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Walking and non-motorized vehicle use in adolescents: the role of neighborhood environment perceptions across urbanization levels

Supplementary Information

The online version of this article (https://doi.org/10.1007/s12662-023-00931-5) contains supplementary material, which is available to authorized users.

Background

Physical activity is important for children's and adolescents' physical health and mental well-being (Chaput et al., 2020; Poitras et al., 2016; Rodriguez-Ayllon et al., 2019). The World Health Organization (Bull et al., 2020) recommends that children and adolescents should engage in at least an average of 60 min of moderate-to-vigorous-intensity physical activity per day. Insufficient physical activity levels are especially prevalent in adolescents (Guthold, Stevens, Riley, & Bull, 2020), which may carry into adulthood (van Sluijs et al., 2021).

Active travel (AT) is an important behavior that contributes to overall physical activity (Martin, Boyle, Corlett, Kelly, & Reilly, 2016) and is a key objective for targeting several United Nations sustainable development goals (United Nations, 2023). It has been reported that AT may be responsible for almost 20% of moderate-to-vigorous physical activity in adolescents (Klinker et al., 2014). This makes AT an important contributor to the sustainable development goal *Good Health and Well-Being*. Furthermore, AT is beneficial for preventing greenhouse gas emissions when chosen over motorized travel modes (Abu-Omar, Chevance, Tcymbal, Gelius, & Messing, 2023). It is estimated that 41% of short car trips could be substituted by walking or cycling. This would save nearly 5% of CO_2 emissions of car travel (Neves & Brand, 2019), contributing to the sustainable development goal *Climate Action*. A change toward AT can offer large benefits to society through creating social capital and better safety in neighborhoods, reducing fossil fuel dependency, and creating economic benefit—and all with little to no negative effects (Giles-Corti, Foster, Shilton, & Falconer, 2010), contributing to the sustainable development goal *Sustainable Cities and Communities*.

When children become adolescents, they grow more independent of their parents and become more involved in the decision-making process for AT (Mitra, 2013; Panter, Jones, & van Sluijs, 2008), can travel longer distances by foot or bike (van Dyck, de Bourdeaudhuij, Cardon, & Deforche, 2010), and can reach more places of interest (e.g., school, recreational facilities, shops) physically active and without parental supervision.

The WHO emphasizes in its "Global Action Plan on Physical Activity" that creating active environments across urban and rural areas is a key pillar for physical activity promotion (World Health Organization, 2018). Hence, perceptions of the physical environment are important in the decision-making process of whether to engage in AT (Panter et al., 2008). A recent review found that several perceptions of the environment such as short travel distances, traffic safety, walking and cycling infrastructure, esthetics, and street connectivity are associated with AT (Klos et al., 2023). However, most studies included in this review were limited to single cities or districts and only focused on school transport modes. Thus, there is limited evidence on whether environmental perceptions are associated with active transport beyond active school commutes.

To date, few studies have assessed adolescents' AT behavior in rural and urban areas. This is especially important since physical activity shows detrimental trends in children and adolescents in rural areas (Nigg et al., 2022). From a socioecological perspective (Sallis et al., 2006), neighborhood environment characteristics are crucial for AT, such as walkability, infrastructure, and connectivity (Giles-Corti et al., 2022). These characteristics are usually more common in urban areas, making them, in general, more inducive to AT than rural areas. The few studies investigating AT across urban and rural areas found that urban adolescents are more likely to engage in

AT than their rural counterparts (Christiana, Bouldin, & Battista, 2021; Hermosillo-Gallardo, Jago, & Sebire, 2018; Marzi et al., 2023). However, commuting actively (Johansson, Laflamme, & Hasselberg, 2012) and especially cycling to school (Reimers, Jekauc, Peterhans, Wagner, & Woll, 2013; Reimers et al., 2021) is more common in medium-sized towns compared to cities, suggesting a non-linear relationship between urbanicity level and AT. Regarding neighborhood environment characteristics, more urban areas are characterized by a higher population and intersection density as well as a higher overall walkability than rural areas (Rahman, Pocock, Moore, & Mandic, 2020). Conversely, urban areas are perceived to be less safe to walk or cycle than rural areas (Rahman et al., 2020). Therefore, environmental perceptions and their influence on AT may differ across urbanicity levels. For example, Kamargianni and Polydoropoulou (2014) found that the network condition of the sidewalks was only relevant in rural areas whereas traffic lights were only associated with AT in urban areas.

Regarding AT modes, a distinction should be made between walking and using non-motorized vehicles (NMV) such as cycling or longboarding. As NMVs are usually faster than walking, feasible distances for walking are significantly shorter than, e.g., cycling (van Dyck et al., 2010) and are used for different trips. Further, walking is perceived as less dangerous and relies on different road and safety infrastructure than NMVs (Cook, Stevenson, Aldred, Kendall, & Cohen, 2022; Mandic et al., 2017). The Netherlands and Denmark are renowned for their walking- and cycling-friendly cities. By contrast, Germany remains a car-centric country even though increasing efforts are made to promote walking and cycling, especially in bigger cities (Buehler, Pucher, Gerike, & Götschi, 2017). Helping to understand what is important for adolescents' active travel decision-making across Germany, this study may guide policymakers to promote sustainable travel for the next young generation.

Therefore, this study aimed to assess the relationship between perceived environment and walking as well as NMV use stratified across urban and rural areas in adolescents living in Germany.

Methods

Sample

Cross-sectional data from two cohorts of the Motorik-Modul Longitudinal Study (MoMo) were used. MoMo is a part of the German Health Interview and Examination Survey for Children and Adolescents (KiGGS) conducted by the Robert Koch Institute. MoMo has collected data on physical fitness, physical activity, and social and environmental determinants of children and adolescents across 167 sample points in four measurement waves between 2003 and 2021. Each wave consists of a representative cross-sectional sample including children and adolescents aged 4–17 years and a longitudinal sample. Further information on MoMo can be found elsewhere (Wagner et al., 2014; Woll et al., 2021).

For this study, cross-sectional data from participants aged 11–17 years from MoMo wave 2 (2014–2017) and MoMo wave 3 (2018–2020) were used. As the MoMo assessments were interrupted at the start of the COVID-19 pandemic, only data collected before the first lockdown in Germany in March 2020 were included since physical activity engagement in rural and urban areas cannot be generalized in pandemic and non-pandemic times (Nigg et al., 2021; Nigg et al., 2022).

MoMo was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Karlsruhe Institute of Technology Ethics Committee (wave 2 and 3, 2014–2017 and 2018–2021, respectively). MoMo was also approved by the Federal Commissioner for Data Protection and Freedom of Information. All participants were informed in detail about the study, gave written consent, and participated voluntarily. The presence and consent of a legal guardian were mandatory for participants younger than 15 years of age.

Variables

Age, gender, socioeconomic status (Lampert, Hoebel, Kuntz, Müters, & Kroll, 2018), environment perceptions, walking, and NMV use were assessed via a questionnaire (Schmidt, Will, Henn, Reimers, & Woll, 2016). The 167 sample points were drawn to be representative of Germany, accounting, e.g., for region and urbanicity (Woll et al., 2021). Multiple points were drawn in Hamburg and Berlin since they are large cities. Participants of these cities were allowed to take part in any of the scheduled assessments to allow for a reduced travel time for participants to the test locations. Thus, the sample points were summarized for Hamburg and Berlin, respectively, resulting in 162 instead of 167 sample points in the analyses.

Outcome: walking and non-motorized vehicle use

Walking was assessed by asking, "How long is the distance you walk per day?" Possible answer categories were, "I almost never walk"; "I walk less than 1 km per day"; "I walk between 1 and 2 km per day (15–30 min per day)"; "I walk 3–5 km per day (30–60 min per day)"; "I walk 6–10 km per day (1–2 h per day)"; and "I walk 10 km and more per day (more than 2 h per day)." NMV use was assessed by asking, "How long is the distance that you go by bike (only transport, not cycling for exercise/sport) and other non-motorized transportation (e.g., longboard)?" Possible answers were, "I almost never go by bike/longboard or the like"; "less than 1 km per day"; "1–5 km per day (5–10 min per day)"; "6–10 km per day (10–30 min per day)"; "11–20 km per day (30–60 min per day)"; and "more than 20 km per day (more than 60 min per day)."

Neighborhood environment perceptions

Adolescents' perceptions of the physical environment were assessed by 12 items concerning the accessibility of public recreation facilities (public sports facilities and playgrounds), private sports providers (sports clubs and commercial sports providers). safety and infrastructure (safe pedestrian infrastructure, safe cycling infrastructure, presence of cars, youth playing outside, safety from crime, pleasant neighborhood for walking and cycling), and accessibility (access to shops, access to public transport). All items were assessed using a 4-point Likert scale with higher values indicating a more AT-friendly environment except for one item assessing the presence of cars with an inverse order. The scale showed moderate test–retest reliability (Reimers, Jekauc, Mess, Mewes, & Woll, 2012). Single items were used instead of the factor structure from Reimers et al. (2012) as some items showed opposing relationships with walking or NMV use within factors.

Urbanicity

Urbanicity is based on the number of residents in the participants' hometowns. Participants were categorized into four urbanization levels: Rural areas (< 5000 residents), small towns (5000–19,999 residents), medium-sized towns (20,000–99,999 residents), and cities (≥ 100,000 residents) based on the categorization of the Federal Institute of Research on Building, Urban Affairs and Spatial Development (n. d.).

Socioeconomic status

Education, occupation, and equivalized disposable household income were assessed for both parents. Answers were categorized and given a score between 1 and 7 for each category. The highest score between parents was used to calculate the socioeconomic (SES) sum score ranging between 3 (lowest) and 21 (highest) points. If participants had only one parent, the score of this parent was used (Lampert et al., 2018). This index is an established instrument used in health-monitoring studies in Germany (Lampert, Kroll, Müters, & Stolzenberg, 2013).

Statistical analysis

All analyses were conducted using R (R Core Team, 2023) and RStudio (Posit team, 2023). Descriptive statistics (i.e., means and standard deviations for continuous variables and counts and frequencies for categorical variables) of the samples were calculated stratified by urbanicity level.

To analyze relationships between environmental perceptions and walking and NMV use, cumulative link mixed models were calculated stratified by urbanicity level using the *ordinal* package (Christensen, 2022). The central assumption for cumulative link mixed models is the proportional odds assumption meaning that the relationship between any pair of the ordered categorical outcome variable is the same. To test the assumption, a series of cumulative logit mixed models were calculated where the ordinal variable is collapsed into two categories and for each combination, a binary logistic regression is run (Williams, 2016). Plotting the coefficients across the different logistic regressions, the parallel odds assumption was met across the large majority of models. The outcomes are reported as odds ratio (OR), which represents the change in the odds of being in a higher category of the dependent variable associated with a one-unit increase in the predictor.

Intraclass correlation coefficients (ICCs) of the null models indicated that sample points should be included as a random factor for the NMV use models (ICC = 0.10–0.15) and may be included in the walking models (ICC = 0.01–0.05). For all but two models (walking in rural areas and small towns), model fit improved significantly (decrease in the Akaike information criterion > 5) when adding random intercepts for the sample points. Differences in fixed effect estimates for those two models with and without random factors were negligible, and thus sample points were included in all models to maintain comparability between models. The predictors of interest were the 12 perceived environment variables as fixed factors. Since physical activity has shown associations with sociodemographic characteristics, the final models also included age, gender (n_{boys} = 1935; n_{girls} 2041), and SES. A

Abstract

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Walking and non-motorized vehicle use in adolescents: the role of neighborhood environment perceptions across urbanization levels

Abstract

Promoting active travel is key to achieving the sustainable development goals of sustainable communities, climate action, and health and well-being. Walking and non-motorized vehicle use (e.g., cycling, longboarding) are influenced by the perceptions of the neighborhood environment. However, most evidence is limited to studies conducted in urban areas. This study aims to assess the relationship between perceived environment and walking as well as non-motorized vehicle use stratified across different levels of urbanicity in adolescents in Germany. Cross-sectional data of 3976 adolescents aged 11–17 (51% female) from the nationwide Motorik-Modul Longitudinal Study in Germany were used. Age, gender, socioeconomic status, neighborhood environment perceptions, duration of walking, and non-motorized vehicle use were assessed via questionnaire. Separate cumulative link mixed models were calculated to analyze the relationships between environment perceptions and walking as well as non-motorized vehicle use across rural areas, small towns, medium-sized towns, and cities. The presence of public sports facilities was related to both walking and non-motorized vehicle use across urbanicity levels. Relationships with other aspects of the perceived environment, such as traffic safety concerns and walking or cycling infrastructure, were more context-specific meaning that associations differed based on active travel mode and urbanicity level. Additionally, non-motorized vehicle use differed considerably across sample points. To conclude, when creating active and sustainable environments for active travel, it is crucial to target specific travel modes and take the urbanicity and regional context into account.

Keywords

Youth · Active transport · Cycling · Built environment · Rural · Urban

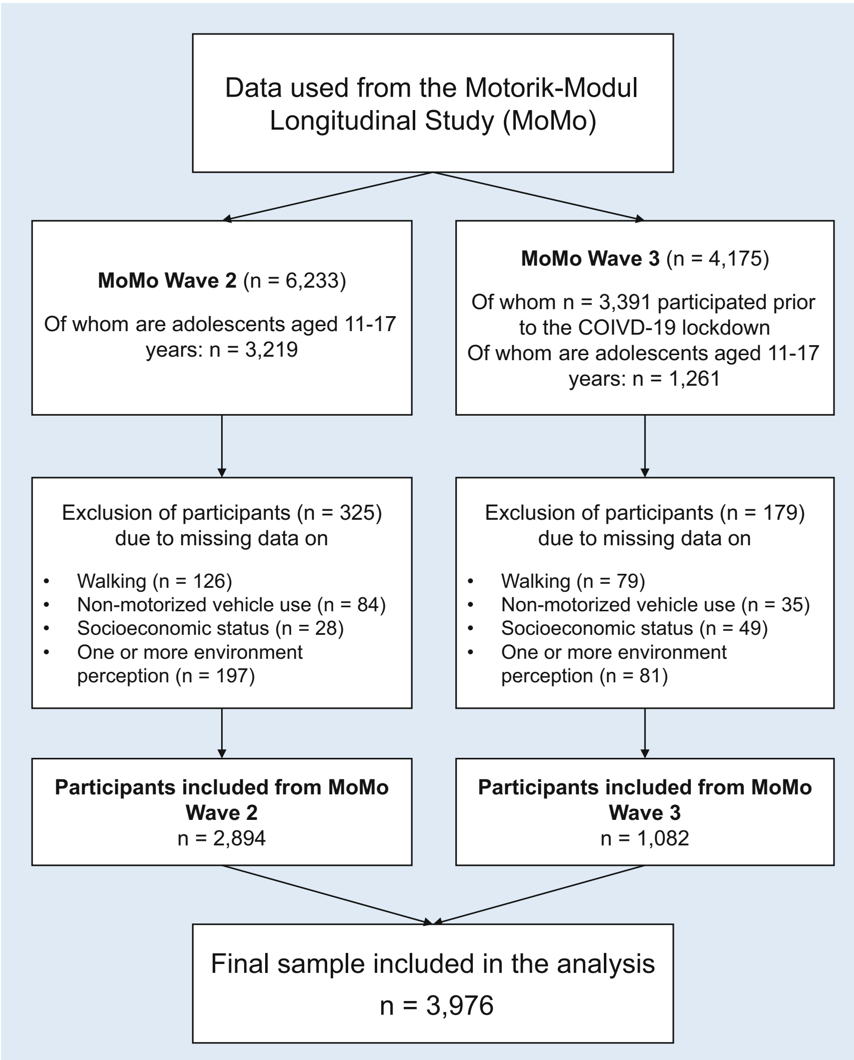

Fig. 1 ▲ Flowchart of the participants' included in the analyses

dummy-coded measurement-wave variable was added to account for potential cohort effects ($n_{\text{wave } 2} = 2894$; $n_{\text{wave } 3} = 1082$). Sample points were included as a random factor, allowing for different intercepts for walking and NMV use scores for each sample point. Logit models with standard unstructured thresholds were selected for all models based on model fit. Model summaries were created using the *sjPlot* package (Lüdecke, 2023). All cases with complete data were considered for the analysis.

Results

In wave 2, 3219 adolescents aged 11–17 participated, of whom 2894 had complete data (10.0% removed due to missing data). In wave 3, 1261 adolescents aged 11–17 participated, of whom 1082 had complete data (14.2% removed due to missing data). Reasons for exclusion were missing data on SES ($n = 77$), walking ($n = 205$), NMV use ($n = 119$), and/or in one or more environment variables ($n = 278$; for details see **Fig. 1**). Excluded participants from wave 2 were not different to those included. In wave 3, participants excluded due to missing data were more likely to have a low SES (30% vs. 20%).

The sample was on average 14.5 ± 2.0 years old, 51% were girls, and most participants lived in small ($n = 1323$) and medium-sized towns ($n = 1136$). While walking was distributed similarly across urbanicity levels, NMV use for 10 or more minutes per day was highest in medium-sized towns (see **Table 1**). Cities had the highest rate of adolescents who (almost) never use NMV (36%). Participants from MoMo wave 2 were slightly older (14.6 ± 2.0 vs. 14.3 ± 2.0 years) and had a lower SES score (14.0 ± 3.8 vs. 15.2 ± 3.3) than participants from MoMo wave 3 (see Supplementary Table 1 for details).

Environment perceptions across urbanicity levels

As presented in **Fig. 2**, perceptions of the neighborhood environment differed between urbanicity levels. Perceptions of the presence of sports and recreational facilities, walking and cycling infrastructure presence, and access to shops and bus stops by foot were higher in more urban areas. However, rural adolescents perceived their neighborhood to have fewer cars and a higher crime safety and to be more pleasant for walking and cycling. Some perceptions, such as the presence of sports clubs and commercial sports facilities as well as cycling paths, were rated highest in medium-sized towns, showing a non-linear pattern across urbanicity levels.

Relationship between perceived environment and walking

In rural areas, the perceived presence of public sports facilities (OR = 1.29, $p = 0.025$), cycling paths (OR = 1.30, $p < 0.001$), and cars (OR = 0.81, $p = 0.026$) was associated with walking (see **Table 2**). In medium-sized towns, the presence of public sports facilities (OR = 1.32, $p = 0.002$), and playgrounds (OR = 1.28, $p = 0.006$) was linked to more walking. In cities, access to shops by foot (OR = 1.26, $p = 0.029$) was associated with walking. No associations were observed in small towns. Overall, walking increased with age (OR = 1.11–1.19, all $p < 0.004$). Higher SES was related to more walking in rural areas (OR = 1.06, $p = 0.032$), but to less walking in medium-sized towns (OR = 0.97, $p = 0.029$). Rural participants in MoMo wave 3 engaged in more walking than those in wave 2 (OR = 1.40, $p < 0.001$).

Table 1 Description of the sample stratified by urbanicity level

	Rural, $n=800$	Small town, $n=1323$	Medium-sized town, $n=1136$	City, $n=717$	Overall, $n=3976$
Measurement wave					
MoMo wave 2	580 (73%)	1004 (76%)	836 (74%)	474 (66%)	2894 (73%)
MoMo wave 3	220 (28%)	319 (24%)	300 (26%)	243 (34%)	1082 (27%)
Age[1]	14.5 (2.0)	14.5 (2.0)	14.5 (2.0)	14.5 (2.0)	14.5 (2.0)
Gender					
Male	408 (51%)	630 (48%)	551 (49%)	346 (48%)	1935 (49%)
Female	392 (49%)	693 (52%)	585 (51%)	371 (52%)	2041 (51%)
Socioeconomic status[1,2]	13.4 (3.5)	13.9 (3.5)	14.7 (3.7)	15.5 (3.8)	14.3 (3.7)
Walking					
Almost never	15 (1.9%)	42 (3.2%)	61 (5.4%)	21 (2.9%)	139 (3.5%)
Less than 1 km (< 15 min) per day	121 (15%)	205 (15%)	196 (17%)	82 (11%)	604 (15%)
1–2 km (15–30 min) per day	358 (45%)	515 (39%)	459 (40%)	289 (40%)	1621 (41%)
3–5 km (30–60 min) per day	242 (30%)	443 (33%)	328 (29%)	257 (36%)	1270 (32%)
6–10 km (1–2 h) per day	56 (7.0%)	96 (7.3%)	82 (7.2%)	60 (8.4%)	294 (7.4%)
More than 10 km (> 2 h) per day	8 (1.0%)	22 (1.7%)	10 (0.9%)	8 (1.1%)	48 (1.2%)
Non-motorized vehicle use					
(Almost) no cycling, longboarding, etc.	233 (29%)	334 (25%)	270 (24%)	256 (36%)	1093 (27%)
Less than 1 km per day	194 (24%)	249 (19%)	132 (12%)	116 (16%)	691 (17%)
1–5 km (< 10 min) per day	235 (29%)	414 (31%)	348 (31%)	157 (22%)	1154 (29%)
6–10 km (10–30 min) per day	107 (13%)	252 (19%)	299 (26%)	144 (20%)	802 (20%)
11–20 km (30–60 min) per day	26 (3.3%)	62 (4.7%)	80 (7.0%)	35 (4.9%)	203 (5.1%)
More than 20 km (> 60 min) per day	5 (0.6%)	12 (0.9%)	7 (0.6%)	9 (1.3%)	33 (0.8%)

All measures are in format *n* (%) unless specified otherwise
[1]Mean (standard deviation)
[2]Socioeconomic status is measured on a scale from 3 to 21, with higher values indicating a higher status

Relationship between perceived environment and NMV use

In rural areas, the presence of public sports facilities (OR = 1.33, $p = 0.012$), perceiving the neighborhood to be pleasant for walking and cycling (OR = 1.29, $p = 0.037$), having access to shops (OR = 1.16, $p = 0.037$) and to cycling paths (OR = 1.29, $p = 0.002$) were associated with NMV use (see **Table 3**). In small towns, having public sports facilities (OR = 1.23, $p = 0.020$), a neighborhood pleasant for walking and cycling (OR = 1.26, $p = 0.015$), and access to shops (OR = 1.15, $p = 0.021$) were related to a higher duration of NMV use whereas access to bus stops was related to lower NMV use (OR = 0.80, $p = 0.003$). In medium-sized towns, cycling paths (OR = 1.29, $p < 0.001$) and lower presence of cars (OR = 0.83, $p = 0.034$) were linked to higher NMV use. In cities, public sports facilities (OR = 1.33, $p = 0.011$) and the presence of cars (OR = 0.80, $p = 0.037$) were associated with NMV use. Overall, girls used NMV less than boys did (OR = 0.45–0.71, $p < 0.018$). In rural areas (OR = 0.87, $p < 0.001$) and small towns (OR = 0.87, $p < 0.001$) NMV use decreased with age. Adolescents living in medium-sized towns with a higher SES used NMV longer than those with a lower SES (OR = 1.04, $p = 0.012$).

Discussion

This study aimed to investigate differences in physical environment perceptions and their relationship with walking and NMV use in adolescents across urbanicity levels in a nationwide study in Germany. In summary, perceptions of the neighborhood environment differed across urbanicity levels. Different associations were found between the perceived neighborhood environment and the active travel modes walking and NMV use across urbanicity levels. Overall, there were more associations between environment perceptions and NMV use than for walking. Apart from public sports facilities, different relationships were found with walking and NMV use across urbanicity levels. For example, the presence of cycling paths and a lower presence of cars was associated with walking in rural areas whereas in cities, only the access to shops was relevant. Having a neighborhood that is pleasant for walking and cycling and having access to shops by foot was associated with NMV use in rural areas and small towns while a lower presence of cars was related to NMV use in medium-sized towns and cities.

The role of recreational facilities and public spaces for active transport

Only the presence of public sports facilities in the neighborhood was largely associated with AT across travel modes and urbanicity levels. Living close to recreational facilities and public spaces with opportunities for PA such as parks was associated with the use of such places and therefore an important source for PA in adolescents (Grow et al., 2008; Veitch et al., 2014). An Australian study found that 87% of trips to public spaces such as parks and playgrounds are done actively on foot or by using bikes, skateboards, or scooters across rural and urban areas (Veitch et al., 2014). Therefore, accessible recreational spaces are a key destination

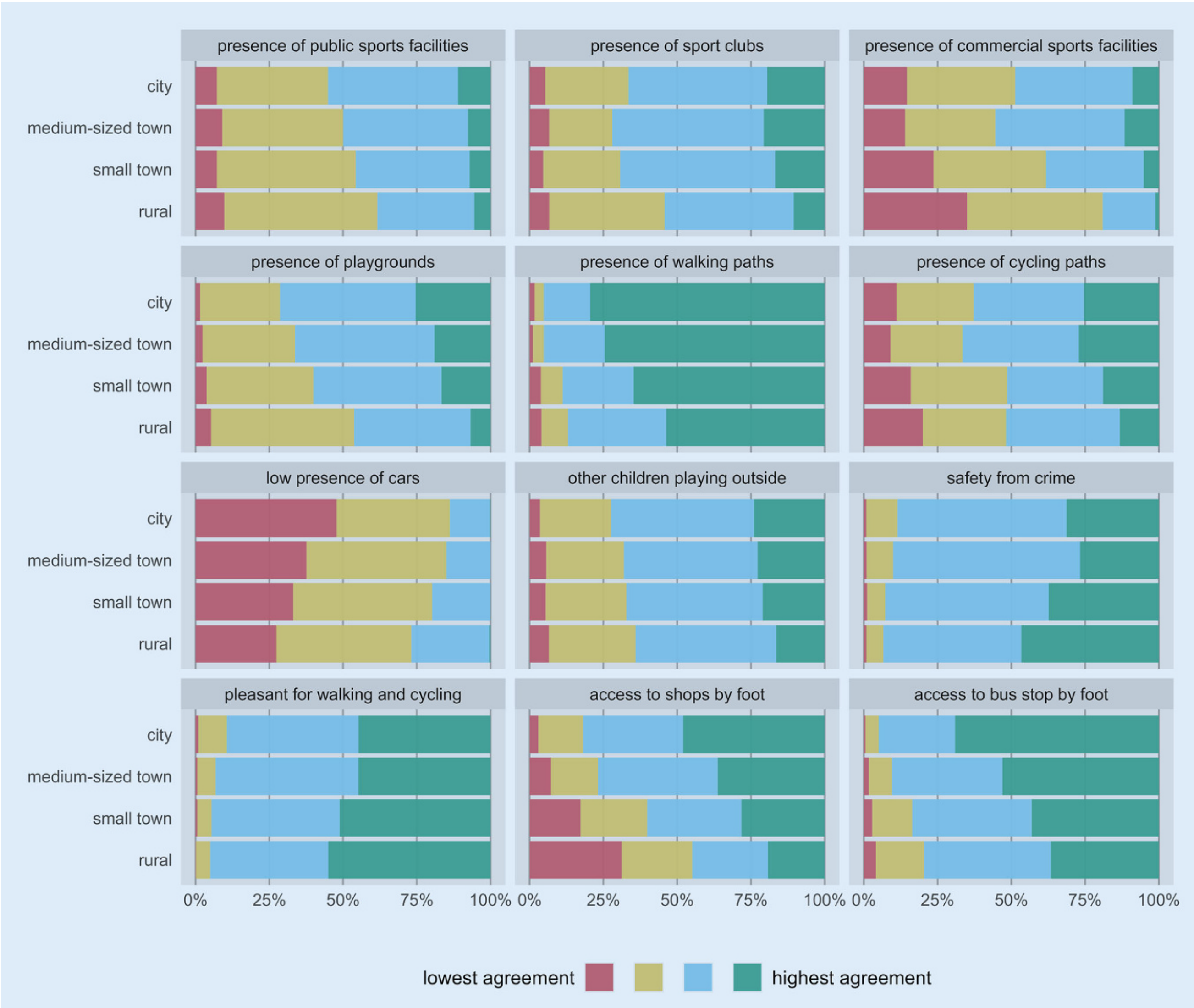

Fig. 2 ▲ Distribution of environment perceptions across urbanicity levels. The item *presence of cars* was reverse-coded for this plot to keep the color scheme consistent (*red* = less PA-friendly neighborhood, *green* = more PA-friendly neighborhood). Data used for this plot can be found in Supplementary Table 2.

for adolescents' AT and thus offer great potential for PA promotion both in rural areas and cities.

Other relationships between perceived environment characteristics and AT are more context-specific and are limited to either walking or NMV use and or specific urbanicity levels. When comparing the relationships between environmental perceptions and walking and NMV use, there were less significant correlates for walking and there was little to no overlap in relevant environment characteristics.

Diverse infrastructure needs and traffic safety concerns for walking and NMV use

Walking and NMV use rely on different road infrastructures, which raise different (traffic) safety concerns. While the perceived presence of walking paths was very high in our study, the presence of cycling paths was rather low indicating a mismatch in infrastructure support for different AT modes (Pucher & Buehler, 2010). Traffic safety is an important factor for AT (Klos et al., 2023) and given the lower infrastructure support, this was a higher concern for NMV users. For example, adolescents in New Zealand perceive cycling to be less safe than walking and also report less sufficient infrastructure for cycling on their way to school (Mandic et al., 2017; Rahman, Moore, & Mandic, 2022). Other NMVs such as skateboards or inline skates have specific needs such as a smooth surface (Platt & Rybarczyk, 2021), requiring more demanding infrastructure to be considered as a means of transport. Thus, infrastructure and traffic safety-related aspects such as having cycle paths, low presence of cars, and living in a neighborhood that is pleasant for walking and cycling are more important for NMV use than for walk-

Table 2 Results of the cumulative link mixed models predicting walking across urbanicity levels

	Rural			Small town			Medium-sized town			City		
Predictors	**OR**	**95% CI**	***P***	**OR**	**95% CI**	***p***	**OR**	**95% CI**	***p***	**OR**	**95% CI**	***p***
Age	1.15	1.07; 1.23	**< 0.001**	1.19	1.13; 1.26	**< 0.001**	1.12	1.06; 1.19	**< 0.001**	1.11	1.04; 1.19	**0.003**
Gender: female (Ref. male)	0.77	0.59; 1.01	0.056	1.08	0.89; 1.33	0.430	1.02	0.82; 1.27	0.845	0.83	0.62; 1.09	0.182
Measurement wave: wave 3 (Ref. wave 2)	1.40	1.03; 1.90	**0.032**	1.20	0.94; 1.54	0.144	1.14	0.87; 1.48	0.342	1.14	0.84; 1.56	0.400
Socioeconomic status	1.06	1.02; 1.11	**0.002**	1.00	0.97; 1.03	0.889	0.97	0.94; 1.00	**0.029**	1.01	0.97; 1.05	0.689
Presence of public sports facilities	1.29	1.03; 1.61	**0.025**	1.17	0.98; 1.39	0.076	1.32	1.11; 1.58	**0.002**	1.13	0.90; 1.41	0.292
Presence of sport clubs	0.97	0.77; 1.22	0.781	1.01	0.85; 1.20	0.930	1.12	0.94; 1.34	0.198	0.84	0.67; 1.05	0.122
Presence of commercial sports facilities	1.00	0.80; 1.24	0.978	0.92	0.79; 1.06	0.250	0.87	0.75; 1.02	0.097	1.13	0.92; 1.38	0.253
Presence of playgrounds	1.23	0.99; 1.53	0.057	1.10	0.93; 1.30	0.259	1.28	1.07; 1.54	**0.006**	0.96	0.77; 1.18	0.682
Presence of walking paths	1.05	0.87; 1.26	0.637	0.85	0.73; 1.00	0.051	1.07	0.87; 1.31	0.529	0.97	0.74; 1.26	0.796
Presence of cycling paths	1.30	1.11; 1.52	**0.001**	1.05	0.94; 1.18	0.377	0.90	0.79; 1.04	0.149	1.06	0.89; 1.25	0.531
Presence of cars	0.81	0.67; 0.97	**0.026**	0.96	0.83; 1.11	0.605	0.99	0.84; 1.18	0.936	1.00	0.81; 1.24	0.964
Other children playing outside	1.06	0.88; 1.27	0.547	1.12	0.97; 1.29	0.117	1.05	0.90; 1.22	0.554	0.95	0.77; 1.17	0.622
Safety from crime	1.08	0.87; 1.35	0.472	1.00	0.84; 1.18	0.964	0.84	0.69; 1.02	0.082	1.04	0.82; 1.32	0.734
Pleasant for walking and cycling	0.97	0.76; 1.23	0.775	1.08	0.90; 1.29	0.425	1.11	0.92; 1.34	0.279	0.87	0.70; 1.08	0.212
Access to bus stop by foot	0.88	0.73; 1.06	0.190	1.04	0.90; 1.20	0.559	0.93	0.79; 1.11	0.440	0.79	0.60; 1.05	0.105
Access to shops by foot	0.95	0.83; 1.09	0.500	0.99	0.88; 1.11	0.835	1.04	0.91; 1.19	0.587	1.26	1.02; 1.55	**0.029**
Random effects												
σ^2	3.29			3.29			3.29			3.29		
τ_{00}	0.02			0.03			0.14			0.18		
ICC	0.01			0.01			0.04			0.05		
$N_{\text{sample points}}$	48			65			63			39		
Observations	800			1323			1136			717		
Marginal R^2/Conditional R^2	0.111/0.116			0.048/0.056			0.059/0.096			0.036/0.085		

OR odds ratio, *CI* confidence interval (format: lower limit; upper limit), σ^2 residual variance, τ_{00} variance between sample points, *ICC* intraclass correlation coefficients

ing. In summary, adolescents use different environmental perceptions for their decision-making on whether to walk or use NMVs and therefore different active transport behaviors should be considered separately. Given the higher safety requirements for cyclists, a stronger emphasis should be put on safe infrastructure for cyclists while also considering the needs of other NMV users, which often is not appropriately addressed both in research and urban planning (Cook et al., 2022).

Factors influencing travel mode choices: proximity, distance, and competing alternatives

Walking is the slowest travel mode, meaning that in most cases only destinations in direct proximity are reached by foot while for more distant destinations, adolescents might use the bicycle (Mandic et al., 2023). For example, in Belgian older adolescents, distances up to 2 km are considered feasible to walk to school while feasible cycling distances are up to 8 km (van Dyck et al., 2010). However, for longer distances, public transport might compete with cycling as a more convenient alternative (Simons et al., 2013) This supports the results of our study, with having access to bus stops being related to less NMV use in small towns. The decision to walk or use NMVs is determined not only by distance and the perceived environment but also by the type of destination and available alternatives (Marzi et al., 2023), While our study cannot provide context on frequency, distance, and destination of trips, other studies such as the ARRIVE study (Reimers et al., 2022) can provide more details on the decision-making process for walking and cycling trips in adolescents in the future.

Associations between urbanicity, active transport, and environmental perceptions

There are some differences in associations between urbanicity levels. Few studies have assessed associations between perceptions of the environment and AT in rural areas and few relationships have been found (Hofer-Fischanger, Grasser, & van Poppel, 2022; Kamargianni & Polydoropoulou, 2014). Both studies, conducted in Greece and Austria, report that having a well-maintained and safe walking and cycling network is related to AT in rural areas. Similar results were found in our study, with the presence of cycling paths being related to both walking and NMV use and having a pleasant neigh-

Table 3 Results of the cumulative link mixed model predicting NMV use across urbanicity levels

	Rural			Small town			Medium-sized town			City		
Predictors	**OR**	**95% CI**	***p***	**OR**	**95% CI**	***p***	**OR**	**95% CI**	***p***	**OR**	**95% CI**	***p***
Age	0.87	0.81; 0.93	**< 0.001**	0.87	0.83; 0.92	**< 0.001**	1.02	0.97; 1.08	0.457	0.99	0.92; 1.06	0.703
Gender: female (Ref. male)	0.45	0.35; 0.59	**< 0.001**	0.47	0.39; 0.58	**< 0.001**	0.67	0.54; 0.83	**< 0.001**	0.71	0.54; 0.94	**0.017**
Measurement wave: wave 3 (Ref. wave 2)	0.89	0.65; 1.23	0.485	0.79	0.60; 1.03	0.084	0.83	0.63; 1.09	0.172	0.99	0.73; 1.35	0.957
Socioeconomic status	0.97	0.93; 1.01	0.135	1.00	0.97; 1.03	0.788	1.04	1.01; 1.07	**0.012**	1.04	1.00; 1.08	0.081
Presence of public sports facilities	1.33	1.07; 1.66	**0.012**	1.23	1.03; 1.46	**0.020**	1.00	0.84; 1.20	0.990	1.33	1.07; 1.67	**0.011**
Presence of sport clubs	0.99	0.79; 1.24	0.957	1.11	0.93; 1.32	0.232	1.11	0.93; 1.33	0.234	1.13	0.90; 1.42	0.297
Presence of commercial sports facilities	0.87	0.70; 1.09	0.223	1.10	0.94; 1.28	0.230	0.96	0.82; 1.13	0.662	0.97	0.79; 1.18	0.742
Presence of playgrounds	1.13	0.90; 1.42	0.278	0.87	0.73; 1.03	0.112	0.99	0.83; 1.19	0.932	0.95	0.77; 1.18	0.654
Presence of walking paths	1.02	0.84; 1.23	0.858	0.99	0.85; 1.17	0.941	0.94	0.76; 1.16	0.557	1.06	0.81; 1.39	0.655
Presence of cycling paths	1.29	1.10; 1.51	**0.002**	1.11	0.98; 1.25	0.094	1.29	1.13; 1.48	**< 0.001**	1.13	0.95; 1.34	0.156
Presence of cars	1.03	0.85; 1.24	0.778	1.10	0.95; 1.28	0.183	0.83	0.71; 0.99	**0.034**	0.80	0.64; 0.99	**0.037**
Other children playing outside	0.97	0.81; 1.17	0.785	1.12	0.97; 1.29	0.108	1.09	0.93; 1.28	0.273	1.00	0.81; 1.24	0.983
Safety from crime	0.86	0.69; 1.07	0.164	1.02	0.86; 1.21	0.830	1.07	0.88; 1.30	0.472	0.91	0.72; 1.15	0.415
Pleasant for walking and cycling	1.29	1.02; 1.64	**0.037**	1.26	1.05; 1.51	**0.015**	0.91	0.75; 1.10	0.325	1.12	0.89; 1.40	0.349
Access to bus stop by foot	0.84	0.70; 1.02	0.072	0.80	0.69; 0.92	**0.002**	0.94	0.80; 1.12	0.504	0.81	0.62; 1.07	0.133
Access to shops by foot	1.16	1.01; 1.34	**0.037**	1.15	1.02; 1.29	**0.021**	0.97	0.84; 1.11	0.627	1.06	0.86; 1.31	0.558
Random effects												
σ^2	3.29			3.29			3.29			3.29		
τ_{00}	0.28			0.39			0.40			0.50		
ICC	0.08			0.11			0.11			0.13		
$N_{\text{sample points}}$	48			65			63			39		
Observations	800			1323			1136			717		
Marginal R^2/Conditional R^2	0.115/0.183			0.090/0.188			0.044/0.148			0.056/0.181		

OR odds ratio, *CI* confidence interval (format: lower limit; upper limit), σ^2 residual variance, τ_{00} variance between sample points, *ICC* intraclass correlation coefficients

borhood for walking and cycling being related to NMV use only. However, for medium-sized towns and cities, it is not the pleasantness of walking and cycling that is associated with NMV use but the lower presence of cars. Thus, in rural areas, a lack of well-maintained and safe walking and cycling networks might limit NMV use. By contrast, in more urban areas, heavy car traffic may be the main problem. Therefore, decreasing car traffic volume and enhancing infrastructure for NMVs are important measures for AT promotion (Benoit et al., 2022).

Variability in NMV use: regional factors and implications for policy and research

Finally, NMV use differs considerably across sample points in contrast to walking, where almost no variance between sample points was found. Even when accounting for urbanicity level, sociodemographic factors, and environmental perceptions the sample points explain between 8% and 13% of the variance in the NMV use models. Although cycling for transport has gained popularity in Germany over the past few decades, especially in cities (Hudde, 2022), there are large differences between cities regarding the friendliness of cycling (Klinger, Kenworthy, & Lanzendorf, 2013). While there were few perceptions directly related to cycling, there might be other region-specific (environmental) features that impact NMV use that were not measured in this study. Exploring characteristics of specific cities or towns with the highest and lowest NMV use could help to understand those differences, e.g., by looking at local cycling-related policies. This would make it possible to identify "cycling cities" or "cycling towns" to find good practice examples for public health advocates, policymakers, and transport planners. In research, large-scale, representative studies are needed to further analyze the differences in NMV use across regions while also incorporating more comprehensive measures of the perceived environment, objective measures of the built environment, and topography.

Creating sustainable cities and communities built for AT can create local social and economic benefits and improve the health well-being of residents (Nigg & Nigg, 2021). On a global scale, AT contributes to planetary health by reducing greenhouse gas emissions. The transport sector in Europe contributes to over one fourth of the CO_2 emissions, which have been steadily growing over recent decades despite increasing effort to reduce them (European Environment

Agency, 2022), highlighting the need for more decisive actions. Therefore, it is important to bring together the disciplines of sports and exercise science, public health, transport planning, and urban planning to create sustainable and safe environments for AT (Koszowski et al., 2019). Transdisciplinary research focusing on a bottom–up approach to create sustainable and physical activity-friendly neighborhoods can best account for the local context (Wäsche, Beecroft, Trenks, Seebacher, & Parodi, 2021).

Strengths and weaknesses

This study is the first nationwide study in Germany focusing on the relationship between perceived environment and walking and NMV use in adolescents. Given the representative sampling in 167 points across Germany, we were able to present reliable cross-sectional data across different urbanicity levels pooled across two measurement waves.

Whereas most studies on active transport focus on walking and cycling only (Cook et al., 2022), we summarized bicycles and other NMVs such as skateboarding or inline-skating into one category—acknowledging transport niches or trends. Although we were able to also include other modes of NMV, we were not able to differentiate further how many of the NMV users were not cycling. While the environment questionnaire is reliable, more comprehensive questionnaires (e.g., ALPHA environment questionnaire; Spittaels et al., 2009) would facilitate a more thorough assessment of the environment perceptions. An analysis based on subscales rather than single items would have led to more generalizable results but was not possible due to opposing relationships with walking and NMV use within scales. Parents' perceptions also play a significant role in adolescents' travel choices (Klos et al., 2023; Mandic et al., 2020; Panter et al., 2008). However, those were not assessed in MoMo.

Cumulative link mixed models were chosen as they effectively accommodated the non-linear characteristics of the outcome variables while simultaneously considering the ordinal structure. The majority of variables in each model satisfied the parallel odds assumption, with only a few exceptions potentially leading to a few slightly less precise estimates. Compared to alternative approaches such as collapsing categories for binary logistic regression or employing (unordered) multinomial logistic regression, these models provided a superior solution that acknowledged the complex nature of the data without sacrificing interpretability.

It also needs to be acknowledged that this was a cross-sectional study, and no causal relationships between environment perceptions and walking or NMV use can be assessed. Finally, the urbanicity measure was merely based on population size. While this measure, as the political community size system allows, facilitates communication to policymakers, other urbanicity measures that do not only account for population size but also take the geographic context into account (e.g., population density or the European Degree of Urbanization) may be more suitable in the research context.

Conclusion

Promoting walking and use of non-motorized vehicles (NMV) can improve individual health and well-being, helps to create sustainable cities and communities, and contributes to climate action. In this representative, nationwide study, we showed that different environmental perceptions relate to walking and NMV use. These relationships differ across travel modes and urbanicity levels, highlighting the complex nature between the perceived environment and active transport. Based on these findings, public sports facilities or shops in proximity to adolescents' homes, and providing safe infrastructure for NMVs such as bikes, skateboards, and inline skates, should be the main goals for public health advocates and urban/traffic planners while keeping local conditions in mind. In research, more nationwide or representative studies are needed to validate our findings and to further explore differences in regional contexts.

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Declarations

Conflict of interest. L. Klos, J. Fiedler, C. Nigg, C. Niessner, H. Wäsche and A. Woll declare that they have no competing interests.

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