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Pedaling towards autonomy: a multidisciplinary exploration on children's independent cycling mobility

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ABSTRACT

Children's autonomous cycling, understood as the ability to travel independently by bicycle, is increasingly constrained by car-oriented planning and socio-cultural norms that emphasise supervision and risk aversion. Although active travel has been widely studied, the behavioural and developmental determinants of children's cycling autonomy remain fragmented and underexamined. This narrative review synthesises cross-disciplinary evidence using a socio-ecological perspective informed by the Theoretical Domains Framework (TDF). The TDF enables an integrated analysis of capability, opportunity and motivation, revealing four interrelated domains shaping children's independent cycling: (1) personal and interpersonal influences, (2) the built environment, (3) broader societal norms, and (4) essential preconditions such as cycling skills and bicycle access. The resulting conceptual model brings together developmental, material, social and discursive factors, offering a more mechanistic understanding than existing CIM frameworks. For transport researchers, it highlights new leverage points; reshaping norms, aligning infrastructure with children's developmental capacities, and incorporating children's perspectives into mobility policy. The review thus supports more inclusive and equitable transport systems by positioning children as legitimate actors within urban mobility.

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Children's independent mobility; cycling; autonomy; socio-ecological model; determinants

1. Introduction

Children's Independent Mobility (CIM) refers to children's freedom to travel without adult supervision (Hillman et al., 1990). Cycling plays a central role in this autonomy, especially in early and middle childhood. Understanding how individual, social, and environmental factors interrelate is therefore essential for explaining contemporary patterns in children's cycling independence.

Recent work underscores the need to understand children's cycling within wider developmental and environmental contexts. While most young people acquire cycling skills, continued use depends on bicycle access, socialisation and everyday spatial contexts (Schassmann et al., 2024). Experimental studies show that reduced traffic exposure and

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improved street design enhance spatial perceptions and environmental mastery (Appleyard, 2022). Economic evaluations also highlight the societal benefits of cycling infrastructure, particularly for safety and accessibility (Rich et al., 2021). Together, these studies illustrate how individual, social and infrastructural factors intersect to shape children's opportunities for autonomous mobility.

Over the past decades, research has consistently documented restrictions in CIM across Europe (Karsten, 2005; Mackett et al., 2007). Fyhri et al. (2011) report a decrease in children's walking and cycling and a rise in car travel in Denmark, Finland, Great Britain and Norway. Large-scale analyses across 16 countries similarly indicate that most children face substantial limitations on their independent travel (Shaw et al., 2015). Yet cross-country variation persists: many Finnish children gain some autonomy by age seven, whereas in other contexts similar freedoms are often not granted until early adolescence. Despite Finland's relatively favourable position, CIM there has also declined over the past twenty years (Kyttä et al., 2015).

This decline has been attributed partly to increasing car ownership, safety concerns, and the growing distance between home, school, and leisure destinations (Kyttä et al., 2015). These patterns mirror broader European trends, where urban sprawl, traffic density, and shifting parental perceptions of risk have collectively constrained children's everyday autonomy (Berg et al., 2023; Fyhri et al., 2011). These contextual factors are not unique to Finland but reflect developments observed across Europe**.** Recent work indicates that children's independent mobility remains constrained in the 2020s (Berg et al., 2023; Frohlich & Collins, 2024), while drawing attention to evolving contextual influences such as parental risk perceptions, traffic exposure, and post-pandemic routines (Duffy et al., 2024; Litsmark et al., 2023). Context-specific evidence from Belgium further details contemporary patterns of accompanied versus independent trips by age and urbanisation (Fults et al., 2025; Flemish Department of Mobility and Public Works, 2023).

Across these contexts, children appear to gain their CIM "license" at increasingly older ages (Hillman et al., 1990; Hillman & Adams, 1992; Tillberg Mattson, 2002; O'Brien et al., 2000; Pooley et al., 2005). In Belgium, children aged 6–11 are mostly chauffeured. However, from the age of 12, when they transition from primary to secondary school, a sharp increase in active travel takes place (Fults et al., 2025).

Active travel provides important physical and mental health benefits (Mackett & Paskins, 2008) and autonomy is a key developmental task during early adolescence (Berk, 2013; Spear & Kulbok, 2004). While parental support for autonomy contributes positively to well-being (Hwang & Jung, 2022; Reed et al., 2016), children's mobility behaviours are shaped by a broader constellation of influences. Systems approaches and socio-ecological models conceptualise behaviour as the outcome of interacting individual, social and environmental conditions (Berkman & Kawachi, 2000; Foster-Fishman et al., 2001; Kok et al., 2008; Trochim et al., 2006). Previous reviews have examined CIM determinants from various disciplinary perspectives, including built environment factors (Qiu & Zhu, 2017; Sharmin & Kamruzzaman, 2017), psychological and social influences (Ferreira et al., 2024; Marzi & Reimers, 2018; Schoeppe et al., 2013) and measurement approaches (Bates & Stone, 2015; Zougheibe et al., 2021). Marzi and Reimers (2018) provided the most comprehensive socio-ecological synthesis to date.

Building on this foundation, this review advances the field by focusing specifically on children's autonomous cycling and by adopting the Theoretical Domains Framework

(TDF) as it's analytical lens. The TDF synthesises 128 theoretical constructs and integrates the COM-B model and the Behaviour Change Wheel (Atkins et al., 2017; Michie et al., 2011), offering a comprehensive structure for examining capability, opportunity and motivation. This makes it well suited to analyse the multi-level determinants of children's cycling autonomy. In addition, the review applies a narrative synthesis approach suited to integrating evidence across diverse conceptual and methodological traditions (Baumeister & Leary, 1997).

In doing so, this review contributes a novel, cycling-specific synthesis to a CIM literature that has so far focused mainly on general mobility patterns, and it is the first to apply the TDF as an integrative behavioural lens to children's independent cycling.

Beyond applying the TDF as an analytical lens, this review also develops a new conceptual model of children's autonomous cycling mobility. Previous research on children's independent mobility has drawn on a variety of conceptual and theoretical models, including socio-ecological approaches (Marzi & Reimers, 2018), child-friendly city frameworks (UNICEF, 2018), and broader developmental and participatory models emphasising children's rights and agency (Hart, 2002; Percy-Smith & Thomas, 2009). While these frameworks have been instrumental in highlighting the multi-level nature of children's mobility and its links to environmental, social, and cultural contexts, they tend to conceptualise independent mobility in general terms, without distinguishing cycling as a behaviour with unique developmental, infrastructural, and material requirements. Moreover, existing CIM frameworks typically provide descriptive categorizations of influences but offer limited theoretical integration with behaviour change mechanisms.

By introducing the Theoretical Domains Framework (TDF) into this field, the present review links CIM research to a well-established behaviour change model that synthesises capability, opportunity, and motivation processes. This integration allows for a more fine-grained analysis of how psychological, developmental, social, and environmental determinants interact to shape children's cycling autonomy; something not accomplished in prior reviews. The conceptual model developed from this synthesis builds on socio-ecological insights but adds two contributions: (1) it identifies cycling-specific preconditions (skills and bicycle access) that existing CIM frameworks have not treated as foundational behavioural determinants, and (2) it articulates the dynamic interdependencies between individual, interpersonal, infrastructural, and cultural domains, thereby offering a more mechanistic understanding of how children gain or lose autonomous cycling mobility. In doing so, this review provides a theoretically grounded, cycling-specific model that complements and extends existing CIM scholarship, while also enabling more actionable intervention and policy development.

The framework also holds practical value for public health and mobility practice. Adapted versions of the TDF are widely used in health promotion to guide intervention development, policymaking, and practitioner training. Applying this behaviour-change framework to children's autonomous cycling mobility therefore supports a stronger bridge between scientific evidence and real-world implementation. Moreover, it highlights potential intervention avenues, such as addressing social norms, developmental needs and the positioning of children's perspectives in mobility policy. It further draws attention to how urban design influences children's visibility and legitimacy in public space, and how cultural beliefs about "good parenting" can shape expectations and practices around children's mobility autonomy (Silonsaari et al., 2024)

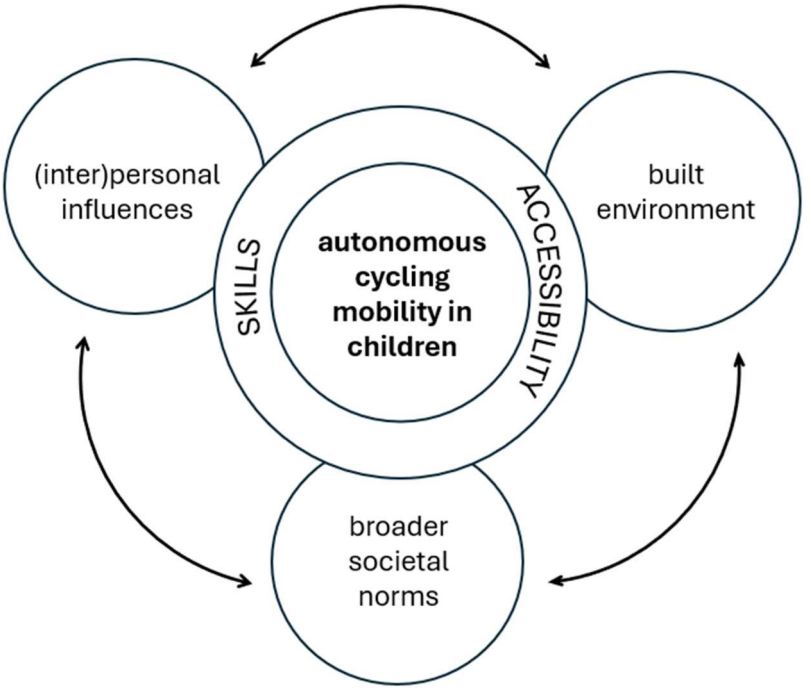

Figure 1. Conceptual model of key determinants influencing children's autonomous cycling mobility.

The central research questions guiding this review are: (1) What are the key determinants influencing children's autonomous cycling mobility across different levels of the socio-ecological system? (2) How can the TDF support a more integrated understanding of these determinants? (3) What implications do these findings hold for the design of policies and interventions that aim to promote children's cycling autonomy?

By answering these questions, the review contributes to theoretical advancement in child mobility and health promotion while also providing practical insights for interventions. In doing so, it supports the development of more equitable, healthy and sustainable communities where children's rights to mobility and autonomy are respected (Figure 1).

The paper is structured as follows. Section 2 outlines the methodology used to identify, select, and analyse the literature. Section 3 presents the main findings, organised according to the levels of influence in the applied framework. Section 4 introduces and discusses the conceptual model (Figure 2) in relation to the research questions, and highlights implications for policy and future research. In the fifth section, the paper concludes by summarising the key insights and outlining a research agenda.

2. Methodology

2.1. Research strategy

This narrative literature review synthesised evidence from diverse disciplines to understand determinants of children's autonomous cycling mobility. To ensure transparency, the review followed the PRISMA 2020 guidelines (Page et al., 2021).

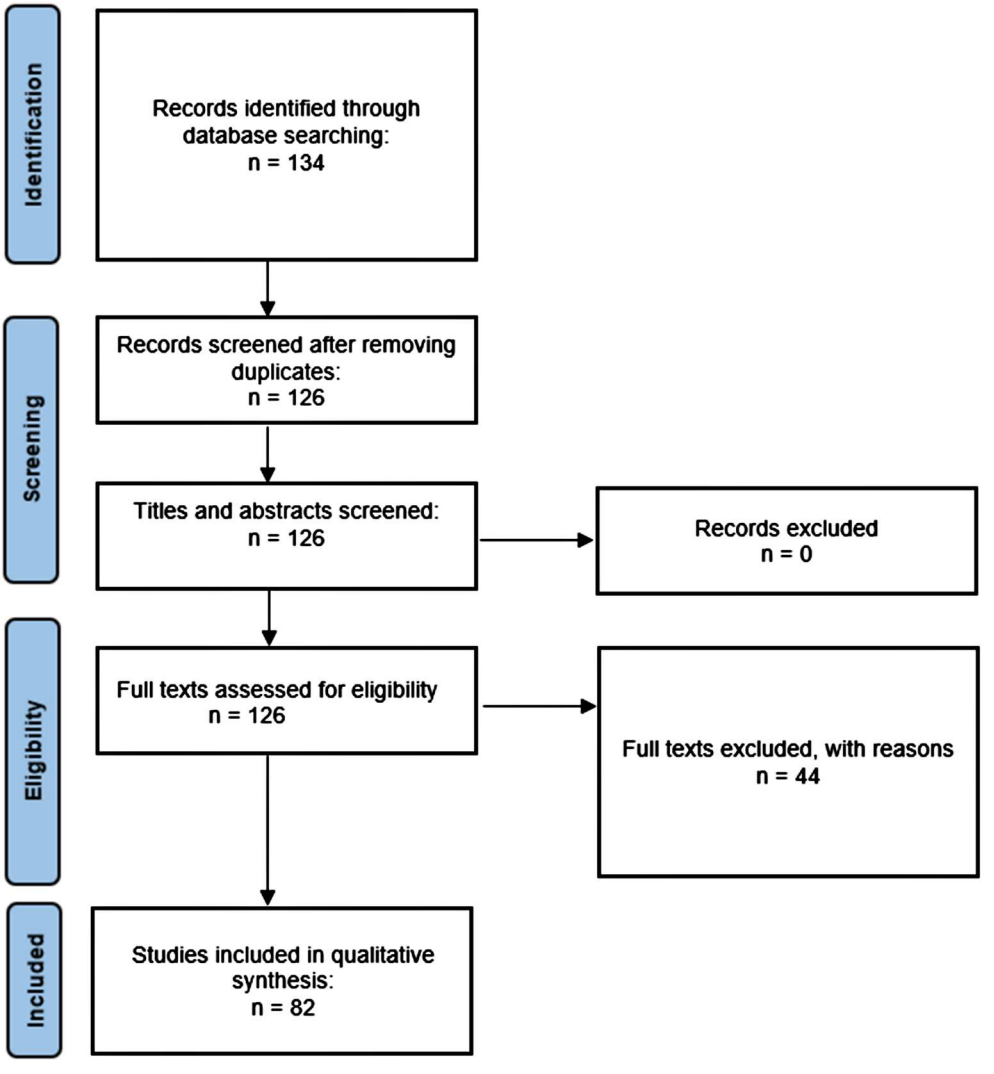

Figure 2. PRISMA flow diagram of the literature review on autonomous cycling mobility of children.

A systematic search strategy was employed to identify relevant literature across four academic databases: Google Scholar, Scopus, Web of Science, and PubMed. To ensure a broad and multidisciplinary approach, the search included a variety of keywords and Boolean combinations, such as: "autonomous mobility", "autonomy", "independent", "child*", "childhood", "youth", "adolescent", "teen", "teenager", "teenage", "cycling", "bike", "bicycle", "cycle", "active", "mobility license", "CIM", "health", "play", and "determinant*". Terms were combined using Boolean operators (e.g. "child" OR "youth" AND "autonomy" OR "independent" AND "cycle" OR "cycling"*) to maximise the breadth and relevance of the results.

2.2. Inclusion and exclusion criteria

Studies were included when they provided empirical (qualitative, quantitative, or mixed-methods) insights into children's autonomous cycling mobility. Peer-reviewed articles, book chapters, conference papers and relevant institutional reports were eligible.

The population of interest comprised children and youth up to the age of 18. Where studies covered broader or overlapping age ranges, they were retained when findings were relevant to children's or adolescents' independent cycling mobility. Age was considered a key contextual factor, and information on the age group studied was extracted for each included paper. Studies involving families, caregivers, or policymakers were included only if their primary focus related directly to understanding mechanisms underlying children's cycling autonomy.

In addition to empirical work, conceptually driven studies were also included when they offered theoretical or interpretive insights into behavioural mechanisms underpinning children's cycling autonomy (e.g. autonomy, parental control, motonormativity). These sources helped clarify constructs and bridge perspectives from health, psychology and spatial planning.

Studies were included when conducted in Europe or when findings could be meaningfully interpreted within European mobility and planning contexts. Publications were accepted in English, Dutch, French and German; studies in other languages were excluded to avoid misinterpretation.

2.3. Screening procedure

An iterative screening process was used. Titles were first screened for relevance to children's independent mobility, cycling, autonomy and independent outdoor play. Given terminological overlap (e.g. "active travel", "independent mobility", "autonomous play"), broad inclusion was initially adopted. Abstracts were then screened, followed by full texts to confirm conceptual fit. The Theoretical Domains Framework (TDF) (Atkins et al., 2017) informed screening decisions by helping identify behavioural determinants relevant to children's cycling autonomy.

Of the initially identified records, 44 were excluded during full-text screening. The main reasons were: (a) limited conceptual of thematic relevance to children's autonomous mobility ($n = 17$); (b) populations not including children of adolescents under 18 years ($n = 9$); (c) exclusive focus on general physical activity, organised sports, without reference to autonomy, independence or travel behaviour ($n = 11$); and (d) inaccessibility of full texts in the eligible languages ($n = 7$). A total of 82 studies and conceptual works were retained (Figure 2).

2.4. Data extraction and synthesis

For each study, data were extracted on location, age group, methodology, setting, and identified determinants (mapped to TDF domains). A full overview of the 82 studies is provided in Appendix 1.

The TDF informed both the screening and synthesis phases. The framework was used to categorise and interpreted the determinants identified across studies. Although no

software was used for formal meta-synthesis, principles of narrative analysis were applied to identify recurring patterns, contradictions and contextual nuances.

Findings were organised across interrelated levels of influence: (a) individual (skills, development, motivation); (b) (family, peers, norms), and (c) environmental (infrastructure, policy, design).

2.5. Conceptual scope and limitations

No publication date limits were applied, allowing inclusion of seminal contributions relevant to CIM scholarship, consistent with narrative review principles (Baumeister & Leary, 1997). Including both empirical and conceptual studies reflects the interdisciplinary nature of the field, where theoretical discussions often inform empirical work.

Conceptual papers were therefore retained when they clarified mechanisms linking social norms, parental practices or spatial design to children's autonomy. Studies were included when findings could be meaningfully related to autonomous cycling, even when broader forms of active mobility (such as walking) were discussed.

Despite a structured search and theory-informed screening, fixed search terms, language restrictions and stepwise screening inevitably narrowed the scope. However, the diversity of included studies and the absence of new determinants in later stages suggest conceptual saturation (Lewis-Beck et al., 2004).

2.6. Conceptual model development

The synthesis informed the development of a conceptual model (Figure 1) illustrating key determinants of children's autonomous cycling, spanning interpersonal, environmental and societal domains and highlighting foundational preconditions such as cycling skills and bicycle access. These domains interact dynamically over time.

Although the model is grounded in existing empirical and conceptual evidence, it should be viewed as a theoretical synthesis rather than a validated framework. Its purpose is to guide hypothesis generation and future empirical testing. The model may therefore serve as a foundation for subsequent studies that apply mixed-methods approaches (such as surveys, observations, or participatory research with children and caregivers) to evaluate and refine its components and relationships.

3. Findings

A total of 82 empirical and conceptual works were included in the review. An overview of all included studies (summarising their publication year, country or region, population and age range, methodological design, and primary thematic focus) is provided in Appendix 1. The studies reflect the interdisciplinary nature of research on children's autonomous mobility, spanning health sciences, psychology, transport geography, and urban planning.

The TDF framework was used to categorise and interpret the determinants identified across the studies. Cycling was not always the exclusive focus across studies; many addressed children's independent or active travel more broadly, with cycling examined alongside walking. Nonetheless, in Northern and Western European contexts (particularly

the Netherlands, Belgium, Denmark, and Finland) cycling consistently emerged as a dominant or culturally embedded mode of children's active mobility (Ghekiere et al., 2016; Kyttä et al., 2015; Masoumi et al., 2020). Across these studies, a substantial proportion of school-aged children reported using bicycles for everyday travel, although the share of children cycling independently (i.e. without adult accompaniment) was considerably lower. Independent cycling was highly sensitive to age, gender and distance, rising markedly around ages 10–12 (D'Haese et al., 2011; Fyhri & Hjorthol, 2009; Shaw et al., 2015; Zwerts et al., 2010).

In contrast, studies from Southern Europe (Italy, Portugal) reported much lower levels of cycling and independent travel, with walking and chauffeured trips predominating (Alparone & Pacilli, 2012; Masoumi et al., 2020; Mercê et al., 2021). Outside Europe, similar patterns appeared in Canada and Australia (Larouche et al., 2016; Schoeppe et al., 2015; Freeman & Quigg, 2009), reflecting environmental, infrastructural and cultural contexts less conducive to routine cycling. Despite these differences, a consistent pattern emerged: independent cycling increases notably in late childhood, particularly around the transition to upper primary school, when parental trust and mobility responsibility expand (Ducheyne et al., 2012; Ghekiere et al., 2016).

3.1. Social influences of children's autonomous cycling mobility

Social determinants of behaviour refer to the interpersonal processes that influence how individuals act, think and make decisions (Atkins et al., 2017). Parents, peers and siblings are especially influential, while broader societal norms and discourses define the context in which mobility decisions are made.

3.1.1. Parental influences

Parents play a central role in shaping autonomy (Ghekiere et al., 2016). As the primary source of support, parents not only motivate their children to engage in activities like cycling, but also serve as role models (Ghekiere et al., 2016; United Nations, 1989). A positive parental attitude towards cycling has been shown to significantly boost children's likelihood of adopting this behaviour (Ghekiere et al., 2016).

The development of independent travel is often described in terms of gaining a "Children's Independent Mobility (CIM) license", where children gradually move from full dependence on adults towards greater autonomy (Vissers et al., 2005). Research by Riazi et al. (2021) identifies four key conditions that influence how children gain autonomy in their travel behaviours and the distance they are allowed to travel independently: (1) parents' own childhood experiences, (2) the perceived skills of the child for independent travel, (3) the level of trust and communication between parent and child, and (4) the parents' perceptions of safety and community connectedness. These key conditions by themselves can also be influenced: literature shows that cycling together allows parents to build their child's confidence and traffic skills, in turn fostering greater independence (Ghekiere et al., 2016).

Age and gender shape these processes. Younger children and girls are more likely driven than boys, and are more often accompanied when cycling to school (Zwerts et al., 2010). Parental concerns about traffic safety play a significant role in determining whether children are allowed to travel independently. When parents are faced with

heavy traffic or perceive high risks, they are more likely to restrict their children's mobility (Björklid & Gummesson, 2013; Ducheyne et al., 2012; Ghekiere et al., 2015). This concern extends to not just travel, but also activities such as autonomous street play (Bringolf-Isler et al., 2010). As the distance from home increases, parents also tend to impose stricter restrictions (Zwerts et al., 2010).

Interestingly, mothers are more likely than fathers to make decisions regarding the restriction of mobility (Zwerts et al., 2010), aligning with previous findings indicating that mothers are more involved in accompanying children or transporting them (Zwerts et al., 2007). Furthermore, when parents' social connections within their community weaken, a study by Alparone and Pacilli (2012) suggests that their feelings of social danger tend to increase, leading to greater restrictions on their children's daily activities. Similarly, Johansson (2003) also found that feelings of social danger in parents impact their children's mobility. The process of negotiating autonomous mobility between parents and children may occasionally result in conflicts, highlighting that children play an active role in organising their movements (Fotel & Thomsen, 2003). Han et al. (2022) found that while both parents and children ideally work together to promote autonomy, tensions can arise when a child desires more independence but lacks parental support, or when parents enforce restrictions that the child does not agree with.

3.1.2. Influence from peers and siblings

Peers and siblings also shape cycling behaviour. Research by van den Berg et al. (2020) demonstrated that primary school children prefer to travel with friends, and engaging in social activities while travelling leads to greater satisfaction with the experience. Additionally, cycling with friends and receiving social support from peers increases the likelihood of children aged 10–12 engaging in cycling as well (Ducheyne et al., 2012; Ghekiere et al., 2016).

Zwerts et al. (2010) highlight that the social aspects of travel are especially important for girls compared to boys. A similar effect was found by Fults et al. (2025), where children aged 12 and older travelled more independently; however, girls were more likely to make these trips together (accompanied independent travel), whereas boys tended to travel alone.

Sibling influence can also play a role in cycling behaviours. Mercê et al. (2021) found that younger children in both Northern and Southern Europe tend to learn to cycle at a younger age than their older siblings. This has been linked to social learning processes (Barr & Hayne, 2003), as well as practical factors such as inheriting bicycles from older siblings.

3.1.3. Dominant societal norms and discourse

Children are often excluded from participating in the design of public spaces and urban planning (Skelton, 2017; Verhetsel & Witlox, 2006). Professionals may claim to act in children's "best interests", yet adult assumptions frequently diverge from children's views (Cele & Ekman Ladru, 2015).

In many Western societies, children are primarily framed as vulnerable and "not fully equal citizens" (Percy-Smith, 2015). This discourse informs expectations around "good parenting", often equated with keeping children safe and limiting unsupervised mobility (Riazi et al., 2021). However, these ideals vary. For some parents, promoting their

children's autonomous mobility is central to their understanding of being a "good parent" (Silonsaari et al., 2024). In this context, Faircloth (2014) argues that parents do not universally adopt the ideals of intensive parenting. Instead, these ideals serve as a cultural framework through which parents interpret, evaluate, and navigate their own practices, roles, and identities (Silonsaari et al., 2024).

Childhood has also become increasingly institutionalised, with leisure time shifting from unstructured play toward organised, adult-led activities (Adler & Adler, 1994). To accommodate these routines, many families rely on cars to manage fragmented schedules, reinforcing car dependence in children's everyday mobility (Silonsaari et al., 2024).

3.2. Environmental context and recourses influencing autonomous cycling mobility

The following paragraphs focus on how the broader environmental context, including both the built environment and the material and social resources available to children, can either support or hinder the development of independence, skills and adaptive functioning (Atkins et al., 2017). While the built environment refers to the physical layout and infrastructure of streets, neighbourhoods and transport systems, the broader environmental context also encompasses accessibility, resource distribution, and social-spatial opportunities that shape children's mobility practices. The review specifically examines three interrelated aspects: urban design, traffic engineering and bicycle accessibility.

3.2.1. Urban design

A built environment that is designed with children in mind is crucial for fostering their physical, mental, emotional and social development (United Nations, 1989). Vibrant and sustainable cities are typically characterised by inclusive, play-friendly neighbourhoods; however our urban design is frequently oriented around cars rather than human-scale environments (Bishop & Corkery, 2017; Caroll et al., 2015; UN-Habitat 2012, 2013; Hart, 2002). Children's mobility is often confined to designated play areas due to concerns about vulnerability or disruption in public space (Scott et al., 1998; Valentine & McKendrick, 1997). While intended to protect children from traffic and other hazards, such designs have also reduced their visibility in public space (Ball et al., 2019; Brussoni et al., 2018; Hart, 2002; Woolley & Lowe, 2013).

Empirical studies demonstrate how neighbourhood form directly influences children's daily mobility patterns. Fults et al. (2025), analysing travel diaries of children aged 6–17 in Belgium, found that the level of urbanisation and the child's age were significant predictors of independent travel. Children living closer to the urban core reported higher rates of autonomous movement compared to those in peripheral areas. D'Haese et al. (2011) similarly showed that proximity to school and the walkability of routes within about 3 km are important for active commuting among 11–12 year-olds, with cycling preferred where distances exceed typical walking ranges.

While this review focuses on autonomous cycling, it is acknowledged that in some contexts (particularly among older adolescents) public transport can also serve as a form of independent mobility. However, as the reviewed literature primarily conceptualised autonomy through active modes such as walking and cycling, public transport fell beyond the present study's scope.

3.2.2. Impact of traffic engineering choices

In relation to traffic engineering, studies reveal that dead-end streets with low traffic levels can positively influence children's autonomous mobility and play (Hochschild, 2013). However, the meaning and effects of dead-ends vary considerably across contexts. In the Netherlands and Denmark, for example, cul-de-sacs are often embedded within permeable street networks that maintain high connectivity for walking and cycling, making them safe and attractive spaces for children. In contrast, in more car-oriented systems such as the United States, dead-ends tend to be part of low-connectivity suburban layouts, which can reduce route choice and limit children's independent movement. These contextual differences suggest that the benefits of dead-end streets depend not only on traffic levels but also on the wider street network configuration.

Research with children aged 10–12 reveals a strong preference for active transportation modes, as long as the spaces for these modes are safely designed (wide enough and separated from traffic). The children also consistently favoured green spaces that serve multiple purposes, such as traffic calming measures, safety barriers from motorised traffic and aesthetic value. Additionally, social spaces were important in their street design, reflecting the significance of peer interaction for young people (Hook & David, 2025).

Research conducted by Ghekiere et al. (2015) highlights this further. Micro-environmental factors such as even cycle paths, low speed limits, separation from traffic, low traffic density and well maintained environments have been found encouraging cycling in children. For teenagers, factors like location, accessibility, and the spatial connections between different areas often take precedence over the exact design or aesthetic of public spaces (Vanderstede, 2011).

3.2.3. Bicycle access

A fundamental prerequisite for autonomous cycling mobility is access to a bicycle, an essential material resource situated within the broader environmental context (Masoumi et al., 2020). Without such access, opportunities to develop cycling skills and integrate cycling into daily routines remain limited.

However, bicycle ownership is not evenly distributed across socioeconomic groups. Tandon et al. (2012) found that children from lower-income households are significantly less likely to own bicycles, highlighting how structural inequalities in access reinforce broader disparities in physical activity and mobility opportunities.

This dimension underscores that the built environment alone cannot explain differences in independent cycling. Access to material, infrastructural, and social resources is equally central, as these collectively define the structural conditions within which children's cycling autonomy can develop.

3.3. Skills and the development and physiology of children

Skills are defined as "the ability or proficiency acquired through practice," with a focus on competence and practical experience (Atkins et al., 2017). In the context of cycling, these skills intersect with developmental and physiological characteristics that shape children's readiness for independent travel.

3.3.1. Motor skill development and bicycle riding

Learning to ride a bicycle is widely recognised as a significant developmental milestone in childhood (Cordovil et al., 2022). By the age of five, many children have already acquired the basic ability to ride a bicycle independently (Zeuwts et al., 2016). Mastery of this physical skill is fundamental for achieving autonomous mobility by bicycle. From a motor skills perspective, cycling requires the coordinated integration of multiple bodily functions, as children must simultaneously pedal, balance, and steer, each demanding a high level of control and precision (Mercê et al., 2021).

Research focusing on children with disabilities further highlights the critical role of physical attributes, such as leg strength, in developing cycling proficiency and independence (MacDonald et al., 2012; Ulrich et al., 2011). Additionally, the ability to mount and dismount a bicycle smoothly is an essential skill in cycling mobility, with most children typically mastering this skill by the age of seven (Zeuwts et al., 2016).

3.3.2. Physiological and developmental factors affecting children's cycling mobility

Apart from motor skills, various physiological and developmental factors significantly influence children's ability to cycle independently. These factors include vision, stature and physiology, cognitive development and the ability to perceive and react to traffic situations.

Vision plays a crucial role in children's ability to navigate traffic safely. While the human eye does not fully mature until early adulthood, children's depth perception and focus are generally well-developed by the age of 7–9 (Brown & Zoethout, 2009). However, refractive errors such as myopia and hyperopia, which are related to the shape of the eyeball that changes during maturation, tend to stabilise closer to age 18.

These errors can impact children's ability to accurately perceive traffic situations and assess risks (Brown & Zoethout, 2009). Myopia, or near-sightedness, can make it difficult to see distant objects clearly, such as approaching vehicles, while hyperopia, or farsightedness, can impair the ability to focus on nearby objects, such as pedestrians or road signs, both of which are crucial for safe navigation in traffic.

Children's limited stature presents significant challenges in traffic environments, as it impairs their ability to perceive oncoming vehicles and reduces their visibility to drivers. Between the ages of four and seven, children's understanding of traffic is predominantly egocentric; they often assume that if they can see a vehicle, the driver can also see them (Schieber & Thompson, 1996). This developmental limitation may prevent them from identifying hidden hazards, such as vehicles obscured by parked cars (Demetre, 1997). Children of this age may also prefer deemed unsafe crossing paths, like diagonal routes at intersections instead of taking a straight, perpendicular path (Barton et al., 2012). Such diagonal movement increases the time spent in the roadway, complicates the predictability of their movements for drivers, and exposes them to multiple traffic streams.

Prior to age four, it is assumed that children typically lack the motor, sensory, and cognitive capacities required for independent navigation in traffic. Their behaviour tends to be erratic, and their ability to assess risk remains underdeveloped (Vissers et al., 2005).

By approximately age seven, children begin to acquire the ability to interpret drivers' intentions based on behavioural cues, often described as learning to "read the road"

(Barton et al., 2012; Foot et al., 2006). Nevertheless, difficulties with accurately estimating vehicle speed and timing persist. Around the age of ten, many children are capable of identifying and avoiding common traffic hazards, although their hazard perception and reaction times remain inferior to those of older adolescents and adults (Meyer et al., 2014). Even up to age fourteen, children may continue to struggle with complex traffic scenarios (Twisk et al., 2018). During adolescence, risk-taking behaviours also emerge (Reyna & Farley, 2006).

In the event of a traffic-related injury, children are at heightened risk of severe outcomes due to anatomical and physiological differences. Their skulls are more pliable, their thoracic walls thinner and more compliant, and their abdominal musculature less protective, all of which increase vulnerability to head and internal injuries (Özdülger, 2024; World Health Organisation, 2015).

3.4. Intrinsic motivations and children's insights on autonomous cycling

Beyond external factors such as infrastructure or parental influence, children's own motivations and perceptions also play a key role. This section explores how children themselves experience autonomous cycling and how they navigate the social and emotional landscape tied to their mobility.

3.4.1. Happiness, freedom and peer culture

Cycling is not merely a practical means of transportation for children; it is often perceived as a highly enjoyable activity providing happiness (Költő et al., 2021). Wonder, discovery, playfulness, adventure, meandering, … are all different sensory experiences that come into mind when children are free to wander about, according to research from Weir (2023). Shaw et al. (2015) found that children consistently express a strong preference for cycling. Similarly, van den Berg et al. (2020) shows that children report greater travel satisfaction when their preferred mode of transport, often the bicycle, is available to them.

Beyond enjoyment, cycling serves as a symbol of autonomy and freedom. These everyday choices reflect children's growing need for agency and align with peer culture in spaces less regulated by adults (Wales et al., 2021). Age also plays an important role in how children experience this sense of freedom. As they grow older, their desire for autonomy intensifies, and cycling becomes both a practical and symbolic expression of that growing independence (Shaw et al., 2015; Zwerts et al., 2010).

Rutberg et al. (2025) state that cycling (and active mobility in general) gives children the freedom to decide how and when to travel to school, which strengthens their sense of capability and independence. Further, the study shows that children highly value independent mobility and express a desire to participate in decisions regarding their travel.

For adolescents, social belonging becomes increasingly important. Teenagers seek spaces where they can meet and interact with peers; places that support their emotional, social, and identity development (McGrath et al., 2009). Vanderstede (2011) argues that a well-integrated and flexible spatial network is needed to meet these evolving needs, as cycling often becomes a key tool for social participation during this stage.

3.4.2. Gender differences and social travel preferences

Motivations for autonomous cycling are not uniform across all children. According to Zwerts et al. (2010), boys tend to value independence and the opportunity to multitask while travelling, whereas younger girls often prefer car travel for its comfort, though this changes with age. Social aspects of travel, such as walking or cycling together, are generally more important for girls than for boys (Zwerts et al., 2010).

These gender differences do not only reflect distinct preferences but also mirror broader social norms and parental expectations. Girls' preference for accompanied travel and their comfort with car transport are often shaped by parental safety concerns and gendered perceptions of vulnerability (Fults et al., 2025; Bhosale et al., 2017; Zwerts et al., 2010). Consequently, girls' cycling autonomy may depend less on personal motivation and more on the level of freedom parents are willing to grant.

3.4.3. Confidence, self-efficacy and fears

Children's confidence in their own cycling ability plays a crucial role. Those with higher self-efficacy, such as being unafraid to cycle in bad weather or when tired, are more likely to engage in independent cycling (Ghekiere et al., 2016). Caroll et al. (2015) found that children living in inner-city areas and neighbourhoods with an average socio-economic status, also referred to as mid-decile neighbourhoods, more frequently reported fears related to both traffic safety and "stranger danger." These concerns may be influenced by the environment they live in, where busy roads, fewer safe spaces to play, and less supervision can make children feel more vulnerable when moving around independently.

Regarding fear transmission, research by De Groof (2008) suggests that higher levels of parental supervision are associated with increased environmental fears in adolescents, which in turn can hinder their willingness or motivation to cycle independently.

3.4.4. Awareness of environmental impact and social norms

Children demonstrate surprising awareness of their environment and the social structures surrounding their mobility. Girls and younger children, in particular, are more sensitive to the negative environmental impact of car traffic, including noise and pollution (Zwerts et al., 2010). They are also cognizant of adult-imposed mobility rules and seem to recognise the power imbalances in traffic systems (Fotel & Thomsen, 2003). Some children report feeling disrespected by adult road users (Thomsen, 2004), framing these challenges as a natural part of daily life. Further, children also report feelings of constriction regarding play in public space (Bourke, 2014) and being aware of the fact that they are not being involved in policy making processes related to their environment (Wales et al., 2021).

4. Discussion

This section connects the findings to the research questions and outlines implications for policy and future research. A thematic analysis using the TDF as a sensitising framework yielded four interconnected domains: (1) personal and interpersonal influences, (2) the built environment, (3) broader societal norms, and (4) essential preconditions: skills and bicycle access. These domains interact dynamically over time rather than operating in isolation, as illustrated in Figure 1.

Across the 82 included studies, the distribution of attention across determinants is markedly uneven (Appendix 2). Social influences and environmental context dominate the literature, whereas children's skills, perceived capabilities, intrinsic motivations and cognitive processes are addressed far less frequently. These imbalances highlight that children's autonomous cycling is shaped not only by physical environments, but equally by social permission, psychological readiness and children's own interpretations of mobility. The conceptual model (Figure 1) therefore reflects both the breadth of determinants identified in this review and the blind spots that remain, pointing to clear priorities for future research.

Building on this model, the remainder of the Discussion focuses on the practical implications of the four domains for policy and intervention design.

4.1. Personal and interpersonal influences: children, parents and peers

Children's independent cycling is shaped by their developmental characteristics and by the attitudes and decisions of parents, peers and siblings. Parental perceptions of safety, communication styles and past experiences remain central in granting or restricting autonomy, with younger children and girls typically facing more limitations. Peers and siblings can provide motivation, companionship and modelling.

Many children perceive cycling as enjoyable and liberating, reinforcing autonomy and social belonging. Gendered patterns persist: girls often emphasise social travel and safety in groups, while boys highlight independence. Children with higher perceived self-efficacy cycle more independently, showing the importance of psychological readiness alongside skill acquisition. Some children also express awareness of mobility inequalities and environmental concerns, indicating a capacity to critically reflect on their mobility environments.

4.2. Built environment: enabling or restricting cycling

The physical environment strongly shapes children's ability to cycle alone. Dead-end streets, traffic calming, cycle paths, safe crossings and green spaces facilitate autonomy, whereas car-centric design and fast traffic reduce perceived and actual safety. Children living closer to urban centres also cycle more independently (Fults et al., 2025).

Yet the built environment cannot act alone. Environmental improvements only enable autonomy when aligned with parental permission and children's developmental capacities. Urban design must therefore reflect children's limited visibility, shorter stature and developing traffic skills, and support their legitimacy in public space (Soja, 2010) rather than relying on adult-centric standards.

4.3. Broader societal norms: good parenting, participation and the discourse of childhood

Cultural expectations around safety, responsibility and childhood shape mobility decisions across all domains. Norms of "good parenting" prioritise supervision and risk avoidance, restricting autonomy even in objectively safe contexts. These expectations intersect with gender norms and with constructions of children as vulnerable, not-yet-

rational citizens. Although children are increasingly invited into planning processes, participation often remains symbolic. Creative methods such as drawing, photography and role play can uncover perspectives overlooked in adult-led approaches (Honkanen et al., 2017; Kondo & Sjöberg, 2013).

Discourses strongly influence mobility futures. As Tschoerner-Budde (2020) notes, academic, political and media narratives are embedded in dominant mobility cultures. Protection-oriented framings (e.g. helmet use) can overshadow debates about autonomy, while car-centric narratives (motonormativity) marginalise child-centred imaginaries (Walker & te Brömmelstroet, 2025; Hendawy et al., 2024). These discourses both reflect and reproduce societal norms, shaping how children's movement is valued and regulated.

4.4. Essential preconditions: skills and access to bicycles

Even under favourable social and environmental conditions, children require foundational capacities: cycling skills and access to a suitable, well-maintained bicycle. Treating these jointly highlights that autonomy depends not only on environmental design or social permission, but also on developmental and socioeconomic resources.

Motor, perceptual and cognitive skills mature gradually, yet many environments implicitly demand adult-level competence, creating a design–development mismatch. Bicycle access similarly constitutes an overlooked structural inequality: children without a suitable bike are effectively excluded from autonomous cycling, linking mobility opportunities to broader socioeconomic disparities.

4.5. Interconnected dynamics and future directions

The four domains identified in this review interact dynamically rather than functioning independently. Infrastructural improvements may influence parental attitudes, increased visibility of cycling children can reshape cultural norms, and evolving discourses can steer policy agendas. Understanding children's autonomous cycling therefore requires attention to temporal processes and feedback loops across domains.

Research remains heavily concentrated on children aged 10–12, leaving younger and older age groups (as well as children with disabilities) underrepresented. The evidence base also focuses predominantly on school travel, overlooking mobility related to leisure, socialising or everyday neighbourhood activities. These gaps limit understanding of how cycling autonomy is negotiated across contexts and developmental stages. There is also a need for stronger baseline data on children's autonomous cycling, including consistent measurement across countries, age groups and trip purposes, to enable meaningful comparison and long-term monitoring.

Future work should empirically test and refine the conceptual model proposed here, investigate how determinants evolve over time, and examine how infrastructure can better reflect children's cognitive and physiological development. Greater attention is also needed to material access and its interaction with social and spatial inequalities. Longitudinal and intervention studies are particularly valuable for assessing how built environment changes intersect with parental decisions, cultural norms and children's developing skills.

Finally, the societal narratives that frame children's mobility warrant deeper scrutiny. Discourse analysis and critical policy studies can reveal how dominant framings either support or constrain child-friendly mobility futures. Children's perspectives also remain insufficiently represented; expanding creative, participatory and child-led methods can provide deeper insights into how they experience autonomy and public space (Bernardi, 2020). Comparative governance research may further illuminate institutional barriers and opportunities for embedding child-centred mobility agendas. Together, these directions support more inclusive and forward-looking mobility systems that recognise children as rights-bearing citizens and contributors to the urban environment.

5. Conclusion

This review develops a conceptual model, grounded in the Theoretical Domains Framework, that synthesises the key determinants shaping children's autonomous cycling; ranging from personal and interpersonal factors to the built environment, societal norms, and essential preconditions such as skills and bicycle access. The findings show that children value cycling for the autonomy and freedom it provides, yet their mobility remains constrained by adult-centred norms, safety perceptions, and planning practices. Supporting cycling autonomy therefore requires more child-inclusive design and decision-making. Future research should prioritise younger and underrepresented groups, look beyond school travel, and examine how cultural narratives legitimise or restrict children's movement. Promoting cycling autonomy is ultimately a matter of equity and participation.

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