Transportation Research Part A 179 (2024) 103893

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

Is multimodality advantageous? Assessing the relationship between multimodality and perceived transport adequacy and accessibility in different travel contexts

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ARTICLE INFO

Keywords:
Multimodality
Transport adequacy
Accessibility
Car dependence
Multimodal transport

ABSTRACT

Multimodality is regarded as essential to promoting sustainable mobility because of the widely found environmental benefits, although it is unclear whether individuals experience multimodality as a benefit or a burden. This study aims to investigate the relationship between multimodality and perceived transport adequacy and accessibility in different travel contexts. Using data collected in two large Dutch cities, we realized the research aim from three perspectives. First, a multigroup multimodality index was constructed to measure the variability of transport mode use at both major-category and sub-category levels, which somehow addressed the mode classification issue in measuring multimodality. Second, by performing a regression analysis on the factors associated with multimodality, we found that multimodality occurs in different travel contexts related to certain conditions or constraints. Third, the effects of multimodality as well as the interaction effects of car-related factors and multimodality on two factors of perceived transport adequacy and perceived accessibility are assessed using stepwise regression models. Results show that multimodality is burdensome, especially for those who rely on cars. Specifically, being more multimodal is generally associated with higher perceived disadvantage and lower perceived accessibility; for people who experience the ease of driving or have limited access to a car, being more multimodal results in even lower perceived achievement or perceived accessibility. The results indicate that even in compact and less car-dependent urban settings, multimodality lacks attraction and reducing car use is difficult. The findings inform multimodal transport policies and planning to balance social and environmental values by assessing and minimizing the negative individual externalities.

1. Introduction

Car-dependent societies face various transport-related problems. Multimodal transport, a coordinated system of various forms of transport, is widely referred to in transport policies and practices to address the environmental problems and inequalities of car dependency by promoting the use of multiple transport modes. In travel behaviour studies, an individual's use of multiple transport modes for travel within a certain time period is defined as multimodality (Buehler & Hamre, 2013; Kuhnimhof et al., 2006; Nobis, 2007). Multimodality has been found to be an environmentally friendly way of travelling because multimodal travellers are likely to

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https://doi.org/10.1016/j.tra.2023.103893
Received 5 December 2022; Received in revised form 18 September 2023; Accepted 13 November 2023
Available online 24 November 2023
0965-8564/

travel more by public and non-motorized modes and less by cars (Buehler & Hamre, 2015; Diana & Mokhtarian, 2009). In the long run, multimodal travellers tend to own fewer private vehicles (Heinen, 2018; Nobis, 2007). Thus, promoting multimodality has the potential to shift an ownership-based transport system to an access-based one, reducing energy consumption and carbon emissions (Chlond, 2012; Circella et al., 2019; Heinen & Mattioli, 2019b).

Despite the clear environmental benefits of multimodality (Deschaintres et al., 2021; Wong et al., 2020), it remains unclear whether and in which contexts, at the individual level, travellers experience multimodality as a benefit or a burden. Since supporting daily needs and improving accessibility are also goals of multimodal transport (TDOT, 2018), it is crucial to understand to what extent and in what form multimodality benefits individuals. However, insights into the effects of multimodality on individuals' travel outcomes (e.g., accessibility, overall travel satisfaction, different dimensions of travel experiences, health, and well-being outcomes) are lacking. Current studies mainly investigated the characteristics and determinants of multimodality, and some indirect evidence from these studies indicated that whether multimodality is experienced as more or less positive may depend on the context in which it occurs (Kuhnimhof et al., 2006; Molin et al., 2016).

Multimodality is found to be a free choice for situational optimization based on diverse options, in which context multimodality may be beneficial. People with more transport options and more freedom in mode choice such as those living in the city centre, having more private vehicles, and having better access to public transport are found to be more multimodal (Blumenberg & Pierce, 2014; Diana, 2012; Scheiner et al., 2016). They have the privilege to choose the optimal mode for a given trip, and using a combination of optimal travel modes may result in a better travel experience. Furthermore, compared to unimodal travellers who only use the habitual mode, travellers who deliberately choose multimodality are found to have higher flexibility in switching travel modes and have a higher intention to change travel patterns (Heinen, 2018; Kroesen, 2014). Such multimodal travellers may better adapt to changes in transport policies and benefit more from emerging transport technologies, thereby experiencing fewer travel limitations and better access to destinations (Kroesen, 2014; Lättman et al., 2020). Therefore, multimodality out of choice may lead to higher transport adequacy, defined as the subjective assessment of the quality and sufficiency of one's transport options (Ettema et al., 2023), and higher perceived accessibility, defined as the subjective assessment of individuals' access to daily activities and destinations (Kroesen, 2014; Lättman et al., 2020).

Other studies, however, found that multimodality might be a necessity due to not being able to purchase or use a car (Buehler & Hamre, 2015), in which context multimodality may be a burden. Car-less travellers need to consider which mode to use based on limited options and may need to switch between modes in one single trip to reach a destination (Nobis, 2007). Thus, they have to use a combination of less attractive modes which may result in experiencing lower transport adequacy and lower accessibility. Such car-less travellers have been studied in the context of transport poverty, where due to insufficient and low-quality transport, they met disadvantages such as lower access to resources and opportunities, excessive time and money spent on daily travel, or difficulty in realizing life achievements (Lucas et al., 2016; Ettema et al., 2023).

Since findings on the contexts in which multimodality occurs are mixed and empirical studies on the effects of multimodality on individual travel outcomes are scarce, the fragmented information is far from answering the question of whether and in which contexts multimodality benefits individuals. So far, it is unclear under what circumstances multimodality is a free choice or a necessity, leading to higher or lower transport adequacy and accessibility. Therefore, this research aims to resolve this ambiguity by investigating in which travel contexts people show what degree of multimodality and how the degree of multimodality is associated with perceived transport adequacy and accessibility in different travel contexts. The research can contribute to the knowledge gap in multimodality from the perspective of travellers' experiences and inform multimodal transport policy and planning.

The remainder of this paper is organised as follows. Section 2 reviews the literature on the measurement, determinants, and individual outcomes of multimodality. Section 3 introduces the data, measurements, and models of this study. Section 4 presents and discusses the modelling results. The paper concludes with the key findings, prospects for future research, and practical and policy implications.

2. Literature review

2.1. *Definition and measurement of multimodality*

The definitions of multimodality are considerably uniform. The most widely accepted definition is by Nobis (2007): "*Multimodality is the use of various modes of transportation for travel within a certain period*". According to specific situations and research aims, studies defined multimodality in different time periods, such as a trip, a day, a week, or a longer period (Buehler & Hamre, 2013, 2016; Kuhnimhof et al., 2006). In addition, Astroza et al. (2017) suggested that *the extent to which an individual is flexible concerning their mode use should also be considered as a measure of multimodality*. In this study, we use the most common definition, measuring multimodality as the variability of transport mode use, and investigate the effects of availability and accessibility of transport modes (i.e., the flexibility of options) on multimodality.

Previous studies measured multimodality in three main ways. In the first and second ways, travellers are grouped into a certain number of modality styles. First, some studies set up certain standards or thresholds and then categorized travellers into different predefined groups. For example, Klinger (2017) defined travellers using more than one transport mode daily or 1–3 days per week as multimodal. Second, some studies cluster travellers into data-driven groups by clustering analysis. For example, Molin et al. (2016) used latent class clustering analysis to classify modality groups using the frequency of different transport modes use as measurement indicators. Buehler and Hamre (2015) defined modality groups into monomodal car users, multimodal car users, and non-car users. Their results show that multimodal car users are a group in-between monomodal car users and non-car users, which indicates that there may be a continuum of mobility types ranging from monomodal car users at one end to non-car users at the other end.

Then, in a third way, several studies used continuous indicators to describe the level of multimodality. They used indices from different disciplines, ranging from welfare economics (Gini, Dalton, and Atkinson indices) to information theory and ecology (Shannon entropy, Herfindahl index) (Astroza et al., 2017; Diana & Pirra, 2016). Diana and Pirra (2016) put forward several issues to be considered when measuring multimodality, referring to the object to be measured (i.e., the flexibility of travel options or the variability of actual mode use), the measurement unit of mode use (e.g., durations, distances, frequencies), the classification of transport modes (i.e., aggregation or segmentation), and different combinations of modes (e.g., driving + bus vs. walking + bus). However, most studies only considered the first two issues, ignoring the classification or combination. Heinen and Chatterjee (2015) used two different classifications of transport modes to measure multimodality by Herfindahl–Hirschman Index, with one categorizing all transport modes into three main categories and the other categorized into eight subcategories. They found that the two classifications had different results on the predictors of multimodality. Typically, being females predicts a higher level of variability than males when measuring for eight subcategories, while lower when measuring for three main categories, suggesting that women use a larger variety of sub-modes than men. Thus, different classifications of transport modes may lead to different situations. Diana and Pirra (2016) also tested a broad set of indices and found that there is no measure of multimodality that consistently outperforms all the others in any circumstance. Thus, the measurement of multimodality depends on the problem under consideration. Since existing methods to measure multimodality are sub-optimal, we construct our own index to measure multimodality in this study.

2.2. Determinants of multimodality

Direct research evidence of the underlying reasons for multimodality is limited. Based on fragmented information from research on characteristics and determinants of multimodal travel behaviour, multimodality may be a joint consequence of different travel conditions and constraints (Clewlow, 2016).

Previous studies mainly assessed the correlations between multimodality and factors including socio-demographics, mode availability, lifestyles and attitudes, and the built environment (Circella et al., 2019; Klinger, 2017). The results show that low income, mobility difficulties, and low access to public transport are related to the lower level of multimodality (Buehler & Hamre, 2015; Heinen & Chatterjee, 2015). People living in dense areas with better access to public transport are more likely to be multimodal compared to those living in small settlements and suburban areas (Circella et al., 2019; Heinen & Chatterjee, 2015). Heinen and Mattioli (2019a) found that people who have a public transport pass or season ticket are more multimodal. Whether a person is tech-savvy might also influence their modality style. For example, Astroza et al. (2017) found that people who use digital devices for travel information are more multimodal. In addition to these explicit characteristics, studies also found that people with a green lifestyle propensity, and those who have a more positive attitude towards travel, especially public transport, are more likely to be multimodal (Astroza et al., 2017; Molin et al., 2016). Accordingly, a higher level of multimodality is correlated with several conditions including higher socio-economic status, better access to resources, positive travel attitudes, and familiarity with technologies, while a lower level of multimodality is correlated with certain disadvantages including limited budget and disability.

Although most studies suggest that travellers do multimodal because they have the privilege to choose, multimodality is also found to be related to some constraints such as lack of vehicle ownership and transport access, especially access to a car, which forces them to use a combination of less accessible or less attractive modes (Buehler & Hamre, 2015; Heinen & Chatterjee, 2015; Mao et al., 2016).

The motivation for multimodality was not unanimously agreed upon, as most studies only assessed correlations with little further discussion of underlying mechanisms. It is unclear under which circumstances multimodality is optional or forced, and this may determine whether individuals experience multimodality as a benefit or a burden. Nonetheless, the above findings imply that the motivation for being multimodal may be linked to travel contexts, such as vehicle ownership, mode availability and accessibility. Hence, the experience of multimodality may depend on travel contexts.

2.3. Individual outcomes of multimodality

Although the environmental benefits of multimodality have been recognized, the effects of multimodality at the individual level are still unclear. A limited number of studies have investigated the relationship between multimodality and travel satisfaction or subjective well-being (Cobbold et al., 2022; Diana, 2012; Makarewicz & Németh, 2018; Mao et al., 2016). Regarding travel satisfaction, Diana (2012) found that there is no correlation between multimodal travellers' satisfaction with public transport and the frequency of using public transport, while Mao et al. (2016) found that multimodal commuters tend to feel less satisfied with commuting trips by alternative modes. However, the information provided by these studies is how multimodal travellers experience specific travel modes or trips rather than how they experience multimodality itself. Regarding subjective well-being, Makarewicz and Németh (2018) found that multimodal travellers have higher subjective well-being, in particular for low- and middle-income people, and Cobbold et al. (2022) found that multimodal travellers have higher subjective well-being only when using a combination of public transport and active modes. However, although these studies found multimodality might be associated with individuals' quality of life, it is unclear in what ways and in what contexts they are linked. Studies have already found that travel behaviour affects living standards/well-being through experiences during travel, activity participation enabled by travel, transport disadvantage, transport-related social exclusion, and perceived accessibility (Awaworyi Churchill & Smyth, 2019; De Vos et al., 2013; Delbosc & Currie, 2018; Lättman et al., 2016). Thus, we move one step closer to looking into the relationship between multimodality and individuals' perceptions towards these factors directly related to travel, which may provide more direct and concrete insights for multimodal transport policies.

Multimodality may be linked with individuals' subjective assessment of the quality and sufficiency of transport and what they achieve through travel, simply put, transport adequacy (Ettema et al., 2023). Studies hypothesized that multimodality was a combination of optimal transport modes for different travel purposes (Kuhnimhof et al., 2006; Vij et al., 2011), in which case multimodality may be related to perceiving better quality and sufficiency of transport as well as being able to engage in social activities and gain social opportunities through transport. This might be the underlying mechanism of Makarewicz and Németh (2018) finding that multimodal travellers are more satisfied with what they are achieving in life. However, multimodality in the case of being a combination of alternatives to the preferred mode may do the opposite (Molin et al., 2016). Being unable to use the preferred mode can induce a sense of inadequacy and the comparison between different travel modes can result in worse travel experiences (Mao et al., 2016), for example, feeling unhealthy to using public transport compared to cycling (Cobbold et al., 2022). Frequently transferring between different transport modes can also cost more time and money, especially for low-income people who cannot afford a car, which can bring them a lot of burdens (Chlond, 2012). With the increasing proportion of access-based modes including public transport and shared mobility in the urban transport system, individuals who lack personal vehicles are able to access these affordable options and may take advantage of multimodality (Diaz Olvera et al., 2015; Klinger, 2017). Therefore, multimodality may increase transport adequacy for these certain groups and reduce the mobility barrier posed by the previous ownership-based system. However, if new transport modes like shared mobility become a more prominent part and replace traditional public transport, there will be more restrictions for some people to realize multimodal behaviours because they must have tools like smartphones or credit cards to access these services (Groth, 2019). In this case, multimodality may widen gaps in transport adequacy across populations.

Multimodality may be linked with individuals' perception of accessibility to daily activities and destinations. Perceived accessibility is how easy it is to participate in everyday life by the transport system (Lättman et al., 2018; Pot et al., 2021). As studies suggested, multimodal travellers are familiar with different transport modes and they can flexibly adjust their travel modes according to different situations (Buehler & Hamre, 2015; Vij et al., 2011). When their plans are suddenly disrupted or the habitual mode is temporarily unavailable, multimodal travellers can flexibly switch to alternatives, enabling them to easily access daily activities and destinations (Mao et al., 2016). However, for those who are multimodal due to not being able to use the optimal mode, especially a car, unsatisfactory alternatives or heavy transfers may make them forego some trips, thus resulting in lower perceived accessibility (Lättman et al., 2020).

The aforementioned transport adequacy and accessibility have been proposed to be essential to transport equity and have been found to be associated with individuals' subjective well-being (Awaworyi Churchill & Smyth, 2019; Ettema et al., 2023; Lättman et al., 2018). However, these travel outcomes have not been linked with multimodality. To fill this knowledge gap and answer how travellers experience multimodality, this study aims to investigate the relationship between multimodality and individuals' perceptions of transport adequacy and accessibility.

3. Data and methods

3.1. Data

Survey data were collected in February of 2021 in Rotterdam and Utrecht, two major cities in the Netherlands. The survey was part of Mobimon project that aimed to develop a quantitative method to measure transport poverty. The survey data was collected by a local agency (Labyrinth) specializing in research among vulnerable groups. The targeted group of the survey consisted of two subsamples. The first subsample (n = 654) was taken from a low-income population segment, where a certain proportion of people do not have a driver's license. Another subsample (n = 424) was taken from a higher-income population segment, most of whom have a driver's license. The research sample overrepresents low-income groups and people who have no driver's license. As we want to compare the experiences of multimodal travellers who face barriers to car access and who have more transport options, the targeted group of the survey is suitable for the analysis.

The sample size of the current analysis is 1009 participants, among which 494 are from Rotterdam and 515 are from Utrecht. Rotterdam is the second largest city in the Netherlands, with a population of 651,631 in 2021. Rotterdam is a diverse city with a high percentage of migrants and single-person households. Rotterdam has a local public transport system with bus, tram and metro. Utrecht is the fourth largest city in the Netherlands, with a population of 359,370 in 2021. Utrecht has a young population, with many residents between the ages of 20 and 30. Utrecht has a local public transport system with bus and tram. In Utrecht, journeys by bicycle are more than any other mode of transport.

Table 1 presents the socio-demographic characteristics of the sample. Among them, urbanicity is a categorization of neighbourhood address density. The neighbourhood address density is measured by the number of addresses within a circle with a radius of one kilometre around each address, divided by the area of the circle. Statistics Netherlands (CBS) categorize urbanicity into five levels according to neighbourhood address density (see Table 1) to determine the degree of concentration of human activity—living, shopping, and working[1]. The urbanicity level of each PC4 is determined by the average neighbourhood address density of all addresses in the PC4. Compared to census data[2], this dataset overrepresents females, young groups (21–40 years old), single-person households and low-income groups. The Utrecht sample overrepresents young groups, females, and highly educated groups, and the Rotterdam sample overrepresents people living in extremely urbanised areas, single-person households and people working full-time.

[1] Statistics Netherlands (CBS), https://www.cbs.nl/en-gb/our-services/methods/definitions/degree-of-urbanisation

[2] Statistics Netherlands (CBS), https://www.cbs.nl/en-gb/visualisations/dashboard-population

Table 1
Socio-demographic characteristics of the sample.

Attributes	Rotterdam		Utrecht		Sample total	
	Count	Percent %	Count	Percent %	Count	Percent %
Age						
<=20	20	4.05	42	8.16	62	6.14
21–30	155	31.38	173	33.59	328	32.51
31–40	122	24.70	119	23.11	241	23.89
41–50	73	14.78	63	12.23	136	13.48
51–60	73	14.78	66	12.82	139	13.78
>=61	51	10.32	52	10.10	103	10.21
Gender						
Female	265	53.64	314	60.97	579	57.38
Male	229	46.36	201	39.03	430	42.62
Urbanicity						
Extremely urbanised	418	84.62	364	70.68	782	77.50
Strongly urbanised	58	11.74	127	24.66	185	18.33
Moderately urbanised	13	2.63	21	4.08	34	3.37
Hardly urbanised	1	0.20	2	0.39	3	0.30
Not urbanised	4	0.81	1	0.19	5	0.50
Household income						
Lower than average	152	30.77	158	30.68	310	30.72
Higher than average (including equal to)	342	69.23	357	69.32	699	69.28
Living status						
Single without children	149	30.16	136	26.41	285	28.25
Single parent with children	37	7.49	46	8.93	83	8.23
Couple without children	139	28.14	146	28.35	285	28.25
Couple with children	75	15.18	63	12.23	138	13.68
Other	94	19.03	124	24.08	218	21.61
Work status						
Full-time job	216	43.72	166	32.23	382	37.86
Part-time job	149	30.16	190	36.89	339	33.60
Student	55	11.13	78	15.15	133	13.18
Retired	14	2.83	17	3.30	31	3.07
No job	60	12.15	64	12.43	124	12.29
Education level						
Low education	83	16.80	56	10.87	139	13.78
Medium education	199	40.28	138	26.80	337	33.40
High education	212	42.91	321	62.33	533	52.82
Total	494	100.00	515	100.00	1009	100.00

3.2. Measurement

3.2.1. Multimodality

Previous studies have used various indices to measure different dimensions of multimodal travel behaviour (Diana & Pirra, 2016; Heinen & Chatterjee, 2015). These indices mainly consider the diversity and evenness of transport mode use. Diversity is measured by the number of different modes used in a certain period, and evenness is measured by the relative intensity of mode use. However, there is another issue that matters, which is the classification of transport modes. For example, if bus, tram, and metro are considered at the aggregation level as one single category, some individuals' multimodality will be underestimated. While if we consider them separately, the difference between the three modes of public transport is regarded as the same as the difference between them and car, which leads to an overestimation of some individuals' multimodality.

Based on the continuous, classification-related and research question-dependent issues in measuring multimodality summarised in the literature review, we constructed a multigroup multimodality index to measure the extent of multimodality. The index simultaneously considers the continuum property, two-level classification of modes (aggregation level and sub-mode level) and variability in the frequency of mode use (Fu et al., 2023).

First, transport modes are aggregated into groups according to their similarity and usage in the Netherlands. The survey recorded the frequency of use of thirteen modes (Fig. 1). Due to low usage, we did not involve regiotaxi or belbus, cargo bike and (electrical) scooter in our classification, and we categorized the rest ten modes into five groups (Fig. 2). The first group is active transport consists of walking and cycling (including e-bike). The second group is local public transport including bus, tram, and metro. In our study areas, Rotterdam has all three modes, while Utrecht only has bus and tram. The third group is intercity public transport that only includes train. The Netherlands has a complete train system connecting cities and regions, and intercity travel, including intercity commuting, is quite common in the Netherlands. The fourth group is car, including car as the driver and car as the passenger. Considering the distinct roles of drivers and passengers in a household presumably due to contexts like the limited number of household cars or the different divisions of household labour, we distinguish these two modes while aggregating them into one group. The fifth group consists of two motorised modes that are not commonly used, and both have certain usage requirements—using a moped, motorcycle or speed pedelec requires a license and taking a taxi or using ride-hailing services (Uber) is expensive in the Netherlands.

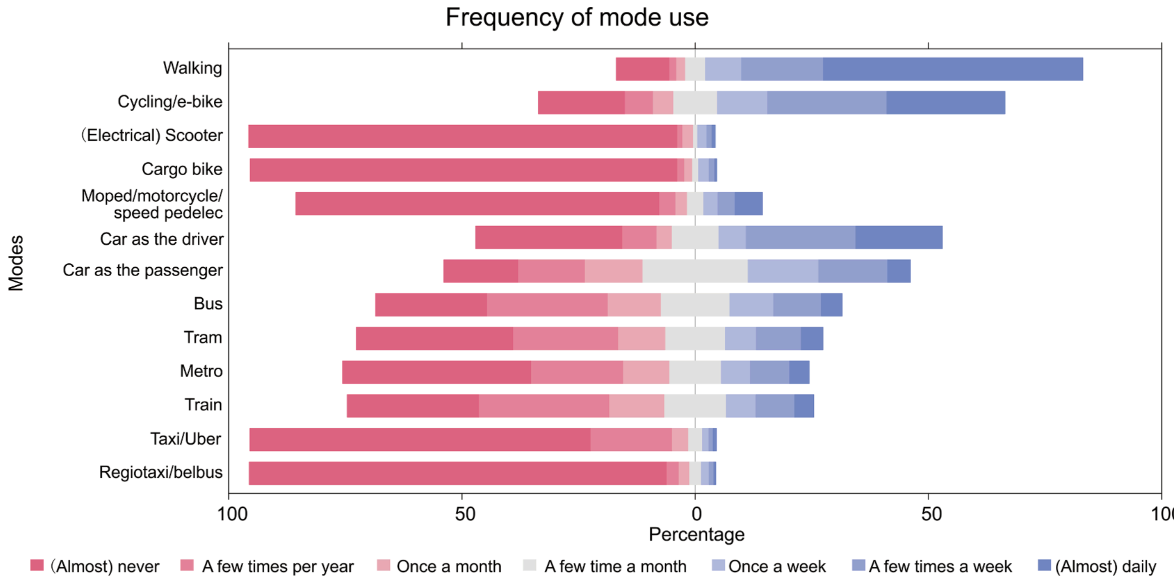

Fig. 1. Frequency of mode use.

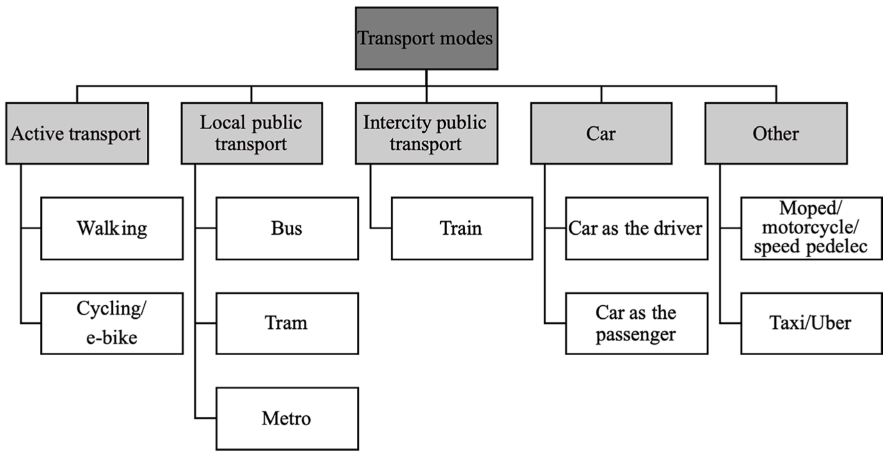

Fig. 2. Classification of transport modes at two levels.

Second, we define the multigroup multimodality index based on multigroup entropy used to measure regional ethnicity diversity in the field of social ecology (Reardon & Firebaugh, 2002), by modifying the Shannon entropy index to arrive at a nested entropy index:

$$MMI = \sum_{g=1}^{G}\left\{p_g\left(\log_G\frac{1}{p_g}\right)\sum_{i=1}^{n}\left[p_{ig}\left(1+\log_n\frac{1}{p_{ig}}\right)\right]\right\} \quad (1)$$

Where

$$p_g = \frac{max(f_{ig})}{\sum_{g=1}^{G} max(f_{ig})} \quad (2)$$

$$p_{ig} = \frac{f_{ig}}{\sum_{j=1}^{n} f_{jg}} \quad (3)$$

G refers to the number of groups, n refers to the number of transport modes in Group g, and f refers to the frequency of use of Mode i in Group g. If p_g or p_{ig} equals to 0, $\log_G\frac{1}{p_g}$ or $\log_n\frac{1}{p_{ig}}$ is converted to 0.

The frequency of mode use is measured by how many days a person uses the mode in a year, which is converted from a seven-level scale of a travel log (for each travel mode, namely, 'almost daily', 'a few times a week', 'once a week', 'a few times a month', 'once a month', 'a few times per year', 'almost never'). The corresponding number of each level is respectively: 365, 180, 52, 30, 12, 5, 0. The index has a minimum value of 0 when an individual uses transport modes from only one single group. The maximum of the index depends on the number of groups and the number of transport modes in each group. If there are G groups in total, of which x groups contain only one transport mode, and the remaining (G-x) groups contain more than one transport modes, then the maximum of the index is [x + 2(G-x)]/G = 2-x/G. Thus, the range of the index is [0,2-x/G]. In this case, there are 5 groups of transport modes, with 1 group having only one mode and 4 groups having two or more modes. The index has a maximum of 1.8 when an individual uses all modes in all groups with the same frequency. The distribution of the multimodality scores in this study is presented in Fig. 3, with a median score of 0.745.

3.2.2. Travel contexts

Travel contexts describe the defining interrelated conditions in which travel decisions occur (Lamondia & Bhat, 2012). In previous studies, individuals' travel contexts were depicted by a series of contextual variables, such as availability of personal vehicles, accessibility to public transport systems, level of service of public transport, ease and convenience of travel, and traffic conditions (Diana & Mokhtarian, 2009; Ettema et al., 2010; Lamondia & Bhat, 2012; Liao et al., 2020). The literature review suggested that travel contexts, including personal skills, vehicle ownership and mode access, travel constraints and perceptions of transport modes, may be related to the motivation and experience of multimodality. Thus, we derive a series of variables from the survey data to measure these four aspects of travel contexts (Table 2). Personal skills include the variables *holding a driver's license* and *using online mobility services*, respectively measuring the ability to drive and the ability to use digital devices for trip planning. Vehicle ownership and mode access include the variables *car ownership, bike ownership, public transport subscription* and *access to bus, tram, or metro* in neighbourhoods. The travel constraint variable *using mobility aids* measures whether the individual uses mobility aids or devices when travelling, which represents constraints of physical condition and capability.

Perceptions of transport modes are obtained from the exploratory factor analysis (Table 3). A battery of nine statements was formulated about individuals' feelings about car driving and public transport in neighbourhoods. Individuals were asked to report to what extent they agree with each statement on a five-point Likert scale ranging from (1) completely disagree to (5) completely agree. In factor analysis, we identified two factors, the first factor is represented by all statements related to car driving and the second factor is represented by all statements related to public transport. We named the first factor as *ease of driving* and the second factor as *good quality of PT*, and used them as two variables of the perceptions of transport modes. For each factor, if an individual scored higher than average, the individual was defined as category "Yes" for that variable; while if the score was below the average, then the individual was defined as category "No" for that variable.

3.2.3. Perceived transport adequacy and accessibility

According to the literature review, multimodal travel behaviour may influence an individual's assessment of the sufficiency and quality of transport and the accessibility to daily activities, so we use perceived transport adequacy and accessibility as individual outcomes to explore how individuals experience multimodality. Perceived transport adequacy and accessibility are measured by

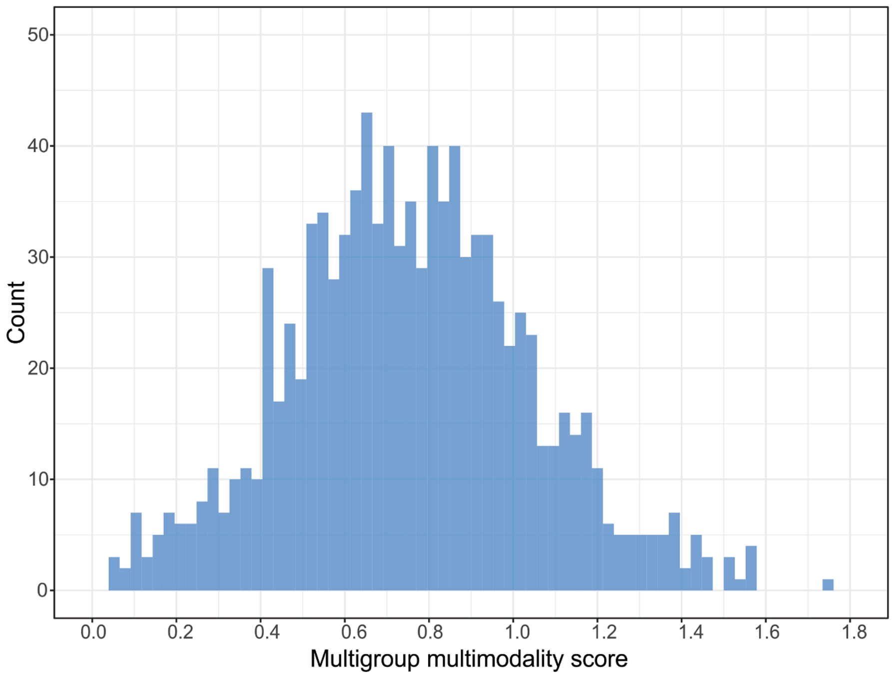

Fig. 3. The distribution of multimodality scores.

Table 2
Descriptive of travel contextual variables.

Variable		N	P (%)	Descriptive *Does/Is the individual…*
Personal skills				
Holding a driver's license	Yes	721	71.46	…hold a driver's license
	No	288	28.54	
Using online mobility services	Yes	510	50.55	…use online mobility services to plan trips
	No	499	49.45	
Vehicle ownership and access				
Car ownership	Personal car	419	41.53	…have a personal car
	Household car	104	10.31	…have a household car (rather than individual car)
	No car	486	48.17	…have no access to a car
Bike ownership	Yes	826	81.86	…have access to a personal bike (e-bike)
	No	183	18.14	
PT subscription	Yes	468	46.38	…have public transport subscription (student package)
	No	541	53.62	
Bus access	Yes	911	90.29	…have access to a bus in neighbourhood
	No	98	9.71	
Tram access	Yes	582	57.68	…have access to a tram in neighbourhood
	No	427	42.32	
Metro access	yes	417	41.33	…have access to a metro in neighbourhood
	No	592	58.67	
Travel constraint				
Using mobility aids	Yes	73	7.23	…use one or more mobility aids for travelling
	No	936	92.77	
Perceptions of transport modes [a]				
Ease of driving	Yes	440	43.61	…feel comfortable, easy, and enjoyable to drive
	No	569	56.39	
Good quality of PT	Yes	426	42.22	…feel PT affordable, accessible, and flexible in the neighbourhoods
	No	583	57.78	

[a] These two variables were generated from a factor analysis, the statements and their loadings for each factor are presented in Table 3.

Table 3
Factor loadings of perceptions of transport modes.

Statements	Factor loadings	
To what extent do you	Ease of driving	Good quality of PT
…feel comfortable driving a car	0.905	
…have a lot of experience driving a car	0.861	
…find it hard to drive under difficult conditions	−0.703	
…prefer not to drive	−0.836	
…feel PT available at times that are useful for him/her		0.809
…feel PT easy to understand how to use		0.800
…feel PT able to reach destinations or activities that are important		0.798
…feel PT accessible to people with reduced mobility		0.676
…feel PT affordable		0.663
Kaiser-Meyer-Olkin Measure of Sampling Adequacy: 0.785		

Rotation Method: Varimax with Kaiser Normalization.

exploratory factor analysis based on Mobimon scale developed by Ettema et al. (2023). The scale of perceived transport adequacy is based on Lucas et al. (2016)'s definition of transport poverty. Transport poverty is a binary state of whether transport is sufficient or insufficient, and transport adequacy on this basis measures the sufficiency and quality of transport on a continuous scale. The perceived transport adequacy scale combines factors that defined transport poverty by Lucas et al. (2016) with factors derived from perceived accessibility scale by Lättman et al. (2016), covering travel limitations, travel experience, access to destinations, and life outcomes. The scale of perceived accessibility consists of statements about the ease of reaching daily activities and destinations by transport (Table 4).

Respondents were asked to report to what extent they agree with each statement on a five-point Likert scale ranging from (1) completely disagree to (5) completely agree. Exploratory factor analysis was conducted on these two sets of items to further explore whether there are underlying attributes of perceived transport adequacy and accessibility. Two factors were extracted from the transport adequacy set, and they were defined as *perceived travel-related achievement* and *perceived travel-related disadvantage*. Perceived travel-related achievement measures an individual's perception of the extent to which transport options fulfil their daily needs with a minimal negative impact on health and safety, or in other words, the extent to which transport contributes to realizing life achievements. Perceived travel-related disadvantage measures an individual's perception of the extent to which the amount of time and money spent on travel is over budget. One factor was extracted from the accessibility set, so it was defined as *perceived accessibility*.

Table 4
Factor loadings of perceived transport adequacy and accessibility.

Set of items	Factor loadings	
Set 1 Transport adequacy		
To what extent do you agree with the following statements? With the transportation options available to me,	**Perceived travel-related achievement**	**Perceived travel-related disadvantage**
I can reach all my regular destinations and activities	0.808	
I feel safe while travelling to my regular destinations and activities	0.762	
I am able to live my life as I want to	0.741	
I can travel in a way that is suited to my physical condition and abilities	0.720	
There is always a transport option available to me at the times I need it	0.715	
I can travel without negative consequences to my health	0.641	
I have to spend more money on necessary travel in a week than I can afford		0.654
I spend much more time travelling than I would like		0.634
Kaiser-Meyer-Olkin Measure of Sampling Adequacy: 0.864		
Set 2 Accessibility		
To what extent do you agree with the following statements? With the transportation options available to me,	**Perceived accessibility**	
I can easily reach my GP, pharmacy, health centre	0.844	
I can easily reach the supermarket, local shopping area	0.821	
I can easily reach the hospital	0.802	
I can easily reach friends and family at their home	0.777	
I can easily reach the gym, team, hobby	0.730	
Kaiser-Meyer-Olkin Measure of Sampling Adequacy: 0.842		

Rotation Method: Varimax with Kaiser Normalization.

Perceived accessibility measures an individual's perception of how easy it is to reach daily activities and destinations by transport.

3.3. Analysis

In two analysis phases, the research respectively investigates how different travel contexts are associated with the degree of multimodality and how the degree of multimodality is associated with perceived transport adequacy and accessibility in different travel contexts.

In the first phase, we use multiple linear regression to evaluate the associations between a series of travel contextual factors as independent variables and the degree of multimodality as the dependent variable. Considering the heterogeneity in the degree of multimodality across different population segments, as well as the possible correlations between socioeconomic status and travel contexts, we additionally control for some socio-demographics in the model.

Then in the second phase, we use multiple linear regression to evaluate the associations between the degree of multimodality and each factor of perceived transport adequacy and accessibility. The regression is performed with a stepwise adjustment: step 1 regress the degree of multimodality as the explanatory variable on perceived transport adequacy and accessibility, while controlling for travel contexts and socio-demographics; step 2 further includes the interaction terms between the degree of multimodality and some car-related variables as explanatory variables on the basis of step 1. Such a stepwise form allows us to see whether the individual outcomes of multimodality depend on the travel contexts.

4. Results

4.1. Travel contexts associated with multimodality

Table 5 presents the results of regression on multimodality. Multimodality has associations with several travel conditions and constraints. Individuals who hold a driver's licence are less multimodal than those who do not. This result is consistent with previous studies showing that license holders are more likely to be monomodal drivers (Circella et al., 2019). It also indicates that those who cannot drive tend to be more multimodal. Driving can be the most flexible and fast way to reach certain destinations, but those without a license do not have the option to drive in any circumstances, even though it is the best way, so they need to use alternatives depending on the situation. The result suggests that multimodality could be a result of not being able to drive a car and having to use a combination of alternatives.

Having access to a personal car or household car is related to being more multimodal. Previous studies have tested the relationship between the number of household vehicles and multimodality, and the results show that people having more household vehicles have a higher possibility of being monomodal car users (Buehler & Hamre, 2015). However, these studies did not distinguish between drivers and passengers, which may lead to different results. Given the distinct roles of drivers and passengers in our index, individuals who have access to a car have two more options than those who have no access to cars, and may be more multimodal. Also, our research sample is from urban areas in the Netherlands, where active modes, especially cycling, also make up a high percentage of the mode share (Ton et al., 2019). Our regression results show that people who own a personal bike are significantly more multimodal than those who do not, and previous studies also suggested that there is a considerable number of multimodal drivers who frequently use active

Table 5
Regression on multimodality scores.

Dependent variable: multimodality (score)		Coefficient	t-value
Intercept		0.600***	13.169
Personal skills			
Holding a driver's licence		−0.065*	−2.359
Using online mobility service		0.029	1.657
Vehicle ownership and access			
Car ownership (ref = No car)			
	Personal car	0.069**	2.727
	Household car	0.069*	2.221
Owning a bike		0.128***	6.143
Having PT subscription		0.023	1.275
Bus access		0.016	0.623
Tram access		0.044*	2.164
Metro access		0.052	1.885
Constraints			
Using mobility aids		0.209***	5.509
Perceptions of transport modes			
Ease of driving		−0.008	−0.367
Good quality of PT		0.020	1.225
Socio-demographics			
Age		−0.080***	−7.328
Gender (ref = Male)			
	Female	−0.046*	−2.444
City (ref = Utrecht)			
	Rotterdam	0.033	1.114
Urbanicity (ref = lower levels)			
	Extremely urbanised	−0.053**	−2.821
Household income (ref = higher than average)			
	Lower than average	0.003	0.181
Single		−0.028	−1.436
Living with children		−0.024	−1.061
Work status (ref = Full-time job)			
	Part-time job	0.036	1.792
	Student	0.045	1.560
	Retired	0.103*	2.461
	No job	−0.061*	−2.056
Education level (ref = Medium education)			
	Low education	−0.050	−1.908
	High education	0.016	0.845
R^2		0.255	
Adjusted R^2		0.236	

*, **, and *** denotes significant at the significance level of 0.05, 0.01, and 0.001, respectively.

modes in the Netherlands (Molin et al., 2016). Therefore, personal car owners may also use active modes, while a few people may choose not to own a car because active modes can meet their daily travel needs, which makes personal car owners even more multimodal than those who have no access to cars. This result suggests that multimodality could be a free choice for situational optimization.

Tram access has a positive effect on multimodality, which implies that having better access to public transport may enable multimodal travel behaviour. The result can be explained by the evidence that public transport is always jointly used with active modes, which has been found in several Dutch studies (Kroesen, 2014; Molin et al., 2016). Surprisingly, individuals using mobility aids are more multimodal. Those who are disabled but can still use mobility aids like a cane or walker to travel have limited mobility. They are excluded from some transport modes, such as cycling and driving, while relying on others, such as public transport, taxi, and car as a passenger, so they may need to deliberately choose a travel mode in every certain situation considering the availability and accessibility of transport modes. The descriptive analysis of our data indicated that people who travel with mobility aids frequently use different kinds of public transport and travel as car passengers, as also found in another research by van den Berg et al. (2011).

Specific socio-demographic characteristics are associated with different levels of multimodality. Age has a strong negative association with multimodality. This result is consistent with the findings of most studies that young people are more likely to be multimodal (Buehler & Hamre, 2015; Heinen & Chatterjee, 2015). Nonetheless, our results show that retirees are more multimodal, which is in line with some previous studies (Heinen & Chatterjee, 2015; Nobis, 2007). A study on key life events and multimodality also found a significant increase in multimodality after retirement (Scheiner et al., 2016). This is presumably because retirees have flexible schedules and can engage in diverse activities, and they may choose different travel modes to different destinations (Oakil et al., 2014). The descriptive analysis of our data indicated that retirees more frequently use public transport in addition to the frequent use of bikes and cars, which may be explained by that in the Netherlands people over retirement age can use public transport for a discounted fee or for free (van den Berg et al., 2011). Contrary to most previous studies (Kuhnimhof et al., 2012; Vij et al., 2011), our model shows that women are less likely to be multimodal than men. Previous studies found that men are more monomodal because they are more car-dependent than women (Diana & Mokhtarian, 2008; Scheiner et al., 2016). However, in areas with a high proportion of active modes use, men, although more car-oriented, may also use active modes for daily travel, while women may travel mainly by active modes. Thus, different from studies based on car-oriented regions like the US and Germany, women in our study based on urban areas in the Netherlands are less multimodal.

People living in higher urbanised locations have a lower level of multimodality. It is different from the findings of Diana (2012) and Blumenberg and Pierce (2014), their studies based on Italy and the USA show that higher urbanicity correlates with a higher level of multimodality. In the Netherlands, where cities are more compact and active modes share a high percentage, people living in dense locations have better access to destinations and active modes can fulfil most needs. Compared with fully employed people, unemployed people are less multimodal. It is consistent with the findings of Heinen and Chatterjee (2015) and Buehler and Hamre (2015).

4.2. *Effects of multimodality on perceived transport adequacy and accessibility*

In this section, we assess the relationship between multimodality and the three indicators of perceived transport adequacy and

Table 6
Regression on perceived transport adequacy and accessibility.

	Perceived transport adequacy				Perceived accessibility	
	Perceived travel-related achievement		Perceived travel-related disadvantage			
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	−0.692***	−0.837***	0.153	0.521**	−0.398*	−0.680***
Multimodality (score)	−0.128	−0.031	0.454***	0.228	−0.369**	−0.476**
Personal skills						
Holding a driver's licence	0.046	0.074	−0.368***	−0.369***	0.149	0.169
Using online mobility services	−0.011	−0.008	−0.160**	−0.157*	0.106	0.103
Vehicle ownership and access						
Car ownership (ref = No car)						
Personal car	0.087	0.055	−0.032	−0.044	0.061	0.037
Household car	0.174	0.178	0.015	−0.009	0.054	0.086
Owning a bike	−0.036	−0.021	−0.240**	−0.240**	−0.020	−0.013
Having PT subscription	−0.068	−0.068	−0.010	−0.013	−0.129*	−0.134*
Bus access	0.266**	0.275**	0.092	0.081	0.137	0.131
Tram access	0.143*	0.144*	−0.017	−0.019	0.125	0.129
Metro access	−0.017	−0.010	−0.074	−0.067	0.058	0.070
Constraints						
Using mobility aids	−0.471***	−0.458***	0.049	0.070	−0.407***	−0.379**
Perceptions of transport modes						
Ease of driving	0.364***	0.354***	−0.284***	−0.288***	0.322***	0.329***
Good quality of PT	0.569***	0.567***	−0.076	−0.080	0.523***	0.514***
Socio-demographics						
Age	0.068	0.079*	−0.018	−0.017	−0.035	−0.031
Gender (ref = Male)						
Female	0.087	0.093	−0.103	−0.111	0.147*	0.144*
City (ref = Utrecht)						
Rotterdam	−0.181	−0.183	−0.003	−0.014	−0.154	−0.171
Urbanicity (ref = lower levels)						
Extremely urbanised	0.184*	0.192**	0.151*	0.148	0.062	0.062
Household income (ref = higher than average)						
Lower than average	0.014	0.031	0.183**	0.191**	−0.086	−0.070
Single	−0.164*	−0.179*	0.018	0.012	−0.055	−0.052
Living with children	−0.079	−0.088	0.165*	0.173*	−0.020	−0.029
Work status (ref = Full-time job)						
Part-time job	0.029	0.029	−0.155*	−0.140	0.137	0.150*
Student	−0.062	−0.068	0.007	−0.004	−0.053	−0.033
Retired	−0.059	−0.065	−0.563**	−0.553**	0.379*	0.388*
No job	−0.007	0.007	0.145	0.147	0.027	0.040
Education level (ref = Medium)						
Low education	−0.144	−0.151	−0.064	−0.069	−0.202*	−0.209*
High education	0.117	0.116	0.013	0.011	0.012	0.002
Interaction terms						
Holding a driver's licence × Multimodality		0.307		0.394		0.544
Personal car × Multimodality		−0.090		0.188		0.040
Household car × Multimodality		−0.320		0.401		−1.046**
Ease of driving × Multimodality		−0.659**		−0.384		−0.483
R^2	0.235	0.241	0.164	0.169	0.204	0.214
Adjusted R^2	0.215	0.218	0.142	0.143	0.183	0.189

*, **, and *** denotes significant at the significance level of 0.05, 0.01, and 0.001, respectively.

accessibility, while focusing specifically on the moderating effects of license ownership, car ownership and ease of driving. Table 6 presents the results of step-wise models. We plotted the quantitative assessments between the interaction terms and perceptions to further illustrate their relationship (Fig. 4).

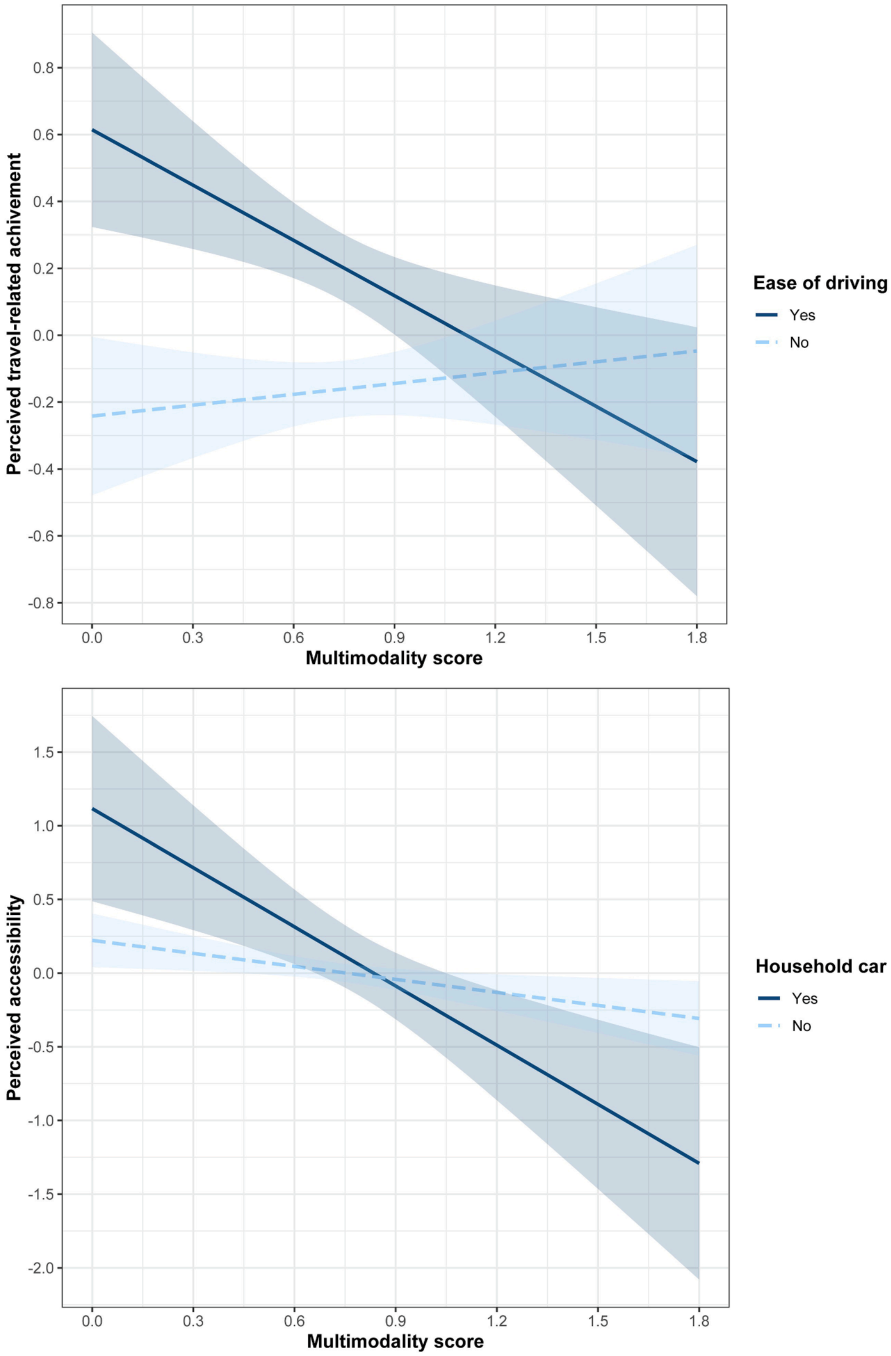

Fig. 4. Relationship between perceived transport adequacy and accessibility and the interactions of car-related travel contexts and multimodality. In each line chart, the x-axis represents the multimodality score, and the y-axis represents the predicted value of the corresponding perception. Since the moderators (car-related travel contexts) in our analysis are all dummy variables, there are two lines in each chart, with the slope indicating effect size and the shadow area indicating the confidence interval for each category. The slope is the total of the conditional effect of multimodality on the perception (the coefficient of the single variable in the second model of each perception in Table 6) and the effect brought by the change of the moderator (the coefficient of the interaction term in Table 6). In our analysis, the effect size for the reference group is equal to the conditional effect.

4.2.1. Perceived travel-related achievement

Perceived travel-related achievement (hereinafter referred to as perceived achievement) is the first component of perceived transport adequacy which measures to what extent the individual's daily activity needs and living standards are achieved with low health and safety impacts through their daily travel. On the whole, multimodality has no significant effect on perceived achievement. Among all vehicle ownership and access variables, only bus access has a positive effect on perceived achievement, implying that having bus access in the neighbourhoods may help individuals achieve their daily needs. Perceptions of both the ease of driving and good quality of public transport have a strong positive effect on perceived achievement. These two variables are measured based on individuals' experience, so having a better experience using a car or public transport may also improve the experience of daily activities enabled by travel and reduce safety and health concerns in daily travel. Using mobility aids has a negative effect on perceived achievement, indicating that disability restricts daily activities and may increase safety and health concerns in daily travel.

The influence of multimodality on perceived achievement depends on whether the individual experiences the ease of driving (Fig. 4). For people who can drive with ease, multimodality has a negative effect on perceived achievement, while for those who do not, the effect is positive, although very small. Previous studies have shown that monomodal car users are the largest monomodal group and have low intentions to change their travel behaviour (Molin et al., 2016). People who can drive with ease may have a greater propensity to travel by car; if they are more multimodal, they may be subject to certain restrictions on driving in some circumstances. Failure to meet all needs in a preferred way may reduce satisfaction. Meanwhile, taking driving as a reference, comparisons of travel experiences make them feel worse when using less attractive modes and may make them feel unsafe and unhealthy. Still, the ease of driving reflects a better driving experience, so individuals who feel the ease of driving have higher perceived achievement than those who do not, as long as they are not particularly multimodal.

4.2.2. Perceived travel-related disadvantage

Perceived travel-related disadvantage (hereinafter referred to as perceived disadvantage) is the second component of perceived transport adequacy which measures the extent to which an individual spends excessive time or money on daily travel. On the whole, a higher level of multimodality is related to higher perceived disadvantage. This finding supports the idea of Nobis (2007) that the use of multiple transport modes, especially during one trip, is always associated with higher "transaction costs", in the sense of higher requirements for the procurement of information and geographic and temporal organization.

Personal skills (holding a driver's licence and using online mobility services) are both possible to reduce perceived disadvantage. Driving is a fast and flexible choice in many circumstances and being able to drive results in lower time and money budgets (Kent, 2014). Using online mobility services makes it easier to obtain travel information, adjust travel plans in time and avoid unnecessary troubles, which helps people save time and money during travelling (Miramontes et al., 2017). Thus, the results suggest that the better ability to get information and organize geography and time reduces the use of money and time. Owning a personal bike reduces perceived disadvantage significantly. Since the urban settings and cycling infrastructures are friendly to cyclists in the Netherlands, cycling is a convenient and affordable travel mode. In our sample, more than 80% of people own a personal bike. Those who do not have a bike may be unable to cycle or have to travel longer distances in daily life, so they may spend more time and money on transport. Feeling the ease of driving reduces perceived disadvantage. Having better driving experiences can be related to travelling fast and within budget. Low-income households have higher perceived disadvantage due to a limited travel budget. People living with children have higher perceived disadvantage possibly because they not only travel to meet their own needs but also travel to meet their children's needs, which makes them restricted by more family matters and have less liberty. Part-time jobs and retirement make people perceive fewer disadvantages, possibly because their schedule is more flexible and do not need to travel at specific times, such as rush hours.

No interaction terms are significant in this model, so the effects of multimodality on perceived disadvantage do not differ between multimodality with and without cars.

4.2.3. Perceived accessibility

Perceived accessibility measures an individual's feeling of how easy it is to access their regular activities or daily needs. On the whole, multimodality has a negative effect on perceived accessibility. If individuals are more multimodal, they probably have to reach some regular activities using multiple transport modes within a single trip, which makes the individual feel inconvenienced and perceive lower accessibility (Weliwitiya et al., 2019). Ease of driving and high-quality public transport both have positive associations with perceived accessibility. Having a better experience using a car or public transport may also make people feel that it is more convenient to reach their destinations and activities. However, having a public transport subscription is associated with lower perceived accessibility. People who use public transport for regular activities and destinations are more likely to have a public transport subscription. Since public transport is found often not to the users' preference (De Vos, 2018; Kroesen et al., 2017), they may be reluctant riders who are forced to use public transport due to not being able to use the preferred mode (Anable, 2005). Individuals using mobility aids have a lower level of perceived accessibility. This finding shows that disability does constrain daily activities and reduce living standards.

The interaction of household car and multimodality has a significant negative effect on perceived accessibility (Fig. 4). For people who have a household car (rather than a personal car), being more multimodal is related to even lower perceived accessibility than those who have no access to cars. At a medium level of multimodality, individuals having a household car or having no access to a car perceive the same level of accessibility, if they are less multimodal, those having a household car perceive higher accessibility; while if they are more multimodal, having a household car perceive lower accessibility. Having a household car rather than a personal car means that an individual needs to share one car with other family members, so if they are more multimodal, they may have fewer chances to use the car and have to use alternatives, which makes them perceive lower accessibility (Li et al., 2022). Mao et al. (2016) also found that multimodal travellers with driving as the main travel mode have lower trip satisfaction, which may relate to the household car being occupied by the spouse. Thus, not being able to drive in some circumstances may force a habitual driver or a car-dependent individual to be multimodal, in which context multimodality can lead to an even lower perceived accessibility.

5. Discussion and conclusion

Multimodality is presented as essential in the move toward more sustainable mobility because it is associated with a reduction of car use and carbon emissions, although it is unclear whether the impact of multimodality at the individual level is negative or positive. To investigate how individuals experience multimodality, the study constructed a multigroup multimodality index to measure a continuum of multimodality, and then used the generated scores to analyse how different travel contexts are associated with multimodality and how multimodality influences perceived transport adequacy and accessibility in different travel contexts. The findings can inform policymakers and practitioners on how to balance environmental and social values in the promotion of multimodal transport.

The first finding is that multimodality could either be a free choice based on diverse options or a necessity due to the inability to use a car or other specific modes. Being more multimodal is associated with certain conditions including using online mobility services, owning a personal car, and having access to a tram in neighbourhoods. This finding is consistent with most previous studies showing that multimodality is a case of situational optimization for people with more options and resources (Buehler & Hamre, 2015; Heinen & Chatterjee, 2015; Kuhnimhof et al., 2006). On the other hand, our results show that certain constraints including not having a driver's licence, and using mobility aids or devices are also related to a higher level of multimodality. This finding indicates that multimodality could be a consequence of being not able to use a car or being excluded by certain modes and having to use a combination of alternatives. Furthermore, in contrast to the study by Diana (2012) in Italy and the study by Blumenberg and Pierce (2014) in the US, our results show that in the Netherlands, people living in high-density locations are less multimodal. This may be because of the different urban forms and transport systems in different countries since Dutch cities are more compact and have a higher active mode share. These results suggest that multimodality can be a joint consequence of different transport conditions and constraints, and research on multimodality should consider different situations, depending on different socioeconomic and spatial contexts.

The second and main finding is that multimodality is generally felt as a burden because multimodal travellers experience more inadequacies of transport and lower accessibility, and those who experience the ease of driving or have limited access to cars experience multimodality even worse (Fig. 5). Using multiple transport modes requires higher procurement of information and better organization of time and space, which costs more time and money (Nobis, 2007) and results in higher perceived travel-related disadvantage. The need to switch between different modes of transport may reduce travel intention, resulting in a limited space for daily activities and fewer opportunities for socializing, which makes individuals perceive lower accessibility. For those who experience the ease of driving, being more multimodal could mean not being able to use a preferred way for all trips, which results in a worse travel experience; comparing the travel experiences between driving and other modes may also lead to a lower perception of fulfilment and more concerns about safety and health. For those who share one car with other family members, being more multimodal could mean having fewer chances to use the car, and having to use alternatives in certain circumstances; inflexibility in car use may reduce the flexibility of travel time and space, which may also limit access to certain activities and destinations.

In conclusion, even in a highly urbanised context, multimodal travellers spend more time and money on daily travel, and they

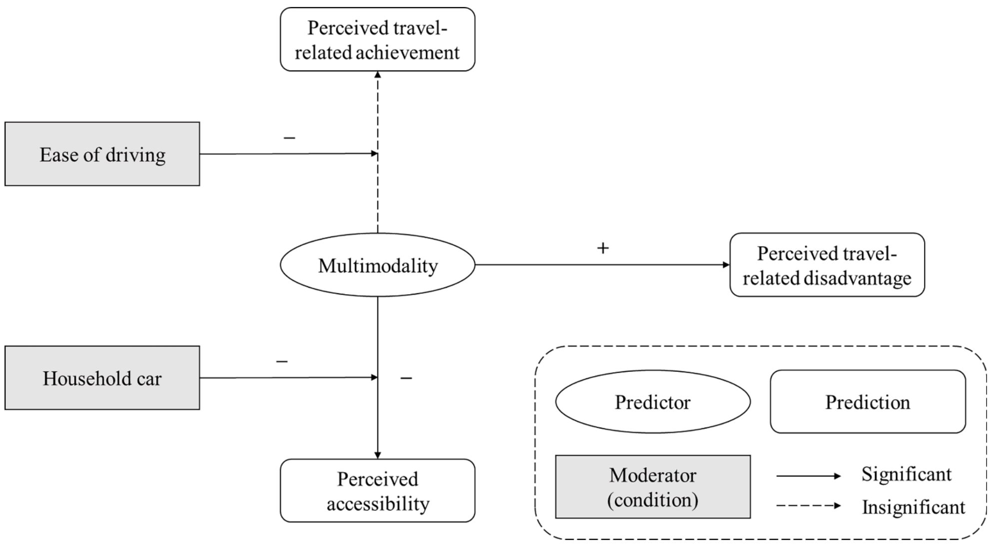

Fig. 5. The relationship between multimodality and perceived transport adequacy and accessibility in different travel contexts.

experience more inconvenience and difficulty reaching regular activities and destinations, especially for those who rely on cars but have to be multimodal due to limited access to cars. Thus, multimodality, in its current form, may not be attractive. Enhancing or simply maintaining transport adequacy and accessibility while encouraging multimodality is a big challenge for policymakers and practitioners.

Our research proposed a new measure of multimodality and increases the understanding of the contexts in which multimodality occurs and how individuals experience it. Future research may extend the present study in the following ways. The first is about multimodal measurement. Previous studies have found that the degree of multimodality may depend on the time period of observation, with longer time periods capturing greater variability in travel behaviour and showing higher levels of multimodality (Buehler & Hamre, 2016; Mao et al., 2016; Nobis, 2007). Our measurement is based on a relatively long time period. In future research, travel information including self-reported frequency, and travel diaries from different periods can be used to compare multimodality in different dimensions. The second is the inference of motivations for multimodality. Based on the information contained in Mobimon survey, we used some indirect evidence as a proxy of whether people choose multimodality or are forced to do so. Future work requires a more detailed survey design for multimodality as the main research object, directly measuring what are the motivations for multimodality. The third is to simultaneously measure the degree of multimodality and distinguish the patterns of multimodality. The present study used an index to investigate associations between the degree of multimodality and perceived transport adequacy and accessibility. Future research may further look into how these outcomes related to different patterns of multimodality in terms of the combination of modes, for example, a combination of public transport and active modes may differ from a combination of driving and active modes.

Our research findings may provide policy implications in promoting multimodality and reducing car use from two perspectives. First, current policies may underestimate the negative externalities in the promotion of multimodality. A more comprehensive assessment of the effects of multimodality on the environment, society and different population segments is needed when formulating multimodal policies and planning. Although the environmental benefits of multimodality have been widely acknowledged, possible negative individual outcomes have been overlooked. Based on our findings, multimodal travellers more often report suffering lower transport adequacy and accessibility, especially those relying on driving but being multimodal due to limited access to cars. Thus, current policies and interventions that motivate people to reduce car use and switch to multimodal travel may not be so effective because people are reluctant to use alternatives to cars. Some people may be forced to do so due to not being able to drive, which may reduce their quality of life. In Utrecht, for example, the municipality plans to reduce the number of parking spaces by 750 to 1,500 per year to stimulate the use of alternatives to cars. To aid this policy, there is a need to assess which groups to which extent will be negatively affected and add complementary measures to enhance their transport option set and minimize adverse impacts.

Second, policymakers should be concerned about making multimodality more affordable and convenient. Our findings show that multimodality costs excessive time and money in daily travel and reduces accessibility to regular activities and destinations. They also show that multimodality is more likely to be related to the combined use of public transport and slow modes. Thus, the excessive costs can be the result of heavy transfers between different modes and expenses on separate segments by public transport. Improving the transfer facilities and increasing the connectivity between public transport and slow modes can reduce the inconvenience by shortening transfer time. For example, making a railway station more accessible to pedestrians by providing more walkable streets and more entrances/exits, shortening transfer distances for cyclists by providing bike parking next to public transport stations. Providing travel products consisting of different modes of public transport and shared micro-mobility (e.g., shared bike, shared e-bike) with a discounted price may make multimodality more affordable and attractive. For example, in the Netherlands, since train, local public transport, and shared micro-mobility are operated by different agencies, travellers have to subscribe to season tickets for different travel modes separately. People may be captive to a certain transport mode that they subscribe to, as our findings show that having a public transport subscription is related to lower perceived accessibility. Therefore, if packages bundling various transport modes are offered, travellers can purchase one combination on an on-demand basis, and flexibly choose the optimal mode for different trips.

CRediT authorship contribution statement

Xingxing Fu: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft, Visualization. **Dea van Lierop:** Conceptualization, Methodology, Data curation, Writing – review & editing, Supervision. **Dick Ettema:** Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration.

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.

Acknowledgements

The authors wish to thank all participants of the Mobimon survey. We would also like to thank the Chinese Scholarship Council for providing the PhD scholarship. This study was funded by an NWO Pop Up Grant (438.19.174) and with financial support of the city of Rotterdam.

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