Hegewisch & Gornick, 2011). Consequently, the effects of daycare on children's health and development has received much attention (Burger, 2010; Vermeer & van IJzendoorn, 2006). Daycare centers' pedagogical approaches have become increasingly diverse, and, today, a number of daycares offer outdoor activities and play-based learning approaches. For example, daycare centers differ in the quantity of outdoor activities offered (Copeland, Khoury, & Kalkwarf, 2016; Ministry of Education and Research, 2006). In Scandinavia, daycare centers increasingly offer high quantities of outdoor time; some centers offer up to 9 h of daily outdoor time, irrespective of weather and season (Borge, Nordhagen, & Lie, 2003). Given the increased diversity in the use of outdoor activities and pedagogical approaches in early childcare, there is a need to know whether such

various approaches promote children's cognitive and behavioral development.

Some literature indicates that exposure to outdoor environments may be beneficial for children's health and cognitive development (Chawla & Nasar, 2015; Gill, 2014). Thus, one might expect developmental differences between children attending daycare centers offering the recommended minimum of 1 h outdoor time per day and those attending centers that offer 7–9 h per day. Such differences in development may be visible in the short term or the long term once the children start attending formal school. Moreover, the relation between outdoor time and children's development may be linear, but curvilinear or threshold links are also possible. For example, a specific number of outdoor hours may be enough for a beneficial effect, or there may be a dose-response relationship. It is also possible that the relation between outdoor time and cognitive-behavioral development is explained by other qualities particular to the daycare centers, such as ideology and type, or that it is confounded with socio-economic status (Geoffroy et al., 2007). Thus, a longitudinal perspective and a continuous approach to outdoor time need to be adopted while controlling for a host of confounding factors to isolate the effect of outdoor time on children's development and determine the nature of this association. These are the goals of the present study, which is set in

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Norway, a leading country with respect to the use of outdoor time in daycare centers (Borge et al., 2003).

1.1. A historical-philosophical perspective

In Scandinavia, it is considered to be common sense that the outdoor environment promotes health and prevents mental and somatic problems (Borge et al., 2003). This idea is inspired from philosophers, such as Thoreau and Muir, who established a fascination for the wilderness and laid the roots for later environmentalists (Naess, 1984). In line with this concept, Froebelian kindergartens were established in Germany, the United Kingdom and the United States of America during the 19th century. The concept of “kindergarten” meant a garden for – not of – children. Froebel believed that placing children literally in the garden would engage them to play and act out in the real world, which was deemed to be good for intellectual development (Bruce, 2012). Similarly, Rousseau advocated child-rearing principles of “back to nature”, sending children to the woods, and Dewey created an educational approach based on school gardens where children might discover mathematics from seeds and gardens (Chung & Walsh, 2000). Of course, these philosophical ideas remain only ideas if not backed up by empirical evidence.

In Norway, daycare centers usually offer between 1 and 9 h of daily outdoor time. In accordance with government guidelines, daycare centers are often placed in spots that secure good weather conditions and that are rich in vegetation (Ministry of Education and Research, 2006). The intention is to stimulate play, shield from noise and traffic, and promote an appealing context. The daycare centers are encouraged to provide children with climbing structures, large sandboxes, hard surfaces (asphalt and concrete), and a place to hose off the children before going back indoors. Children may play with mud and sand in the rain, and need solid rain-proof clothing and warm shoes. In winter time, slopes and hills enable skiing and tobogganing (a simple sled used on snow by the children to ride downhill). Some daycare centers have access to an outdoor environment that is large, without fences, and distant from the buildings. Often, the buildings are old-fashioned cabins or turf huts. In Scandinavia, specific shelters (*lavvu*) in the shape of a tepee have an open fire, benches with reindeer skins to keep the children warm, and a place to store bags and food. In sum, the outdoor environment is rich in fresh air and provides experiences of seasonal changes, physical activity and allows for noisy activities requiring lots of space.

1.2. Daycare environments and children's development

Studies show that the daycare centers' structural environments may be associated with the quality of care that is provided (NICHD Early Child Care Research Network, 2000) and children's cognitive development (Peisner-Feinberg et al., 2001). For example, child-adult ratio, group size, and caregiver's education level and involvement with the children are factors associated with the quality of care that is provided (NICHD Early Child Care Research Network, 2000). Further, the quality of daycare has been associated with children's cognitive development and attention skills (NICHD Early Child Care Research Network, 1998; Wylie, Hodgen, & Thompson, 2003). The effects of daycare on children's development also tend to be moderated by child and family characteristics, such as child's gender and family harmony (Bekkhus, Rutter, Maughan, & Borge, 2011; Côté, Borge, Geoffroy, Rutter, & Tremblay, 2008), parents' socioeconomic status (Geoffroy et al., 2007), and child temperament (De Schipper, Tavecchio, Van IJzendoorn, & Van Zeijl, 2004). There are also a number of empirical studies showing short-term gains from exposure to environments similar to those offered

in outdoor daycare centers (Chawla & Nasar, 2015; Gill, 2014). For example, in a large cross-sectional study, Kuo and Faber Taylor (2004) found that children diagnosed with ADHD showed lower levels of parent-reported inattention and hyperactivity symptoms following after-school activities in green outdoor settings than following activities in built outdoor or indoor settings. However, to our knowledge, no previous large-scale studies have investigated whether the quantity of time spent outdoors during daycare is associated with children's development in the short and long run.

Attention restoration theory gives credence to a possible positive link between exposure to outdoor environments and children's cognitive and behavioral functioning (R. Kaplan & Kaplan, 1989). Attention restoration theory suggests that natural elements found outdoors help focus attention. Nature may bolster children's attention and self-regulatory skills by allowing neural inhibitory mechanisms to rest and recover from use (Berman, Jonides, & Kaplan, 2008). For example, the indoor noise level of daycare centers is sometimes comparable to highway noise, with potentially adverse effects on child well-being (Werner, Linting, Vermeer, & Van IJzendoorn, 2015). Outdoor time may be beneficial because the outdoor environment allows for restoration of attentional resources that have been depleted by noise and other distractions. Of note, although attention restoration theory largely explains short-term effects of exposure to nature, working memory has been described as a bottleneck for cognitive functioning (Vogel & Machizawa, 2004). Short-term benefits of outdoor time on attention may thus translate into long-term benefits by allowing children to engage in advanced learning activities (i.e. readiness to learn) (Fitzpatrick & Pagani, 2012). For example, children might engage in longer and more focused sequences of play, and they might be able to perform more complex tasks, as their attention skills are enhanced (Ruff & Lawson, 1990). Accordingly, children spending a lot of time outdoors during their preschool years may develop more self-regulatory and cognitive skills than their counterparts who are confined to indoor daycare. As a consequence, they could also become better prepared for formal school.

However, the opposite is also possible, in that indoor environments may encourage the use of effortful attention, which is beneficial for cognitive development. In line with a strength model of self-regulation (Baumeister, Vohs, & Tice, 2007), children's attention skills might mature faster in environments that require high levels of effortful attention, because of continued practice in dealing with conflicts and distractions. Also, the indoor daycare environment resembles the formal school and workplace environments where the children will spend many years. At least in the long-term, outdoor time may therefore have iatrogenic effects on attentional development if the demand for effortful attention in the outdoor environment is too low. Children spending a lot of time outdoors during preschool might thus miss out on effortful attention practice and therefore become less prepared for school.

So far, a few studies on this topic provide support for a positive link between exposure to natural environments and children's attention skills (Dadvand et al., 2015; Kuo & Faber Taylor, 2004; Mårtensson et al., 2009; Taylor, Kuo, & Sullivan, 2002; Wells & Evans, 2003). For example, a recent study that followed urban school children for one year, found that the level of vegetation surrounding homes, schools and commuting routes, as measured by satellite photos, were associated with improved working memory and a reduction in inattentiveness in 7–10 year old children (Dadvand et al., 2015). Also, Wells and Evans (2003) found that high amounts of vegetation near the homes of children mitigated the association between life stress and children's psychological distress and self-worth. In fact, Mårtensson et al. (2009) found that preschool children playing in green outdoor environments were rated by teachers as showing less inattentive behavior.

However, some of the above mentioned studies are limited by cross-sectional designs (Kuo & Faber Taylor, 2004) and small samples (Wells & Evans, 2003). In addition, none of the studies examined whether the relationship between outdoor time and children's behavioral and cognitive development is linear or nonlinear. Even if exposure to outdoor daycare during preschool is associated with better developmental adjustment, it is possible that this "positive effect" diminishes once children enter the more contrived and less outdoor-oriented formal school setting. Longitudinal research covering the transition from preschool to elementary school is necessary to address this issue. Finally, and importantly, few of the naturalistic large scale studies controlled for possible confounders.

1.3. The present study

1.3.1. Covariates

The quantity of daily outdoor activities may be related to and confounded by type of daycare centers. Nature-based daycare is a type of daycare with centers that offer up to 9 daily hours of outdoors activities. These centers are placed in green settings, surrounded by vegetation and with high emphasis on qualities of the outdoor environment. However, other types of daycare centers may be placed in both urban and rural settings and usually offer 2–6 daily hours of outdoor activities (Ministry of Education and Research, 2006). These activities might be set in contexts that are more or less high in quality. With this study, we want to examine whether outdoor time in naturalistic settings is beneficial for children, independent of type of daycare and daycare quality.

Our study included a variety of daycare centers in terms of the quantity of time spent outdoors and the type or quality of the environment, such that the possible overlap or interactive effect could be examined and controlled. However, it is possible that these centers differ in other aspects that may be important for children's development. For example, the quality of the daycare centers may also be associated with the quantity of outdoor time they offer. Moreover, children may be selected to daycare centers in terms of demographic or family factors, which could possibly confound an association between outdoor time and children's development. High parental education and income, as well as family harmony, have been found to be associated with group daycare attendance in Norway, indicating that social selection to group daycare in Norway works in the opposite direction from those in North America (Bekkhuis et al., 2011). Thus, we will control for potential confounding factors, such as socioeconomic status and family harmony, to avoid possible selection bias. Children who attend daycare centers offering high quantities of outdoor time may also come from families that use nature extensively after school hours or during weekends. To control for such an effect, we included parents' extracurricular use of nature with the child and use of nature on their own as control variables. Finally, in order to account for other important risk factors that may be related to children's development through gene-environment correlations, we included measures of children's temperament and parents' inattention-hyperactivity symptoms and psychological functioning as control variables. These variables represent phenotypic manifestations of both parents' and children's genetic liability.

1.3.2. Study objectives and hypotheses

The main objective of this study was to examine whether the time devoted by 28 daycare centers to outdoor activities is linked, both concurrently and prospectively, to children's cognitive skills and behavior, net of a host of confounding factors. In this study, we focused on the number of hours spent outdoors and children's adjustment according to a dose-response perspective. As already

mentioned, attention restoration theory and empirical findings from the previously indicated studies suggest that high exposure to outdoor settings may foster cognitive and behavioral development. However, it is theoretically possible that this is only a short-term effect. Specifically, although children with high outdoor exposure may enjoy a better cognitive and behavioral development during the preschool period, they may have difficulties adjusting to a contrived environment once they start formal school. Finally, even if the link between outdoor time and children's development is found to be generally beneficial over time, it remains to be seen whether outdoor time (i.e., between 2 and 9 h daily) is linearly incremental or whether there is an optimal dose after which the trend becomes reversed or levels off (i.e., quadratic and a threshold effect respectively).

Based on previous research on the effect of exposure to outdoor environments (Amoly et al., 2014; Berman et al., 2008; Dadvand et al., 2015) and our goal to examine children's behavioral and cognitive development, we chose inattention symptoms, hyperactivity symptoms and digit span as our outcomes of interest. These measures correspond to the main outcomes examined in previous studies environments (Amoly et al., 2014; Berman et al., 2008; Dadvand et al., 2015) and are good indicators of cognitive and behavioral functioning. Importantly, we controlled for gender, daycare center quality, children's temperament, maturational age, socioeconomic status, parent mental health symptoms, family harmony, and the use of nature after school hours. Finally, as the putative effect of outdoor time could vary across genders (i.e., boys may benefit from outdoor time more than girls because they can channel their higher need for physical activity; alternatively, girls may benefit from outdoor time more than boys because of the opportunities for social interactions fostered by unstructured outdoor activities), we also explored the potential moderating effect of child gender.

2. Methods

2.1. Participants

The 562 children participating in this study were part of a longitudinal study taking place in two suburban municipalities with populations of approximately 15 000 and 9000 (Statistics Norway, 2014c). These municipalities were typical of Norway and situated near Oslo, the capital of Norway. The median income after taxes for households with children in these municipalities was NOK 623 000 (98 000 \$), while the median income for Norway, except Oslo, was NOK 633 000 (100 000 \$) (Statistics Norway, 2017b). The average number of people in households was 2.32 in the two municipalities, while the Norwegian average was 2.22 (Statistics Norway, 2017a). There were 33 daycare centers in total and all centers agreed to participate. Five minor family centers with 4–8 children were closed down during the study, leaving 28 centers for the current study. Out of the entire population of children born between 2000 and 2005 ($N = 1507$), a total of 996 children were eligible as they attended one of the daycare centers, whereas the parents of 619 (62%) children agreed to participate by giving their informed written consent. Participants were included in the study if they were registered with at least one response from the child, parent or teacher ($n = 562$). Of these, 555 children participated at the first data collection, while 516 children participated at the fourth and final data collection. At the first data collection, children's age ranged between 12 and 78 months (Mean age = 52.45 SD = 15.96). Since some children had attended daycare for some years by the first data collection, we asked parents when the children had first enrolled in daycare. A total of 205 (36.48%) children first enrolled in daycare between the age of 1 and 2 years, 206 (36.65%) children

enrolled between the age of 2 and 3 years, 133 (23.67%) children enrolled between the age of 3 and 4 years, and 18 (3.20%) children enrolled between the age of 4 and 6 years.

2.2. Demographics

In this sample, the average maternal educational level was higher than the Norwegian national average in 2007 (Statistics Norway, 2014b); 45% of mothers had some form of tertiary education compared to 28% in Norway. This reflects a possible social selection among parents choosing to send their children to group daycare (Bekkhus et al., 2011; Borge, Rutter, Côté, & Tremblay, 2004). However, the children attending daycare centers that offered high quantities of outdoor activities did not differ from the children in daycare centers offering low quantities of outdoor activities in terms of socioeconomic status and gender.

The mean age of the mothers at the child's birth was 29.3 years (SD 4.3), which is close to the national average (Statistics Norway, 2014a), and only 1.9% of mothers in the study gave birth at age 20 or earlier. Only 1.4% of the children were living in a household with four or more siblings. The mothers' mean age was 34 years (SD 4.7), 93% were married or cohabited with the child's father or other partner, 84% of mothers and 96% of fathers were employed at the time of the first data collection and the median household income was approximately NOK 623 000. This income was slightly lower than the national Norwegian average for households with children aged 0–5, but higher than the regional average for the two municipalities where the families lived.

2.3. Procedure

The sample was followed longitudinally from 2006 to 2009 with annual data collections in 28 daycare centers and 13 elementary schools. As illustrated in Fig. 1, the sample consisted of six cohorts born between 2000 and 2005. At each data collection, cohorts were purposefully excluded from the study if the children were younger

than 3 years or older than 7 years. Similar to an accelerated longitudinal design, data from a total of 135 three-year-olds, irrespective of the time of data collection, comprised the baseline measure that was coded as time = 1. In the same manner, four-year-old children comprised time 2 (n = 272), five-year-old children comprised time 3 (n = 402), six-year-old children comprised time 4 (n = 486) and lastly, seven-year-old children comprised time 5 (n = 396). The children aged seven years were just about to finish first grade of elementary school.

Data collections were performed each spring to ensure that the teachers had become familiar with the children. Data were drawn from parent- and teacher-rated questionnaires, standardized tests administered individually, and interviews with daycare managers. Parents were asked to complete a questionnaire to provide information about the family and the child's personality and behavior. Teachers were asked to complete separate questionnaires regarding each child's behavior. The same procedure was repeated at all four data collections. Daycare managers were interviewed retrospectively in 2011 to obtain information about the daycare centers. The Norwegian Regional Committee for Medical Research and the Norwegian Data Inspectorate approved the study.

2.4. Measures

2.4.1. Inattention and hyperactivity

Teachers completed the Strengths and Difficulties Questionnaire (SDQ) (Goodman, 1997, 2001). From ages 3 to 6, daycare staff (preschool teachers) completed the questionnaire, whereas first grade school teachers completed the questionnaire for seven-year-olds. The SDQ is a brief behavioral screening instrument that assesses the level of externalizing symptomatology in children, which has been validated in a Norwegian population sample (Heiervang, Goodman, & Goodman, 2008). Teachers were instructed to give their answers on the basis of the child's behavior over the last few months. Response options ranged from *true* (0), *somewhat true* (1) and *not true* (2). The items measuring hyperactivity symptoms were

Fig. 1. Flow Chart Illustrating Study Design.

Note. No part = no participation; Not in dc = not enrolled in daycare.

1) *restless, overactive, cannot keep still*, 2) *squirmy, fidgety*, 3) *quickly changes from one activity to the other* ($\alpha = 0.86$). The items measuring inattention were 1) *easily inattentive and has poor concentration*, and 2) *complete tasks, has good concentration* ($\alpha = 0.71$). Finally, we summarized the mean score.

2.4.2. Digit span

The digit span is a subtest of the Weschler Intelligence Scale for Children (WISC-IV) that measures executive functions, such as attention and short-term memory (Sattler, 2008). Children were individually tested by trained students in a quiet, separate room at the daycare centers. The examiner read aloud sequences of numbers to the children, who were then asked to repeat these number sequences back to the examiner. The test consisted of two tasks with 16 trials each. In the first task, the numbers were repeated back by the child in the same order, whereas in the second task the child was asked to repeat the numbers in the reverse order. Each task started with two-digit trials and increased by one digit every two trials until the trials reached nine digits. The tasks were discontinued when the child had failed two successive trials. One point was assigned for each correct trial. Since 96.6% of the children between ages 40 and 52 months and 68.9% of the children between ages 52–64 months got zero points for the backward test, the backward digit span was excluded from the analysis due to insufficient variation in score results for the youngest children.

2.4.3. Children's temperament

Information about child temperament was gathered at time 2 from parent interviews using the Toddler Temperament Scale (Carey & McDevitt, 1978). This is a nine-item scale with questions about toddler temperament. The items probe for the following aspects of temperament: Activity level; regularity and routine of physical symptoms; adjustment to new routines; reaction to new or unfamiliar situations; sensitivity to sensory input and stimulation; intensity of emotional reactions; average daily mood; regulation of behavior at home; regulation of behavior in play with children; regulation of behavior in unfamiliar public situations. All items were coded on a 1 to 5 Likert scale where 1 indicated the easiest temperament and 5 indicated the most difficult temperament. All items were averaged to provide a composite temperament score with higher values indicating more difficult temperament. The internal consistency was adequate ($\alpha = 0.50$).

2.4.4. Daycare center quantity of outdoor time

The number of daily outdoor hours at each daycare center was obtained from daycare managers. The leaders were asked questions concerning the amount of daily hours spent outdoors in fall-winter and in spring-summer, respectively. Most daycare centers tended to offer fewer hours outdoors in fall-winter ($M = 3.89$, $SD = 1.81$, range 1–9) than in spring-summer ($M = 6.51$, $SD = 2.06$, range 3–9). The correlation between the scores was moderate ($r = 0.37$). For each daycare center, the numbers of daily outdoor hours in fall-winter and in spring-summer were averaged together to create a composite score reflecting the number of daily hours spent outdoors throughout the year.

2.4.5. Daycare center quality

Information about daycare center quality was collected from interviews with the daycare managers. Based on previous research on structural indicators of daycare quality (NICHD Early Child Care Research Network, 2000), the following indicators were assessed: Staff education level, employment stability, child-caregiver ratio, child group size and staff sensitivity towards children.

Staff education level was extracted by calculating the number of full time positions for three different education levels: 1) Unskilled,

2) skilled and 3) higher education. The “unskilled” category included employees without relevant education. However, most unskilled employees had completed high school. The “skilled” category included employees with two years vocational training after high school and employees with one year of relevant college education. The higher education category included employees with three to four years of formal preschool teacher education in college or university. The number of full time positions within each category was multiplied with 1 for the “unskilled” category, with 2 for the “skilled” category, and with 3 for the higher education category. The weighted scores were then averaged ($M = 1.98$; $SD = 0.40$). Employment stability was measured by asking managers how they would rate the employment stability of their daycare center. Three options were possible: Unstable (1 point), relatively stable (2 points) and stable (3 points) ($M = 1.15$; $SD = 0.58$). Child-caregiver ratio was based on the number of children in each daycare center, divided by the number of teachers. The scores ranged from 2 to 8.10 ($M = 5.2$, $SD = 0.55$). Group size was reported by managers. The number of children in each class ranged from 4 to 24 ($M = 17.19$, $SD = 5.00$). The interviewer registered whether the daycare manager mentioned sensitivity towards children during the interview. If sensitivity was mentioned as an important value, this item was scored 1. It was scored 0 if not mentioned; 59% of managers mentioned sensitivity to children during the interview. Finally, a composite score was created by averaging the z-transformed scores (Cohen, Cohen, West, & Aiken, 2013).

2.4.6. Socioeconomic status

At the first assessment, parents reported information about mothers' and fathers' income levels and mothers' and fathers' highest education. Education level ranged from junior high school (1) to higher university degree (6). Income level ranged from no income (1) to more than 500 000 NOK (6). 500 000 NOK is approximately 77 000 US\$. The four variables were averaged to provide a composite SES score.

2.4.7. Parents' psychological functioning

At the first assessment, parents completed an eight-item version of the 25-item Hopkins Symptom Checklist (Strand, Dalgard, Tambs, & Rognerud, 2003). The scale consists of eight items measuring symptoms of anxiety and depression. Items were rated on a 4-point scale according to how much parents felt bothered by these symptoms, from 1 (not at all bothered) to 4 (very much bothered). The scores were averaged into a measure of psychological symptom load ranging from 1.00 to 3.63. The internal consistency was adequate ($\alpha = 0.83$). Short-form versions of SCL correlate highly with the total score of the original scale and have good psychometric properties (Strand et al., 2003).

2.4.8. Parents' own inattention-hyperactivity symptoms as a child

At the fourth assessment, parents were asked to complete the Strengths and Difficulties questionnaire. The parents were instructed to give their answers on the basis of their own behavior when they were a child. Response options ranged from *not true* (0) to *somewhat true* (1) and *true* (2). The items measuring hyperactivity symptoms were 1) *restless, overactive, cannot keep still*, 2) *Squirmy, fidgety*, 3) *quickly changes from one activity to the other*. The items measuring inattention were 1) *easily inattentive and has poor concentration*, and 2) *complete tasks, has good concentration*. Finally, we summarized the mean score. The internal consistency was adequate ($\alpha = 0.71$).

2.4.9. Family harmony

Family harmony was measured at the first assessment using a scale from the Ontario Child Health Study (Boyle et al., 1987; Côté

et al., 2008). The scale consists of 13 items that parents rated on a 4-point scale, from (1) completely agree to (4) completely disagree. The items focused on interpersonal support, conflict resolution, and the emotional climate in the family. A total score was created as the sum of all items. High scores indicate high levels of family harmony. The internal consistency was adequate ($\alpha = 0.85$).

2.4.10. Family use of nature

At the first assessment, parents were asked the questions “How often do you spend time in the forest, park or mountains with your child?” and “How often do you spend time in nature by yourself?” The items were coded on a scale ranging from 0 (never) to 4 (five times or more weekly).

2.5. Analytic strategy

The dataset was analyzed using IBM SPSS Statistics Version 20. We used multilevel mixed modeling to test whether growth curves for each of the two dependent variables (composite inattention-hyperactivity symptoms, digit span scores) were predicted by the quantity of outdoor hours in daycare. Covariates were included when they were significantly correlated with outdoor hours and at least one of the dependent variables, as indicated by bivariate correlations (see more details below and Table 2). Covariates that were excluded from the final models based on these criteria include parents' psychological functioning, parents' use of nature, and parents' use of nature with the child after daycare or school hours.

Subjects were included in the study if they were registered with at least one response. Overall, there were 20.39% missing data points. Missing data was handled with full information maximum-likelihood estimation in SPSS. To rule out a possible attrition bias, independent t-tests were used to examine whether children with complete data differed from children with incomplete data on any of the variables. No significant differences were found.

In multilevel models, a hierarchy consists of lower-level observations nested within higher-level observations. In this study, multilevel models were run as a three-level model, where repeated outcome measures (level 1) were nested within children (level 2), who were nested within daycare centers (level 3). The repeated observations of inattention-hyperactivity symptoms and digit span scores were included as level 1 variables. Child and family level variables (age in months, socioeconomic status, family harmony, parents' inattention-hyperactivity symptoms as a child, child temperament, and gender) were included as level 2 variables, while daycare level variables (daycare type, daycare quality and outdoor hours) were included as level 3 variables. Outdoor hours, child temperament, family harmony, gender, age in months, parents' inattention-hyperactivity symptoms as a child, daycare quality, daycare type, socioeconomic status and time of assessment were treated as fixed effects. Time was centered at baseline (i.e., the first assessment) and coded as 1 (age 3), 2 (age 4), 3 (age 5), 4 (age 6) and 5 (age 7). Both linear and nonlinear effects of time were tested. Time² was included to test for nonlinear effects and was coded as 1 (age 3), 4 (age 4), 9 (age 5), 16 (age 6) and 25 (age 7). The dependent variables were tested separately in two models that each comprised four steps. The first step included a fixed effect (to estimate the mean) and a random effect (to estimate the variance) of the Level 1 intercept of the repeated measures in addition to random effects of the level 2 and 3 intercepts. In the second step, we added fixed main effects of main predictors (outdoor hours, time and time²), and control variables (gender, age in months, daycare quality, daycare type, socioeconomic status, family harmony, temperament, parents' inattention-hyperactivity symptoms as a child). The third step also included a two-way interaction between outdoor hours and time. This allowed to test whether the association between

outdoor hours and the dependent variable was constant throughout the five-year assessment period. In the fourth model, an interaction between outdoor hours and a quadratic time effect was added. This allowed to test whether the association between outdoor hours and the dependent variable was exponential in size. Interactions between outdoor time and gender, daycare quality and child temperament were also tested, but none were found and these analyses are thus not presented for parsimony. The best fitting models were established using -2LL difference tests (which are equivalent to chi-square difference tests) between nested models.

3. Results

3.1. Bivariate correlations between key variables

Distributional properties of study variables are presented in Table 1. Table 2 shows the bivariate correlation coefficients between study variables. On the bivariate level, outdoor hours showed a negative correlation with inattention-hyperactivity symptoms that reached significance at age 4, age 5 and age 6. Amongst the control variables, nature-based daycare centers showed a negative correlation with inattention-hyperactivity symptoms that reached significance at age 4, age 5 and age 6. Boys showed significantly higher inattention-hyperactivity symptoms than girls at age 4, age 5, age 6 and age 7. Daycare center quality showed a negative correlation with inattention-hyperactivity symptoms that reached significance at age 3, age 4, age 5 and age 6. Socioeconomic status showed a negative correlation with inattention-hyperactivity symptoms that reached significance at age 5, age 6 and age 7. Child temperament showed a significant positive correlation with inattention-hyperactivity symptoms only at age 7. Family harmony showed a significant negative correlation with inattention-hyperactivity symptoms at age 6. Parents' retrospective ratings of their own inattention-hyperactivity symptoms as a child were positively correlated with their child's inattention-hyperactivity symptoms at age 6, while children's age in months was positively correlated with their inattention-hyperactivity at age 7.

Outdoor hours were positively associated with digit span scores at age 5, age 6 and age 7. Daycare quality was also positively correlated with digit span scores at age 6. Similarly, socioeconomic status was positively correlated with digit span scores at age 5, age 6 and age 7. Child temperament showed a negative correlation with digit span scores that reached significance at age 4. Girls showed higher digit span scores than boys at age 4 and at age 7. There was a significant and positive correlation between age in months and digit span scores at age 7, and a significant and positive correlation between family harmony and digit span scores at age 5.

3.2. Growth curve analyses

3.2.1. Inattention-hyperactivity symptoms

Table 3 shows the results from the mixed linear growth curve analysis with inattention-hyperactivity symptoms as dependent variable. The unconditional model (step 1) revealed a significant, negative effect of time ($b = -0.18$, $p < 0.01$), indicating that, on average, hyperactivity levels decreased with increasing age. The results from the second step indicated that boys and children from lower SES families showed higher inattention-hyperactivity levels than girls ($b = 0.26$, $p < 0.01$) and children from higher SES families ($b = -0.08$, $p < 0.01$). Family harmony was associated with low inattention-hyperactivity symptoms ($b = -0.01$, $p < 0.01$), and age in months was positively associated with inattention-hyperactivity symptoms ($b = 0.00$, $p < 0.01$). Daycare center quality was negatively associated with inattention-hyperactivity symptoms

Table 1
Descriptive and frequencies statistics for study variables.

Variable	Range	Mean	SD	Skew	Kurtosis	N	Plannedmissing	MissingNAT
Outdoor hours	2.00–9.00	5.20	1.60	0.60	0.25	562	0	0
Girls						298	0	0
Age in months	12.00–78.00	52.45	15.96	−0.37	−0.67	562	0	0
SES	1.50–6.00	3.62	0.86	−0.01	−0.39	536	0	26
Temperament	1.33–3.10	2.29	0.28	0.04	0.55	440	0	122
Family harmony	4.00–52.00	44.82	5.80	−1.40	5.10	521	0	41
Parent in-hy	0.00–1.80	0.27	0.32	7.85	3.89	330	0	232
Parent RPH	1.00–3.63	1.24	0.35	10.49	2.75	535	0	27
Nature with child	0.00–4.00	1.50	0.76	0.48	0.46	524	0	38
Parent in nature	0.00–4.00	1.15	0.92	0.63	0.14	525	0	37
Nature based DCC						66	0	0
DCC quality	−1.62–2.84	0.00	1.00	0.40	0.05	562	0	0
In-hy age 3	0.00–2.00	0.54	0.50	1.03	0.62	119	420	23
In-hy age 4	0.00–2.00	0.48	0.54	1.30	1.00	246	283	33
In-hy age 5	0.00–2.00	0.42	0.48	1.24	0.96	374	148	40
In-hy age 6	0.00–2.00	0.40	0.49	1.38	1.40	441	46	75
In-hy age 7	0.00–2.00	0.48	0.49	1.11	0.70	356	135	71
Digit span age 3	0.00–7.00	1.16	1.82	1.60	1.92	91	420	51
Digit span age 4	0.00–10.00	3.36	2.20	−0.18	−0.69	237	283	42
Digit span age 5	0.00–13.00	4.83	2.00	−0.14	1.08	365	148	49
Digit span age 6	0.00–14.00	5.60	1.96	−0.01	1.58	448	46	68
Digit span age 7	0.00–14.00	6.24	1.81	0.25	1.15	379	135	48

Note. Missing NAT = missing not at random; Planned missing = purposefully missing due to design; Outdoor hours = Number of daily outdoor hours in daycare center; DCC = daycare center; SES = socioeconomic status; Parent in-hy = parent inattention-hyperactivity symptoms as a child; Parent RPH = parents' recent psychological health; In-hy = inattention-hyperactivity symptoms.

($b = -0.03$, $p < 0.01$), while parents' inattention-hyperactivity symptoms as a child was positively associated with their child's inattention-hyperactivity symptoms ($b = 0.18$, $p < 0.01$). There was no significant main effect of outdoor hours on the intercept of inattention-hyperactivity symptoms. The results from the third step revealed a significant main effect of outdoor hours on inattention-hyperactivity symptoms ($b = -0.06$, $p < 0.05$). The results from the fourth step revealed a significant effect of a three-way interaction between outdoor hours and time² on inattention-hyperactivity symptoms ($b = 0.01$, $p < 0.05$). Post hoc probing of the interaction (Holmbeck, 2002) indicated that children attending daycare who spent more time outdoors showed fewer inattention-hyperactivity symptoms at ages 4, 5, 6 and 7, controlling for a host of confounding factors. When testing inattention and hyperactivity separately as dependent variables in the mixed linear growth curve analyses, the analyses revealed similar results for both inattention and hyperactivity.

The graph in Fig. 2 illustrates the development of inattention-hyperactivity symptoms from age 3 to age 7. The line marked with dots represents low levels of outdoor hours which corresponds to 3 daily outdoor hours, while the line marked with diamonds represents high levels of outdoor hours, which corresponds to 7 daily outdoor hours. As can be seen, children exposed to consistently low levels of outdoor hours showed unchanged levels of inattention-hyperactivity symptoms throughout all assessment times. In contrast, children exposed to consistently high levels of outdoor hours, while initially not significantly different from children exposed to low levels of outdoor hours, showed a dramatic decline of inattention-hyperactivity symptoms from age 3 to age 5 and retained these low levels also at age 6. However, their levels of inattention-hyperactivity symptoms increased again as they entered school at age 7.

3.2.2. Digit span forward

Table 4 shows the results from the mixed linear growth curve analysis with scores from the digit span test as dependent variable. The unconditional model (step 1) revealed a significant effect of time, indicating that, on average, digit span scores increased with

increasing age ($b = 2.72$, $p < 0.01$) with a slight tapering off at higher ages. The results from the second step showed a positive and significant main effect of outdoor hours on the intercept ($b = 0.21$, $p < 0.01$). Moreover, girls and children from higher SES families showed better performance at the digit span test than boys ($b = -0.46$, $p < 0.01$) and children from lower SES families ($b = 0.36$, $p < 0.01$). Also, age in months was positively associated with digit span scores ($b = 0.01$, $p < 0.01$). The results from the third step revealed no significant interaction between outdoor hours and time, while results from the fourth step revealed significant interactions between outdoor hours and time ($b = 0.30$, $p < 0.05$), and outdoor hours and time² ($b = -0.04$, $p < 0.05$). As illustrated in Fig. 3, while children with high and low levels of outdoor hours did not differ with respect to performance on the digit span at age 3, the former showed consistently higher levels of digit span performance than the latter from age 4 onward until after school entry (i.e., age 7).

4. Discussion

The goal of our study was to investigate whether exposure to outdoor environments is associated with children's cognitive and behavioral development throughout daycare and the first year of elementary school. Results from growth curve analyses revealed an inverse dose-response relation between daily outdoor hours and teacher-rated inattention-hyperactivity symptoms. The relation was strongest when the children were five and six years old and decreased again when children entered elementary school. Finally, the results also revealed a positive dose-response relation between outdoor hours and the children's attention skills as measured by the digit span test. This relation was also strongest when the children were 5 and 6 years, before declining in strength at age 7.

Our finding that the number of daily hours spent outdoors is associated with lower inattention-hyperactivity symptoms and higher digit span test scores indicates a positive association between outdoor activities in preschool and cognitive-behavioral development.

Table 2
Pearson's bivariate correlation matrix for study variables.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1. Outdoor hours																					
2. Gender	0.01																				
3. Age in months	−0.06	0.03																			
4. Temperament	−0.01	−0.02	−0.05																		
5. SES	0.07	−0.03	−0.02	−0.05																	
6. Family harmony	−0.06	−0.02	−0.04	−0.18**	0.01																
7. Parent in-hy	0.02	0.03	0.03	0.12*	−0.21**	−0.12*															
8. Nature with child	−0.02	−0.05	−0.03	−0.09	−0.01	0.16**	−0.10	0.45**													
9. Parent in nature	0.00	0.03	0.11*	−0.11*	0.13**	−0.02	0.16**	−0.16**	−0.06												
10. Parent RPH	−0.02	0.05	0.09*	0.13**	−0.10*	−0.28**	−0.10*	−0.16**	0.02	0.00											
11. Nature DCC	0.47**	−0.01	0.01	0.01	0.00	−0.02	0.06	−0.02	0.05	−0.04	−0.13**										
12. DCC quality	0.05	−0.02	0.02	0.02	−0.07	0.00	−0.02	0.05	−0.15	−0.03	−0.11	−0.29**									
13. In-hy age 3	−0.16	−0.13	−0.04	0.00	−0.18	−0.05	0.02	−0.15	−0.02	0.08	−0.18*	−0.14*	0.51**								
14. In-hy age 4	−0.17**	−0.19**	0.02	0.01	−0.08	−0.05	0.14	0.06	−0.02	0.00	−0.18**	−0.12*	0.35**	0.48**							
15. In-hy age 5	−0.23**	−0.24**	−0.05	0.05	−0.19**	−0.06	0.10	0.00	−0.09	0.01	−0.18**	−0.10*	0.47**	0.39**	0.57**						
16. In-hy age 6	−0.16**	−0.16**	0.05	0.07	−0.15**	−0.13**	0.22**	0.01	−0.09	0.07	−0.15**	−0.10*	0.41**	0.41**	0.41**	0.55**					
17. In-hy age 7	0.01	−0.28**	0.17**	0.17**	−0.12*	−0.08	0.10	−0.03	−0.05	−0.01	0.05	−0.01	pm	0.32**	0.27*	0.02	pm				
18. Digit span age 3	−0.04	0.06	0.11	−0.11	0.16	0.08	−0.16	−0.07	−0.07	0.04	0.00	−0.07	0.03	0.32**	0.20**	−0.18*	−0.17	0.24*			
19. Digit span age 4	0.10	0.18**	−0.04	−0.20**	0.07	−0.06	−0.01	−0.09	0.00	−0.06	0.10	−0.01	−0.08	−0.24**	−0.20**	−0.18**	−0.20**	−0.08	0.40**		
20. Digit span age 5	0.19**	0.09	0.03	−0.09	0.27**	0.12*	0.05	−0.06	0.03	−0.10	0.00	0.05	−0.35**	−0.22**	−0.21**	−0.18**	−0.29**	0.21	0.33**	0.50**	
21. Digit span age 6	0.15**	0.08	0.04	−0.10	0.18**	0.06	0.01	−0.04	−0.01	0.01	−0.04	0.10*	−0.37**	−0.13	−0.23**	−0.24**	−0.19**	0.21	0.44**	0.32**	0.38**
22. Digit span age 7	0.11*	0.15**	0.22**	−0.01	0.15**	−0.01	−0.08	−0.08	0.07	−0.06	0.00	0.04	pm	−0.07	−0.11	−0.19**	−0.16**	pm	0.44**	0.32**	0.38**

Note. Gender is coded 1 for boys and 2 for girls. Nature DCC is coded 0 for conventional and 1 for nature based day care center; Outdoor hours = number of daily outdoor hours; SES = socioeconomic status; Parent in-hy = parent inattention-hyperactivity symptoms as a child; Parent RPH = parents' recent psychological health; DCC quality = day care center quality; In-hy = inattention-hyperactivity symptoms; Pm = planned missing.

* $p < 0.05$. ** $p < 0.01$.

4.1. The positive effect of time spent outdoors

In his attention restoration theory, Kaplan (1995) suggested that natural environments encourage activities fostering optimal development of the nervous system. As demonstrated in a recent study, 40 s of restorative "micro-breaks" of greenness is enough to sustain attention (Lee, Williams, Sargent, Williams, & Johnson, 2015). Furthermore, children in outdoor settings engage in focused play, peer conflict resolution, and in teacher-directed activities. Outdoor daycare settings may thus offer rich opportunities for both effortless and effortful attention, allowing children to switch back and forth between the two states of attention. This is also in line with a recent review by Gill (2014) who argues that green environments are a necessary part of a balanced diet of childhood experiences.

An experimental study would be necessary to confirm a causal relation between frequent exposure to natural environments and children's cognitive and behavioral development. Moreover, the reason as to why outdoor environments are beneficial for cognitive and behavioral development remains unclear, and future research should address this issue. Effects of outdoor time on children's behavioral and cognitive functioning are probably multifactorial, and it is possible that factors other than attention restoration are at play. For example, children who are frequently outdoors may be more physically active, which could ameliorate attention and decrease hyperactive behavior and hence foster cognitive skills. In line with this notion, physical activity has been associated with better cognitive functioning in children diagnosed with ADHD (Gapin & Etnier, 2010) and is associated with structural growth in the prefrontal cortex and hippocampus (Erickson, Leckie, & Weinstein, 2014), areas of the brain that are important for working memory. Future studies should use accelerometers measuring children's activity levels (Storli & Hagen, 2010) to examine the mediating effect of physical activity on the association between exposure to outdoor environments and children's cognitive and behavioral functioning. Another alternative explanation of the beneficial effects of outdoor activities on child development is that air quality in outdoor environments is superior to that of indoor environments. Poor air quality in schools is associated with poor cognitive performance in children (Bakó-Biró, Clements-Croome, Kochhar, Awbi, & Williams, 2012). Measures of carbon monoxide levels in daycare centers could be conducted to test whether air quality at least partially explains the association between exposure to outdoor environments and children's levels of hyperactivity-inattention and digit span performance. Furthermore, children who spend the better part of the day outdoors are exposed to high levels of daylight. Light exposure is the principal cue permitting circadian rhythm regulation in animals (Cao et al., 2015) and is associated with attention (Cajochen, 2007), sleep, and emotions (LeGates, Fernandez, & Hattar, 2014). Thus, future studies should also examine exposure to daylight as a potential explanatory mechanism.

As in any non-experimental study, however, another alternative explanation can be the presence of a selection effect. Although children exposed to high versus low levels of outdoor hours did not differ in terms of their inattentive-hyperactive behavior or their digit span performance at the first assessment time (age 3), they may have differed on other, non-measured characteristics. Ideally, randomized controlled trials should be used to test our research question. However, an experimental intervention would be difficult to implement. Children would have to be randomized to various types of daycare, and it would not be possible to offer the intervention to control participants after the study, as the children age and commence school. Furthermore, the preschool period may be a critical time when children are especially susceptible to effects of

Table 3Fixed effects estimates and variance-covariance estimates for models of the predictors of inattention and hyperactivity symptoms ($n = 517$).

Parameter	Model 1	Model 2	Model 3	Model 4
Intercept	0.74 (0.08)**	Fixed effects 0.54 (0.11)**	0.55 (0.11)**	0.53 (0.11)**
Time	–0.18 (0.05)**	Level 1 (repeated measures) –0.19 (0.04)**	–0.19 (0.05)**	–0.19 (0.05)**
Time ²	0.03 (0.01)**	0.02 (0.01)**	0.02 (0.01)**	0.02 (0.01)**
Gender		Level 2 (children and families) 0.26 (0.03)**	0.26 (0.03)**	0.26 (0.03)**
Age in months		0.00 (0.00)*	0.00 (0.00)*	0.00 (0.00)*
SES		–0.08 (0.02)**	–0.08 (0.02)**	–0.08 (0.02)**
Temperament		0.08 (0.07)	0.08 (0.07)	0.08 (0.07)
Family harmony		–0.01 (0.00)**	–0.01 (0.00)**	–0.01 (0.00)**
Parent in-hy		0.18 (0.07)**	0.18 (0.07)**	0.18 (0.07)**
Nature DCC		Level 3 (day care center) 0.15 (0.08)	0.15 (0.08)	0.15 (0.08)
DCC quality		–0.03 (0.01)**	–0.03 (0.01)**	0.03 (0.01)**
Outdoor h		–0.02 (0.02)	–0.06 (0.03)*	–0.04 (0.05)
Outdoor h/time			0.01 (0.01)	–0.05 (0.03)
Outdoor h/time ²				0.01 (0.00)*
Intercept	0.08 (0.01)**	Random parameters Level 2 (children) 0.06 (0.01)**	0.06 (0.01)**	0.08 (0.01)**
Intercept	0.01 (0.01)*	Level 3 (daycare center) 0.01 (0.00)	0.01 (0.01)	0.01 (0.01)
–2*LL (np)	1725.28 (14)	1613.97 (23)	1610.46 (24)	1605.18 (25)

Note. Gender is coded 1 for boys and 2 for girls. Nature DCC is coded 1 for nature-based and 0 for conventional; Standard errors are in parentheses. Np = number of parameters. SES = socioeconomic status; Temperament = child temperament; Parent in-hy = parent inattention-hyperactivity symptoms as a child; DCC quality = daycare center quality; Outdoor h = number of daily outdoor hours; 2*LL = 2*log likelihood.

* $p < 0.05$. ** $p < 0.01$.

Fig. 2. Inattention-Hyperactivity Growth Curves for High and Low Levels of Outdoor Hours.

Note. Post hoc probing of interaction effects (Holmbeck, 2002); Outdoor hours = daily outdoor hours.

their environment, so receiving the intervention at a later time might not have the same effect. Nevertheless, our study is in line with previous studies that have applied longitudinal designs to investigate how various daycare characteristics are related to children's development (Belsky et al., 2007; Côté et al., 2008; NICHD Early Child Care Research Network, 2000). Teacher reporting bias might also have affected the results of this study. Outdoor time in green settings may positively affect teachers' mood, attention and impulsivity (Berry, Repke, Nickerson, Conway Odum, & Jordan, 2015; Berto, 2005; White, Pahl, Ashbullby, Herbert, & Depledge, 2013). Teachers may therefore experience the children's inattention-hyperactivity symptoms as less disturbing when outdoors, and rate the children's symptoms as better because they themselves are better equipped to deal with such symptoms.

Future studies might consider effects of outdoor time on teachers' attention skills and on the interactions between teachers and children.

Furthermore, it is possible that non-measured environmental or genetic factors influencing children's hyperactivity symptoms and digit span test scores also influence the type of daycare they are exposed to. For example, socioeconomic status may act as a confounding variable if it is associated with both parents' choice of daycare centers and their children's levels of inattention-hyperactivity symptoms and digit span test scores. Likewise, it is possible that outdoor-based daycare centers do better on quality indicators such as group size, child-adult ratio, staff education levels and employment stability. More physically active or outdoor-oriented parents may more readily decide to send their child to an outdoor daycare center. To control for such possible selection effects, parents' use of nature by themselves and with the children after school hours, were explored as possible confounders, but were not associated with the number of daycare center outdoor hours. However, in accordance with previous research (Côté et al., 2008; De Schipper, Tavecchio, Ijzendoorn, & Van Zeijl, 2004; Geoffroy et al., 2007), being a boy, low socioeconomic status, low family harmony, difficult child temperament and low scores on daycare quality indicators were associated with higher levels of inattention-hyperactivity symptoms, whereas only child gender and family socioeconomic status were associated with digit span scores. Because these possible sources of selection effects were controlled in this study, they are unlikely alternative explanations for our findings. Nevertheless, other uncontrolled confounding variables cannot be ruled out.

Surprisingly, daycare center quality was significantly associated with inattention-hyperactivity scores in our models. The Norwegian government strictly regulates structural and dynamic quality (Department of Early Childhood Education and Care, 2014; Solheim, Wichstrøm, Belsky, & Berg-Nielsen, 2013). For example, all daycare centers in the sample were high in structural quality parameters, when compared to the daycare centers used in the

Table 4Fixed effects estimates and variance-covariance estimates for models of the predictors of digit span scores ($n = 513$).

Parameter	Model 1	Model 2	Model 3	Model 4
Intercept	–1.09 (0.34)**	Fixed effects –1.04 (0.48)**	–1.02 (0.47)*	–0.97 (0.47)*
Time	2.72 (0.21)**	Level 1 (repeated measures) 2.68 (0.21)**	2.67 (0.21)**	2.65 (0.21)**
Time ²	–0.25 (0.03)**	–0.25 (0.03)**	–0.24 (0.03)**	–0.24 (0.03)**
Gender		Level 2 (children and families) –0.46 (0.13)**	–0.46 (0.13)**	–0.46 (0.13)**
Age in months		0.01 (0.00)*	0.01 (0.00)*	0.01 (0.00)*
SES		0.36 (0.08)**	0.36 (0.08)**	0.36 (0.08)**
Temperament		–0.32 (0.26)	–0.32 (0.26)	–0.32 (0.26)
Family harmony		0.02 (0.01)	0.02 (0.01)	0.02 (0.01)
Parent in-hy		0.15 (0.27)	0.15 (0.27)	0.14 (0.27)
Nature DCC		Level 3 (day care center) 0.24 (0.34)	0.25 (0.34)	0.25 (0.34)
DCC quality		0.02 (0.04)	0.02 (0.04)	0.02 (0.04)
Outdoor h		0.21 (0.06)**	0.14 (0.12)	–0.27 (0.24)
Outdoor h/time			0.02 (0.03)	0.30 (0.14)*
Outdoor h/time ²				–0.04 (0.02)*
Random parameters				
Intercept	0.90 (0.23)**	Level 2 (children) 0.66 (0.23)**	0.66 (0.23)**	0.66 (0.23)**
Intercept	0.29 (0.14)*	Level 3 (daycare center) 0.11 (0.07)	0.11 (0.07)	0.11 (0.07)
–2*LL (np)	5782.07 (14)	5728.97 (23)	5728.58 (24)	5724.50 (25)

Note. Gender is coded 1 for boys and 2 for girls. Nature DCC is coded 1 for nature-based and 0 for conventional; Standard errors are in parentheses. Np = number of parameters. SES = socioeconomic status; Temperament = child temperament; Parent in-hy = parents' inattention-hyperactivity symptoms as a child; DCC quality = daycare center quality; Outdoor h = number of daily outdoor hours; 2*LL = 2*log likelihood.

* $p < 0.05$. ** $p < 0.01$.

Fig. 3. Digit Span Scores Growth Curves for High and Low Levels of Outdoor Hours. Note. Post hoc probing of interaction effects (Holmbeck, 2002); Outdoor hours = daily outdoor hours.

NICHD study (NICHD Early Child Care Research Network, 2000). In other countries with greater variability and less governmental support and quality regulations, daycare quality may play an even larger role (Bennett, 2008). Importantly, however, daycare quality did not explain the observed association between exposure to outdoor hours and children's cognitive and behavioral functioning.

4.2. Strengths, limitations, and implications

All daycare centers in the municipalities agreed to take part in the study, representing a variety of forms and models of daycare centers. The study used a multidisciplinary approach, including cognitive tests and interviews with the children, parental questionnaires and in-depth interviews with daycare management. The

children were prospectively followed from preschool to elementary school, while the study was of a cross-sectional nature during the preschool years. Against that background some limitations should be mentioned. We did not have explicit measures of mechanisms underlying our findings. This means we can only speculate why children who are exposed to outdoor environments have lower levels of inattention-hyperactivity symptoms and higher scores on the digit span test than children exposed to indoor daycare environments. Also, we did not have a pre-treatment assessment of the children's behavior and cognitive skills as all children had attended daycare for at least one year by the first assessment. The explanation for our findings may be multifactorial, and future studies should test to what extent attentional restoration mediates the relation between outdoor hours in preschool and cognitive-behavioral functioning. Other possible explanations such as physical activity levels, daycare center air quality, daylight exposure and child-teacher interactions should also be explored as possible underlying mechanisms.

5. Conclusion

Overall, the findings from this study suggest that high exposure to outdoor environments might be a cheap, accessible and environmentally friendly way of supporting and enhancing children's self-regulatory capacities and cognitive development. It may also be a safe intervention for children suffering from attention disorders. For some children, high doses of nature may be an effective alternative to medication. This is however still speculative, and research on clinical populations is required. Nature is easily accessible even in urban areas. Large cities usually have parks and vegetation. Placing daycare centers near parks enables daily trips to green environments.

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Environmental Light Exposure, Circadian Stability, and Symptoms of Inattention and
Hyperactivity: An Observational Study of Australian Preschoolers.

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Abstract

Background: Environmental light increases acute alertness and is the main regulator of circadian stability in humans. In turn, circadian stability is strongly associated with inattention and hyperactivity symptoms in both children and adults. Evidence from animal studies suggest that light exposure may affect inattention and hyperactivity related behaviors during critical windows in early development. However, very little is known about the associations between light exposure, circadian stability and symptoms of inattention and hyperactivity in young human children.

Objective: Our first aim was to examine whether circadian stability and the dosage, intensity and duration of environmental light were associated with symptoms of inattention and hyperactivity in children between 3 and 6 years of age. Our second aim was to examine whether there was an interaction between light exposure and circadian stability in predicting symptoms of inattention and hyperactivity.

Methods: The present study used a subsample of the E4Kids Study. Objective measures of light exposure and circadian stability were collected from 48 preschool children continuously over a period of two weeks. Parental reports of inattention and hyperactivity symptoms were collected concurrently and again 12 months later.

Results: Longer durations of light exposure were strongly associated with lower levels of hyperactivity symptoms at baseline ($b = -0.64$, $CI = -.97; -.25$), but not at follow up. Circadian stability was associated with hyperactivity symptoms at follow up ($b = -0.44$, $-.81; -.08$), but not at baseline. Neither circadian stability or light exposure were associated with inattention symptoms.

Conclusion: We provide the first evidence that the duration and intensity of environmental light exposure is inversely and strongly associated with symptoms of hyperactivity in young children in a naturalistic setting. Potential mechanistic pathways are discussed.

Introduction

Attention deficit hyperactivity disorder (ADHD) is the most common neurodevelopmental disorder in child populations with a prevalence of approximately 7 % (Thomas, Sanders, Doust, Beller, & Glasziou, 2015). Typically emerging in early childhood, ADHD is characterized by impulsivity, inattention and hyperactivity (World Health Organization, 1992), as well as impairments in alertness, attention and executive functions (Aguilar, Eubig, & Schantz, 2010). The impacts of ADHD continue throughout childhood and into adulthood, through academic underachievement, conduct problems, anxiety, depression and marital problems (Biederman, 2005). ADHD is a highly heterogeneous condition involving multiple levels of risks, including genetic, perinatal, postnatal and environmental influences (Rivas et al., 2019; Taylor & Sonuga-Barke, 2008). However, we are still far from a complete understanding of its etiology. Of those children diagnosed with ADHD, up to 78% suffer from delayed circadian phase and delayed melatonin peak (Bijlenga, Vollebregt, Kooij, & Arns, 2019; Van der Heijden, Smits, Someren, & Boudewijn Gunning, 2005; Van Veen, Kooij, Boonstra, Gordijn, & Van Someren, 2010). Circadian phase is a recurring pattern in a range of psychological, behavioural and physiological functions that repeat every 24 hours, and light exposure is the most potent environmental signal that affects circadian phase and stability (Czeisler, 2013).

It has been postulated that there may be strong links between the timing and intensity of light exposure, circadian stability, and the development of inattention and hyperactivity symptoms (Bijlenga et al., 2019). Experimental animal studies have demonstrated that marmosets who are exposed to high levels of daylight during sensitive periods in early development are less likely to develop inattention-hyperactivity-like symptoms in adulthood (Koshiba et al., 2015). A similar link has been observed in studies of humans, finding that the prevalence of ADHD is lower in geographical areas with high levels of sunlight exposure

(Arns, van der Heijden, Arnold, & Kenemans, 2013), and that children who spend long periods of time outdoors in early childhood are less likely to develop inattention-hyperactivity symptoms (Ulset, Vitaro, Brendgen, Bekkhus, & Borge, 2017). However, these links are poorly understood and little is known about the role of light exposure and circadian stability in the pathophysiology of inattention-hyperactivity symptoms in children attending preschool.

In mammals, the master circadian pacemaker is situated in the suprachiasmatic nuclei (SCN) of the anterior hypothalamus. The SCN is strongly entrained by environmental light exposure that is received by retinal ganglion cells in the eye, via the retinohypothalamic tract (Hughes, Jagannath, Hankins, Foster, & Peirson, 2015; Zele, Feigl, Smith, & Markwell, 2011). The SCN is responsible for regulating the secretion of the glucocorticoid stress hormone cortisol and the sleep hormone melatonin, both of which exhibit a clear circadian pattern (Keller et al., 2006; Nováková et al., 2011). Cortisol plasma level peaks within one hour after waking, and is amplified by environmental light exposure in the morning (Scheer & Buijs, 1999; Van Someren & Riemersma-Van Der Lek, 2007). Conversely, melatonin secretion is inhibited by environmental light exposure. Melatonin is suspended during the day, starts to increase before bedtime, and peaks between 02:00 and 03:00 during the night (Brainard et al., 1988; Coogan, Baird, Popa-Wagner, & Thome, 2016). Light exposure in the evening disturbs circadian stability by inhibiting melatonin secretion, shifting the circadian clock to a later time (Khalsa, Jewett, Cajochen, & Czeisler, 2003; Zeitzer, Dijk, Kronauer, Brown, & Czeisler, 2000). In turn, low circadian stability is associated with a range of mental health problems and neurodegenerative disorders, such as depression (Howland & Thase, 1999), onset of bipolar episodes (Malkoff-Schwartz et al., 2000), schizophrenia (Wulff, Dijk, Middleton, Foster, & Joyce, 2012), anxiety, dementia and hyperactivity (Wulff, Gatti, Wettstein, & Foster, 2010). Disturbances in circadian stability may also have adverse consequences for attention, memory and executive functions (Wulff et al., 2010).

There is growing evidence of association between circadian processes and ADHD symptomologies. For example, children diagnosed with ADHD exhibit shorter durations of daily melatonin secretion, and a delayed sleep phase (Van der Heijden et al., 2005), that seem to be related with a delayed offset of melatonin in the morning (Nováková et al., 2011). Further, an experimental study of adults with ADHD, found that light exposure in the morning shifted melatonin onset and sleep midpoint to an earlier time, and that this shift was associated with less hyperactivity symptoms, but not inattention (Fargason et al., 2017). Studies have also shown a weakened reactivity of the HPA-axis (i.e. decreases in cortisol levels during the day) in children with the hyperactive-impulsive subtype of ADHD (Hong, Shin, Lee, Oh, & Noh, 2003), but not for those with the inattentive subtype of ADHD (Van West, Claes, & Deboutte, 2009). It has been postulated that chronic low levels of cortisol leads to higher thresholds for sympathetic and limbic arousal, and that children compensate for this under-arousal by engaging in hyperactive behavior (Isaksson, Nilsson, Nyberg, Hogmark, & Lindblad, 2012). Since early timing of light exposure inhibits melatonin and stimulates cortisol secretion, it is possible that intense light exposure during the hours following sleep offset, reduces inattention and hyperactivity through at least two pathways. First, early timing of light exposure may inhibit the release of melatonin in the morning, possibly shifting the circadian clock to an earlier time, resulting in better sleep and reduced ADHD symptoms. Second, it is possible that morning light exposure enhances cortisol secretion, compensating for the weak cortisol response to stress that has been observed in hyperactive children, and thus alleviate ADHD symptoms by lowering the threshold for sympathetic and limbic arousal.

Independent of circadian processes, light exposure also has acute effects on alertness, memory formation, and attention, through a pathway that involves the release of norepinephrine in the prefrontal cortex (Alkozei, Smith, Dailey, Bajaj, & Killgore, 2017;

Vandewalle et al., 2007). In particular, there is evidence of a dose-response relationship for the acute alerting effect of light, that starts at about 10 lux, reaches half of the maximum alerting response at 100 lux, and the maximum alerting response at 9100 lux (Cajochen, 2007). Similar to effects of light exposure on circadian stability, this “acute” pathway involves blue wavelength light that stimulate intrinsically photosensitive retinal ganglion cells in the eye. These cells transmit signals to the SCN, which project to the locus coeruleus of the brain stem (Aston-Jones, Chen, Zhu, & Oshinsky, 2001). In turn, the locus coeruleus stimulates the release of norepinephrine throughout the brain, including the prefrontal cortex (Alkozei et al., 2017; Vandewalle et al., 2007). However, this pathway does not involve suppression of melatonin or a disturbance in circadian stability (Rautkylä, Puolakka, & Halonen, 2012). Norepinephrine is thought to be dysregulated in children with ADHD, and low doses of methylphenidate (a common pharmacological treatment for ADHD) produce increases in synaptic norepinephrine and alleviate ADHD symptoms (Arnsten, 2006). Experimental studies in adults show that brief bright light exposure during daytime (when melatonin is not secreted) enhances immediate and short-term alertness, vigilance, energy and working memory (Alkozei et al., 2016; Ruger, Gordijn, Beersma, de Vries, & Daan, 2006).

These findings suggest that light exposure is a direct alerting factor that may interact with inattention and hyperactivity in a fashion similar to pharmaceutical stimulants. Thus, the timing, duration and intensity of environmental light exposure may be involved in the early development of inattention-hyperactivity symptoms in young children. However, no studies to our knowledge have examined whether the dosage, timing and intensity of light exposure is linked with inattention and hyperactivity in young children.

The present study examined whether children’s circadian rhythms and the timing, duration and intensity of environmental light exposure are associated with inattention-hyperactivity symptoms in healthy children aged 3 to 5 years, both concurrently and at 12

months follow-up. Since there may be different pathways to inattention and hyperactivity symptoms (Diamond, 2005), we examine inattention and hyperactivity separately. We hypothesized that 1) the duration and intensity of light exposure would be associated with lower concurrent and long-term symptoms of inattention and hyperactivity, 2) early timing of light exposure would be negatively associated with inattention and hyperactivity, and 3) the timing, duration and intensity of light exposure would protect (i.e. moderate) against the risk of circadian instability on inattention and hyperactivity symptoms.

Methods

Study Design

Children were recruited to *The Sleep in Daycare Study* from six long-day daycare centers in Brisbane, Australia, from areas that were medium to high in socioeconomic status (recruitment is described in detail elsewhere (Pattinson, Allan, Staton, Thorpe, & Smith, 2015; Pattinson, Staton, Smith, Sinclair, & Thorpe, 2014)). The study was part of a larger study (E4Kids Study) that included a total of 300 preschool centers. Participating families were mailed a 14-day sleep diary, a parent questionnaire and an actigraph (Actiwatch 2 device, Philips). Actigraphs were worn by each child for 14 consecutive days on the wrist of the non-dominant hand. Parents were instructed to not place clothing over the actigraphs. Concurrently, parents completed a sleep diary and indicated if the actigraph had been removed from the child's wrist. Parents also completed a questionnaire, including family and child demographic information and the Strengths and Difficulties Questionnaire (SDQ) (Goodman, 2001). Researchers visited each child's daycare center to measure the children's height and weight, and to observe the daily routine and environment. Actigraphy recordings and baseline measures were gathered between October and December, a period in which the average sunrise took place at 04:55, and sunset took place at 18:17. We also account for

children's levels of physical activity (Archer & Kostrzewa, 2012), body mass (Pattinson et al., 2015), regularity of circadian rhythm (Van der Heijden et al., 2005), sleep duration, age and gender. At the first data collection, complete data was obtained from 49 participants, while the parents of 43 children completed the SDQ at follow-up, reflecting a retention rate of 87.8%. Ethical clearance for this study was obtained from the Queensland University of Technology's Human Research Ethics Committee.

Actigraph Measurements

Using actigraphs, light and activity levels (range: 0.5 - 2G) were measured in 1-minute epochs (i.e. intervals) for 14 days. An actigraph is a wearable sensor that is worn on the wrist, including an accelerometer that collects data about movement, and a lux sensor that collects data about light exposure. Data was cleaned using the Actiware 5.2 software. Periods in which the parent reported that the actigraph was removed from the child's wrist, and any inactive periods that extended longer than 5 minutes, were excluded from the analyses. The full data cleaning procedures are described in detail elsewhere (Pattinson et al., 2015).

Predictor Variables

Light variables were calculated to reflect the duration and timing of exposure to light above a range of lux thresholds (10 lux to 3000 lux), using a methodology first described by Reid and colleagues (Reid et al., 2014) and developed for this child sample as described, with published R script (Pattinson et al., 2015). Data was smoothed using a 5-minute rolling average, and then aggregated over 24-hours for each child. Time above threshold (TAT) reflects the average daily number of minutes spent above a given lux threshold, while mean light timing above threshold (MLiT) reflects the distribution of light exposure throughout the day. MLiT integrates information about the duration (number of minutes above a threshold),

intensity (lux threshold) and timing (clock time of each minute above the threshold) of light exposure (Pattinson et al., 2015; Reid et al., 2014). For example, an MLiT100 score of 780 (i.e. 780 minutes from midnight, or 13 hours) would indicate that one's light exposure that is greater than 100 lux is on average centered around 13.00. Data was imported into R project at 1-minute epochs. Any 24-hour period with more than four hours of excluded data were not considered in the further analyses.

The circadian rhythm variable was estimated based on interdaily stability, and was calculated using the nparACT package. This is in accordance with other studies on circadian rhythmicity (McGowan & Coogan, 2018). The nparACT uses a non-parametric approach originally described by Blume and colleagues (Blume, Santhi, & Schabus, 2016) to quantify the stability of rest-activity patterns across multiple days. The parameter ranges from 0 to 1, with 0 representing Gaussian noise and 1 indicating a strong coupling to a zeitgeber (most commonly light exposure). Interdaily stability was computed using Equation 1, where n is the total number of sampling points, p is the number of sampling points per day, $\bar{x}_h$ is the average of all data, and x_i denotes the activity value from each 1-minute epoch:

$$Interdaily\ stability = \frac{n \sum_{h=1}^p (\bar{x}_h - \bar{x})^2}{p \sum_{i=1}^n (x_i - \bar{x})^2} \quad [1]$$

Inattention-Hyperactivity Symptoms

Parents completed the Strengths and Difficulties Questionnaire (SDQ) (Goodman, 2001), a brief behavioral screening instrument that assesses the level of externalizing symptomatology in young children, and that has been validated in an Australian sample (Mellor, 2005). Parents were instructed to provide their answers on the basis of the child's behavior during the previous six months. The response options ranged from *not true* (0), *somewhat true* (1) and *true* (2). The items used to measure inattention symptoms were 1)

completes tasks, has good concentration, and 2) easily inattentive and has poor concentration ($\alpha = 0.79$). The items measuring hyperactivity symptoms were 1) *restless, overactive, cannot keep still*, 2) *squirmy, fidgety*, and 3) *quickly changes from one activity to the other*, ($\alpha = 0.82$). Separate composite scores were computed by taking the means of the inattention and hyperactivity items.

Control Variables

Information about children's age and gender was reported by parents. Information about children's height and weight were gathered at baseline and follow up by trained researchers in accordance with WHO guidelines. This procedure is explained in more detail elsewhere (Pattinson et al., 2015). WHO growth charts were used to calculate BMI, that were transformed into age and gender-specific z-scores (Organization, 1995; Pattinson et al., 2015). BMI was used as a control variable within the current study, as previous studies have found that BMI is associated with both timing of light exposure (Pattinson et al., 2015) and children's inattention and hyperactivity symptoms (Hanć et al., 2015). Information about children's physical activity levels was gathered from the actigraph measurements. The physical activity measure that was used for the purpose of this study was the mean of all epochs of activity, over 24 hours, across 14 days of recording. Sleep onset, duration and waking time were assessed with a combination of parent reported sleep diaries and wrist actigraphy (Pattinson et al., 2015). Night time sleep duration was calculated as the mean duration (across the 14 days) of sleep that occurred between sleep onset and waking time, while daytime sleep duration was calculated as the mean duration of sleep occurring between waking and night time sleeping. Total sleep time was derived as a composite of daytime and night time sleep.

Analytical Strategy

All analyses were conducted in R [ver no 1.1.453] (Ihaka & Gentleman, 1996). First, sensitivity analyses were carried out to examine whether the associations between light variables and circadian rhythm and inattention-hyperactivity scores depended on lux threshold levels. Consistent with the procedure used in previous studies (Pattinson et al., 2015; Reid et al., 2014), the light exposure variables with the strongest correlation to circadian rhythm and inattention-hyperactivity symptoms were used in the subsequent analyses. Pearson bivariate correlations between inattention-hyperactivity, the predictor variables and possible confounding variables were examined. Since the residuals of sleep onset were not normally distributed, meaning that the predictive ability of the variable was not consistent across its range, a log-linear transformation was carried out to correct for this before it was entered into the subsequent analyses. Inattention symptoms were not associated with any of the light variables or circadian rhythm, and was therefore not investigated further as an outcome variable. Variables that were associated with light, circadian rhythm or inattention-hyperactivity measures were included within the regression analyses as covariates. Multiple linear regression analysis was used to assess 1) unadjusted model, 2) a model including covariates, and 3) a model including covariates and the other predictor variables.

In the unadjusted models, we assessed the main effect of each predictor (i.e. light exposure variables and circadian stability) on hyperactivity symptoms. In the second model, covariates and the corresponding light variable of the same threshold were added (for instance, in the model examining TAT10, we added MLiT10 as a corresponding predictor, while the corresponding predictor in TAT50 models was MLiT50). For the model assessing circadian rhythm as the predictor, mTAT50 and MLiT50 were included as other predictors. To examine if light exposure moderated potential links between circadian stability and the outcomes, interaction terms between circadian stability and the light variables (at threshold 50

lux) were computed. All predictor variables were standardized and main effects were included as predictors along with the interaction terms. An a-priori sample size analysis for multiple regression (Cohen, Cohen, West, & Aiken, 2013) showed that with an anticipated effect size of $f=0.3$, a power level of 0.8, probability threshold of $p < 0.05$ and with 5 predictors, a sample size of $n = 49$ is sufficient.

Results

Participant Demographics

Table 1 shows descriptive statistics for participant demographics, inattention and hyperactivity symptoms at baseline and follow up, sleep, light and activity characteristics, as well as possible confounding variables. At baseline, the mean age of the 24 boys and 25 girls was 56.49 months (SD = 4.89 months). The level of inattention and hyperactivity symptoms in this sample were slightly higher than Scandinavian non-clinical samples of preschoolers (Elberling, Linneberg, Olsen, Goodman, & Skovgaard, 2010; Ulset et al., 2017). However, they were similar to an Australian sample of seven to ten-year old's (Mellor, 2005), and to samples from the USA (Bloom, Cohen, & Freeman, 2010) and the UK (Meltzer, Gatward, Goodman, & Ford, 2000) consisting of 4- 7 year olds. Across the baseline and follow-up measures of inattention and hyperactivity, 4 boys (18%) and 4 girls (17%) were in the abnormal range, 4 boys (18%) and 6 girls (25%) were in the borderline range, while 14 boys (64%) and 14 girls (58%) were in the normal range of inattention-hyperactivity symptoms. Average duration of physical activity ranged from 4.62 to 9.38 hours a day ($M \pm = 6.7$ hours). The average time for sleep onset was $\pm 20:37$ (SD = 00:39), average waking time was $\pm 06:03$ (SD = 00:36), average sleep duration was ± 9.45 hours (SD) 31.28 minutes), while circadian stability (i.e. interdaily stability) ranged from 0.36 to 0.83 ($M \pm = 0.65$, SD = 0.09), which is similar to mean scores in other samples of both adults (Zuurbier et al., 2014) and children

Table 1. Descriptive statistics of study variables

	n	Missing	Range	Mean $\pm$ (SD)
Baseline variables				
Gender	49	0	24 B; 25 G	
Age in months	49	0	45.00 - 64.00	56.49 (4.89)
Body mass index	49	0	13.61 - 18.79	15.45 (1.09)
Inattention	44	5	0.00 - 2.00	0.83 (0.66)
Hyperactivity	44	5	0.00 - 2.00	0.63 (0.70)
Follow-up variables				
Gender	43	6	22 B; 21 G	
Age in months	43	6	56.77 - 79.11	69.09 (5.31)
Body mass index	43	6	14.02 - 20.08	15.73 (1.25)
Inattention	43	6	0.00- 2.00	0.91 (0.69)
Hyperactivity	43	6	0.00 - 2.00	0.81 (0.72)
Actigraphy variables				
Activity minutes	49	0	277.36 - 563.87	402.21 (58.40)
Interdaily stability	49	0	0.36 - 0.83	0.65 (0.09)
Sleep onset	49	0	19:23:00 - 22:30:50	20:36:39 (00:39:04)
Sleep offset	49	0	04:57:14 - 07:29:21	06:03:43 (00:36:17)
Night time sleep duration	49	0	501.92 - 639.31	567.06 (31.28)
Day time sleep duration	49	0	0.00 – 131.75	53.88 (38.15)
Total sleep duration	49	0	517.43 - 639.31	579.61 (32.06)
TAT 10 Lux	49	0	442.60 - 730.18	612.11 (66.66)
TAT 50 Lux	49	0	202.17 - 576.82	400.20 (77.11)
TAT 1000 Lux	49	0	45.08 - 213.00	119.66 (35.75)
MLiT 10 Lux	49	0	702.57 - 808.53	753.18 (24.92)
MLiT 50 Lux	49	0	699.61 - 793.33	740.00 (24.22)
MLiT 1000 Lux	49	0	623.97 - 884.98	753.37 (45.25)

(Sebela, Novak, Kemlink, & Goetz, 2017). The average time that the children spent in light above 1000 lux was two hours (SD = 35.75 minutes), and centered at 12:32. The average time that the children spent above 50 lux was $\pm$ 6.67 hours (SD = 77.11 minutes), and centered at 12:20, while the average time spent above 10 lux was $\pm$ 10.20 hours and centered at 12:32.

Sensitivity Analyses and Bivariate Correlations among Key Variables

We examined the bivariate correlations between predictor, control and outcome variables (see Table 1 in supplementary material for correlation matrix) . At baseline, inattention was positively and moderately associated with hyperactivity at both baseline ($r = 0.61, p < 0.001$) and follow up ($r = 0.31, p = 0.05$). Neither inattention at baseline or follow-up were associated with any of the predictor or control variables. At baseline, hyperactivity was moderately and negatively associated with time spent above lux thresholds ranging from 10 lux ($r = -0.31, p = 0.04$) to 1000 lux ($r = -0.30, p = 0.04$) (see Figure 1), but not with timing of light exposure (MLiT) or any of the control variables. At follow up, hyperactivity was moderately and negatively associated with time spent above 10 lux ($r = 0.49, p = 0.002$), meaning that long duration of exposure to light above 10 lux was associated with low levels of hyperactivity at follow-up (see Figure 2), but not with timing of light exposure (MLiT). Hyperactivity at follow up was moderately and negatively associated with circadian stability ($r = -0.40, r = 0.01$), but not with any of the other control variables.

Fig 1. Sensitivity analyses of Pearson's bivariate correlations between hyperactivity at baseline and all TAT light thresholds.

Fig 2. Sensitivity analyses of Pearson's bivariate correlations between hyperactivity at 12 months follow-up and all TAT light thresholds.

Fig 3. Sensitivity analyses of Pearson's bivariate correlations between circadian stability at baseline and the timing of light exposure (MLiT) across all lux thresholds.

Among the predictor variables, circadian rhythm was moderately and positively associated with timing of light exposure (MLiT), ranging from 50 lux ($r = 0.32$, $p = 0.03$) to 2500 lux ($r = 0.30$, $p = 0.03$), meaning that high regularity of rest-activity rhythms was associated with later timing of light exposure (see Figure 3). The duration of time spent above light threshold of 1000 lux (TAT) was moderately and negatively associated with timing of light exposure (MLiT) above 1000 lux ($r = -0.30$, $p = 0.04$), meaning that long durations of exposure to light (TAT) was associated with earlier timing of that light exposure.

Among the predictor and control variables, children's age in months was positively and moderately associated with both TAT10 ($r = 0.35$, $p = 0.02$) and MLiT10 ($r = 0.36$, $p = 0.01$), meaning that older children were exposed to light for longer durations and that the timing was later in the day. BMI at follow up, but not at baseline, was associated with TAT10 ($r = 0.38$, $p = 0.02$) and TAT50 ($r = 0.32$, $p < 0.05$). Time of sleep onset was negatively and moderately associated with time spent above thresholds of 50 lux (-0.41 , $p = 0.004$) and 1000 lux (-0.29 , $p = 0.02$), and with the timing of light exposure (MLiT) above 10 lux ($r = 0.40$, $p = 0.004$), 50 lux ($r = 0.30$, $p = 0.04$), and 1000 lux ($r = 0.30$, $p = 0.03$), meaning that children who went late to bed were exposed to shorter durations of light above these lux thresholds, and that the light exposure was centered later in the evening.

Accordingly, waking time was positively and moderately associated with the timing of light exposure at 10 lux, 50 lux, and 1000 lux. The strongest association was between MLiT10 and waking time ($r = 0.60$, $p < 0.001$), meaning that light exposure was centered later in the day for children who went late to bed and who woke up late. Girls had later sleep onsets and later waking times compared to boys, as gender was positively associated with both sleep onset ($r = 0.33$, $p = 0.02$) and waking time ($r = 0.39$, $p = 0.006$). An independent samples t-test revealed a significant mean difference of 25 minutes ($p = 0.02$) between sleep onset for girls (20:49) and boys (20:23). The duration of sleep was negatively associated with sleep onset ($r = -0.49$, $p < 0.01$), but not with any of the predictor or outcome variables.

Multivariate Regression Analysis

To control for possible confounding variables and to assess the simultaneous contribution of the timing of light exposure, duration of light exposure, and circadian

stability, multivariate regression analyses were performed. We examined the effects of TAT and MLiT at thresholds of 10, 50 and 1000 lux, as well as circadian stability, on both baseline and follow hyperactivity symptom scores (see Table 2).

Table 2 . Linear regression models predicting hyperactivity at baseline and 12 months follow-up

	Model 1 Unadjusted		Model 2 Adjusted	
Baseline hyperactivity	b (95% CI)	p	b (95% CI)	p
TAT10	-0.33 (-0.64, -0.02)	0.039	-0.39 (-0.84, 0.06)	0.085
TAT50	-0.48 (-0.76, -0.19)	0.002	-0.64 (-0.97, -0.25)	0.002
TAT1000	-0.31 (-0.61, -0.01)	0.043	-0.35 (-0.74, 0.05)	0.083
mLiT10	-0.03 (-0.35, 0.29)	0.844	0.05 (-0.44, 0.55)	0.830
mLiT50	-0.07 (-0.39, 0.26)	0.681	-0.29 (-0.71, 0.12)	0.160
mLiT1000	0.20 (-0.11, 0.52)	0.200	0.16 (-0.21, 0.52)	0.248
IS	0.01 (-0.30, 0.31)	0.972	-0.03 (-0.43, 0.37)	0.892
mTAT50*IS	0.08 (-0.30, 0.31)	0.565		
mLiT50*IS	0.01 (-0.22, 0.36)	0.963		
Follow-up hyperactivity	b (95% CI)	p	b (95% CI)	p
TAT10	-0.52 (-0.83, -0.21)	0.002	-0.23 (-0.60, 0.14)	0.219
TAT50	-0.38 (-0.69, -0.07)	0.017	-0.21 (-0.62, 0.20)	0.309
TAT1000	0.04 (-0.30, 0.38)	0.807	0.09 (-0.26, 0.44)	0.605
mLiT10	-0.26 (-0.59, 0.08)	0.126	-0.38 (-0.79, 0.04)	0.074
mLiT50	-0.13 (-0.47, 0.21)	0.443	-0.17 (-0.61, 0.26)	0.425
mLiT1000	0.00 (-0.33, 0.34)	0.980	0.11 (-0.23, 0.46)	0.509
IS	-0.48 (-0.85, -0.11)	0.013	-0.44 (-0.81, -0.08)	0.018
mTAT50*IS	0.15 (-0.15, 0.48)	0.285		
mLiT50*IS	0.05 (-0.44, 0.33)	0.785		

Note. IS = Interdaily stability. TAT refers to time above threshold (i.e. duration of light exposure). MLiT refers to timing of light exposure above threshold. Standardized regression coefficients are shown. Control variables in baseline models: children's age, duration of daytime sleep and time of sleep onset. Control variables in follow-up models: children's age; time of sleep onset; duration of daytime sleep, body mass index; baseline hyperactivity. TAT variables at the corresponding lux threshold were used as control variable for MLiT, and vice versa. Both mTAT50 and MLiT50 were used as control variables in the IS models.

In the unadjusted models, TAT10, TAT50, and TAT1000 were moderately and inversely associated with baseline hyperactivity symptoms. None of the MLiT variables, nor circadian stability was associated with hyperactivity at baseline. In the adjusted models, controlling for children's age, duration of daytime sleep and sleep onset, TAT50 was strongly and negatively associated with hyperactivity symptoms. There were no significant interactions between circadian stability and MLiT50 or TAT50 in predicting baseline hyperactivity.

In the unadjusted models predicting follow-up hyperactivity, TAT10, TAT50, and circadian stability were strongly and negatively associated with hyperactivity at 12 month follow up. When controlling for age, time of sleep onset, duration of daytime sleep, body mass index and baseline hyperactivity, there was a strong negative association between circadian stability and follow-up hyperactivity symptoms. There were no significant interactions between circadian stability and MLiT50 or TAT50 predicting follow-up hyperactivity.

Figure 4 shows the mean light exposure levels across 24 hours for the upper and lower quartiles of hyperactivity scores. The figure reveals an M-shaped curve, where the children in the low hyperactivity group were exposed to higher levels of light throughout the day. Group differences that lie between the blue horizontal line (10 lux threshold) and the red horizontal line (50 lux threshold), reflects the significant correlation between TAT10 and hyperactivity symptoms. Group differences that lie above the red horizontal line (50 lux threshold), timed mostly between reflect the significant association between TAT50 and baseline hyperactivity scores.

Fig 4. Mean light exposure for children belonging to top and low hyperactivity quartiles.

* $p < 0.05$

Note. The figure presents the means of the first five week days (Monday – Friday), using a 15 min rolling average. Light exposure was Log10 transformed before means were calculated.

Discussion

To our knowledge, this is the first study to examine whether the timing, duration and intensity of environmental light exposure and circadian stability is linked with symptoms of inattention-hyperactivity in young children. We found that high durations and intensities of environmental light exposure was associated with lower levels of children's hyperactivity symptoms at baseline, but not with inattention symptoms. The timing of light exposure was not associated with inattention nor hyperactivity. Children with high circadian stability were less likely to exhibit hyperactivity symptoms at follow up, but not concurrently, however

contrary to our hypothesis this link was not moderated by the timing, duration or intensity of light exposure. Our findings are consistent with those from studies using animal models (Koshiba et al., 2015), which indicate that high levels of light exposure early in life may have positive effects on psychosocial development. For each hour increase in light exposure above 50 lux, there was a large (0.50 SD) decrease in hyperactivity symptoms at baseline. Contradicting our hypothesis that early timing of daylight would improve circadian stability and thereby alleviate ADHD symptoms, we did not find a significant timing effect of light exposure on hyperactivity. Rather, children with fewer hyperactivity symptoms were exposed to longer durations of light throughout the whole day. This lends support to the hypothesis that daylight exposure may operate in an acute manner, similar to that of pharmaceutical stimulants. However, there was a moderate positive correlation between the timing of daylight exposure and circadian stability, that in turn was associated with hyperactivity at follow up. Identification of significant mediating effects of circadian stability on the link between light exposure and hyperactivity might be possible in a larger sample.

The current study was observational, and as such, causal mechanism explaining the negative association between the duration and intensity of light exposure and children's hyperactivity can only be speculated. Indeed light may be the cause or the consequence of hyperactivity, or they may have shared causes. There are, however, several potential mechanisms that could explain the relationship between light exposure and ADHD and warrant further examination in future studies.

First, similar to the effects of stimulant medication, light exposure may stimulate the release of norepinephrine in the prefrontal cortex, leading to increased vigilance, alertness, and attention (Alkozei et al., 2017, 2016). When children are better able to maintain attention, they may also be able to engage in longer sequences of focused play, which contrasts with characteristics of hyperactive behaviour. However, such a norepinephrine pathway between

light exposure and hyperactivity should theoretically also reduce children's symptoms of inattention. In the current study we did not observe any associations between light exposure and symptoms of inattention.

Second, early light exposure may compensate for a “cortisol resistance” that has been observed in hyperactive children. In the morning, the HPA-axis releases cortisol into the blood stream, probably to prepare the physiology of the body for the beginning of the day (Scheer & Buijs, 1999). However, the cortisol response in children with the hyperactive subtype of ADHD seems to be weakened, suggesting that hyperactivity is an attempt to compensate for under-arousal (Hong et al., 2003). Since the morning cortisol response is enhanced by light exposure (Scheer & Buijs, 1999; Van Someren & Riemersma-Van Der Lek, 2007), it may be that light exposure prevents hyperactivity symptoms via a glucocorticoid pathway, by compensating for low cortisol levels in at-risk children. This hypothetical explanation is consistent with our finding that light exposure was linked with hyperactivity, but not inattention. In this study we did not examine biological markers, but future studies may examine whether the link between light exposure and hyperactivity is mediated by cortisol reactivity or adrenergic activity.

Finally, daylight exposure may be the consequence of hyperactivity, or that they have shared causes. For example, children with hyperactivity symptoms may shy away from bright light. In fact, photophobia is overrepresented among adults diagnosed with ADHD (Kooij & Bijlenga, 2014). There may also be other environmental or social explanations. For example, children who spend extended times in low light contexts, such as indoors, may exhibit more hyperactive behaviours due to a lack of opportunity for physical play.

Limitations

There are limitations to our study. First, the sample size of this study was too small to rule out the possibility that circadian stability mediates a link between timing of light

exposure and hyperactivity symptoms. Future studies in larger samples would allow for more nuanced understanding of the potential mediating relationship of circadian stability. Second, in the current study, inattention-hyperactivity symptoms were treated as a continuum, using a sample of low-risk children. Light exposure may operate differently to predict ADHD symptoms in a clinical sample, for example by mediation of improvements in circadian stability (Fargason et al., 2017). Third, future experimental studies that include samples from clinical populations, such as both medicated and un-medicated children who are diagnosed with ADHD, may provide knowledge about the direction of causation, and examine if there are interactions with children's use of stimulant medications.

Conclusion

We used actigraphy data to examine whether circadian stability and the timing, dosage and intensity of light exposure was linked with inattention and hyperactivity symptoms in a low-risk sample of 3-6 year old children. We found that long durations, but not the timing, of light exposure was linked with fewer concurrent hyperactivity symptoms. We did not find any links between light exposure and inattention. Future studies may examine if light exposure targets a mechanism that is specific for hyperactivity symptoms, such as glucocorticoid resistance.

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Supplementary Table 1. Pearson’s bivariate correlation coefficients among key variables.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1. Gender																					
Baseline measures																					
2. Age in months	.12																				
3. BMI	.05	-.17																			
4. Inattention	-.18	.06	.01																		
5. Hyperactivity	-.07	-.07	.08	.61†																	
Follow-up measures																					
6. Age	.12	.99†	-.16	.09	-.15																
7. BMI	-.04	.03	.79†	-.02	.01	.00															
8. Inattention	-.07	.13	-.02	.62†	.46†	.12	.00														
9. Hyperactivity	-.23	-.05	-.14	.31*	.48†	-.05	-.24	.58†													
Actigraphy measures																					
10. Activity minutes	-.07	.27	-.13	-.17	-.10	.29	-.08	-.22	-.02												
11. Interdaily stability	.11	-.04	-.09	-.09	.01	.12	-.05	-.32	-.40*	.09											
12. Sleep onset	.33*	.06	.09	-.01	.05	.08	.12	.11	.07	-.09	-.09										
13. Sleep offset	.39†	.05	.08	-.08	-.10	.14	.09	.12	-.13	-.18	.03	.66†									
14. Night sleep duration	.04	-.02	-.02	-.08	-.18	.05	-.05	.00	-.21	-.09	.15	-.49†	.34*								
15. Day sleep duration	.07	-.17	-.04	.20	.16	-.17	-.28	.12	.19	.04	-.20	.07	-.22	-.34*							
16. Total sleep duration	-.02	-.04	.09	-.13	-.05	.04	-.09	-.11	.01	-.09	.19	-.10	.36*	.54†	.08						
17. TAT10	.11	.35*	-.11	-.23	-.31*	.23	.38*	-.24	-.49†	.05	.11	-.23	-.19	.08	-.27	-.18					
18. TAT50	.02	.21	0.01	-0.21	-.46†	.14	.32*	-.24	-.38*	.05	-.03	-.41*	-.22	.25	-.24	-.09	.76†				
19. TAT1000	-.25	.11	.20	.02	-.31*	.15	-.06	-.05	.04	.13	-.19	-.29*	-.25	.08	.00	-.04	.12	.52†			
20. MLiT1	.19	.36*	-.16	-.05	-.03	.43†	-.10	.02	-.25	.05	.11	.40†	.60†	.20	-.15	.17	.22	-.06	-.11		
21. MLiT50	.09	.28	-.18	.01	-.06	.45*	-.22	.07	-.13	.18	.32*	.30*	.48†	.18	-.12	.19	-.14	-.21	-.01	.69†	
22. MLiT1000	.18	.09	-.19	.12	.20	.15	-.07	.14	.00	-.03	.28*	.30*	.52†	.23	-.20	.13	-.21	-.21	-.30*	.27	.52†

* < p 0.05, † < p 0.01

RESEARCH ARTICLE

Are unpopular children more likely to get sick? Longitudinal links between popularity and infectious diseases in early childhood

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Data Availability Statement: The data contains sensitive information and can therefore not be made publicly available (General Data Protection Regulation). Since the participants have not given their consent that the data can be made publicly available, data sharing is restricted by the informed consent and the regulations in the Health Research Act (1.07.2009), regulated by the Regional Committees for Medical and Health Research Ethics of Norway. The dataset analyzed during the current study may be requested from the The

Abstract

Social stress and inflammatory processes are strong regulators of one another. Considerable evidence shows that social threats trigger inflammatory responses that increase infection susceptibility in both humans and animals, while infectious disease triggers inflammation that in turn regulates social behaviours. However, no previous study has examined whether young children's popularity and their rate of infectious disease are associated. We investigated the longitudinal bidirectional links between children's popularity status as perceived by peers, and parent reports of a variety of infectious diseases that are common in early childhood (i.e. common cold as well as eye, ear, throat, lung and gastric infections). We used data from the 'Matter of the First Friendship Study' (MOFF), a longitudinal prospective multi-informant study, following 579 Norwegian pre-schoolers (292 girls, median age at baseline = six years) with annual assessments over a period of three years. Social network analysis was used to estimate each child's level of popularity. Cross-lagged autoregressive analyses revealed negative dose-response relations between children's popularity scores and subsequent infection ($b = -0.18$, $CI = -0.29, -0.06$, and $b = -0.13$, $CI = -0.23, -0.03$). In conclusion, the results suggest that children who are unpopular in early childhood are at increased risk of contracting infection the following year.

Introduction

Research suggests that there is a strong social gradient in the risk of contracting infections [1]. Children from families with low socio-economic status are at higher risk of contracting infections from several pathogens, and experience a greater overall burden of infection [2,3]. This phenomenon may in part be explained by differences in parental health behaviours [4], access to healthcare [5] or environmental stress and hazards [6]. However, animal studies and those in adult human populations provide evidence for bidirectional influences between social status and the immune system [7]. This result suggests a co-regulation between social behaviour, inflammatory processes and infection that is deeply rooted in our evolutionary history [8,9].

Matter of the First Friendship Study by contacting data manager Tormod Eide (tormod.eide@psykologi.uio.no) or project manager Mona Bekkhus (mona.bekkhus@psykologi.uio.no) at the Department of Psychology, University of Oslo, Forskningsveien 3A, 0373 Oslo. Data access can be given via the services for sensitive data provided by the University of Oslo, after application and approval from the Regional Committees for Medical and Health Research Ethics of Norway. Researchers will then be able to replicate the findings presented by following the protocol in the methods section.

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For example, experimental animal studies demonstrate that a decrease in social rank is followed by subsequent changes in gene expression and immune system activity, that in turn increase infection susceptibility in macaques [9]. Similar results have been found in studies of humans. For example, exposure to social threats and rejection in early childhood have been linked with chronically elevated inflammation [10]. In human adults and in animals, chronic inflammation increases the risk of attracting a cold [11,12]. One might speculate if early social experiences may influence the long-term health of children via parallel biological mechanisms, such that social stress in early childhood increases the risk of attracting infections. To our knowledge, no studies to date have examined whether social status as perceived by peers is associated with young children's risk of attracting an infectious disease.

The preschool years are a time when children's immune systems develop defence strategies against their local disease ecology [13]. During this period, most children encounter their first experiences of social inclusion and rejection, possibly setting the stage for the first social influences on infection susceptibility. Typically, young children make their first friends, and form social hierarchies already from preschool age [14–17]. In these social hierarchies, popular children typically engage in more prosocial behaviours such as helping, sharing and comforting other children. However, children who are perceived as being popular by their peers also engage in more physical, verbal and relational aggression [18]. Preschool and the transition to school can be harsh and stressful for young children. Social exclusion is extremely common [19], and both verbal and physical aggression occur frequently, especially at times when social dominance relationships are negotiated [20]. Day-care attendance and the transitioning to school is associated with increased cortisol excretion [21–23], and particularly those children who are perceived as unpopular by their peers exhibit higher cortisol levels and experience more aggressive interactions and peer rejection [24]. In the long term, the stress following frequent subjection to physical, verbal or relational aggression may alter immune functioning, and can ultimately lead to a variety of mental and somatic health problems in both animals and humans [25–27].

Experimental studies provide evidence that subordination to higher-ranking individuals affects immune functioning and increases susceptibility to infection in animals [9]. The primate brain tends to appraise social devaluation, exclusion and rejection as threat information [3]. Such social stressors may cause an up-regulation of inflammatory processes, as the immune system prepares to deal with potential consequences of either fight or flight, such as tissue damage. Exposure to an episode of acute social stress causes an immediate and significant up-regulation of the inflammatory response, that is worth the physiological cost because it increases the likelihood of survival [28]. This is related to the release of epinephrine from the adrenal medulla, which in turn seem to activate the immune system to release cytokines into the bloodstream [29]. However, increased epinephrine levels also cause the hypothalamus to activate the hypothalamic-pituitary-adrenal axis (HPA-axis), one end result being increased release of cortisol from the adrenal cortex. One effect of cortisol is the down-regulation of the acute high levels of cytokines, which is important since cytokines have a cytotoxic effect (e.g. they may kill or damage nerve cells).

However, when stressors (e.g. physical aggression) occur frequently, several negative consequences may occur. The chronically increased levels of cytokines cause long-term activation of the inflammatory response, which represents a state of allostasis and “wear and tear” of the body. Also, immune cells become less sensitive to cortisol, meaning that high levels of cortisol are no longer able to down-regulate the activity of the immune system. That is, immune system cells develop glucocorticoid resistance and continue to produce and release cytokines into the bloodstream [12]. Experimental studies show that mice develop glucocorticoid resistance when they are repeatedly exposed to social stress [30], which in turn is accompanied by less

social approach behaviour and higher levels of subordination to aggressive individuals [31]. Humans may also develop glucocorticoid resistance. One study found that healthy adults demonstrated glucocorticoid resistance following a stressful life event, and that those who developed glucocorticoid resistance had higher levels of proinflammatory cytokines, and were at greater risk of catching a cold [12]. Hence cortisol is no longer able to turn the immune system either on or off, but the immune response is instead chronically activated on a heightened but not maximum level (tonic rather than phasic function) [32]. This level is high enough to represent a physiological toll on the cells, but not adequate to fight real threats when they are experienced (e.g. bacteria and viruses). This is why chronic exposure to social stressors may represent an increased risk of attracting infectious diseases.

Conversely, an infectious disease may also influence children's social behaviour. Historically, infectious disease puts humans and other animals in a very vulnerable situation, where it is important to stay away from harmful individuals, but also to elicit care and support from close others [7]. This notion is supported by findings that adults who are experimentally exposed to endotoxins that trigger inflammation show higher levels of social pain-related neural activity [33] and report increased feelings of social disconnection compared with control participants [34]. Other experimental studies suggest that inflammation may lead to a general sensitivity to both positive and negative social cues [35], and that inflammation increases the perceived need to be with significant others [36]. Currently, no studies have investigated whether infection in childhood is linked with children's social development; however, a large population-based study has identified associations between a wide range of infectious diseases in childhood and a subsequent increase in the risk of being diagnosed for a mental disorder [37].

This response to infection may be linked with the activity of pro-inflammatory cytokines that activate anhedonia, fatigue, dysphoria and changes in social approach behaviours, also termed sickness behaviours [38,39]. For example, injections that stimulate the release of cytokines have a negative effect on social exploration in mice [40], and when the cytokines interferon- α and interleukin-2 is administered to humans (usually as treatment for cancer or hepatitis C) they cause fatigue, sleepiness, irritability, cognitive changes and loss of appetite [41]. Analogous mechanisms may operate in young children. For example, it may be that sickness behaviours affect children's social functioning in two reinforcing ways. First, feelings of social disconnection, fatigue and dysphoria may lead to avoidance of other children, particularly peers who are not perceived as close friends. Second, some authors have proposed that sickness behaviours may serve as a signal that warns other children of contamination risk, possibly leading classmates to avoid individuals with infectious diseases [42,43]. However, very few empirical studies have investigated whether children actually avoid sick peers. The only empirical evidence to our knowledge is an experimental study finding that 6 and 7 year old children, but not 4 and 5 year olds, avoided proximity to and contact with peers who they were told were sick [43]. It is possible that this dynamic arise because of the evolved 'behavioural immune system' that is biased towards the avoidance of pathogens, and hence elicits a strong withdrawal response from possible contamination sources [44–46], to prevent pathogens from entering the body [47,48]. This avoidance, in turn, can contradict children's evolved propensities for rough-and-tumble-play, social approach and connection [49]. Therefore, there may be a complex evolutionary trade-off between selection for social approach behaviours and for the avoidance of pathogens. Because pathogens such as bacteria, viruses and parasites have shaped the evolution of all organisms, it has been argued that the large individual cost of infection has pushed for a bias towards pathogen avoidance in humans [46,50].

The main goal of this study is to examine the bidirectional longitudinal links between popularity (as an indicator of social status) and the risk of contracting common infectious diseases.

On the one hand, infections in early childhood may be associated with social withdrawal and rejection, that in turn may affect children's social status development. On the other hand, and in parallel with mechanisms observed in the animal and immunological literature, low social status may increase infection risk via immunological and endocrine pathways. There may also be a bidirectional dynamic between infection and social status, in which self-reinforcing cycles between health and social status may cause upwards and downward 'spirals'. Thus, in a similar vein with findings from animal studies and the few studies on adult populations, we expect to find negative bidirectional associations between popularity as perceived by peers and infectious diseases that are common in early childhood.

Methods

Ethics statement

The data collection has received full ethics clearance from the Regional Committees for Medical and Health Research Ethics of Norway (2.2005.1665). The parents of the children who participated in this study provided an informed written consent.

Participants

The 579 participating children in this multi-informant study were part of the Matter of the First Friendship Study [51,52], a longitudinal study that took place in two suburban Norwegian municipalities with a total population of 24 000. The sampling frame was representative of Norway and comprised children born between 2000 and 2005 that attended one of the 33 day-care centres and 13 primary schools in the two municipalities. A total of 996 children were eligible to participate because they attended one of the day-care centres, while 619 children (62%) were given informed written consent by their parents to participate in the study. As illustrated in Fig 1, a total of 579 participants were registered with at least one response and included in the social network analyses, while 447 participants (243 girls) were registered with complete data on at least one time point and were included in the autoregressive cross-lagged analysis. At the time of the first data collection, the children's age ranged between 24 and 90 months (mean age = 64.14 months, SD = 15.96).

Parents responded to mailed questionnaires regarding their children's health. To assess the structures of their social networks and each child's level of popularity within his or her network, the children were interviewed in their day-care centre or school. In this sample, the maternal education level was higher than the national average, with 45% of mothers having some form of tertiary education. The mean age of the mothers was 35 years (SD 4.7), and 93% were married or cohabitated with a partner. The median income was slightly above the national average for households with children, and slightly higher than the regional average for the municipalities where the families lived.

Children's infections

Parents replied to mailed questionnaires, where they provided information about their child's health. Parents were asked, 'Has your child experienced one of the six following health problems? If yes, how many times over the previous year?' (1) eye infection, (2) ear infection (e.g. otitis media), (3) throat infection, (4) lung infection, (5) gastrointestinal tract infection and (6) common colds. To establish a baseline, parents were asked to complete the same list of questions, but retrospectively for the time that their child had just enrolled in day care. A composite score for the mean number of infections for three developmental periods was computed: (1)

Fig 1. Sample recruitment and follow-up.

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Baseline, based on parent's retrospective accounts of their children's infections at the time they enrolled in preschool, (2) Time 2, based on data collected when children were between 4 and 8 years, and (3) Time 3, based on data collected when the children were 5–9 years. The frequency of infection was coded as 0, 1, 2, 3 or '4 or more', and the items correspond to those used in previous studies of infections in preschool [53–55]. At each assessment, parents were asked whether the child had any serious or long-term illnesses. The presence of a serious or long-term illness was coded 1 for "yes" and 0 for "no".

Fig 2. Social networks at Time 1 (N = 447). Note. Nodes represent children. Colors indicate popularity score which is the number of receiving popularity nominations. For parsimony, edges indicate an undirected social tie between two children. Only children with complete data are represented.

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Children's popularity

Popularity was assessed using a well-known and validated peer-nomination technique [56]. Trained research assistants interviewed the children in their preschool or school, in a separate and quiet room. For children aged two through six years (still in preschool), we used photographs of the children in their group and a cardboard bus for illustration, as the children were given the following instructions: 'We will now pretend-play that we are going for a trip in a bus. You can sit behind the bus driver. Who do you want to bring on the bus trip?' The children were asked to place their own picture behind the driver, and then to nominate up to five classmates to bring on the bus. The children indicated who they wanted to bring along by placing the nominated children's pictures on the cardboard bus. After transitioning to elementary school, children (age seven through nine years) were asked to nominate whom they would like to bring on a bus trip by saying their names. They were not restricted to nominating their classmates, and some children had friends in other classes or from their old day-care group. We operationalized popularity as the total number of nominations received [57], standardized by the number of total possible nominations (i.e. the size of their social network). Fig 2 illustrates the distribution of popularity scores across social networks.

Analytical strategy

All statistical models were fitted using the software package Mplus [58]. To examine the bidirectional links between popularity and infectious diseases, we used autoregressive cross-lagged analysis. This approach is in accordance with previous studies that used such analysis with popularity network data [59]. The frequency of infectious diseases and popularity at Time 3 were regressed on assessments of the same variables at Time 2, while Time 2 measures were regressed on Time 1 measures. We allowed for residuals of infection and popularity at the same time points to be correlated. To correct for a skewed distribution of infection scores, we

employed a robust maximum likelihood estimator. There were no missing data in the popularity scores. Missing data in the infection variables (16.77%) were handled using a full information maximum likelihood procedure.

Popularity scores were standardized by social network size (i.e. the number of possible nominations), before they were entered into the autoregressive cross-lagged model. We used community detection [60] to identify the sizes of the social networks. Social network analyses were carried out in R studio using the igraph package [61].

Results

The distributional properties and descriptive statistics of the study variables are presented in Table 1. There was a decrease in infection scores between Times 1 and 3 (40.30%). For popularity scores, there was a small increase (6.59%) between Times 1 and 3. Popularity scores were evenly distributed across 0, 1, 2, 3 and 4 or more nominations. On average, 17.60% of the children received zero popularity nominations, 23.53% received one nomination, 22.00% received two nominations, 15.50% received three nominations and 16.80% of the children received four popularity nominations or more (see Fig 2). Children's age was negatively correlated with infection at T2 ($b = -0.19$, $p < 0.00$), and positively correlated with popularity at T1 ($b = 0.21$, $p < 0.001$) and T2 ($b = 0.10$, $p = 0.03$). Independent samples t-tests revealed no significant differences between girls and boys in popularity scores. However, boys showed higher scores on infection at T2 (boys $M = 0.57$, girls $M = 0.49$, $F = 6.55$, $p = 0.02$), and at T3 (boys $M = 0.37$, girls $M = 0.43$, $F = 2.00$, $p = 0.40$). Boys also showed higher scores on infection at T1 (boys $M = 0.72$, girl $M = 0.62$) but this difference was not significant ($p = 0.06$).

Table 1 shows the bivariate correlation coefficients between all variables. On the bivariate level, there were small to moderate positive correlations between infection at Times 1 and 2, and between infection at Times 2 and 3. All time points of popularity were moderately and positively correlated with each other. There was a small negative association between popularity at Time 1 and infection at Time 2, and between popularity at Time 2 and infection at Time 3. The prospective correlations between popularity and infections at the following year, are illustrated with line plots in Fig 3. The line plots in Fig 3 reveal a dose-response relation between popularity and infections. The infection scores of children who received zero

Table 1. Pearson's bivariate correlations and descriptive statistics.

	1	2	3	4	5	6
1. Infections T1						
2. Infections T2	0.29***					
3. Infections T3	0.03	0.23***				
4. Popularity T1	-0.06	-0.18***	-0.06			
5. Popularity T2	-0.03	-0.08	-0.15**	0.34***		
6. Popularity T3	0.07	-0.04	-0.07	0.27***	0.27***	
N	386	404	330	579	579	579
Mean	0.67	0.53	0.40	1.67	1.75	1.78
SD	0.54	0.34	0.29	1.39	1.91	1.37
Min–Max	0–4	0–2.5	0–2	0–4	0–4	0–4

* $p < 0.05$,

** $p < 0.01$,

*** $p < 0.001$

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Fig 3. Dose-response relations between popularity and infections at Time + 1. Note. Error bars in the plot indicate a 95% confidence interval.

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popularity nominations ($M = 0.57$), were on average across time points 28.33% higher than for those children who received four or more popularity nominations ($M = 0.39$).

Autoregressive cross-lagged analysis. The results from the autoregressive cross-lagged model examining bidirectional relations between popularity and infections are shown in Fig 4. The model fit was excellent ($\chi^2 = 5.60$, $df = 14$, $P = 0.23$, CFI = 0.98, RMSEA = 0.033, Standardized Root Mean Square Residual = 0.023). At both Times 1 and 2, high popularity scores predicted lower levels of infections with respect to the following measurement. One standard deviation increase in popularity was associated with a 0.13 (Time 2) and 0.18 (Time 3) standard deviation decrease in infection. There were no residual associations between infections and popularity within the same time points, nor any significant cross-lagged effects of infections on popularity on the subsequent measurement wave. Additional analyses showed that controlling for children's age and gender, or whether the children had a serious or long-term illness, did not impact the estimates of the model (changes in the standardized coefficients ranged from $b = 0.01$ to 0.03). At Time 1, parents of 23 children (2%) reported that their child had a serious or long-term illness.

Fig 4. Autoregressive and cross-lagged relations between children's popularity and infectious diseases. Note. For simplicity, only significant standardized regression coefficients are shown, with confidence intervals in brackets. Significant paths are highlighted with solid arrows.

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Discussion

The main aim of this study was to examine bidirectional associations between children's popularity as perceived by their peers, and the frequency of a variety of common infections as reported by their parents. Results from autoregressive cross-lagged analyses suggest that high popularity scores were associated with low levels of infection in the following assessment. Surprisingly, we found no concurrent links between popularity and infection within the same time points, nor any prospective effects of infections on popularity scores. There were dose-response associations between popularity and subsequent infection, a result which is consistent with previous studies demonstrating a graded link between social status and a wide range of health outcomes, including infection [1,6,62].

Our finding that children's popularity is associated with subsequent infection risk is in accordance with extensive evidence from animal studies showing that reductions in social status changes inflammatory processes and increases infection susceptibility in animals [3]. Previous studies found that social stress in childhood is related to subsequent inflammatory changes [10], and we add to this knowledge by demonstrating links between popularity and rates of contracted infectious diseases.

Moreover, we found links between popularity and infectious diseases the following year, but not the concurrent year. These long-term links may reflect a delayed response of infection susceptibility to social stress, similar to those observed in animal models [63]. However, another explanation might be that the results are influenced by developmental timing effects. Some researchers have suggested that infections and social experiences have more implications for later development if they occur early in life [13]. It is possible that the interwoven processes between social and immunological development are in place very early on in life, and that there are different developmental windows with somewhat unique challenges to both health and social systems. As such, the strength and relative directionality of their interrelations may vary as well over time. This would be an important point to examine in future studies.

Our finding that popularity as perceived by peers is associated with infectious diseases in childhood suggests that early social dynamics may precipitate long-term differences in health. Because our study was observational and did not involve measures of cortisol or immune functioning, we can only speculate on the causal mechanisms that underlie our findings; however, we outline some possible mechanisms here.

From an evolutionary perspective, children who are excluded from their group have historically been under major risk of being attacked and wounded by predators. To anticipate tissue injury, the immune system therefore reacts to social exclusion by up-regulating pro-inflammatory gene expression, and as a consequence down-regulating anti-viral responses. This process is a highly conserved transcriptional response to social adversity in non-human primates [64] and adult humans [65]. This conserved transcriptional response to social adversity may have become maladaptive in modern educational settings because prolonged pro-inflammatory responses to social exclusion may, in the long run, promote health problems [42,66].

For some children, educational settings set the stage for experiences of social stress, bullying, subordination and rejection [67]. At the same time, children in preschool and school are confined to crowded settings where they are exposed to commutable pathogens and are at increased risk of contracting infections [53]. The risk of being attacked and wounded by predators or a fellow human is low compared with the historical contexts where humans evolved. A conserved transcriptional response to social adversity may be maladaptive in modern society, and only contribute to exacerbating negative effects of low social status (such as lack of social support), by also increasing the risk of contracting an infection. This supposition, however,

remains speculative, and needs to be investigated with both prospective and experimental studies, incorporating measures of gene expression.

The experience of being unpopular may increase allostatic load when children repeatedly experience social rejection or aggression from their peers. In non-human primates, dominance–subordination relationships are frequently maintained by the dominant individuals' aggression, threats and intimidation. This pattern can also be observed in children because children who engage in higher levels of physical, verbal and relational aggression often are perceived as being popular by their peers [18]. When people experience social threats, they respond with highly adaptive sympathetic responses leading to activation of their fight or flight response [68]. When these responses are frequently repeated, stress allostasis becomes chronically elevated, ultimately down-prioritizing anti-inflammatory and -viral responses as energy expenditure is reallocated to deal with immediate threats [13]. Such exposure to social threats in early childhood may lead to epigenetic changes, inflammatory changes and dysregulation of the hypothalamic–pituitary–adrenal (HPA) axis [27]. Future studies should examine whether associations between popularity and infection are mediated by indicators of stress, such as the HPA hormone cortisol.

To our surprise, we did not find significant links between infection and subsequent or concurrent popularity. According to the behavioural immune system hypothesis, children would distance themselves from sick individuals to prevent pathogens from entering their bodies [44], while infected children would withdraw from social situations because of cytokine-induced sickness behaviours [39]. One possible explanation for our non-finding may be that avoidance of sick peers is mainly temporary, and that most children who have been sick are included again as soon as the infection has passed. In addition, sick children will normally be kept at home by their parents, limiting the exposure to peers during the course of infection.

A major strength of our study was the use of a multidisciplinary approach, including parental questionnaires and extensive interviews with the children. Participants were followed prospectively throughout preschool and elementary school, and our sample represents a variety of forms, sizes and models of preschools, to date the largest prospective study with child interviews. However, some limitations should be mentioned. Parents did not report information about the duration or severity of the infections. We did not measure the possible causal mechanisms that underlie our findings, in terms of biological markers of inflammation, stress or genetic mediators. Our study is a prospective longitudinal one, meaning that we cannot rule out unmeasured confounders, such as systematic variation in genetic susceptibility to both infections and popularity. In particular, it is possible that children who are highly popular also have high degrees of fitness-related traits that make them popular, such as intelligence and emotional stability, and that these traits are, in turn, genetically related to other fitness-related characteristics such as immunological functioning. Hence, correlations between popularity and effective immune functioning can, at least in part, have shared genetic influences (See [69]). Importantly, however, our finding is a strong indicator of a dose–response relation between popularity and infection, demonstrates the direction of this relationship over time, and converges with experimental animal studies that demonstrate strong links between social status and infection susceptibility [70].

Conclusion

Our findings suggest that popular children are less likely to contract infectious diseases. We did not find any associations between infectious disease and subsequent popularity, nor did we determine any concurrent associations between popularity and infectious disease. Attempts to understand the early development and maintenance of social differences in health should

consider children's social status as perceived by their peers. Future studies should examine whether biological regulation mediates this link between children's popularity and subsequent risk of infection.

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