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Weather, transport mode choices and emotional travel experiences

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ABSTRACT

With climate change high on the political agenda, weather has emerged as an important issue in travel behavioural research and urban planning. While various studies demonstrate profound effects of weather on travel behaviours, limited attention has been paid to subjective weather experiences and the psychological mechanisms that may (partially) underlie these effects. This paper integrates theoretical insights on outdoor thermal comfort, weather perceptions and emotional experiences in the context of travel behaviour. Drawing on unique panel travel diary data for 945 Greater Rotterdam respondents (The Netherlands), this paper aims to investigate how and to what extent weather conditions affect transport mode choices, outdoor thermal perceptions and emotional travel experiences. Our findings point out that observed dry, calm, sunny and warm but not too hot weather conditions stimulate cycling over other transport modes and – via mechanisms of thermal and mechanical comfort – lead to more pleasant emotions during travel. Overall, public transport users have less pleasant emotional experiences than users of other transport modes, while active mode users appear most weather sensitive. The theoretical contributions and empirical findings are discussed in the context of climate change and climate-sensitive urban planning.

1. Introduction

With the increased scientific evidence for climate change (IPCC, 2013) and political interest in climate change adaptation and mitigation, weather and climate change have become important issues in transport planning and travel behavioural research. Research initially focussed predominantly on the effects of weather extremes on transport infrastructures (for an overview see e.g. Transportation Research Board, 2008). Recently, various scholars have investigated the effects of daily weather conditions on individual travel behaviours, including the use of transport modes (for reviews, see Koetse and Rietveld, 2009 and Böcker et al., 2013a). Many recent studies link objectively measured weather conditions to existing or self-gathered travel behaviour data and generally conclude that higher – but not too high – air temperatures enhance walking and cycling over the use of motorised transport modes, whereas precipitation sum and wind speed have opposite effects (e.g. Sabir, 2011; Ahmed et al., 2010; Creemers et al., 2014). In contrast, we know very little about how weather is perceived during travel, how it affects our emotions, and via which mechanisms it affects transport mode choices. Addressing these research gaps is crucial (1) to better understand the effects of weather and changing climate conditions on travel behaviour,

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(2) to assess its impact on daily emotional wellbeing during travel, and (3) to expand climate-sensitive urban planning (Eliasson et al., 2007; Lenzhölzer and Wulp, 2010) to places and infrastructures of (active) mobility.

Existing knowledge on the experience of weather and its effects on emotions can be found mostly outside, and disconnected from, the field of transport studies. Exceptions are a Dutch study on transport mode choices in relation to weather, outdoor weather perceptions and place valuations (Böcker et al., 2015), and a Portuguese study investigating bus travel experiences in relation to (amongst other factors) subjective indoor thermal comfort (Carreira et al., 2014), both of which use structural equation modelling. To deeper investigate these subjectivities, this paper draws on biometeorological insights into the relationships and discrepancies between objectively measured and subjectively perceived weather conditions in terms of thermal and mechanical comfort (e.g. Thorsson et al., 2007; Eliasson et al., 2007; Oliveira and Andrade, 2007), and psychological insights into the relationship between weather, moods and emotions (for a review, see Kööts et al., 2011). We integrate these insights, both theoretically and empirically into the context of travel behaviour, hereby addressing recent calls for a more interdisciplinary approach of this subject (Eliasson et al., 2007; Böcker et al., 2013a).

It is our aim to investigate how and to what extent weather conditions affect transport mode choices, outdoor thermal perceptions and emotional travel experiences. Hereto, purposely-designed Greater Rotterdam (Netherlands) travel diary data (n = 945) – including ecological momentary assessments (EMA) of outdoor thermal perceptions and emotions (i.e. happiness, irritation, fear and tiredness) – are connected to local urban form and hourly meteorological data and analysed in structural equation models. This paper first summarizes the main findings from the literature on the effects of weather on transport modes, outdoor thermal comfort, and emotions and moods. Second, it introduces the study area, dataset and modelling framework. Third, it describes and explains the main findings in relation to the literature. Finally, it concludes with a discussion of the main findings and its policy and research implications.

2. Literature

Over the last few decades, transport research, originating mostly from maritime and continental climates in Europe, North America and Australia, has investigated the effects of temperature, precipitation and wind on transport mode choices (for literature reviews, see Koetse and Rietveld, 2009; Böcker et al., 2013a). Studies typically link (national) travel survey data to publicly available weather records from nearby meteorological stations. Regarding air temperature, studies generally find a positive effect on walking and cycling compared to motorised transport, particularly car usage (e.g. Hanson and Hanson, 1977; Sabir, 2011; Creemers et al., 2014; Liu et al., 2015). However, some others point out that this relationship between temperature and transport mode choice may be nonlinear. Above a certain optimum between 24 °C and 30°, high temperatures have been found to negatively affect walking in Montreal (e.g. Aultman-Hall et al., 2009), or cycling in Melbourne (e.g. Phung and Rose, 2008; Ahmed et al., 2010) and the Netherlands (Thomas et al., 2013; Böcker and Thorsson, 2014). When it comes to precipitation sum and wind speed, studies generally agree on more or less linear negative effects on walking and cycling and positive effects on particularly car usage (e.g. Phung and Rose, 2008; Sabir, 2011; Böcker and Thorsson, 2014; Creemers et al., 2014; Liu et al., 2015).

Where transport researchers have mostly analysed the effects of objectively measured weather conditions, biometeorologists and health scientists have also linked people's behavioural responses to weather conditions and their subjective assessments in terms of *outdoor thermal comfort*. Hereby, outdoor thermal comfort is commonly defined as "that condition of mind which expresses satisfaction with the outdoor thermal environment and is assessed by subjective evaluation" (ANSI/ASHRAE, 2004: 2). For instance three studies on urban park attendances in Japan and Sweden (Thorsson et al., 2007; Eliasson et al., 2007), a study on individual psychological weather adaptations in the United Kingdom (Nikolopoulou and Steemers, 2003), and a study on leisure activities in the USA (McGinn et al., 2007), point out that outdoor thermal comfort results from combinations of different meteorological variables, such as air temperature, relative air humidity, solar radiation and wind speed. The relationship between weather and comfort has not only thermal aspects. The exposure to wind or precipitation – or a combination of both as wind-driven rain – may have direct implications for comfort levels, for instance related to related to moist in the eyes, flapping clothes, hair disturbances, or even loosing balance and being blown over (e.g. Bottema, 1993; Blocken and Carmeliet, 2004). Such direct physical aspects, often referred to as *mechanical comfort*, have mostly been studied through wind tunnel experiments in the field of wind engineering (e.g. Blocken and Carmeliet, 2004), but are in reality often difficult to disentangle from thermal comfort (Oliveira and Andrade, 2007).

To acquire insights into the relationships between weather and emotions during travel, we need to draw on existing psychological knowledge of weather and longer-term moods (e.g. Kööts et al., 2011). Mood has often been linked to seasonality, for instance via the cyclical syndrome Seasonal Affective Disorder (Rosenthal et al., 1984), usually referring to winter depression. Also amongst the general population, scholars have confirmed the idea that moods are worst in winter and best in summer (e.g. Oyane et al., 2008), although also empirical evidences for mood dips outside winter exist (e.g. Ozaki et al., 1995; Huibers et al., 2010). Other studies link moods directly to individual weather conditions. First, the number of sunshine hours and the level of solar radiation have been found to increase mood levels (e.g. Cunningham, 1979; Schwartz and Clore, 1983; Howarth and Hoffman, 1984; Barnston, 1988; Albert et al., 1991; Denissen et al., 2008; Ciucci et al., 2011). More specifically sunshine has been found to reduce sadness (Ciucci et al., 2011), cynicism, doubtfulness (Howarth and Hoffman, 1984), tiredness and sluggishness (Denissen et al., 2008), and increase optimism, concentration (Howarth and Hoffman, 1984) and mental activeness (Albert et al., 1991). The relationship between exposure to sunshine and positive mood is strongly embodied:

exposure to sunlight, via the production of vitamin D_3 in the skin, influences levels of serotonin in the human brain and elevates mood and energy levels (Lambert et al., 2002; Lansdowne and Provost, 1998). In addition to sunshine, higher air temperatures have been found to increase general levels of mood (e.g. Cunningham, 1979; Barnston, 1988; Denissen et al., 2008). More specifically Howarth and Hoffman (1984) point out that higher air temperatures increase levels of concentration and very low temperatures (under −8 °C) increase feelings of aggressiveness. Both heat (e.g. Palamerek and Rule, 1980; Bell, 1981) and extreme cold (Schneider et al., 1980) can be seen as sources of discomfort that may lower the barrier for people to behave aggressively. Compared to air temperature and sunshine, psychological mood research paid relatively little attention to the effects of precipitation and wind speed. Nevertheless, Denissen et al. (2008) document a link between wind and negative aspects of mood; Barnston (1988) finds that rain reduces morale and increases irritation; Schwartz and Clore (1983) link rain to a lack of positive mood aspects; and Howarth and Hoffman (1984) find rain to increase scepticism.

The above-mentioned three strands of literature on the effects of weather on respectively travel behaviour, weather comfort and emotions, can be brought together into a travel situational framework. Hereto, we need to theorise about the causalities between transport mode choices, outdoor thermal perceptions, and emotional experiences. First, because the literature indicates that outdoor thermal perceptions play an important role in experiencing comfort, emotional experiences can be seen as a consequence of outdoor thermal perceptions. Second, both outdoor thermal perceptions and emotional experiences reported during the trip can be seen as consequences of the different environmental exposures resulting from the transport mode choices, which are made in advance of a trip. In this travel situational framework, the effects of weather conditions on mode choices, outdoor thermal perceptions and emotional travel experiences cannot be viewed separately from other contextual factors, such as personal, household, trip and spatiotemporal contexts. For instance, thermal comfort studies indicate that women (e.g. Karjalainen, 2012; Kenawy and Elkadi, 2012*)* and older people (e.g. Tuomaala et al., 2013) experience cold weather as colder and warm weather as warmer than men and younger age groups. Also peoples' physical activity levels and clothing (e.g. Havenith et al., 2002) as well as peoples (culturally defined) weather preferences and attitudes towards being outdoors and staying in the sun (e.g. Knez and Thorsson, 2006; Thorsson et al., 2007) may play a role in the way people perceive weather and in the way it affects their emotional experiences. Finally, the exposure to weather, and therefore its effect on peoples' emotional travel experiences, may differ between different spatial configurations within the city. For instance, some studies demonstrate that green, wind-exposed or shadowed environments are perceived as colder than concrete, sunlit or wind-sheltered environments (e.g. Nikolopoulou and Lykoudis, 2007; Phung and Rose, 2008; Lenzhölzer and Wulp, 2010), although others point out that the relationships between urban form and microclimate conditions may differ significantly between different seasons (e.g. Theeuwes et al., 2014).

3. Methodology

3.1. Study area and data

The study area for this research is Greater Rotterdam: a coastal port region in the west of the Netherlands, which is part of the densely populated and economically important Randstad Holland region (Fig. 1). The region has a maritime climate with mild winters (lows: 1 °C; highs: 6 °C), warm summers (lows: 12 °C; highs: 21 °C), and precipitation ranging from 158 mm in spring to 258 mm in autumn (KNMI, 2013). The rationale for selecting Greater Rotterdam as a study area is threefold: First, the area has a diverse population in terms of socio-demographics, socio-economic status and cultural backgrounds. Second, the area offers a large variety of spatial environments, ranging from post-Second-World-War mid- and high-rise areas in the city centre to a mix of compact historic towns, lower-density satellite towns, and villages in surrounding areas. Third, local politicians pursue and promote active policies regarding both climate change mitigation and adaptation, which makes the region interesting in terms of knowledge dissemination.

This study is based on a travel diary survey (used in four earlier studies: Böcker and Thorsson, 2014; Helbich et al., 2014; Böcker et al., 2015, 2016) conducted from August 2012 to February 2013. From an existing Internet panel, 945 respondents aged 18 or older were randomly assigned six regular days[1] (two in summer, two in autumn and two in winter), to participate in a travel diary research. Following Moskowitz and Young (2006) an ecological momentary assessment (EMA) methodology was used, which implicates that respondents report repeated measurements of weather perceptions and emotional experiences in on site travel diaries, which can then directly be linked to reported travel behaviours. Respondents were distributed equally over different residential environments (see Fig. 1) and we oversampled for people aged 65 or older and people with non-western ethnicities, because of lower expected response rates and unique weather preferences for these groups. Although representativeness has never been a primary aim, our sample represents the Greater Rotterdam population well on several key socio-demographic statistics like gender, age and household size (CBS, 2013), but non-western ethnicities and lower-educated are underrepresented. For more information on the sample composition, see Böcker and Thorsson (2014) and Böcker (2014).

The trip data from the travel diaries are enriched with external data in two steps. First, through geocoding of trip origins and destinations based on Dutch cadastral data (2014) and subsequent shortest path estimations based on ESRI street data (2008), trip data are spatially linked in ArcGIS to route-specific urban form and land use characteristics. Following

[1] Regular days contain weekends and weekdays, but exclude respondents' vacations or days of illness.

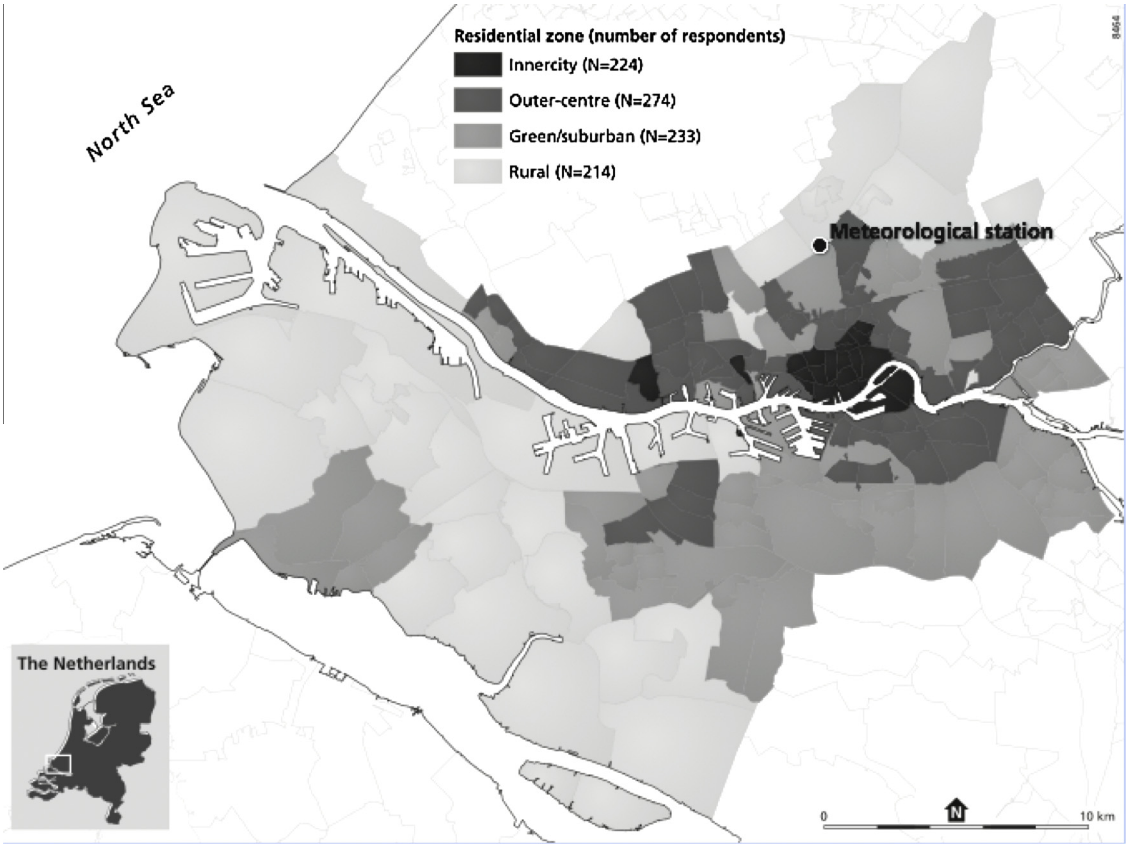

Fig. 1. Study area. *Source:* Böcker and Thorsson (2014). Administrative level: 4-digit postal codes.

Schlossberg et al. (2006), a 200 m buffer is used, which is small enough to capture most of the nearby surroundings that have most impact on the traveller, while giving some margin with regard to peoples' potential route deviations from the calculated shortest paths. From a 100 m^2-cell grid three urban form and land use indicators are extracted: address density (number of residential and non-residential addresses per cell); greenness index (surface-area proportion of green space); and a Shannon index for building usage diversity (a value of 0 refers to one single building usage; higher values refer to areas with more mixed building usages like residential, offices, shops and public services).[2] Second, trip data are linked to hourly meteorological data from a local Royal Dutch Meteorological Institute (KNMI, 2013) weather station (Fig. 1). Our analysis includes the effects of hourly average air temperature,[3] precipitation sum, wind speed, and clearness index. The latter indicates whether sky conditions are clear (values close to 1) or cloudy (values close to 0) and is defined as the ratio between the observed and the theoretical maximum incoming solar radiation given the specific time and location on the earth's surface (Crawford and Duchon, 1999). Additionally, we control for whether or not snow-cover had been accumulated on the ground, as this may affect travel behaviours and emotions. During the survey period, the Greater Rotterdam area had been subjected to a wide range of weather conditions (Fig. 2), such as dry and warmer-than-average weather (with a peak of 34 °C) in late August; warmer-than-average but very wet weather in December; and colder-than-average weather in mid-January with sub-zero maximum air temperatures and permanent snow-cover on the ground.

3.2. Multivariate modelling techniques

In our multivariate analyses use is made of Structural Equation Modelling (SEM), via the software package Mplus. SEM is chosen over other multivariate modelling techniques, such as regular and multinomial logistic regression, because it (1) combines factor and structural models and (2) allows analysing multiple equations simultaneously (Hair et al., 2010).

[2] Building usage diversity and address density are extracted from the 2014-dataset 'Basisregistraties, Adressen en Gebouwen (BAG)'. Greenness is extracted from the 2001-dataset 'Landelijk Grondgebruiksbestand Nederland (LGN)'.

[3] Instead of hourly air temperature, we have also explored analysing the effect of hourly Physiological Equivalent Temperature (PET). This is a thermal index, based on the human heat balance equation that combines air temperature, solar radiation humidity (Mayer and Höppe, 1987). Because of limited differences between the two, air temperature is preferred to ease interpretability.

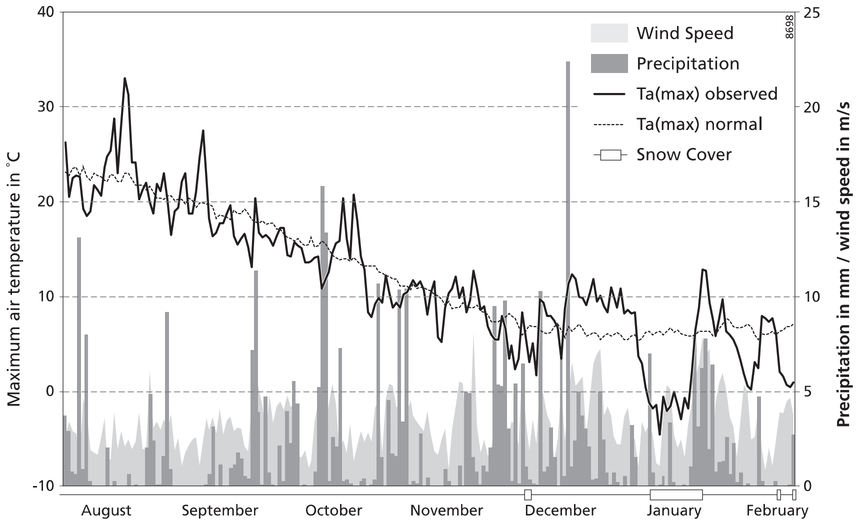

Fig. 2. Rotterdam weather conditions during survey period. *Source:* Helbich et al. (2014).

First, SEM enables us to analyse the effects on emotional travel experiences in a *factor* model based on four separate items – i.e. happiness, fear, irritation and tiredness – covering several emotional dimensions including positive/negative affect and level of activeness. Hereto we asked respondents to respond on 5-point Likert scales to the following four statements: "During my trip I feel predominantly: *sad*-1-2-3-4-5-*happy*; *without fear*-1-2-3-4-5-*anxious*; *satisfied*-1-2-3-4-5-*irritated*; *energetic*-1-2-3-4-5-*tired*" (Böcker, 2014). Inspired by Ecological Momentary Assessments (EMA) (Stone and Schiffman, 1994), these measurement scales are directly integrated into the travel diary so that respondents respond *repeatedly* (each trip), *on-site*, and *at the time of travelling*. This minimises inaccurate responses due to information recall (Moskowitz and Young, 2006) and enables us to link emotions directly to weather and travel behavioural choices on the trip level. A principal component analysis was conducted, which revealed a one-factor solution for emotional travel experiences on which happiness loads positively and fear, irritation and tiredness load negatively. We performed an internal consistency reliability analysis,[4] which revealed a respectable Crombach's alpha of 0.81 (Lance et al., 2006) as well as corrected item correlations ranging from 0.53 (for tiredness) to 0.68 (for irritation) indicating a good scale (Ferketich, 1991).

Second, SEM allows integrating this emotional travel experience factor model as a dependent variable into a *regression* model. But unlike regular regression analysis, SEM models may contain more than one dependent variable. In our regression model we analyse the effects of weather on (1) transport mode choices, (2) outdoor thermal perception, and (3) emotional travel experience, whereby we define the mediating mechanisms between these three dependent variables to be based on the causalities discussed at the end of Section 2. Hereby we control for various contextual factors: *personal attributes* (age, gender, ethnicity, obesity[5]) and *attitudes* (favourite season, environmental consciousness,[6] urban/rural orientation[7]), *socio-economic attributes* (income, education), *transport resources* (number of cars in the household, yes or no public transport card ownership, yes or no bicycle ownership and what type), *trip attributes* (trip purpose, trip distance, whether a trip is direct or via a detour), and *temporal/spatial attributes (*weekday/weekend, peak/off-peak, day/nighttime, address density, building usage diversity, greenness). The above-mentioned control variables as well as the earlier mentioned weather variables are all directly measured and included as independent variables in the model. Age, number of cars, the three attitude variables, the three spatial attributes and the weather variables are included as continuous variables. The other independent variables are categorical and are therefore recoded into binary variables (dummies) with reference categories. Fig. 3 presents the final SEM modelling framework.

4. Analysis

4.1. Descriptive analysis

This section provides a descriptive overview of the effects of objectively measured weather on the three dependent variables in this study: outdoor thermal perceptions, transport mode choices, and emotional travel experiences. Table 1 demon-

[4] Just to run the internal consistency reliability analysis we inverted the happiness scale into a sadness scale indicating 1 for happy and 5 for sad, so that it is in line with the direction of the other three scales.

[5] Respondents are categorised obese if their Body Mass Index (weight in kg divided by squared height in m) ⩾ 30.

[6] To what extent a respondent is overall environmentally conscious in his/her daily life (e.g. regarding saving energy, recycling, consumption, travel), measured on one 5-point Likert scale as an ordinal variable.

[7] To what extent a respondent is urban- (values street-life/shops/amusements of the city) or rural-oriented (values natural amenities) measured on a two-sided 5-point Likert scale as an ordinal variable (following Knez, 2005).

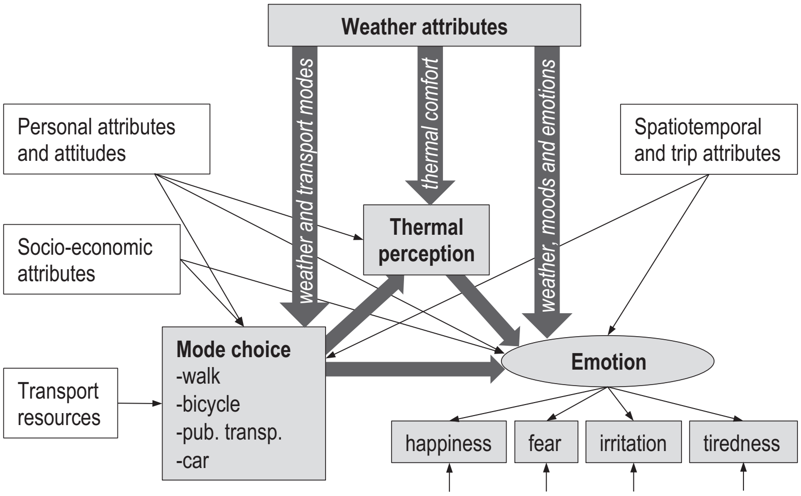

Fig. 3. SEM modelling framework.

Table 1
Distribution of subjective outdoor thermal experience for different air temperature intervals.

	Percentage of respondents who perceive outdoor thermal conditions as (thermal comfort score[a] in parentheses)...									Thermal comfort score[a]
	Very cold (−4)	Cold (−3)	Cool (−2)	Slightly cool (−1)	Comfortable (0)	Slightly warm (1)	Warm (2)	Hot (3)	Very hot (4)	
Objective T_a										
<0 °C	29%	57%	9%	2%	4%					−3.1
0–5 °C	4%	48%	29%	8%	12%					−2.3
5–10 °C		24%	40%	19%	17%					−1.7
10–15 °C		8%	30%	28%	32%	2%				−1.1
15–20 °C			11%	19%	49%	12%	8%			−0.1
20–25 °C				1%	27%	18%	40%	11%		1.3
25–30 °C					7%	8%	44%	31%	10%	2.2
⩾30 °C					4%	2%	14%	47%	33%	2.9
Total	3%	17%	21%	14%	25%	6%	10%	4%	1%	−0.8

[a] Nine-point (−4 to 4) score for perceived outdoor thermal comfort (based on Matzarakis and Mayer, 1996).

strates the relationship between objectively measured air temperature and peoples' subjective outdoor thermal perceptions. Naturally, colder conditions are experienced as colder and warmer conditions as warmer. Overall, it appears that people perceive air temperatures as most comfortable at 15–20 °C. Considerable thermal discomfort during travel is perceived from 0 to 5 °C downwards (too cold) and from 25 to 30 °C upwards (too hot). However, in line with the literature (e.g. Thorsson et al., 2007) clear discrepancies can be observed between objectively measured thermal conditions and outdoor thermal perceptions. These are illustrated by the bandwidths of subjective thermal interpretations during similar air temperature intervals. Based on these figures, it could be hypothesised that similar air temperatures are perceived differently under different combinations of weather conditions, amongst different people using different transport modes, and/or in different geographical settings. Via our SEM model in Section 4.2 we will further examine this hypothesis.

Fig. 4 compares the mean modal split averages for different classifications of hourly weather conditions. Congruent to the literature (e.g. Sabir, 2011; Creemers et al., 2014) higher hourly air temperatures lead to an increased usage of open-air active transport modes, especially cycling, while car and public transport shares decrease. However, the relationship between air temperature and transport modes is not entirely linear. In line with other studies (e.g. Phung and Rose, 2008; Ahmed et al., 2010; Thomas et al., 2013; Böcker and Thorsson, 2014) it seems that above a thermal optimum between 20 and 25 °C, the above-mentioned positive effects of air temperature flatten out, or when it comes to cycling even reverse. Also when air temperatures fall below zero, walking and public transport shares increase while car usage decreases, potentially related to slippery road conditions. When looking at the effects of sky clearness, it can be seen that clear, sunny sky conditions (higher CI values) increase active transport modes over car and public transport usage, while dark or heavily clouded sky conditions (lower CI values) have opposite effects. Finally, congruent to the literature (e.g. Sabir, 2011; Creemers et al., 2014), precipitation sum and higher wind speeds (above 4–6 m/s) decrease the usage of active over motorised transport modes. An exception is walking, which increases for the higher precipitation classes.

Fig. 5 indicates the effects of hourly weather conditions on emotions experienced while travelling. Positive effects of an increase of air temperature and sky clearness can be observed on happiness reported during trips, and slightly negative

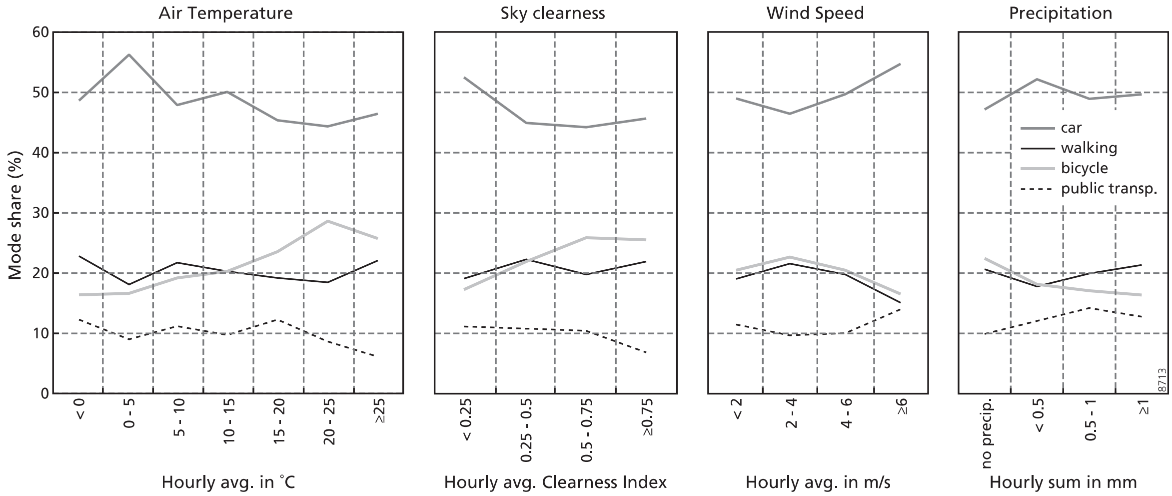

Fig. 4. Weather and modal split.

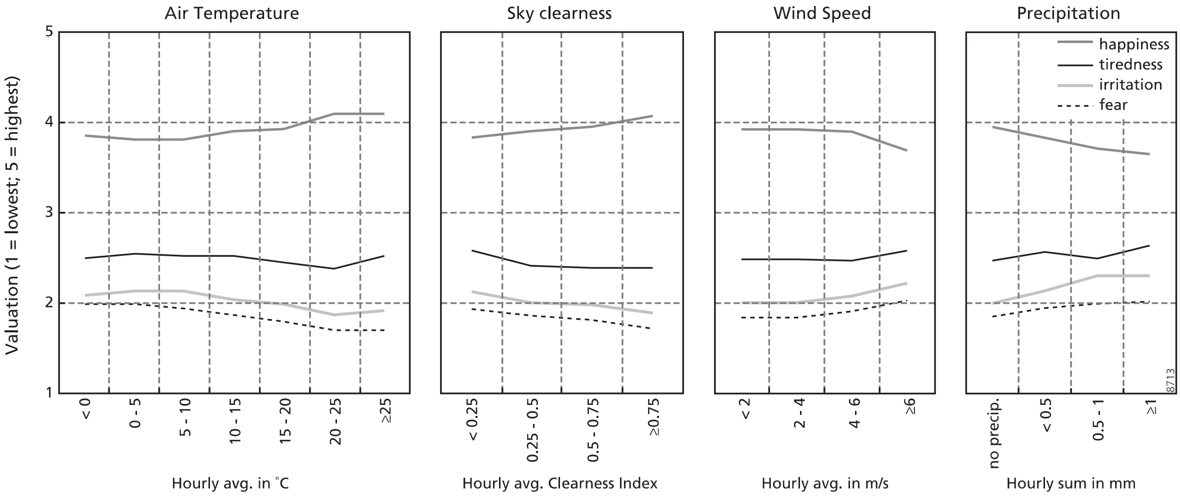

Fig. 5. Weather and emotional travel experiences.

effects on tiredness, irritation and fear. These findings are in line with the literature on weather and moods demonstrating that higher air temperature and sunshine enhance positive affects like happiness and enthusiasm while decreasing negative affects like fear, irritation and disgust (e.g. Cunningham, 1979; Denissen et al., 2008; Howarth and Hoffman, 1984) and aspects of fatigue like tiredness and sleepiness (Goldstein, 1972; Howarth and Hoffman, 1984). An exception is our finding that above 25 °C happiness no longer increases, fear no longer decreases and tiredness and irritation even increase. This indicates that not only cold but also hot weather conditions may negatively affect emotions, as suggested in some earlier studies (e.g. Schneider et al., 1980; Bell, 1981). In contrast to air temperature and sky clearness, precipitation sum and wind speed (although only above 4–6 m/s) have negative effects on emotional experiences, which is in congruence with e.g. Schwartz and Clore (1983).

4.2. Multivariate analysis

Table 2 presents four SEM-models. The models are similar, but each utilizes another dependent dummy variable for mode choice. The three columns in each model present standardized coefficients and their significance levels for the three dependent variables: mode choice, outdoor thermal perception (Tfeel), and emotional travel experience (emotion). The factor model in the upper section of Table 2 indicates that the item happiness loads positively on emotion and the items tiredness, irritation and fear load negatively. The regression model has been constructed, based on the paths presented in Fig. 3. The models fit rather well to the data, as indicated by a Root Mean Square Error of Approximation (RMSEA) well below the critical 0.05 level and Comparative Fit (CFI) and Tucker Lewis indices (TLI) well above the critical 0.95 levels.

Table 2
Full-sample structural equation models for the different transport modes.

	SEM: Standardized coefficients: estimator = WLSMV[a], cluster = person-id[b], N = 11759 trips											
	Model 1: Walking			Model 2: Cycling			Model 3: Public transport			Model 4: Car		
	Walk	Tfeel	Emotion	Bicycle	Tfeel	Emotion	Pub. tr.	Tfeel	Emotion	Car	Tfeel	Emotion
Factor model												
Happiness			0.877			0.878			0.877			0.877
Irritation			−0.827***			−0.827***			−0.827***			−0.827***
Fear			−0.768***			−0.768***			−0.768***			−0.768***
Tiredness			−0.657***			−0.657***			−0.658***			−0.657***
Regression model[c]												
Personal & attitudes												
Age	0.071***	−0.021	0.108***	−0.114***	−0.028**	0.116***	−0.066	−0.020	0.105***	0.063**	−0.024*	0.113***
Male (D)	−0.037*	0.036***	0.073*	−0.069*	0.033**	0.074**	0.058	0.035***	0.076**	0.077***	0.033**	0.073**
Nonwestern ethn. (D)	0.005	−0.007	0.011	−0.073**	−0.010	0.014	0.068**	−0.008	0.017	0.018	−0.007	0.012
BMI: Obese (D)	−0.061***	0.007	0.014	−0.057*	0.005	0.013	0.007	0.008	0.011	0.105***	0.004	0.014
Summer person (D)	0.019	−0.022*	0.046	−0.014	−0.023*	0.047	−0.005	−0.022*	0.046	0.017	−0.023*	0.047
Environm. conscious	0.028	−0.005	0.143***	0.094***	−0.001	0.141***	−0.018	−0.005	0.143***	−0.094***	−0.002	0.141***
Rural-oriented	−0.026	0.017	−0.009	0.074**	0.021*	−0.013	−0.038	0.018	−0.014	−0.013	0.018	−0.011
Socio-economic												
Educ. middle (D)	−0.026		−0.004	0.008		−0.005	0.004		−0.004	0.034		−0.004
Educ. higher (D)	0.018		−0.093*	−0.036		−0.091*	−0.085*		−0.099**	0.056		−0.090*
Hh-income €3–4 K (D)	−0.015		0.068*	−0.042		0.068*	0.009		0.068*	0.031		0.067*
Hh-income >€4 K (D)	−0.017		0.017	0.010		0.016	−0.037		0.013	0.003		0.016
Hh-income unkn. (D)	−0.029		−0.031	−0.011		−0.032	0.044		−0.029	0.007		−0.032
Transport resources												
# Cars in hh	−0.042**			−0.125***			−0.274***			0.274***		
Pub-tr. card (D)	0.002			0.057*			0.255***			−0.194***		
Bike for city (D)	−0.031			0.302***			0.037			−0.135***		
Sports/e-bike(D)	−0.038			0.341***			−0.059			−0.145***		
Trip attributes												
Travel together (D)	0.012		0.031	−0.198***		0.039*	0.034		0.035*	0.149***		0.036*
Detour (D)	0.051***		0.001	0.030**		0.002	−0.016		0.002	−0.077***		0.001
Weekend (D)	0.017		0.048*	−0.002		0.049*	−0.078**		0.042	0.022		0.049*
Peak hour (D)	0.005		−0.025*	0.013		−0.025*	0.043*		−0.021	−0.026*		−0.025*
12 AM–6 AM (D)	0.004		0.007	0.031**		0.006	−0.006		0.007	−0.025**		0.007
Trip for work (D)	−0.717***		0.037	−0.391***		0.016	0.167***		0.016	0.217***		0.009
Errands (D)	−0.201***		−0.126***	0.017		−0.136***	0.145***		−0.124***	0.124***		−0.132***
Social (D)	−0.078***		−0.079***	0.014		−0.083***	−0.136***		−0.094***	0.119***		−0.079***
Travel distance	−0.081***		−0.024	0.018		−0.028	−0.062**		−0.033*	0.117***		−0.024
Trip environment												
Building diversity	0.019		0.020	−0.005		0.021	−0.017		0.019	−0.006		0.020
Address density	0.068***		−0.017	0.000		−0.014	0.043		−0.010	−0.132***		−0.018
Green % (log-transf.)	−0.025		0.031	0.059**		0.027	−0.129***		0.019	0.025		0.030
Weather												
Ta >25 °C (D)	0.017	0.144***	−0.042**	−0.005	0.144***	−0.041**	−0.013	0.144***	−0.043**	−0.003	0.144***	−0.041**
Ta >15 – ⩽20 °C (D)	0.025	−0.298***	−0.020	−0.026	−0.299***	−0.017	0.076***	−0.300***	−0.011	−0.03*	−0.297***	−0.020

(continued on next page)

Table 2 (*continued*)

	SEM: Standardized coefficients: estimator = WLSMV[a], cluster = person-id[b], N = 11759 trips											
	Model 1: Walking			Model 2: Cycling			Model 3: Public transport			Model 4: Car		
	Walk	Tfeel	Emotion	Bicycle	Tfeel	Emotion	Pub. tr.	Tfeel	Emotion	Car	Tfeel	Emotion
Ta >10 – ⩽15 °C (D)	0.031[*]	−0.493[***]	−0.015	−0.062[***]	−0.496[***]	−0.010	0.050[*]	−0.495[***]	−0.008	−0.002	−0.494[***]	−0.014
Ta >5 – ⩽10 °C (D)	0.031[*]	−0.691[***]	−0.038	−0.072[***]	−0.694[***]	−0.032	0.071[**]	−0.693[***]	−0.028	−0.008	−0.691[***]	−0.037
Ta >0 – ⩽5 °C (D)	0.002	−0.557[***]	−0.020	−0.064[***]	−0.560[***]	−0.016	0.008	−0.557[***]	−0.018	0.039[**]	−0.559[***]	−0.019
Ta ⩽0 °C (D)	0.034	−0.672[***]	0.038	−0.026	−0.673[***]	0.042	0.035	−0.673[***]	0.044	−0.015	−0.671[***]	0.037
Psum (in mm)	0.010	−0.014[**]	−0.042[***]	−0.031[*]	−0.016[**]	−0.040[***]	0.029[**]	−0.015[**]	−0.038[***]	0.000	−0.014[**]	−0.041[***]
Ws (in m/s)	−0.020	−0.071[***]	−0.031	−0.014	−0.072[***]	−0.031	0.034	−0.072[***]	−0.028	0.026	−0.072[***]	−0.031
Snowcover (D)	0.021	0.000	−0.035	−0.065	−0.003	−0.031	0.039	−0.001	−0.031	0.001	0.000	−0.034
CI ⩾0.5 – <0.75 (D)	0.004	−0.026[***]	−0.009	0.024	−0.025[**]	−0.010	0.047[**]	−0.028[***]	−0.005	−0.026	−0.025[**]	−0.010
CI ⩾0.25 – <0.5 (D)	0.021	−0.050[***]	−0.023	−0.010	−0.051[***]	−0.022	0.040	−0.052[***]	−0.018	−0.009	−0.05[***]	−0.022
CI <0.25 (D)	0.025	−0.046[***]	−0.046[**]	−0.006	−0.046[***]	−0.044[**]	0.012	−0.046[***]	−0.044[**]	−0.013	−0.045[***]	−0.045[**]
CI: darkness (D)	0.002	−0.059[***]	−0.053[**]	−0.067[***]	−0.062[***]	−0.050[**]	0.019	−0.059[***]	−0.051[**]	0.061[**]	−0.061[***]	−0.051[**]
Mediators												
Walk/bike/pub./car (D)[d]		−0.015[**]	0.051		−0.050[***]	0.042		0.025[*]	−0.088[**]		0.038[***]	−0.034
Tfeel			0.118[***]			0.121[***]			0.120[***]			0.117[***]
Model quality												
Dep. var. R^2	0.647	0.692	0.125	0.349	0.693	0.126	0.395	0.692	0.131	0.398	0.692	0.125
Model Chi^2 (df.)	301(156)[***]			312(156)[***]			321(156)[***]			290(156)[***]		
RMSEA/CFI/TLI	0.009/0.989/0.982			0.009/0.988/0.980			0.009/0.990/0.983			0.009/0.988/0.980		

[a] Estimator is weighted least squares means and variance adjusted.
[b] Clustered sampling technique has been applied, which deals with the trip data that are clustered within respondents.
[c] Reference categories for dummy variables (D): female; ethnicity = native-Dutch; BMI = not obese; favourite season is not summer; educ. = lower; hh-income < €3000; no pub-tr. card; bike = none; weekday; off-peak; 6 AM–12 AM; trip purpose = leisure; Ta > 20 ⩽ 25 °C; CI ⩾ .75.
[d] Mediator transport mode is walk (yes vs. no) in walking model, bicycle (yes vs. no) in cycling model, etc.
[*] Significance: $p < .1$.
[**] Significance: $p < .05$.
[***] Significance: $p < .01$.

4.2.1. Mode choices

Table 2 presents the effects on transport mode choices in the first column of each model. Overall, the models explain the variance in transport mode choices relatively well (i.e. 65% for walking, 35% for cycling, and 40% for public transport and car usage), for instance when compared to other Dutch studies (e.g. Sabir, 2011: 32%; Böcker et al., 2013b: 16%). The relatively high explained-variances in this study may be contributed to the inclusion of a detailed set of weather conditions, personal attitudes, and trip specific details (i.e. travel companion and route-environmental attributes) in addition to the standard control variables. In this paper we will focus on the effects of weather conditions on mode choices. The effects of other socio-demographic, socio-economic, transport resource and trip-specific background variables on mode choices are largely in line with earlier studies (e.g. Cervero and Seskin, 1995; Dieleman et al., 2002; Bühler, 2011).

When controlled for all of the above, weather appears to have a relatively modest impact on mode choices. On the plus side, because of this controlling the remaining effects reflect better the true effects of weather on mode choices. In line with our descriptive findings and earlier studies (e.g. Sabir, 2011; Creemers et al., 2014), precipitation sum (Psum) has a negative effect on cycling and a positive effect on public transport usage. Wind speed (Ws) and snow cover have no significant effects. Also daytime sky clearness (Clearness Index –CI) does not have a clear significant effect on transport mode choices. Only during darkness, when CI values cannot be estimated, we observe an increase in car usage at the cost of cycling. Finally, air temperature has a nonlinear effect on transport mode choices. Lower air temperature intervals, when compared to the optimal 20–25 °C riding temperature, have a negative effect on cycling and a positive effect on walking and public transport usage. However, not only lower but also higher air temperatures above 25 °C may negatively affect cycling, although this effect cannot be statistically confirmed. This may indicate a negative impact of heat on cycling found in some earlier studies (e.g. Lewin, 2011; Ahmed et al., 2010).

4.2.2. Outdoor thermal perceptions

Table 2 presents the effects on subjective outdoors thermal perceptions in the second column of each model (indicated by 'Tfeel'). In accordance with the SEM modelling framework (Fig. 3), outdoor thermal perception is regressed on personal attributes, weather conditions, and the mode choice. Socio-economic factors, transport resources and trip attributes are not expected to influence the way people perceive outdoor thermal conditions. The effects of trip environments on outdoor thermal perceptions were tested, but were found non-significant and reduced the model fit. These paths have therefore not been specified. Overall, the models explain a large share of the variance in outdoor thermal perceptions (around 69%).

Most of the variance in outdoor thermal perceptions can be explained by a combination of observed weather conditions. Obviously, a dominant relationship exists between air temperature and outdoor thermal perception. People perceive air temperatures as colder under lower air temperatures than the reference category of 20–25 °C, and as hotter during air temperatures above 25 °C. Additionally, however, outdoor thermal perceptions are affected positively by sky clearness and negatively by wind speed and precipitation. It is thus the combination of higher air temperatures, sunshine, dry and/or calm weather that makes people perceive outdoor thermal environments as warmer, and the combination of low air temperatures, cloudy, dark, wet and/or windy weather that makes people perceive outdoor thermal environments as colder. These findings are in line with several thermal comfort studies on urban park attendances (e.g. Thorsson et al., 2007), but are now confirmed for everyday travel.

Section 4.1 briefly explored the discrepancy between observed and experienced outdoor thermal conditions. Table 2 confirms our expectation that outdoor thermal experiences during travel differ between different people. Our findings are in line with existing biometeorological insights that women (e.g. Karjalainen, 2012; Kenawy and Elkadi, 2012) and older age groups (e.g. Tuomaala et al., 2013) experience outdoor thermal environments overall as colder and less comfortable than men or younger age groups. Compared to native Dutch people, people with a non-western ethnicity, often originating from warmer climate backgrounds, have colder outdoor thermal experiences, but this effect is non-significant. This non-significance may be related to the relatively small share of non-western ethnicities in the sample (10.4%). In line with e.g. Tuomaala et al. (2013), obesity was not found to influence outdoor thermal conditions. Finally, weather preferences seem to play a role. People who reported summer as their favourite season perceive outdoor thermal conditions as colder, than those who have other favourite seasons. In contrast to Eliasson et al. (2007) we could not statistically confirm a difference in outdoor thermal sensation between urban and rural-oriented people.

In line with our expectations, transport mode choices significantly affect the way people perceive outdoor thermal conditions. Weather-exposed active mode users, especially cyclists, perceive colder air temperatures as colder and therefore less comfortable than users of motorised modes. Especially the weather protected and climate-controlled car user seems to experience less discomfort related to cold weather conditions. Unfortunately, because of the limited sample of extremely warm days in our data, we were not able to run a separate SEM model specifically for hot days to investigate whether during hot weather these relationships would be the same. However, additional descriptive comparisons give an indication that during hot weather (above 25 °C) different transport mode users' outdoor thermal experiences are more similar.

4.2.3. Emotional travel experiences

Table 2 presents the effects on the construct of emotional travel experiences in the third column of each of the four models. As pointed out in the factor model at the top of Table 2, emotional travel experience is constructed on the positively loaded item happiness and the negatively loaded items irritation, fear and tiredness. The models explain less of the variance in emotional travel experiences (around 13%) than of the variances in transport modes and outdoor thermal perceptions. This comes as no surprise, as emotional experiences may be affected by many other factors not included in the model.

First, we will investigate the effects of personal backgrounds on emotional travel experiences. This analysis shows that emotional travel experiences differ between people. Men and older people report more pleasant emotions than women and younger people. These findings are in line with meta-analyses in the field of subjective well-being, which report modest but significant positive effects of age (e.g. Stock et al., 1983) and amongst men (e.g. Haring et al., 1984; Inglehart and Rabier, 1986), although others found no significant gender or age effects (for an overview see Diener et al., 1999). Additionally, reported emotional travel experiences are more positive amongst middle-income groups compared to the reference category of lower-income groups, and less positive amongst higher educated. When looked at personal attitudes, environmentally conscious people appear to have more pleasant emotions during travel.

In addition to personal backgrounds, Table 2 presents the effects of trip-characteristics. Most importantly, emotional travel experiences seem to be related to trip purpose. As expected, people experience more pleasant emotions during leisure trips as compared to social and especially errands trips. Surprisingly, no significant differences can be identified between leisure and work trips. It could be that controlling for weekends and travelling during peak hour already captures this variation. As expected, people experience significantly less pleasant emotions on weekdays and during peak hour, although these effects are relatively small. Also longer distance trips lead to slightly less pleasant emotions, but this effect is only significant when controlled for whether or not people travel by public transport. Additionally, people experience marginally more pleasant emotions when travelling together. Travelling deliberately via a detour has no significant effect on emotional travel experiences. Also urban form characteristics of the trip environment have no significant effect on the way people experience emotions during travel. Although it should be mentioned that detailed data on spatial variation may have gone lost due to our spatial matching process – i.e. the lack of route information, buffer size, and aggregation of spatial characteristics over the course of entire trips.

Also weather affects emotional travel experiences. Unlike most existing studies that look at the direct effects of weather on long-term moods (e.g. Cunningham, 1979; Denissen et al., 2008), we identify how weather affects short-term emotional experiences during travel: directly, as well as indirectly, via outdoor thermal perception. Regarding the *direct* effects of weather parameters on emotions, the model confirms the descriptives and the literature. In line with several studies on the relationships between weather and mood (e.g. Cunningham, 1979; Albert et al., 1991; Denissen et al., 2008; Ciucci et al., 2011), low sky clearness indices representing cloudy weather result in less pleasant emotional travel experiences, while sunny weather conditions – known for increasing happiness-enhancing serotonin in the brain (e.g. Lambert et al., 2002; Lansdowne and Provost, 1998) – lead to more pleasant emotions. Also during darkness, when sunshine is absent and sky clearness cannot be calculated, people experience less pleasant emotions. As expected, and in congruence with Schwartz and Clore (1983), Denissen et al. (2008) and Barnston (1988), precipitation and wind speed negatively affect emotional experiences, although the effect of wind speed cannot be statistically confirmed. When it comes to the direct effects of air temperature, hot weather (above 25 °C), has a negative effect on emotions during travel. This gives evidence for a negative impact of heat on emotional well-being as indicated by few studies on weather and moods (e.g. Schneider et al., 1980; Bell, 1981). Colder air temperatures have no direct significant effect on emotions. Instead, temperature affects emotion mostly *indirectly* via outdoor thermal perception. Colder outdoor thermal perceptions strongly negatively affect emotions during travel. Also wind speed, precipitation sum and low sky clearness have indirect negative effects on emotional travel experiences via colder outdoor thermal perceptions, in addition to their earlier discussed direct effects.

When comparing the four different models, it appears that emotional travel experiences differ amongst different transport mode users. As for the effects of weather, both direct and indirect mechanisms can be identified. *Directly*, public transport users experience less pleasant emotions, compared to the other transport modes. This is in line with literature reporting the lowest travel satisfaction amongst public transport users compared to other transport modes (e.g. Friman et al., 2013). However, we observe no positive effect of car usage on emotional travel experiences, as indicated by existing studies mentioning the pleasure, comfort and freedom associated with car usage (e.g. Mokhtarian and Salomon, 2001; Steg, 2005; Jakobsson, 2007; De Vos et al., 2013). In contrast to existing studies (e.g. Friman et al., 2013) our SEM model reveals no significant *direct* effect of the use of active transport modes on emotional travel experiences. *Indirectly* however, weather-exposed active mode users, because they experience outdoor thermal environments as colder and less comfortable, have less pleasant emotional travel experiences. On the other hand, car users, benefiting from self-created comfortable indoor thermal environments for most of their journey, are only limitedly exposed to outdoor conditions. As a result they indirectly experience more pleasant emotions.

5. Conclusions and discussion

With climate change adaptation and mitigation high on scientific and political agendas, over the last decade many studies investigated the effects of weather on travel behaviour, especially on the use of healthy, environmentally friendly, congestion reducing, but weather-exposed active transport modes. However, in these existing transport studies, subjective experiences of both weather conditions and emotions during travel have been largely underexplored. It was our aim to investigate how and to what extent weather conditions affect transport mode choices, outdoor thermal perceptions and emotional travel experiences. Hereto, greater Rotterdam (The Netherlands) diary data on travel behaviour and ecological momentary assessments (e.g. Moskowitz and Young, 2006) of outdoor thermal perceptions and emotions during travel, connected to local urban form and weather data, were analysed by means of structural equation models (SEM).

By integrating biometeorological and wind engineering knowledge on weather comfort and psychological knowledge on weather and moods into the context of travel behaviour, this paper makes two important theoretical contributions to the existing transport literature. First, while controlling for the effect of weather on transport mode choices, two important mechanisms reveal that weather forms an integral part of the emotional travel experience. One is the *direct mechanism* of negative effects of precipitation, wind speed and cloudiness on emotional travel experiences. It highlights the role of *mechanical (dis)comfort* associated with the threat of clouds, blowing wind, and/or getting wet. The other is an *indirect mechanism*, mediated by outdoor thermal perceptions, highlighting the role of *thermal (dis)comfort*. Increased air temperature and decreased precipitation, sky clearness and wind speed result in warmer outdoor thermal perceptions and subsequently more pleasant emotional travel experiences. An exception is when temperatures exceed 25 °C. This negatively affects emotions directly. Second, our findings demonstrate that outdoor thermal perceptions and emotional travel experiences differ across transport mode user groups and population categories. Pedestrians, and especially cyclists, have generally favourable emotional travel experiences, especially when compared to public transport users. However, being weather-exposed, they also experience travel environments as colder and are more sensitive to lower temperatures, clouds, precipitation and wind. Colder thermal perceptions with negative impacts on emotional travel experiences are also found amongst women and older people.

The insights generated in this paper are valuable for policy makers in several ways. When aiming to stimulate the use of sustainable but environmentally-exposed active transport modes, it is more important than for car or public transport policies to look beyond instrumental factors, such as time and financial costs, and pay close attention to perceptions and emotions. Via thermal perceptions and emotional travel experiences, weather appears to have an indirect impact on the quality of walking and cycling. It may be hypothesised that weather conditions affect the value of travel time, especially regarding the use of active transport modes. This could have important implications to the relative competitiveness of different transport modes and the functioning of transport systems. It underscores the importance to integrate currently absent weather aspects in the large-scale transport models and cost benefit analyses that inform and evaluate most transport policy (Böcker et al., 2013a; Liu et al., 2016). The same counts for different scenarios of climate change. Our finding that hot weather and precipitation negatively affect emotional travel experiences already at present highlights the challenges posed by a future climate, which in the Netherlands, as well as many other parts of the world, is expected to feature more frequent, intensified and prolonged episodes of heat and heavy precipitation. Moreover, the here-documented higher weather sensitivities amongst some societal groups, such as women or older people, demonstrate possibilities for differentiated urban and transport policies on these issues.

An important way to improve the attractiveness of active transport modes, and alleviate potential negative consequences of climate change, is through careful spatial planning with climate consequences in mind on multiple geographical scales (Böcker, 2014). On a city-region level, compact and diverse urban design me be preferred, as reduced distances and increased shelter by buildings could reduce weather exposures to pedestrians and cyclists (Helbich et al., 2014). On a neighbourhood level, spatial orientations with regard to natural ventilation, sun and shading patterns, and the expansion of green space, could alleviate heat and improve air quality (Konarska et al., 2014). On a street level, wind barriers, and roofing could provide wind and precipitation shelter, especially in areas heavily frequented by pedestrians and cyclists or on weather exposed infrastructures such as bridges. Finally, on the level of individual buildings, implementation of passive cooling and the use of light, reflective materials (i.e. that absorb less heat) or vegetation on walls, roofs and street-facing gardens could improve indoor and outdoor thermal comfort (Klemm et al., 2013).

To better inform policy makers on these issues, further research is recommended to advance the integrated interdisciplinary knowledge presented in this paper in several directions. First, studies may further explore the complexity of causalities between weather perceptions, emotional experiences and travel behaviour. For instance it may be explored whether travel behaviours not only affect, but are also affected by, weather perceptions and emotions. Hereto, studies with a similar ecological momentary assessment methodology of repeated connected measurements may more explicitly use the longitudinal structure of the data and for instance relate transport mode choices at one point in time to experiences at previous points in time. Second, studies may further explore the lead and lagged effects of weather on transport mode choices and emotional travel experiences. Weather (forecast) observations before a trip may not only affect transport modes, but also weather experiences during a trip when one relates these to weather expectations. Similarly, weather observations after the trip may affect how we evaluate our weather experience. One may feel extra pleased to having experienced sunny weather and be home just in time before one observes the start of pouring rain. Third, it may be investigated if, and to what extent, the here explored effects of weather on comfort and emotional travel experiences are reflected in people's attitudes towards transport modes and people's valuations of travel time. One may generally dislike public transport, but prefer it to cycling when it is cold, rainy or windy. One may also be willing to spend more time walking or cycling, possibly even making detours, under pleasant weather conditions. Fourth, studies may further elaborate on the different weather exposures between social groups; especially the effects on potentially vulnerable target populations, such as elderly, young people, or ethnic groups, each with their distinctive sensitivities and preferences towards weather and mobility. Fifth, empirical studies from different cultural and climatological backgrounds are needed to verify our findings in different climate contexts. For instance, people's weather perceptions and emotional or behavioural responses to weather, may differ considerably in warmer climate regimes where people have to deal with heat, not occasionally but during the course of entire seasons, for instance by developing habits like having a siesta. Finally, in addition to global climate differences, studies should investigate different behavioural and emotional responses to weather on smaller geographical scales (i.e. between regions, cities, neighbourhoods or even streets) and link these differences to local (urban) microclimate conditions, due to for instance built densities, land use designs, water and vegetation patterns (e.g. Stewart and Oke, 2012).

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