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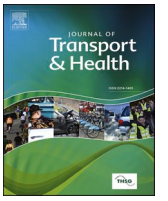

Children's active mobility, physical activity and well-being

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ABSTRACT

Introduction: Globally, children are experiencing declining rates of physical activity, which is mirrored by a reduction in active mobility. While physical activity is generally associated with enhanced psychological well-being, the specific relationship between active mobility, physical activity, and well-being in children remains underexplored.

Methods: This study explored the relationship between active mobility, physical activity, and well-being among children, addressing the critical issue of declining physical activity levels among youth. A sample of 75 Austrian children aged 12–14 participated in the study. Using a travel-and-mobility diary over seven consecutive days, we collected data on both active mobility and physical activity to assess their effects on well-being.

Results: The study reveals that active mobility - particularly undirected walking and cycling - positively impacts children's well-being. However, these forms of activity were relatively infrequent among participants. Physical activity, especially in the form of strenuous exercise, was also linked to higher levels of well-being. Using ordinary and mixed linear models with random intercepts, we differentiated between short-term and long-term effects. It turns out that active mobility had immediate day-to-day benefits, but its overall impact was modest due to its low frequency. Conversely, regular cycling was associated with a higher baseline level of well-being, indicating more long-term benefits.

Conclusions: These findings highlight the importance of both active mobility and physical activity for enhancing children's well-being and suggest that promoting diverse forms of physical engagement could be beneficial. Further research is required to explore the long-term effects and underlying mechanisms of these relationships.

1. Introduction

1.1. Starting point

Declining rates of physical activity among children are reported all over the world. Recent systematic analyses from 168 countries show that the prevalence of insufficient physical activity has increased in high-income countries (Guthold et al., 2018). In particular, younger age groups are not engaging in enough physical activity, which raises concerns about long-term health effects. According to the World Health Organization (WHO), 83 % of schoolchildren in Austria do not meet the recommendations for health-promoting

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physical activity levels (Maier et al., 2017). This is consistent with global estimates, based on 2010 figures, that 81 % of adolescents (aged 11–17 years) do not fulfill the recommendations either (WHO, 2018). Moreover, physical activity tends to decline further, as children grow older (Ramelow et al., 2015; Riddoch et al., 2004).

Reasons for a reduction in physical activity among children and young people are partly attributed to shifting leisure behaviors, with more time spent in front of tablets, smartphones, computers, etc. (WHO, 2016). Additionally, increasing academic demands contribute to a high time commitment, leaving less opportunity for movement (ibid). Adolescents aged 14–19 years spend most of the day (70 %) sitting and lying down (Knechtsberger and Schwabl, 2016). A recent study (2021) shows that about half of students spend at least 5 h a day on their smartphones - a doubling compared to 2018 (Pieh et al., 2021). The COVID-19 pandemic further exacerbated these trends: restrictions of leisure opportunities and regular exercise in school physical education classes led to changes in leisure behavior, for example an increase smartphones use (ibid.), while physical activity (PA) decreased: Meta-analyses have shown a significant reduction in PA during the pandemic compared to before, with decreases ranging from −11 min/day to −91 min/day (Rossi et al., 2021), or by −20 % Neville et al. (2022). However, some positive trends regarding regular exercise and sport have been observed in Austria after the pandemic, possibly as a compensation effect for the reduced activity levels (Felder-Puig, 2023). Nonetheless, it remains uncertain whether this recovery will be sustained or if it is merely a short-term recovery from the lockdown period. The overall trends of decreasing physical activity are also reflected in shifting mobility patterns: In Austria, the share of student trips on foot decreased from 35 % to 25 % between 1995 and 2014, while they are more often driven by car (from 17 % to 25 %) (Tomschy et al., 2016). Alongside this, research indicates a decline in independent mobility (Shaw et al., 2015; Mitra, 2013), despite the fact that children perceive their neighborhood positively and express a desire to active outdoors (Babb et al., 2017).

Alarmingly, the proportion of students with overweight or obesity has been steadily rising since 2014 (Felder-Puig, 2023). Additionally, an Austrian study of more than 1700 adolescents and young adults aged 14 to 29 found that only 35 % of adolescents reported no physical complaints (Knechtsberger and Schwabl, 2016). Studies show also a sharp increase in psychological symptoms among children and adolescents in Austria, a trend that was further aggravated by the COVID-19 pandemic. During the pandemic, the incidence of depressive symptoms and sleep disorders has increased five-to tenfold compared to previous studies (Pieh et al., 2021).

An online survey conducted in Austria in 2021 with 800 people aged between 14 and 24 has shown that the number of young people with mental health problems quadrupled since 2011 (Vrignaud and Anzinger, 2021). According to this study, many factors that negatively impact mental health have increased, in some cases significantly, since 2017. There has also been a continuous decline in life satisfaction among older students since 2014 (Felder-Puig, 2023). In the school year 2021/2022, 31 % of girls and 19 % of boys in Austria reported low life satisfaction (ibid). The Federal Ministry of Social Affairs, Health, Care and Consumer Protection attributes a gradual deterioration of mental health of Austrian adolescents over the last decade due to both individual factors and environmental conditions – particularly those in which young people spend most of their time (BMSGPK, 2023).

Beyond immediate concerns in terms of health, it should be noted that the extent of active mobility in childhood may have important consequences for the formation of transport-specific attitudes and transport use later in life (Baslington, 2008; Bastian, 2010). In view of the entire life biography, a car-oriented childhood could lead to children adopting these habits as adults (Haustein et al., 2009). This would be accompanied by further negative effects in terms of health, traffic safety, and environment.

Altogether, these developments underscore the need for further research into the relationships between mobility behavior, physical activity, and well-being in young age groups.

1.2. Active mobility and well-being

Not only low physical activity through training and sport (e.g. Biddle and Asare, 2011), but also low levels of active mobility in young people's everyday lives is thought to negatively impact children's physical, psychological, cognitive, social, and economic well-being ("five domains of well-being", see Waygood et al., 2020, 2015); however, the mechanisms behind these associations have not been adequately explored (Westman et al., 2020). In particular, research in the psychological domain is limited. Westman et al. (2020) identified five groups of psychological measures in studies of the psychological domain of child well-being and travel: (i) mood (feelings, emotions as a consequence of travel), (ii) travel satisfaction (in relation to the journey like stress, excitement), (iii) confidence (child's sense of having the ability to use different travel modes), (iv) independency (child's sense of being independent), and (v) well-being. The latter involves positive feelings, pleasure, happiness, and the extent to which a person is satisfied with his or her life in general (ibid., Bergstad et al., 2011; Bullinger, 2009). This understanding aligns with Kahneman's (1999) framework, which distinguishes between "experienced well-being", referring to moment-to-moment emotions, and "evaluative well-being", which reflects overall life satisfaction and fulfilment.

Research on adults suggests that people who use active transportation tend to be happier and more satisfied (De Vos et al., 2013; De Vos, 2019). For instance, cyclists rate their physical and mental health better than drivers; pedestrians report more social contact (Avila-Palencia et al., 2018). Moreover, people who switch from car to active travel report higher levels of subjective well-being after the switch (Ettema et al., 2016).

While most studies have primarily focused on adults (Friman et al., 2018), particularly in the context of commuting (Waygood et al., 2019), emerging research suggests that children may experience similar benefits from active travel (Waygood et al., 2017; Stark et al., 2018; Waygood and Cervesato, 2017). For example, Ramanathan et al. (2014) show that active mobility among primary school children in Canada is linked to more positive emotions versus passive travelers. A study on primary school children in Sydney highlights that children associate walking (in contrast to car travel) with joyable experiences on their school trips (Romero, 2015). These positive affective experiences during school travel may also contribute to an overall higher activation during the school day (Westman et al., 2013) and may have a positive impact on academic performance (Westman et al., 2017). This aligns with the

hypothesis that mobility-related well-being, as a dimension of children's overall well-being, likely influences their overall life satisfaction (Khaleghi & Kato, 2023). In their study in Hong Leung and Loo (2017) highlight for primary school children engaging in active transport an impact of their mobility-specific momentary well-being on overall well-being, in particular life satisfaction. A study in Canada, Japan, and Sweden explored how travel satisfaction influences life satisfaction among children aged 9 to 12 (Waygood et al., 2019). The findings indicate that higher travel satisfaction is associated with increased life satisfaction, demonstrating a moderate connection between the two. Similar results were reported by Khaleghi and Kato (2023), who found a significant positive association between travel-related well-being (moods, emotion during a trip) and life satisfaction with five domains (self, school, friends, family, living environment). Unlike many other studies, Khaleghi and Kato (2023) focused on non-school trips of 12 to 15-years-old adolescents (rather than primary school children) living in rural areas in Japan. Data from Austria is scarce. One study examined the link between primary school children's travel modes on school trips and psychological well-being (Stark et al., 2018). They found that active school travel was positively associated with wellbeing. In another study, children from three primary and two secondary schools in Vienna reported their mood and alertness during and after school trips, along with their travel modes, preferences, and attitudes (Stark et al., 2019). It revealed a weak positive association between active travel and well-being.

Providing stronger evidence of the benefits of active mobility on children's well-being could encourage parents to support and promote more active travel behaviors. However, obtaining reliable data on this topic presents a significant methodological challenge. This is largely due to the wide range of well-being and quality-of-life measures used across disciplines such as social sciences and medicine (Salvador-Carulla et al., 2014), each employing different scales and questionnaires. Examples of these include EuroQOL (Kreimeier et al., 2019), WHOQOL (WHOQOL-Group, 1993), the Inventory of Life Quality (ILK) (Mattejat and Remschmidt, 1998), KINDL-R (Ravens-Sieberer, 2003), the Scale of Positive and Negative Experience (SPANE) (Diener et al., 2009), and the Positive and Negative Affect Schedule (PANAS) (Breyer & Bluemke, 2016; Watson et al., 1988).

One well-established instrument for assessing health-related quality of life (HRQoL) in children and adolescents is KIDSCREEN (Ravens-Sieberer et al., 2014). Designed for individuals aged 8 to 18, it conceptualizes quality of life as a multidimensional construct that encompasses physical, emotional, mental, social, and behavioral aspects of well-being. It is available in multiple versions, including 52, 27, and 10-item formats, to provide flexibility depending on research or clinical needs. The blocks of questions cover the topics: (1) Your health & exercise, (2) Feelings, (3) Moods, (4) How do you feel about yourself, (5) Leisure time, (6) Family & home, (7) Your money, (8) Friends, (9) School & learning, and (10) You and others (The Kidscreen Group Europe, 2006). The questions refer to the last week in retrospect. The instrument has been validated internationally, making it a valuable tool for cross-cultural comparisons.

Although quality of life (QoL) is influenced by both physical and psychological conditions, it extends beyond individual well-being or ill-being (Kiss et al., 2024). In their meta-study, Pinto et al. (2017) identify overlapping attributes between the concepts of well-being and quality of life, such as multidimensionality, interpersonal relationships, and happiness. However, distinctions also exist: While well-being emphasizes aspects like happiness and energy, QoL is more commonly associated with factors such as personal development, empowerment, independence, dignity, and the achievement of goals and aspirations (ibid.). Given these conceptual distinctions, our study does not focus on broad, generalized perceptions of life satisfaction. Instead, we specifically examine psychological well-being at a daily level, while maintaining a multidimensional perspective.

We summarize that, despite the growing body of research on travel-related well-being, significant gaps remain - particularly in view of children and adolescents. While studies suggest that active mobility may positively influence children's well-being, most existing research focuses on school trips and primary school-aged children, leaving a lack of understanding about other forms of daily mobility and older age groups. Additionally, many studies related to well-being and travel of children focus on travel satisfaction rather than the psychological dimensions of well-being in relation to daily mobility behavior. In our study, we aim to provide a daily, accumulated perspective, situated between ad-hoc effects of travel on well-being and effects on overall life satisfaction. Specifically, we take a multidimensional perspective on how children feel in their daily lives, encompassing aspects like mood, stress levels, energy, satisfaction with daily activities, and how they experience their environment during their regular routines (e.g., travel, school, hobbies, and social interactions). To achieve this, we conduct a diary-based survey and create a questionnaire in collaboration with children based on existing concepts of travel-related well-being and quality of life measures. By examining both structured exercise and sports as well as transport activities like walking and cycling, we aim to provide a nuanced understanding of how these factors contribute to well-being on a day-to-day basis.

1.3. Objective and innovation

This paper is based on the project "*TRA:WELL* – transport and well-being" (2022–2024), a national research project funded by the Austrian Federal Ministry of Education, Science and Research. The paper relates to the project's main objective, namely, to explore how active mobility (complementary to physical activity) is related to children's well-being. The data was provided by a survey among 12–14 years old children in 2023. The key innovation of this paper is its empirical rigor in two respects: (i) active mobility, physical activity and well-being were measured repeatedly on seven consecutive days, which yields a panel data structure and enables the use of a mixed linear mixed with individual-specific intercept; and (ii) active mobility and physical activity were measured by means of a diary, in which the realized behavior was reported retrospectively on a daily basis. Both innovations allow for a stronger test of the aforementioned relationships compared to studies, which ask the individuals only once for subjective self-assessments of their generalized behavior. The paper is structured as follows: Section 2 describes data and methods. Section 3 presents the results of the descriptive-explorative analysis and the models. Section 4 closes with a discussion of key findings, strengths, and limitations. Section 5 provides conclusions and an outlook.

2. Data and methods

2.1. Sample and study design

Our sample includes 75 children in the 6th and 7th grade of three classes of three different secondary schools of a comparable type. School A and B are located in the densely built 19th district of Vienna, Austria; it is very well accessible with metro, tram and bus. School C is in Korneuburg, a small town of 14,000 inhabitants in the suburban region north of Vienna with a large catchment area; the school is located about 1.4 km from the railway station and accessible by several school busses. The city of Korneuburg is served by a city bus (mainly weekday), single regional bus lines serve the wider area. Data was collected in April and May 2023 by means of an online-survey as described in the following section.

2.2. Questionnaire

2.2.1. Development

The first draft of the questionnaire was based on the KONTIV[1] design (Brög et al., 1983). This concept provides for the collection of household characteristics including mobility tools, socio-demographic characteristics of target persons, as well as their travel behavior. The latter is collected for a predefined reporting day (Hautzinger, 1998) in the form of a diary, in which each trip of the day is reported along with several attributes including start and end point, purpose, etc. As part of an earlier project on travel behavior of adolescents, this original questionnaire concept was taken up and modified for the use of a travel diary for a paper-and-pencil survey (see Stark et al., 2015); it formed the starting point for the development of the survey instrument in this study (Fig. 1). According to our research question, we extended the travel diary by further sections related to the children's physical activity and subjective well-being. Part of the project idea was to involve the children in the development of the survey instrument. Therefore, we presented the draft questionnaire to the children in workshops. The main task - to be carried out in small groups of 3–5 children - was to review the questionnaire; children contributed their ideas to the design, comprehensibility of questions and answer options, and completeness. Options for reporting physical activity at different intensity levels, including examples and scales, were also discussed (see Stark et al.). In a second step, the children's ideas and suggested modifications were summarized and discussed by the project team. The revised questionnaire was subject to a cognitive pretest with four children from the research team's environment, in which we discussed the wording of key questions, e.g. the description of trip purposes and activities. The teachers also commented on the questionnaire.

Another important task in workshops with the children was to capture how children define well-being and which dimensions matter to them. In doing so, pupils were invited to reflect on questions such as 'What is well-being for you? What do you associate with it? Find a definition that suits you.' and 'What influences your well-being?'. The children worked individually and then categorized dimensions of well-being together. In addition, a paper-and-pencil questionnaire was used to determine how important certain influencing factors are for their subjective well-being. The associations and definitions of well-being recorded in the workshops were subject to a deductive-inductive analysis approach to form categories (Gläser and Laudel, 2010) (Annex, Figure A-1). The results show that subjective well-being is perceived as a complex topic by this age group. Aspects that can be assigned to the topic of social interactions (home, family, friends) are named frequently. Well-being is also often associated with certain feelings and moods (e.g. freedom, trust), but also with activities that are largely practiced in leisure time (e.g. mountain biking, tennis). The topics 'eating' and 'sleeping' were conspicuously present while material aspects were less present. Based on the children's assessments, the most frequently mentioned associations, such as 'family and home', also have the strongest (positive or negative) influence on their well-being.

Based on the workshop results, we decided to include thirteen well-being aspects in the questionnaire. These dimensions largely coincide with those in the KIDSCREEN questionnaire (The KIDSCREEN Group Europe, 2006; Ravens-Sieberer et al., 2005 & 2014). However, unlike KIDSCREEN, we incorporated categories such as social media, interactions with other people, and food (see section 2.2.2), while excluding bullying and financial resources, as these were rarely mentioned. It is worth noting that KIDSCREEN assesses quality of life from a broader perspective ('if you think about last week'), rather than a daily level. Additionally, we use a uniform introductory question and consistent scale for most of the well-being dimensions to keep the question block simple and quick to complete.

The final questionnaire was implemented online. It was hosted on a LAMP stack server with a java-based backend (Tomcat9) and the 'Angular' web framework as frontend. The field phase started with another workshop, in which the children were enrolled for the online questionnaire, which they filled in afterwards for seven consecutive days independently every evening. The research team checked the data on a daily basis and provided intensive online and in-school support, for example, to find the correct addresses of travel destinations. Such intensive cooperation was only possible because the three schools were partners in the project and provided lessons for supervision of the pupils.

2.2.2. Content

The questionnaire consisted of a person and a household section to be filled in only once, as well as a diary-like section to be filled repeatedly for seven consecutive days. The *person and household section* was divided into three subsections: (i) me and my home, (ii) my

[1] KONTIV stands for 'Continuous Survey of Traffic Behaviour', which was first carried out in West Germany in 1975/76.

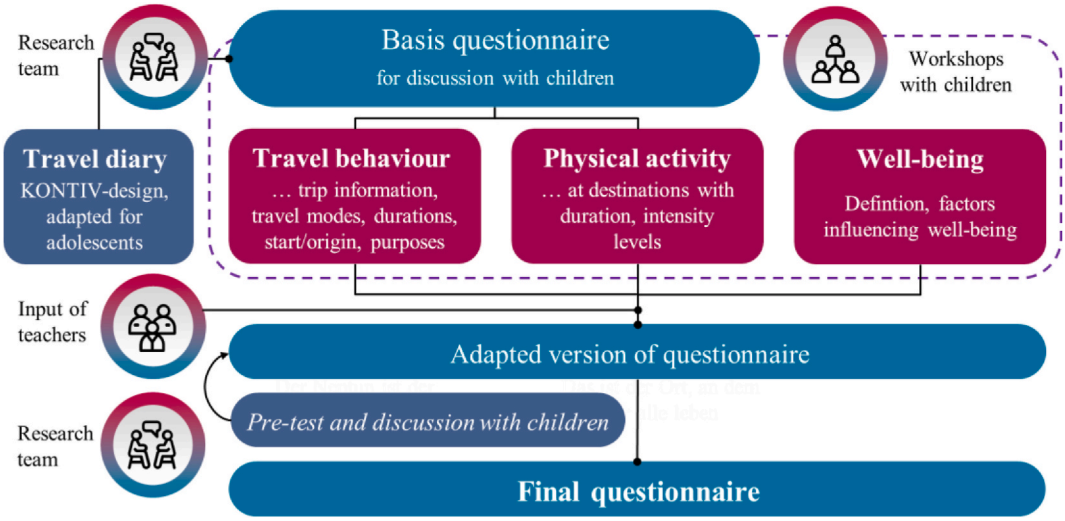

Fig. 1. Development of the survey instrument in a participatory process.

mobility tools, and (iii) my health. In the *diary section*, we asked what time the child got up, if it was out of home on that day, what it did until it started the first trip and how strenuous these activities were according to three intensity levels *[very exhausting, a little exhausting, not exhausting]* according to FGÖ (2020) PA-recommendations for Austria.

For each trip, the children reported start and end time, origin and destination address. We also collected undirected trips (same origin and destination address) that are made for the purpose of the trip itself, without a specific destination or where reaching the destination is not the main purpose, e.g. going for a walk or taking the dog for a walk (Stark et al.). Other trip characteristics were weather conditions, who contributed to the choice of travel modes, and which modes were used *[walking, bicycle, scooter, e-scooter/e-bike, public transport, in a car, other]*. For each travel mode, we further asked the duration as well as accompaniment. At each trip destination, we asked for the main activity type (similar to trip purpose) and how much time was spent there, again divided into three activity intensity levels *[high, moderate, low]*. Thus, physical activities encompass not only exercise such as organized training, school sports, but also other active leisure pursuits as well as active household activities (such as gardening).

In addition to the trip section, each reporting day included an 'evening section' with several questions related to well-being: quality of sleep last night and how the child felt physically and mentally today; responses were provided on a five-point scale *[very bad, rather bad, partly-partly, rather good, very good]*. Furthermore, we asked various dimensions of well-being: 'How did you feel today, thinking about': (1) school, (2) family & home, (3) friends, (4) other people, (5) feelings & moods, (6) satisfaction with yourself, appearance, (7) self-determination, (8) Social media: Instagram, Snapchat, TikTok, (9) exercise, sports, (10) food; responses were provided on a five-point scale with labelled endpoints *[very poor - very good]*. Two concluding questions asked if the child had enough time for him/herself and whether this was a typical day *[no, partly-partly, yes]*.

2.3. Data preparation and analysis

During data input, all text addresses of the trip origins and destinations were encoded with GPS coordinates, which served in turn to retrieve the objective trip durations and distances for four travel modes (walking, cycling, transit, car) using online journey planning services (Verkehrsauskunft Österreich, Google Maps directions service). Variables gathered at the trip-level or trip stage-level were aggregated at the person-day level: for each travel mode, we calculated total duration, total distance, time share, and a dummy indicating whether this mode was used on that day; the physical activity variables were treated analogously. This procedure yields a person-day level dataset with panel structure: each row represents a reporting day of a particular respondent, 7 rows each belong to the same respondent.

All following analyses were conducted in R using mainly two packages: the package 'psych' (Revelle, 2020) for the Principal Component Analysis (PCA) and the package 'lme4' (Bates et al., 2015) for the Mixed Linear Model (MLM). In a first step of the analysis, we applied a PCA to our set of well-being variables to in order to explore the underlying latent dimensions of children's well-being. In a second step, we analyzed the effects of active mobility (AM) and physical activity (PA) on children's well-being using two regression approaches: an ordinary linear model (OLM), which assumes the same baseline level of well-being for all respondents (one global intercept), and a mixed linear model (MLM) with random intercept, which respects the panel structure of our data.

The key advantage of the mixed model is that it captures the effects of AM/PA on well-being exclusively on a day-to-day level. These effects can be interpreted as causal effects with high certainty, since the effects of all potential confounders, which do not vary from day to day (socio-demographics, built infrastructure, etc.), are eliminated. A disadvantage, however, is its excessive rigor: The MLM eliminates *all* effects beyond the daily level, including long-term effects of the predictors that we are interested in (i.e., AM and PA). It could be, for example, that regular physical exercise increases the baseline level of well-being on a longer-term scale, so that the

person reports a higher level of well-being even if he or she did not practice on a particular day. Comparing the result of both the ordinary and mixed model allows to decompose the effects of AM and PA on well-being into those, which take place immediately on a day-to-day level, and those which happen on a larger time scale. It should however be noted that the latter effects could be confounded with other variables as mentioned above, which requires a cautious interpretation.

3. Results

3.1. Sample characteristics

Overall, 71 out of 75 children (68 % female) took part in the survey. They reported a total of 1265 trips on 465 reporting days. The number of children is equally distributed across the three sites. The majority (59 %) lives in a flat, 39 % in a single family or terraced house. Most of them (76 %) live with both parents, 21 % only with their mother; 83 % of them have siblings. Please note that the number of reporting days is sufficient for a robust analysis, but the number of children is rather low and some personal characteristics are distributed unbalanced (such as gender), so that interpretations are always in regard to the sampled group.

3.2. Mobility characteristics

The average daily trip frequency is 2.7 per person and 3.0 per mobile person. It corresponds well to the results for the age group 6 to 14 in the latest national travel survey in Austria (2013)/2014 (2.7 and 3.1 trips per person and mobile person, see Tomschy et al., 2016). Fig. 2 shows the modal split of the sample on trip-level, which means that each trip is assigned to a single "main mode" using a common hierarchical allocation scheme (BMVIT, 2011). 36.8 % of trips were actively traveled, which means that the main mode was walking, cycling, scooter, or another non-motorized mode based entirely or partly on muscle power (FGÖ, 2018). Public transport accounts for a similar share (36.1 %).

The modal split also corresponds well to that reported for 6–14 years old children in the latest national travel survey (walking trips 26.0 %, bicycling 9.7 %, public transit 30.2 %, car-passenger 33.8 %; ibid) with the exception of a higher share of public transit and a lower share of car-passengers in our sample. This follows from the over-representation of Vienna, which is well known for its exceptionally high share of public transit users.

3.3. Dimensions of children's well-being

We developed our measurement instrument for well-being based on existing instruments, but we could not use any of them straight away, because we wanted to measure children's short-term well-being on a day-to-day basis. We thus developed a novel instrument in a participatory process with the children as described in section 2.2.1. The dimensionality of this novel instrument was not known from the outset. We identified the dimensions behind the items using a covariance analysis and a principal component analysis (PCA). Based on the covariance analysis, we excluded two items: "social media" and "enough time for yourself"; they correlate only weakly with the 11 remaining items and do not appear to belong to a broader dimension. A PCA with the remaining 11 items revealed a clear preference for two dimensions (2 Eigenvalues >1; the third is 0.82). Model 1 in Table 1 shows the varimax-rotated solution. The item "movement & exercise, sport" shows a particular behavior in this model: It does not preferably load on one component (as all other items) but almost equally on both, which indicates an intermediate position between both dimensions (we also tried a solution with three dimensions but these items was still not clearly assigned). Therefore, we excluded the item "movement & exercise, sport" from the PCA.

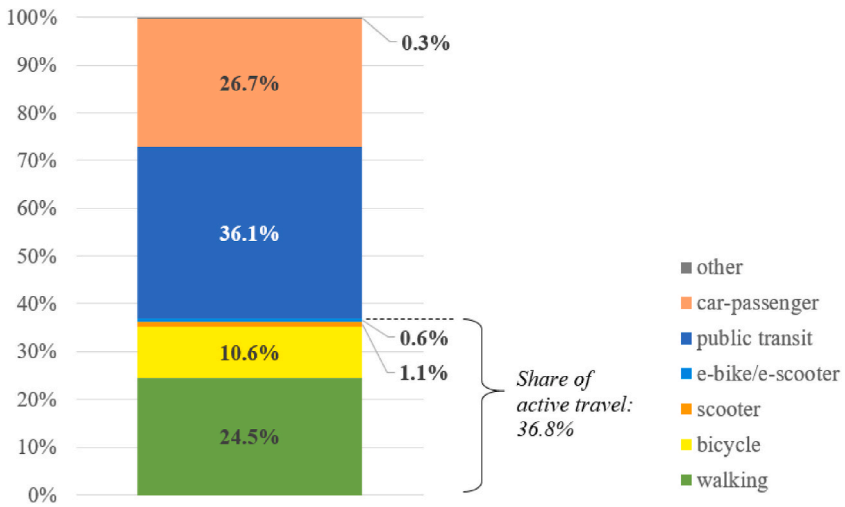

Fig. 2. Modal split, n = 1235 trips.

Table 1
Factor loadings of well-being (WB) items on two dimensions derived from PCA Model 1/2 = with/without variable " WB in relation to movement/exercise, sport" (n = 465).

	Model 1		Model 2	
WB-related variables on reporting day level	PC1	PC2	PC1	PC2
Quality of sleep last night	0.104	0.859	0.111	0.861
How did you feel physically today?	0.178	0.857	0.183	0.853
How did you feel mentally today?	0.396	0.720	0.407	0.731
WB in relation to school	0.636	0.093	0.637	0.083
WB in relation to family and home	0.616	0.336	0.622	0.343
WB in relation to friends	0.654	0.172	0.657	0.172
WB in relation to other people	0.660	0.184	0.663	0.180
WB in relation to your emotions, moods	0.770	0.271	0.773	0.271
WB in relation to satisfaction with yourself, appearance	0.784	0.144	0.789	0.149
WB in relation to your self-determination	0.743	0.222	0.743	0.214
WB in relation to movement/exercise, sport	*0.450*	0.391		
Eigenvalues	3.809	2.471	3.646	2.330
Explained variance	0.346	0.225	0.365	0.233
Cumulative variance	0.571		0.598	

The final model with 10 items and 2 components is shown in Model 2. The 1st component shows high loadings of those 7 items which relate to specific aspects: school, family & home, friends, other people, satisfaction with oneself & appearance, emotions & moods, self-determination. The 2nd component seems to represent an overarching condition with high loadings of sleep quality as well as physical and mental feelings.

3.4. Effects of active mobility and physical activity on children's well-being

An important limitation to be noted upfront is that active mobility (AM) and physical activity (PA) exert a significant effect only on "well-being in relation to movement/exercise, sport". This variable is in turn closely related to the two broad well-being dimensions PC1 and PC2 (see Table 1), but this indirect connection is insufficient to establish a significant direct relationship between AM and PA on the one hand and PC1 and PC2 on the other.

In preparation of the regression models, we developed and tested many different variables for their effect on "well-being in relation to movement/exercise, sport". Table 2 shows which variables resulted from the screening. Particularly many indicator candidates were available for active mobility on the daily level. The travel diary (see section 2.2.1) yields many details for each reported trip, which can in turn be aggregated in different ways to the daily level. For each reporting day and each active travel mode (walking and cycling) we tested whether a trip was made, the number of trips, travel distance, travel time, and time share of the respective mode. We found that walking trips in general are very common but have little effect on children's well-being. Undirected walking trips, which are not made to reach a destination but rather to roam around (see section 2.2.2) are less common but do have an effect. Cycling trips are less frequent overall, here it seems to matter most whether the child has cycled at all on a particular day. For physical activity, there were fewer indicator candidates. We asked the level of physical exertion directly for each activity, so that we did not rely on the type of activity as a proxy (e.g. training), but simply added the times with increased physical activity over the day, regardless of the type (school sports, leisure sports, gardening, etc.). Please note that duration and time share are linearly identical, as each day has 24 h. In the models we use the time share, distinguishing between very exhausting and moderately exhausting activities.

The effects of AM and PA on "WB in relation to movement/exercise, sport" were analyzed at the reporting day level using an ordinary linear model (OLM) and a mixed linear model with random intercept (MLM). The results of both are shown in Table 3.

The OLM with fixed intercept reveals four significant predictors, two of which relate to each of the two domains AM and PA. Three of the four t-values are at similar levels between 3.2 and 3.9: undirected walking trips, cycling trips, and very exhausting activities. It means that the explanatory power of these variables is similar. Moderately exhausting activities (intensity level 2, see section 2.2.2) have a lower effect size and significance than exhausting activities, as one would expect. Another noteworthy aspect is the 'nature' of the predictors: In the case of PA, the time share of activity engagement matters (as expected). In the case of AM, however, the mere engagement (yes or no) matters more than the duration. A possible reason are the different distributions: undirected walking trips and

Table 2
Variables obtained from the screening for the regression models.

Variable	Description (daily level)	Scale	
Wellbeing	WB related to movement/exercise, sport	[1 to 5]	linear
Active mobility	undirected walking trip(s) performed	[0; 1]	dummy
	cycling trip(s) performed	[0; 1]	dummy
Physical activity	time share of very exhausting activities[a]	[0 to 1]	linear
	time share of moderately exhausting activities[b]	[0 to 1]	linear

[a] PA with high level of intensity.
[b] PA with moderate level of intensity.

Table 3
Results of an OLM and MLM regressing children's well-being on active mobility and physical activity on a day-to-day level (n = 465 reporting days of 71 children).

Response variable: WB related to movement/exercise, sport	OLM		MLM with random intercept	
Independent variables	estimate	t value	estimate	t value
intercept	4.017	74.119	4.048	48.681
undirected walking trip(s) performed	0.481	3.253	0.461	3.648
cycling trip(s) performed	0.467	3.913	0.181	1.425
share of very exhausting activities[a]	0.014	3.575	0.014	3.463
share of moderately exhausting activities[b]	0.008	2.008	0.008	2.303
Model diagnostics	R^2: 0.093		conditional R^2: 0.467	
	F value: 11.66		marginal R^2: 0.064	

[a] PA with high level of intensity.
[b] PA with moderate level of intensity.

cycling trips are only performed by few (8 and 13 % of reporting days, respectively), and if the children engage in such trips, they tend to have a substantial duration. Exhausting activities, on the contrary, are performed on 68 % of days, 37 % even very exhausting activities.

The MLM makes use of the panel data structure (repeated reporting days of the children) in combination with an individual-specific intercept. It rigorously controls for all characteristics that do not vary from day to day (socio-demographics, built infrastructure, etc.) because all these effects go into the individual intercept. In doing so, the individual intercept also captures longer-term effects of AM and PA beyond the day-to-day level. Three of the four predictors in Table 3 yield an equal or higher predictive power in the MLM than in the OLM: undirected walking trips as well as moderately and very exhausting activities. These predictors seem to affect the response variable immediately on a day-to-day level; it is most likely a causal effect, as potential confounders are captured by the individual intercept. On the other hand, they do not appear to exert a lasting effect beyond the daily level, otherwise the OLM would yield larger effects than the MLM.

Cycling is very different. It is the strongest predictor in the OLM, but its effect drops below the level of significance in the MLM. The 'technical reason' is that only few children cycled at all (17 out of 71), and those who did have on average a higher baseline level of well-being, which goes into the individual intercept (Fig. 3). The implication is that the immediate effect of cycling on children's well-being is positive but small and insignificant. The long-term effect is potentially very large, but it could also be due to other factors confounded with the group of cyclists in our sample. Promising candidates are gender and school location. We tried to include these variables in the model, but came across limitations: The cyclists show a very uneven distribution, almost all of them come from the suburban school, and most of them are boys. The strong correlation along with the limited sample size of 71 different children made it impossible to include the personal characteristics in the MLM, so that the question of confounding remains unanswered. We will come back to this in the discussion.

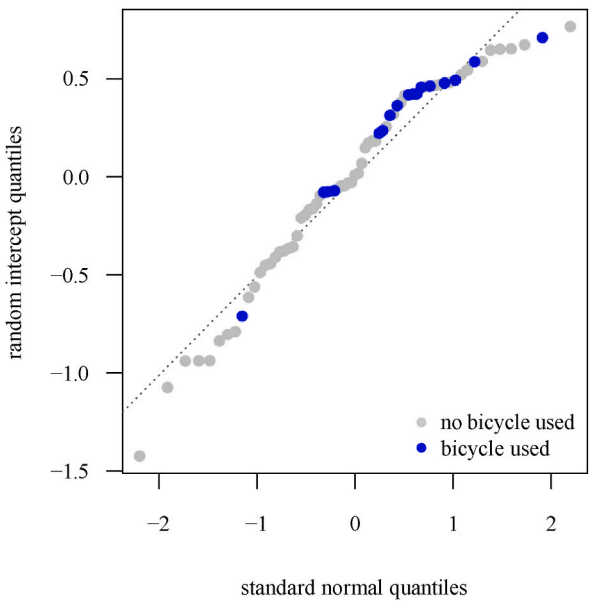

Fig. 3. Distribution of random intercepts of cyclists and non-cyclists in the MLM.

3.5. Extent of and relationship between active mobility and physical activity

In this section, we present further results on those types of active mobility (AM) and physical activity (PA), which were found to contribute positively to children's well-being in section 3.4, i.e., undirected walking trips, cycling trips, and exhausting physical activities. Table 4 shows how widespread these types of activity are in our sample. Only half of the children (53 %) engaged in any of the three types at least once in the reporting week. On a particular day, only 22 % reached this criterion. The most frequent activity on the day-to-day level is cycling (13 %). However, on the person level, cycling is performed by fewer children than undirected walking trips (24 vs. 35 %, respectively). Exhausting physical activities are very widespread but mostly on a low level. To make their effect on well-being comparable with active mobility, we calculated the total effect of both moderately and very exhausting activities using the parameters of the MLM and generated a dummy variable, which is 1 if the total effect of physical activities reaches or exceeds the effect of an undirected walking trip (zero otherwise). The children performed only on 3 % of reporting days physical activities at that level, and only 13 % of children did so at least once in the week. It means that physical activities are rarely performed to an extent that makes a comparable contribution to children's well-being as active mobility does.

Another important question is how these types of activity are related to each other, especially when it comes to promoting a more active lifestyle of children: Does the promotion of a certain type (e.g. cycling) actually increase the total activity level? Or is it counterbalanced by a decrease of other types, e.g. less sport? Table 5 shows low and insignificant relationships between all of the three types of activity, with a weak tendency that those children with a higher level of exhausting physical activities are also more active in their mobility, whereas cycling trips and undirected walking trip seem to be weakly substitutive of each other.

4. Discussion

This study provides a nuanced exploration of the relationship between active mobility (AM), physical activity (PA), and children's well-being (WB), filling significant gaps in the existing literature. Notably, it addresses the under-researched link between children's well-being and mobility, particularly in relation to older age groups and various forms of daily mobility. Our study presents two main innovations: (i) a diary-based approach to capture AM and PA on a daily level, and (ii) a panel dataset with seven repeated observations per individual, which allows us to isolate the effects of AM and PA from potential confounders using random intercepts. In doing so, we gain a more rigorous picture of how active mobility influences their well-being, as opposed to traditional approaches that focus on long-term assessments or ad-hoc effects of travel.

When analysing the relationship between AM, PA, and WB, we identified three distinct components of children's well-being. Two of them are broad dimensions represented by several variables: (i) an overarching condition and (ii) a more specific view on various aspects of well-being. These dimensions do not seem to respond to the daily levels of AM and PA. The 3rd dimension relates to "movement/exercise, sport". It is related to the former two dimensions in equal distance, and also to AM and PA. It may be interpreted to take an interim stage, which mediates the effects of AM and PA to the WB domain. It is plausible that the use of active travel modes and exhausting physical activities might not necessarily impact all WB dimensions, particularly in the group of adolescents, whose well-being is more likely to fluctuate during (oncoming) puberty compared to the relatively stable WB patterns of adults (Larson & Richards, 1991). Their daily well-being can be influenced by a multitude of factors, such as sleep, social interactions, academic pressures, family dynamics etc. The multidimensionality and multicausality is also reflected in our workshop results as well as in other studies on children's well-being (e.g. Office for National Statistics, 2020).

According to our model, two aspects of AM contribute positively children's well-being: the conduction of *undirected* walking trips and *cycling trips*. Directed walking trips (getting from A to B) have no positive effect on well-being. This confirms our experience that walking, although widespread, is neither perceived as real means of transport nor as a physical exercise by most students, but as a simple means to get around. Hook et al. (2021, 2022) identified a clear link between undirected travel and mental health, although for adults. Their studies included activities such as cycling and jogging within the scope of undirected travel. Taking into account that other studies use different age groups (mostly primary school children) and a different concept of travel-related well-being, it can be said that our results are consistent with the findings of a positive relationship between active mobility and well-being (e.g. Stark et al., 2018, 2019; Waygood et al., 2017). Both effective forms of AM are rare in our study: undirected walking and cycling trips occurred on 8

Table 4
Extent of active mobility and physical activity (PA) on day-to-day level (465 reporting days) and on the person level (71 children).

Level	Kind of activity[b]	Number	Percent
reporting days	undirected walking trip(s)	36	7.7
	cycling trip(s)	60	12.9
	exhausting physical activities[a]	16	3.4
	any of the three	104	22.4
children	undirected walking trip(s)	25	35.2
	cycling trip(s)	17	23.9
	exhausting physical activities[a]	9	12.7
	any of the three	38	53.5

[a]) total effect of both moderately and very exhausting activities.
[b] for the sake of comparability, exhausting physical activities are counted only if they were practiced to an extent that causes an equal or greater effect on well-being as an undirected walking trip.

Table 5
Relationships between active mobility and exhausting physical activity (PA); r = Pearson's correlation coefficient (n = 465).

Relationship	r	p value
cycling trips * undirected walking trips	−0.039	0.396
exhausting physical activities[a] * undirected walking trips	0.034	0.470
exhausting physical activities[a] * cycling trips	0.033	0.479

[a] total effect of both moderately and very exhausting activities.

and 13 % of reporting days, respectively. From this follows that the contribution of AM to children's WB is limited despite its large effect size. This might also explain why it is the mere occurrence of these mobility forms (rather than the duration of engagement) which matters most in terms of well-being. The effect of undirected walking is hardly affected by the introduction of a random intercept. Such trips seem to affect children's well-being immediately on a day-to-day level, while there might be little or no lasting effect. Cycling is different: its daily effect is positive but insignificant. However, regular cyclists (17 out of 71 children) exhibit a higher average baseline level of well-being, which might indicate a long-term contribution on a larger time scale. Accounting for this effect in addition to the daily effect makes cycling the strongest predictor of well-being. But the long-term effect cannot be confirmed. It may also be a confounding effect of other characteristics, in particular gender and school location. We could not disentangle these effects, because our sample includes only 71 different children despite the high number of reporting days, and most cyclists are boys from the suburban school, which reflects the distribution in the population. This would require an experimental approach that pays attention to an even distribution of cyclists across both genders and different locations, preferably with a larger sample.

The daily time share of exhaustive activities (along with the level of exhaustion) also has a positive effect on well-being besides active mobility. This finding is in line with other studies on physical activity and health (e.g. Biddle and Asare, 2011; Biddle et al., 2015; Miles, 2007). Exhaustive activities are much more widespread than undirected walks and cycling trips in our sample, but in this case it is the duration that counts. Unfortunately, most exhaustive activities are rather short in duration. Only 3 % of reporting days exhibit exhaustive activities to an extent that makes a similar contribution to well-being as an undirected walking trip. This suggests that, while beneficial, exhaustive physical activities alone may not produce sufficient large-scale, day-to-day improvements in children's well-being.

We also find that AM and PA are only loosely connected to each other. Higher levels of PA tend to come along with more AM and vice versa, indicating weak complementarity. Insofar, it makes sense to promote both types of activity, because they will not substitute each other but add up to the total effect or even reinforce one another. By addressing gaps in the literature, particularly the limited focus on older children and diverse forms of daily mobility, this study contributes to a more comprehensive understanding of how AM and PA influence children's well-being. It highlights the importance of considering both the short-term effects of daily mobility as well as the potential long-term benefits of regular physical activity.

4.1. Strengths and limitations

A key strength of our study is its research focus, which addresses a prominent research gap: the lack of attention to older children and their travel-related well-being. Most studies focus on younger children or on school trips, while we explore a broad range of travel activities of adolescents, which contribute valuable insights to the field.

Another strength is the participative, comprehensive, and detailed survey. We developed the questionnaire in a collaborative process with children, ensuring a relevant and engaging tool with age-appropriate items that reflect the children's experiences. The resulting survey goes beyond previous studies in measuring active mobility (AM), physical activity (PA), and children's well-being (WB) repeatedly on seven consecutive days. This panel design provides a comprehensive and dynamic understanding of daily variations in behavior. Additionally, the retrospective diary-based survey allowed participants to reflect on their experiences at the end of the day, which can help reduce recall bias compared to longer-term retrospectives. Unlike studies that assess momentary well-being and travel satisfaction or well-being over long time spans, we provide a daily, accumulated perspective on multiple aspects of well-being. This approach provides a richer understanding of how daily experiences such as mobility, school, and social interactions affect children's psychological well-being.

Additional value also results from our focus on the full spectrum of children's physical activity - not only structured exercise and sports but also active mobility such as walking and cycling. By taking all forms of movement into account, we provide a holistic understanding of children's activity patterns and their potential impact on well-being.

Finally, the panel data structure in combination with a mixed linear model with individual-specific intercept is also a methodological strength. It allows for a rigorous test of the effects of AM and PA on well-being on a daily level, while controlling for all potential confounders at the person level such as sociodemographic variables, built infrastructure etc. Since the individual intercept also eliminates effects of AM and PA beyond the day-to-day level, we conducted an ordinary linear model in parallel that captures longer-term effects as well.

However, the ordinary linear model also points to a limitation of our study: It suggests that cycling comes with a long-term positive effect on well-being, but this could be confirmed, as it might also be a confounding effect of other characteristics such as gender or school location. The uneven distribution of cyclists (almost all come from the suburban school and most of them are boys) together with the relatively small sample did not allow us to include the personal characteristics in the MLM, so that the long-term effect of

cycling remains inconclusive. The non-randomized sample (drawn from two schools in Vienna and one in a suburban area) might also limit the generalizability of our findings to other regions.

The participatory development of the questionnaire is also not only a strength but a limitation as well. Our questions were inspired by existing instruments (e.g. KIDSCREEN, Stark et al., 2015), but adapted according to the children's input and therefore novel, which implies that the measurement properties have not been tested before.

5. Conclusions and outlook

This study provides valuable insights into the day-to-day effects of active mobility (AM) and physical activity (PA) on children's well-being (WB), using a diary-based survey and a rigorous modelling approach that takes advantage of the panel data structure. Our findings suggest that PA and certain forms of AM, such as undirected walking and cycling, positively impact children's well-being. They also suggest a weak complementary relationship between AM and PA. It underscores the potential benefits of promoting both types of activity, as they reinforce rather than substitute each other. Future policy initiatives should build on these insights to develop strategies that encourage healthier, more active lifestyles for children.

The study also highlights the complexity of children's well-being, which builds on multiple factors such as family, school, and social interactions. While AM and PA positively impact well-being regarding movement and sports on a daily level, their impact on other dimensions remains indirect and inconclusive. Further research with longitudinal surveys and validated instruments could contribute to more precise and reliable measurements of long-term effects of AM and PA, especially in relation to broader well-being dimensions.

Important would also be a larger survey with children from different socio-economic backgrounds, age groups, and regions in order to identify group differences, control for confounded effects, and enhance the generalizability of findings.

CRediT authorship contribution statement

Juliane Stark: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Reinhard Hössinger:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Sandra Wegener:** Investigation. **Valerie Batiajew:** Investigation. **Shun Su:** Investigation.

Ethic approval

All procedures were performed in compliance with relevant laws and institutional guidelines. Pursuant to § 10 (2) of its Rules of Procedure and based on thorough discussion, the Ethics Committee of the University of Natural Resources and Life Sciences concluded that the project proposal complies with the requirements for the ethical conduct of research and studies involving human participants, as all necessary measures are taken to safeguard the rights, safety, and welfare of the human participants and of the researchers during the implementation of the research project. The Ethics Committee has thus granted ethical approval (Reference No: BOKU-2023/008).

Financial disclosure

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Declaration of competing interest

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

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Annex

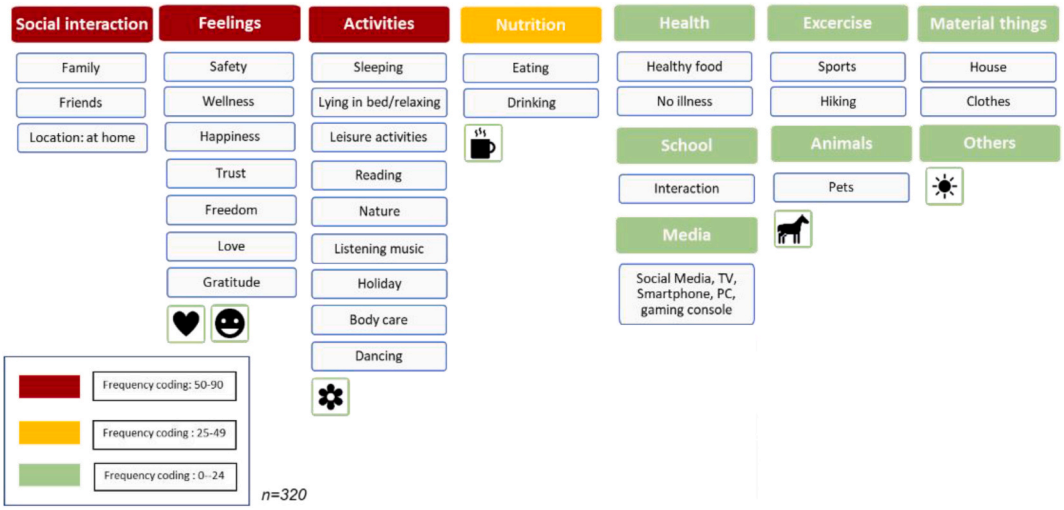

Fig. ure A-1. Qualitative data analysis on subjective well-being, n = 320

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