How do psychological, habitual and built environment factors influence cycling in a city with a well-connected cycling infrastructure?

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Abstract

Many scholars have sought effective ways to encourage people to cycle more. A considerable amount of effort has focused on the role of dedicated cycling infrastructure. However, knowledge on the roles and interactions of other factors that are influential in addition to infrastructure in cities where the cycling network is well-developed remains incomplete. In this study, we examined how various individual-level attributes, namely psychological, habitual, and socio-demographic, in addition to the built environment characteristics relate to cycling behaviour of employees of the Erasmus University Rotterdam, in the Netherlands, where comprehensive cycling infrastructure is provided. Specifically, we investigated how these factors relate to being a cyclist or not, as well as how they are associated with regular and irregular cyclists. An online survey was conducted among employees of the university and logistic regression models were utilised for the analyses. Our results showed that the perception of behavioural control is consistently correlated with different cycling behaviour while controlling for socio-demographic and residential built environment factors. Also, we found evidence supporting a trade-off between attitudes and habit across different types of commuters. Socio-demographic factors such as gender and year of immigration to the Netherlands are only related to being engaged in cycling but not to increasing the level of engagement among employees who cycled already. The type of residential area and population/business density at destinations does not appear as a consistent covariate. We concluded that psychological and habitual factors play key roles in encouraging cycling in a city with an extensive cycling infrastructure network.

Keywords

travel behaviour; cycling; commuting to work; sustainable transport

1. Introduction

The benefits of cycling have been well-documented. It can help in the mitigation of transport issues such as congestion, air pollution and energy consumption (Buehler, 2011; Hamilton & Wichman, 2018), and on a regular basis it can improve physical and mental health (Avila-Palencia et al., 2018; Dinu et al., 2019; Wang et al., 2016). Overall, it has been noted that governments' measures to increase the levels of cycling tend to maintain focus on the expansion of cycling infrastructure (e.g., segregated cycle lanes, bicycle parking etc.), rather than on the diversification of the public investments (e.g., fiscal incentives, exemptions, subsidies, advertising campaigns, or facilities within the workplace, among others).[1]

Several studies conducted in different countries confirm that safe cycling infrastructure plays an important role in increasing cycling activities (e.g. Branion-Calles et al., 2019; Hong et al., 2019; Hull & O'Holleran, 2014). This seems obvious for most countries, especially where the quality of cycling infrastructure is poor. However, it does not seem to hold in all contexts. For instance, a study including 167 European cities shows that the positive relationship between cycling levels and the cycling infrastructure may become of little relevance at a certain state of the infrastructure network size (plateauing at 24.7% of the bicycle trip share) (Mueller et al., 2018).

The Netherlands is well-known for its ample cycling network coverage (Pucher & Buehler, 2008), claiming the highest cycling modal share in Europe (Netherlands Institute for Transport Policy Analysis, 2016). Despite its comprehensive infrastructure coverage, there are still people who do not cycle to workplaces which can be easily reached by cycling. Likewise, among those who do cycle, some do so only occasionally. This reinforces the idea that other determinants of cycling may play important roles in addition to physical interventions in cities with comprehensive infrastructure networks. Increased knowledge on how these factors relate to cycling is relevant because infrastructure is costly, and there might be more cost-effective ways to increase its levels.

Accordingly, a growing strand of literature seeks to fill a gap explaining the roles of other factors on cycling behaviour in addition to physical interventions in cities where cycling

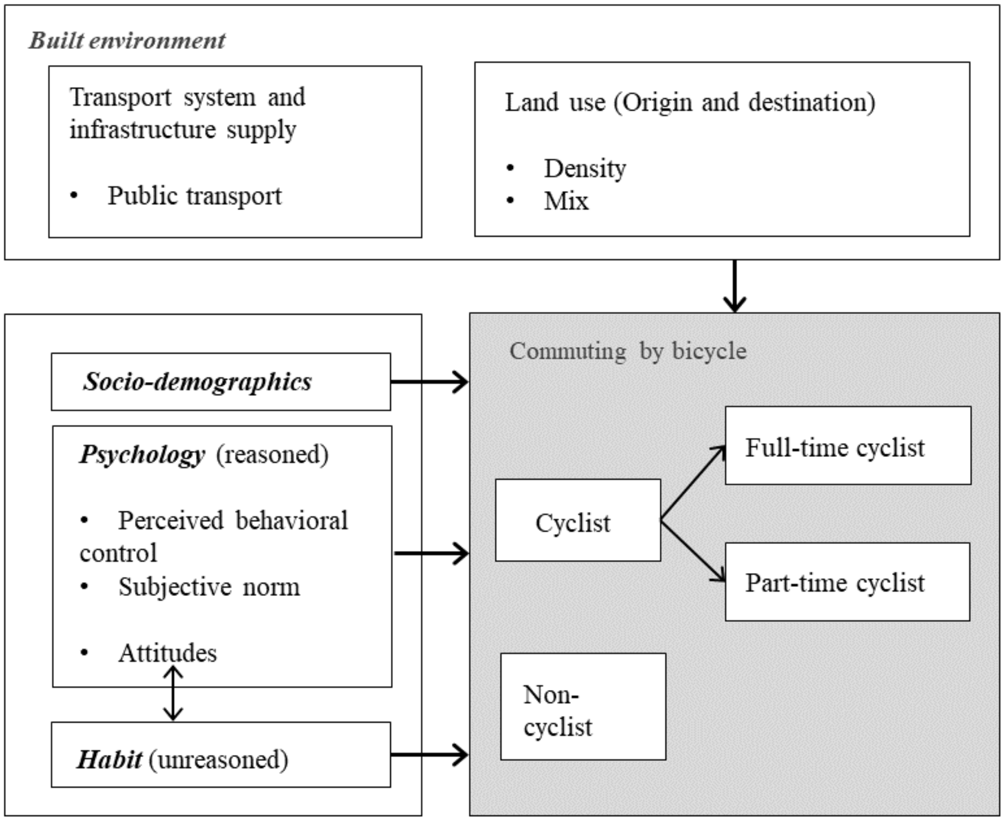
[1] For instance, aiming to attract 200,000 additional bicycle commuters, the Government of the Netherlands announced an investment of 345 million euros in 'ultrafast' cycling routes and additional parking facilities, while alternative strategies appear unaddressed (Government of the Netherlands, 2018).

infrastructure is readily available. For instance, Freudendal-Pedersen (2015b, 2015a) investigated the potential adverse effect of strengthening the positive cyclist narrative on widening the right to the city space for cyclists as well as the hegemonic role of car in policy and planning in Copenhagen, Denmark, from a qualitative perspective. In a quantitative study comparing the case of Stockholm, Sweden and Copenhagen, Denmark, Haustein et al. (2019) concluded that understanding the broad set of factors that define a cycling culture, including social and cultural norms, 'would be highly valuable to cities around the world that are aiming to stimulate cycling'. Gössling (2013) showed that the Copenhagen's urban transport transition from the 1980s to the 2010s comprised a combination of *command-and-control* measures (predominantly referring to infrastructure development) and *soft policy* measures focusing on the positive positioning of bicycle, such as envisaging cycling as *fun, faster, comfortable and safe* or remarking the *personal and societal benefits*.

Our paper adds up to this strand of literature focusing on the roles of psychological, habitual, socio-demographic and built environmental factors on cycling to work in Rotterdam, the Netherlands. Specifically, two research questions are examined: 1) To what extent, do psychological, habitual, socio-demographic and built environment factors are related to being a cyclist or not in a city with an extensive cycling network?; and 2) Do their important roles change for becoming a regular or non-regular cyclist? We focused on commuting trips because: 1) they represent 20% of all trips in the Netherlands (Fioreze et al., 2019); and 2) they can be used as an effective way to increase the level of daily physical activities (Dessing et al., 2014; Dinu et al., 2019).

To answer our research questions we built on the analytical framework used in the Sustainable Transport Approaches project (PASTA) (Götschi et al., 2017). This was chosen because it offers a comprehensive view that acknowledges the various dimensions associated with cycling in the literature in addition to physical interventions. Figure 1 shows the analytical framework employed for this study. We assumed that all four factors are directly related to cycling behaviour (i.e., being a cyclist or not; and being a regular cyclist or not) while there are potential interactions between attitudes and habit as well as gender and age based on evidence shown in Literature review.

Figure 1. Analytical framework for bicycle commuting in a well-connected cycling infrastructure environment



The organization of this paper is as follows. Section 2 provides a literature review of the determinants of cycling. Section 3 describes the data sources and the methods utilised for this study. Section 4 and Section 5 discuss empirical results. Section 6 presents a conclusion and limitations.

2. Literature review

In this section we reviewed the relevant work examining the determinants of cycling which are grouped into three topical domains: psychological and habitual factors; socio-demographic factors; and residential built environment factors, following previous categorizations (Götschi et al., 2017).

2.1 Psychological and habitual factors

The role of psychological factors in travel behaviour studies has been largely examined based on the *Theory of Planned Behaviour (TPB)* (Ajzen, 1991, 2005), e.g., in Bamberg et al., (2003), de Bruijn et al., (2005, 2009), Heinen et al. (2011), Frater el al., (2017). The theory suggests that behaviour is guided by: (1) *attitudes*, defined as the position against or in favour of the behaviour; (2) *subjective norm*, resulting from other people's normative expectations; and (3) *perceived behavioural control*, referring to the perceived ease or difficulty to execute the behaviour. These three elements form *intention*, which precedes behaviour. Perceived behavioural control can also affect behaviour directly, and its conceptualization entails internal aspects (e.g. individual skills, money, etc.) as well as external considerations (e.g. opportunities and constraints) (Ajzen, 2002). Several interesting findings are confirmed in cycling studies based on TPB. In many of these, attitudes are found to play an important role in the desire and decision to use a bicycle (see Lanzini & Khan, 2017). For instance, research from the Netherlands found that employees based their modal choice on attitudinal characteristics related to direct benefits, namely comfort and flexibility (Heinen et al., 2011).

Analytical frameworks adopted in travel behaviour studies have referred to the concepts of TPB as *reasoned* factors but the roles of *unreasoned* components are acknowledged as well (Götschi et al., 2017; van Acker et al., 2010). According to Triandis (1980), habits are "situation-specific sequences that are or have become automatic, so that they occur without self-instruction" (p. 204). It is argued that travel choice, including the decision to commute by bicycle, does not only result from a rational choice (based on reasoned factors), but also responds to habit. Several empirical studies stress the role of habit for cycling (see Willis et al., 2015). In fact, a study in the Netherlands found it to be the strongest predictor for bicycle use after controlling for reasoned factors (de Bruijn et al., 2009). Interestingly, attitudinal factors become insignificant when considering habit. Psychological literature suggests that when the influence of habit is strong, the relationship between attitudes and behaviour becomes weaker, and vice versa (Triandis, 1977, 1980; Verplanken et al., 1994). Furthermore, this strand of literature proposes that reasoned and unreasoned factors interact in their relationship with behaviour. The interaction between attitudes and habit has been confirmed in empirical studies in travel behaviour (Verplanken et al., 1994, 1998). Unfortunately, this is limited in cycling studies.

2.2 Socio-demographics

Socio-demographic factors such as age, gender, income, etc., have been shown to be important determinants of travel behaviour, including cycling. A study in the United States (U.S.) showed that immigrants' travel behaviour became similar to that of the U.S.-born population after ten years of residence in the country (Tal & Handy, 2005). Ethnicity, as categorised by black, Asians, Latin Americans, and whites, was not consistently significant. Research in the Netherlands showed that students with non-Western ethnic backgrounds were less prone to engage in cycling compared to native Dutch (Bere et al., 2008; de Bruijn et al., 2005). In the same context, Heinen et al. (2012) reported that females and older people are less likely to commute by bicycle while Gao et al. (2019) found the opposite results. Another study in Rotterdam did not report significant associations between gender or age and cycling to school among adolescents (Bere et al., 2008). Literature suggests that gender is of little relevance in bicycle-friendly contexts (e.g. Denmark, Netherlands, Germany) (Pucher & Buehler, 2008). However, little is known on how this interacts with other individual factors in such contexts. For instance, research examining interactions with gender in the U.S. showed that age was negatively associated to cycle among females, but this was not significant among males (Emond et al., 2009).

2.3 Built environment factors

Regarding the residential built environment the most widely used variables in active travel behaviour studies are *density*, *diversity*, and *design*, known as the '3Ds' (Appleyard, 2012; Cervero & Kockelman, 1997; Ewing & Cervero, 2010; Klinger et al., 2013). Empirical evidence is mixed. While residential density has a positive correlation with walking in most cases, its association with cycling is less consistent (Muhs & Clifton, 2016). For example, Christiansen et al. (2016) found inconsistent relationships between the use of bicycle for transport and residential density when using data for 14 cities from 10 countries. In Belgium, Verhoeven et al. (2016) reported that residential density was negatively associated with minutes spent cycling to other (non-school) destinations after controlling for psychological variables. Haustein et al. (2019) reported that population density did not play an important role in cycling in a comparative study between Stockholm, Sweden, and Copenhagen, Denmark. In the Muhs and Clifton (2016)' review, six out of the ten studies found significant associations between the access to at least one type of destinations in the residential area and cycling. In the Danish context, it was found that population density is positively associated with cycling while retail job density was negatively related with cycling (Nielsen & Skov-Petersen, 2018). Other empirical studies have found a non-linear relationship between population density and the increase of minutes walking or the reduction in vehicle miles travelled (Cheng et al., 2020; Ding et al., 2018; Hong, 2015). These suggest that once a threshold is reached, effects become marginal. A longitudinal study in Finland showed that intersection density had the largest positive effect on cycling volume (Kärmeniemi et al., 2019). By contrast, Kaplan et al., (2016) found that intersection density was negatively correlated with the bicycle use and positively associated to the distance cycled among children in Denmark. In sum, many empirical studies reported the significant associations between residential built environment factors and cycling, although some variables show inconsistent correlations.

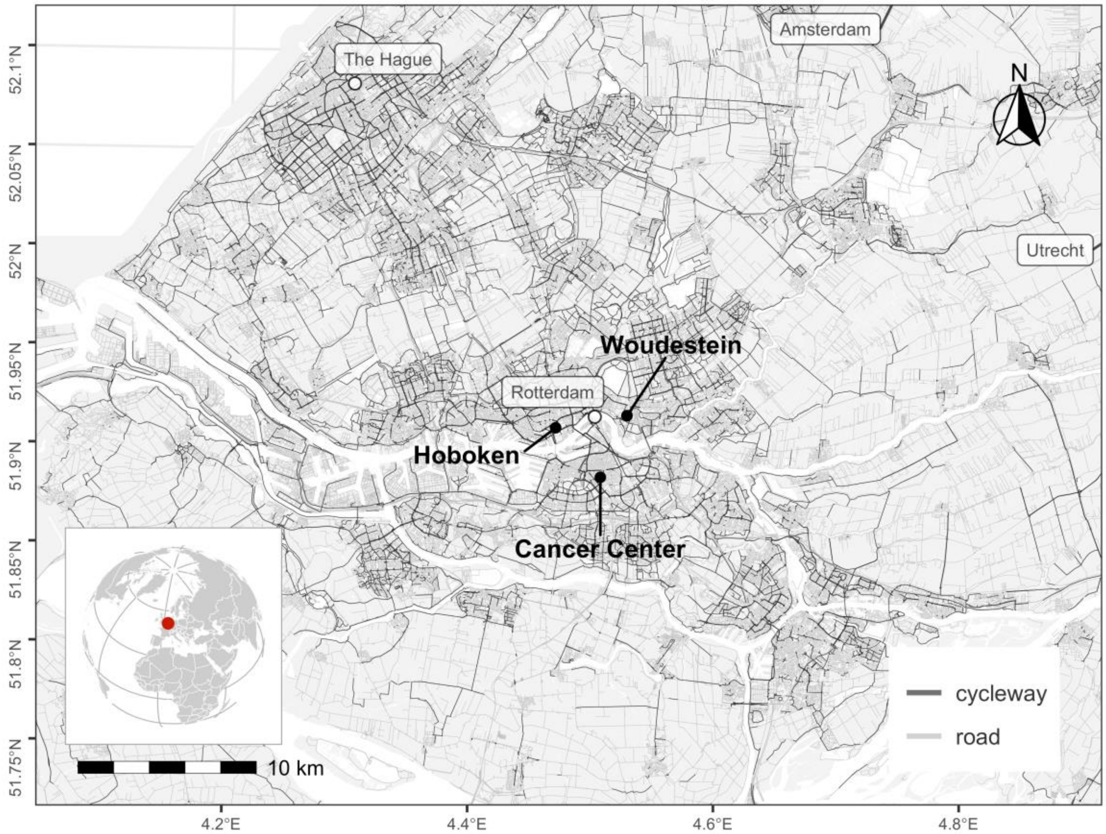
In relation to cycling infrastructure, several quantitative and qualitative studies showed the influences of cycling infrastructure on cycling experience by improving safety, comfort, and continuity (Buehler & Dill, 2016; Hull & O'Holleran, 2014; Koglin, 2018). Although, the extents of the associations between the extension of the network and the share of cycling trips is suggested to vary according to the overall coverage of the infrastructure (Mueller et al., 2018).

3. Methods

3.1 Study area

The Erasmus University Rotterdam (EUR) offers unique characteristics that make it ideal to identify the set of variables of interest. First, the Netherlands offers one of the most comprehensive bicycle infrastructure systems internationally. As seen in Figure 2, the cycling infrastructure network in Rotterdam is very comprehensive. It is also complemented with a predominantly flat terrain and a good coverage of public transport service. Second and third, the diversity of the population in terms of socio-demographic characteristics (e.g., ethnicity, age groups, and socio-economic status), together with a wide range of residential environment types (Helbich et al., 2014) provide valuable insights on the variability of the individual characteristics.

Figure 2. EUR workplace sites and cycleways in Rotterdam area



Source: Own elaboration based on Open Street Maps data.

The population studied is comprised of 2,817 employees affiliated to the schools and institutes of the EUR and 10,225 to the Erasmus Medical Center (Erasmus MC). Our study area includes two EUR work locations within Rotterdam: (1) campus Woudestein and (2) campus Hoboken, the latter hosting most of the Erasmus MC activities which not only include academic and administrative activities, bult also medical practice.

Both work locations are within consolidated areas of the city. The distance to the central business district is 3.5 and 2.25 kilometres from Woudestein and Hoboken, respectively. At the district level, Hoboken has a higher population density and business density as well as shorter average distances for all residents to the nearest train station and major transfer station compared to Woudestein. On the other hand, the average distance for all residents in the area to the nearest major road access is larger (for more details see Table 4s in the Supplement section) (Centraal Bureau voor de Statistiek, 2016).

3.2 Data

An online survey was conducted among the employees of the EUR from June 24th to July 11th in 2014 with the option of answering in English or Dutch. The invitation was sent via email under the following generic subject: *"Commuting to work research"*. This was intended to avoid self-selection bias of participants in relation to bicycle use. To increase the response rate, two reminders with one-week difference were sent to participants. A pilot version was conducted among academic and administrative employees of one academic institute of the EUR in campus Woudestein. The final questionnaire was delivered to 7,879 email addresses. The overall response rate was 12%, with 934 completed questionnaires.

After removing invalid responses, missing values, and participants whose main work location was not one of the referred above, 786 cases were used for the analyses.[2] The quality of the survey was checked against two figures (i.e., gender and age) from the population: female employees, 60% vs 65%; under 35 years old, 41% vs 39%; between 35 and 50 years old, 37% vs 34%; and over 50 years old 21% vs 27%, respectively (EUR, 2013). [3]

3.3 Variables

3.3.1 Commuting by bicycle

Two dependent variables were measured to answer the research questions. First, we categorised *cyclists* (C) and *non-cyclists* (NC). C were those who completed the whole journey from home to their main workplace by bicycle at least twice during the past year. Second, C were split in two groups depending on the frequency of bicycle use: *full-time cyclists* (FTC) or *part-time cyclists* (PTC). Employees who cycled every time they needed to travel to work were categorized as FTC. The remaining cyclists were considered as PTC. This approach was adopted by previous research (Heinen, 2011; Heinen et al., 2012; Stinson & Bhat, 2004) to make: (1) our study results comparable to those of previous studies (validation); and (2) a clear distinction

[2] Single reported working locations by participants that fell outside a 500 m buffer from the two selected university locations were disregarded, as assumed to be misreported.

[3] The figures for gender were complemented by information provided by the Erasmus MC Intelligence Centre. Age comparisons exclude employees from the Erasmus MC, since this data could not be accessed.

between employees who do not use the bicycle to commute the entire journey from home to work virtually at all, and those who use it at least occasionally.

3.3.2 Psychological factors (attitudes, subjective norm and perceived behavioural control)

Answers from five questions in two steps were used to measure *attitudes* toward cycling. In the first step, the survey asks whether the respondent agrees or disagrees with the statements '*For me, bicycling the whole journey to work is* (1) *environmental friendly*; (2) *safe in traffic*; (3) *healthy*; (4) *convenient*; and (5) *time-saving*'. In the second step, the survey asks, '*How strong is your position in regards with your last answer?*'. Responses were recorded in a 3-point Likert scale (from 1, 'somewhat strong', to 3, 'very strong'). Following Lubian (2010), if participants chose 'disagree' in the first step, a negative sign was ascribed to the numeric value (1 to 3) chosen in the second step (i.e., the value ranges from -3 (very strongly disagree) to 3(very strongly agree)).

Factor analysis (FA) was employed to determine which individual items could be assigned to attitudinal factors. The analysis results in a two-factor solution which explains 52% of the variance (full results are shown in **Table s5** in the Supplement section). Based on the results, the *environmental friendly* and *healthy* items are assigned to a latent variable labelled 'Attitude-benefits', and *convenient* and *time-saving* to the second one named as 'Attitude-efficiency'.

Subjective norm was composed of two items. Two questions were asked about the expectations of their colleagues at work and the people at home as follows: '*Which mode of transport do you think your colleagues/ people at home expect you to travel to work with?*'. If the answer was 'bicycle' then we coded it as 'Yes', and 'No' otherwise. Both items were individually included in the analyses.

Perceived behavioural control: The survey asks: '*To what extent do you consider it possible to travel your entire journey by bicycle?*'. The same question was used in the previous study (Heinen et al., 2011) to measure perceived behavioural control. The answers were measured on a 5-point Likert scale, anchored by 1 ('not possible at all´) and 5 ('very possible').

3.3.3 Habit

Verplanken and Orbell (2019) identified *response frequency measures* to assess habit, where respondents are presented multiple scenarios and are asked to select an option in a limited amount of time. In this fashion, the prevalent choice across the different scenarios is considered as a measure of habit. Following this, the questionnaire asks the respondent to choose a transport mode (i.e., *motor vehicle (car or scooter); bicycle; public transport;* and *foot*) in four different scenarios (*shopping*, *social event*, *recreation purposes* and *work*), stressing respondents to choose one option without profound reflexion. If *bicycle* was chosen, it was coded as '1' and '0' otherwise. Habit was measured by summing up the values from these four items.

3.3.4 Built environment factors

The survey asks several questions about interviewees' home locations. The *type of residential area* ('urban/downtown', 'suburban' and 'rural') was used as a proxy for population density and neighbourhood design. For example, urban areas in the Netherlands have compact central areas with high and mid-rise buildings, while rural and suburban areas have open spaces, low housing density and discontinuous urbanized areas (Dieleman et al., 2002; Geurs & van Wee, 2006). For the analysis, we categorized them into two (i.e., urban/downtown and rural/suburban). Diversity considered whether there was a shopping place within 1,000 m (*Shopping 1 km*) and supermarkets within 500 m (*supermarket 500 m*).[4] In addition to the 3Ds, public transport accessibility was measured by two variables, whether there was a bus/tram stop within 500 m (*bus/tram stop 500 m*) and a train station within 1,000 m (*train station 1 km*) (Cervero et al., 2009; Cervero & Kockelman, 1997; Heinen et al., 2012). A binary variable, 'Woudestein' or 'Hoboken' (the reference), was assigned to capture the environment characteristics of the work locations.

Commuting distance (*Distance*) was calculated as the shortest route by bicycle from home to the main work location based on the post code using Google Maps. Several socio-demographic factors were also considered for the analyses.

3.4 Analytical methods

Two sets of logistic regression models were utilised to examine how psychological, habitual, demographic and built environmental factors are related to cycling behaviour (i.e., C vs. NC and

[4] The presence of a supermarket is limited to 500m due to the difficulty of carrying stuff home without using a car as reported in literature (Bostock, 2001; O'Dwyer & Coveney, 2006). A shopping place is assumed to be a delimited area offering diverse types of shops and services. The distance limit follows Cervero et al. (2009).

FTC vs. PTC) in a city with an extensive cycling infrastructure network. Following the suggestion of psychology studies (de Bruijn et al., 2009; Triandis, 1977, 1980; Verplanken et al., 1994), we included the interaction term between attitudes and habit. Additionally, given the inconclusive empirical findings in relation to age and gender in the Netherlands, we tested the interaction between these two factors, based on earlier empirical evidence (Emond et al., 2009). The basic model (without interactions) can be written as follows:

$$\Pr\left(y_i = 1 \middle| X_{Psy,} X_{habit,} X_{SD,} X_{BE}\right) = logit^{-1}\left(\alpha + \beta_{Psy}^{\intercal} X_{Psyi} + \beta_{habit} X_{habiti} + \beta_{SD}^{\intercal} X_{SDi} + \beta_{BE}^{\intercal} X_{BEi}\right)$$

where, y_i indicates cycling (i.e., C vs. NC & FTC vs. PTC) and $X_{Psy}, X_{habit}, X_{SD,} and\ X_{BE}$ represent psychological, habitual, socio-demographic and built environmental factors, respectively.

4. Results

4.1 Descriptive statistics

Table 1 shows the descriptive statistics. Regarding attitudes related to benefits, both cyclist and full-time cyclists show lower scores than non-cyclists and part-time cyclists, respectively. By contrast, attitude-efficiency scores are higher for employees who use bicycle at least occasionally or at all times, compared to those who do not commute by bicycle or do it occasionally. About 70 percent are not expected to commute by bicycle by people at their workplace or home while 73% of FTC are expected to cycle at work and 81% at home. On average, our participants do not perceive constraints for cycling. FTC have the highest value for *habit* compared to NC and PTC. The average age of the participants in the full sample is about 40 years. Overall, 82% are born in the Netherlands (NL born). A relatively higher percentages of C and FTC migrated to the Netherlands before 2010 compared to NC and PTC, respectively. About 77% have a postgraduate degree. There are 2.6 household members on average.

The average commuting distance (*Distance*) is about 23 km in the full sample. The distance is substantially shorter for C and FTC than NC and PTC, respectively. The work location is evenly distributed between the two workplaces. About half of the respondents live in urban/downtown areas, with relatively more urbanites in C and FTC compared to NC and PTC, respectively. In general, cyclists live in neighbourhoods with good levels of public transport and accessibility compared to non-cyclists.

Table 1.
Descriptive statistics for C and NC as well as FTC and PTC for individual and built environment characteristics

	Overall (N=786)	Non-Cyclist (N=581)	Cyclist (N=205)	Part-time cyclist (N=87)	Full-time cyclist (N=118)
Psychological					
Attitudes-Benefits	0.01 (0.75)	0.06 (0.80)	-0.12 (0.58)	-0.03 (0.63)	-0.18 (0.52)
Attitudes-Efficiency	-0.00 (0.94)	-0.28 (0.88)	0.77 (0.57)	0.48 (0.67)	0.99 (0.35)
Subjective norm-work	225 (28.63%)	100 (17.21%)	125 (60.98%)	39 (44.83%)	86 (72.88%)
Subjective norm-home	226 (28.75%)	85 (14.63%)	141 (68.78%)	46 (52.87%)	95 (80.51%)
Perceived behavioural control	3.11 (1.76)	2.51 (1.65)	4.80 (0.59)	4.54 (0.83)	4.99 (0.09)
Habit	1.92 (1.34)	1.62 (1.27)	2.76 (1.18)	2.36 (1.28)	3.05 (1.00)
Socio-demographic					
Gender: Male	313 (39.82%)	225 (38.73%)	88 (42.93%)	34 (39.08%)	54 (45.76%)
Age	39.89 (11.94)	40.19 (11.80)	39.04 (12.33)	36.49 (11.21)	40.92 (12.83)
Year of immigration					
- NL born	646 (82.19%)	474 (81.58%)	172 (83.90%)	73 (83.91%)	99 (83.90%)
- 2014-2010	77 (9.80%)	62 (10.67%)	15 (7.32%)	8 (9.20%)	7 (5.93%)
- Pre 2010	63 (8.02%)	45 (7.75%)	18 (8.78%)	6 (6.90%)	12 (10.17%)
Education					
- Low	73 (9.29%)	59 (10.15%)	14 (6.83%)	6 (6.90%)	8 (6.78%)
- Medium	109 (13.87%)	86 (14.80%)	23 (11.22%)	11 (12.64%)	12 (10.17%)
- High	604 (76.84%)	436 (75.04%)	168 (81.95%)	70 (80.46%)	98 (83.05%)
Household size	2.62 (1.25)	2.61 (1.24)	2.66 (1.28)	2.69 (1.28)	2.64 (1.29)
Built environment					
Work Location: Woudestein	424 (53.94%)	326 (56.11%)	98 (47.80%)	38 (43.68%)	60 (50.85%)
Distance (km)	23.38 (25.09)	29.21 (26.69)	6.86 (5.11)	8.33 (5.92)	5.77 (4.12)
Type of residential area: Urban/downtown	397 (50.51%)	285 (49.05%)	112 (54.63%)	42 (48.28%)	70 (59.32%)
Tram/bus stop 500m	621 (79.01%)	443 (76.25%)	178 (86.83%)	78 (89.66%)	100 (84.75%)
Train station 1 km	353 (44.91%)	251 (43.20%)	102 (49.76%)	34 (39.08%)	68 (57.63%)
Supermarket 500m	559 (71.12%)	406 (69.88%)	153 (74.63%)	68 (78.16%)	85 (72.03%)
Shopping 1 km	553 (70.36%)	407 (70.05%)	146 (71.22%)	58 (66.67%)	88 (74.58%)

Note for descriptive statistic values: numeric variables= M(SD); Categorical variables = N (%).

4.2 Cyclists (C) vs non-cyclists (NC)

Table 2 shows the results about the relationship between psychological, habitual, socio-demographic and built environmental factors and cycling (i.e., being a cyclist or non-cyclist). Model 1 shows that the odds ratio of being a cyclist are 41% higher for every additional attitudes-efficiency score. Employees who are expected to cycle to work by people at home have about 90% higher odds of being cyclists compared to those not expected to do it. An additional unit in perceived behavioural control increases the odds of being a cyclist by a factor of 2.5. Likewise, people with higher bicycle habit are more likely to cycle for commuting.

The significance and magnitude of associations for psychological factors and habit are similar when controlling for socio-demographic factors in Model. The odds of being a cyclist for employees who immigrated between the year 2014 and 2010 are about 70% less compared to people born in the Netherlands. However, those who immigrated before 2010 are not significantly different. This makes sense because people with a longer time of residence in the Netherlands may become similar to the native population. Also, people from larger households are more likely to use a bicycle. This may be related to the structural composition of the household and the transport requirements of each household type (e.g., family with children, couples without children, etc.).

In Model 3, the same psychological, habitual, and socio-demographic variables, except household size, remain significant when considering the residential built environment factors. Work location does not provide statistically significant association with cycling. This implies that there is no significant link between destination built environmental factors and cycling. The result shows that as the commuting distance increases, people are less likely to be cyclists (odds are reduced by 5% for each additional kilometre). Similarly, living in an urban or downtown area decreases the odds of being a cyclist by almost 60%, compared to commuters who reside in rural or suburban areas. A possible interpretation of this is that participants who live in urban or downtown locations have more transport alternatives and may choose to walk or use public transport, for example. Also, suburban and rural areas are associated with more open spaces and lower traffic volumes, which may incentive cycling, especially among less experienced cyclists (Hull & O'Holleran, 2014) .

In Model 4, the interactions between attitudes related to efficiency and habit as well as age and gender are examined. The result shows that as males become older, they are more likely to be cyclists than females. However, habit does not mediate the relationship of attitudes-efficiency to be FTC.

Table 2
Logistic regression analyses for being a cyclist or not in relation to psychological, habitual, demographic plus built environmental factors (ref: non-cyclist)

	Dependent variable: Commuter type (ref: non-cyclist)			
	Model 1 OR *(CI 95%)*	Model 2 OR *(CI 95%)*	Model 3 OR *(CI 95%)*	Model 4 OR *(CI 95%)*
Psychological				
Attitudes-Benefits	0.76	0.73^{*}	0.76	0.74
	(0.41, 1.12)	(0.35, 1.10)	(0.38, 1.14)	(0.34, 1.13)
Attitudes-Efficiency	1.41^{*}	1.51^{**}	1.58^{**}	2.10^{**}
	(1.02, 1.79)	(1.11, 1.91)	(1.16, 2.01)	(1.43, 2.77)
Subjective norm-work	0.84	0.89	0.76	0.76
	(0.27, 1.40)	(0.30, 1.47)	(0.15, 1.36)	(0.15, 1.38)
Subjective norm-home	1.91^{**}	1.74^{*}	1.81^{*}	1.74^{*}
	(1.30, 2.51)	(1.12, 2.37)	(1.17, 2.45)	(1.09, 2.39)
Perceived behavioural control	2.55^{***}	2.62^{***}	2.08^{***}	2.06^{***}
	(2.29, 2.81)	(2.35, 2.89)	(1.76, 2.40)	(1.73, 2.38)
Habit	1.31^{***}	1.28^{**}	1.37^{***}	1.50^{***}
	(1.13, 1.50)	(1.09, 1.47)	(1.17, 1.57)	(1.25, 1.75)
Socio-demographic				
Gender: Male (ref: Female)		0.94	1.01	0.11^{***}
		(0.49, 1.39)	(0.55, 1.48)	(-1.47, 1.69)
Age		0.99	0.98	0.96^{***}
		(0.97, 1.01)	(0.96, 1.01)	(0.93, 0.99)
Education: University (ref: High-school or lower)		1.08	1.05	1.20
		(0.13, 2.02)	(0.11, 1.99)	(0.23, 2.18)
Postgraduate		1.08	1.09	1.10
		(0.26, 1.89)	(0.28, 1.90)	(0.26, 1.94)
Year of immigration: 2010-2014 (ref: NL born)		0.32^{***}	0.28^{***}	0.26^{***}
		(-0.38, 1.02)	(-0.44, 1.01)	(-0.47, 0.99)
Pre 2010		1.02	0.98	1.05
		(0.26, 1.78)	(0.20, 1.76)	(0.25, 1.84)
Household size		1.21^{**}	1.15	1.17^{*}
		(1.04, 1.38)	(0.97, 1.33)	(0.98, 1.35)

Built environment				
Work location: Woudestein (ref: Hoboken)			0.79	0.86
			(0.33, 1.26)	(0.38, 1.33)
Distance in km			0.95**	0.95***
			(0.92, 0.99)	(0.91, 0.99)
Urban/downtown (ref: suburban/rural)			0.41***	0.41***
			(-0.13, 0.95)	(-0.14, 0.95)
Tram/bus stop 500 m			1.38	1.32
			(0.71, 2.05)	(0.63, 2.00)
Train station 1 km			1.18	1.20
			(0.69, 1.68)	(0.70, 1.70)
Supermarket 500 m			1.19	1.24
			(0.64, 1.74)	(0.67, 1.80)
Shopping 1 km			0.77	0.80
			(0.25, 1.29)	(0.27, 1.33)
Interactions				
Attitudes-Efficiency x Habit				0.86
				(0.60, 1.12)
Male x Age				1.06***
				(1.02, 1.10)
Observations	786	786	786	786
Log Likelihood	-271.00	-263.00	-252.00	-247.00
Akaike Inf. Crit.	556.00	554.00	547.00	541.00
Note:		Significance code: *** p < 0.01; ** p < 0.05; * p < 0.1; OR = odds ratio; CI = confidence interval.		

4.3 Part-Time Cyclists vs Full-Time Cyclists

Results about the relationship between psychological, habitual, socio-demographic and built environmental factors and the type of cyclist (FTC or PTC) are presented in Table 3. As shown in Model 5, cyclists who have positive efficiency-related attitudes towards bicycle use and perceive they are able to cycle to their workplace are more likely to be FTC than PTC. While the same psychological variables remain significant in Model 6, only age is significantly associated with cyclists' behaviour. Older employees are more likely to cycle on a daily basis. This can be linked with the household context and personal circumstances, e.g. more flexible time (Gao et al., 2019).

When considering built environment factors in Model 7, the same factors mentioned above remain significant. Additionally, it is shown that the odds ratio for commuting by bicycle full-time to Woudestein are 2.5 higher than to Hoboken, where both population and business density are higher. This could be related to high level of access to public transport facilities in the latter. Another possible explanation is related to the type of activities in Hoboken which sometimes involve medical practice out of regular office hours. In contrast to this, people living in areas with access to a train station within 1 km are more likely to become a FTC. Previous research reported competition effects between access to public transport facilities within the residential environment, discouraging cycling. However, this do not seem to hold for FTCs. The association could be explained by the correlation of this and other unobserved characteristics of the residential built environment. In Model 8, we examined the interactions considered in Model 4. The result shows that as habit becomes stronger, the association between efficiency-related attitudes and being a FTC becomes weaker and vice versa.

Table 3
Logistic regression analyses for being a FTC or PTC in relation to psychological, habitual, demographic plus built environmental factors (ref: PTC)

	Dependent variable: Cyclist type (ref: PTC)			
	Model 5 OR *(CI 95%)*	Model 6 OR *(CI 95%)*	Model 7 OR *(CI 95%)*	Model 8 OR *(CI 95%)*
Psychological				
Attitudes-Benefits	0.90	0.79	0.77	0.93
	(0.33, 1.46)	(0.18, 1.39)	(0.10, 1.43)	(0.23, 1.63)
Attitudes-Efficiency	3.75***	4.79***	4.68***	125.00***
	(2.95, 4.55)	(3.89, 5.68)	(3.74, 5.62)	(122.00, 128.00)
Subjective norm-work	1.84	1.78	1.73	1.87
	(0.96, 2.71)	(0.84, 2.72)	(0.70, 2.76)	(0.82, 2.93)
Subjective norm-home	0.86	0.67	0.67	0.61
	(-0.13, 1.85)	(-0.39, 1.73)	(-0.49, 1.84)	(-0.59, 1.80)
Perceived behavioural control	8.81**	11.90**	20.50***	18.60**
	(6.70, 10.90)	(9.68, 14.00)	(18.20, 22.80)	(16.20, 21.00)
Habit	1.27	1.29	1.22	3.56**
	(0.96, 1.58)	(0.96, 1.62)	(0.86, 1.58)	(2.57, 4.56)
Socio-demographic				
Gender: Male (ref: Female)		1.22	1.13	1.36
		(0.48, 1.95)	(0.32, 1.94)	(-1.55, 4.27)

Age		1.06***	1.10***	1.11***
		(1.02, 1.10)	(1.05, 1.14)	(1.05, 1.17)
Education: University (ref: High-school or lower)		0.89	0.80	0.96
		(-0.94, 2.72)	(-1.20, 2.81)	(-1.25, 3.16)
Postgraduate		0.85	0.72	0.76
		(-0.67, 2.37)	(-0.94, 2.37)	(-1.01, 2.52)
Year of immigration: 2010-2014 (ref: NL born)		1.68	1.17	1.39
		(0.33, 3.04)	(-0.22, 2.56)	(-0.09, 2.87)
Pre 2010		1.16	0.94	1.06
		(-0.13, 2.44)	(-0.43, 2.31)	(-0.42, 2.53)
Household size		0.84	0.85	0.79
		(0.56, 1.13)	(0.54, 1.17)	(0.45, 1.12)
Built environment				
Work location: Woudestein (ref: Hoboken)			2.50**	2.54**
			(1.64, 3.35)	(1.67, 3.41)
Distance in km			0.93	0.90*
			(0.83, 1.03)	(0.79, 1.01)
Urban/downtown (ref: suburban/rural)			0.71	0.64
			(-0.22, 1.64)	(-0.31, 1.59)
Tram/bus stop 500 m			0.84	0.66
			(-0.34, 2.02)	(-0.61, 1.94)
Train station 1 km			3.30***	3.40***
			(2.46, 4.13)	(2.54, 4.26)
Supermarket 500 m			0.73	0.76
			(-0.27, 1.73)	(-0.30, 1.82)
Shopping 1 km			1.36	1.21
			(0.54, 2.18)	(0.35, 2.06)
Interactions				
Attitudes-Efficiency x Habit				0.30**
				(-0.68, 1.28)
Male x Age				1.00
				(0.92, 1.07)
Observations	205	205	205	205
Log Likelihood	-108.00	-101.00	-91.20	-87.60
Akaike Inf. Crit.	231.00	230.00	224.00	221.00
Note:		Significance code: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$; OR = odds ratio; CI = confidence interval.		

5. Discussion

This study utilised an online-survey and logistic regression models to examine the associations between psychological, habitual, socio-demographic and built environmental factors and bicycle use for commuting to work to the two main locations of the Erasmus University Rotterdam, in the Netherlands, where cycling infrastructure is well-connected.

Whereas perceived behavioural control appears as a consistent correlate in all our models, other psychological and habitual factors seem to play distinct roles for specific types of cycling behaviour. Our results show that efficiency-related attitudes are consistently associated with the decision to cycle to work and its every-day use but not attitudes related to individual or broader benefits. These results are partially consistent with earlier studies. While some previous research in the Netherlands found significant associations between commuters' overall attitudes and cycling to workplaces (Gao et al., 2019; Heinen et al., 2012), others did not report significant associations, especially when controlling for habit (de Bruijn et al., 2005, 2009). Conversely to attitudes, habit is significantly related to being a cyclist but not being a FTC. From these results, it can be argued that an unreasoned process is more closely associated with the decision to cycle than a reasoned one in a city with a high level of cycling. However, cycling every day to work is more demanding than cycling irregularly, and it is less common even in this context. Therefore, under these circumstances, attitudes seem to play a leading role among cyclists. Furthermore, our empirical results partially confirm the trade-off effect between attitudes and habit highlighted in cognitive and travel behaviour literature (Triandis, 1977; van Acker et al., 2010; Verplanken et al., 1994, 1998), at least for attitudes related to efficiency. This holds even when controlling for socio-demographic and built environment factors. This implies a form of compensatory mechanism in which efficiency-attitudes become less relevant among cyclists with strong habit and vice versa.

Socio-demographic factors are shown to have different associations with the types of cycling behaviour. In particular, the number of people in the household is significantly associated with being a cyclist, but not a FTC. Previous investigation in the Netherlands emphasised the role of the household type for the choice of transport mode (Dieleman et al., 2002; Gao et al., 2019). For instance, it is suggested that the presence of children in the household decreases the probability of using a bicycle to travel to work. In our results, age is negatively related to being a cyclist when considering the socio-demographic interaction gender x age in the model while having a consistent positive association with being a FTC. As discussed in section 2.2, previous studies in the same context reported opposite findings. We estimated its interaction with gender to examine the potential complex relationship between them. It is shown that while older employees are less likely to be cyclists generally, older males are more likely than their older female counterparts. This is in line with the finding reported in the U.S, where age was negatively associated only with females (Emond et al., 2009). Yet, this interaction was not significant in relation to FTC employees. We also found an association between the length of residence in the Netherlands and cycling behaviour. The employees who moved to the Netherlands within the previous four years were less likely to be a cyclist compared to their Dutch-born peers while no significant difference was found between those who moved more than four years ago and native Dutch people. This result is consistent with findings from previous studies (Tal & Handy, 2005), where migrants show similar travel behaviour patterns to those born in the same country after ten years. It is noteworthy that this significant association is not shown among cyclists.

The associations between the built environment factors and cycling behaviour are mixed. While commuting distance and the type of residential area are associated with being a cyclist, only the working location and public transport access in the residential area are significantly linked to being a FTC. Regarding total travel distance, previous studies have reported its negative relationship to cycling (Bere et al., 2008; Heinen et al., 2012; Ortega et al., 2008; Panter et al., 2008; Van Dyck et al., 2010), yet our findings suggest that this does not play a significant role in the day-to-day choice when considering social-demographic, psychological and habitual factors. Concerning the workplace, it is worth noting that although Hoboken is more centrally located and embedded in an area with higher population and business densities than Woudestein, it does not appear to be more attractive to cyclists. Moreover, it is less likely to be reached by full-time cyclists. One difference between the workplaces is that Hoboken has better access to public transport than Woudestein, which may facilitate modal shift. Also, some specific conditions of employees, such as schedule and type of activities at work may play a role. In addition, respondents who live in urban or downtown areas are less likely to be a cyclist compared to those who reside in suburban or rural areas. Despite the contrasts with the 3D literature (Appleyard, 2012; Cervero & Kockelman, 1997; Ewing & Cervero, 2010; Klinger et al., 2013), these observations are in line with findings in Denmark which reported a negative association between the number of retail jobs within 1 km around homes and cycling (Nielsen & Skov-Petersen, 2018), as well as other studies in similar contexts (Van Holle et al., 2014; Verhoeven et al., 2016). A further possible explanation is the non-linear relationship between population density and travel behaviour. It suggests that increasing density beyond a certain point has marginal effects on the reduction of vehicle miles travelled or even negative associations with total walking time (Cheng et al., 2020; Ding et al., 2018; Hong, 2015). Hence, future research is required to clarify the potential non-linear relationship between built environment and cycling to work. The presence of a train station within 1km was positively associated with being a FTC. A similar finding was reported in Denmark, where a train station within 3km is positively related with cycling (Nielsen & Skov-Petersen, 2018).

6. Conclusion

Although academic literature and governments recognise the bicycle as an efficient mode of urban transport, the focus of the investments made up to now have been usually in favour to physical interventions. Drawing on a comprehensive conceptual model for active travel (Götschi et al., 2017), our framework recognize the role of psychological, habitual, socio-demographics, and built environmental factors on cycling for commuting in a well-connected cycling environment. Our findings show that the perception of the behavioural control is consistently correlated to cycle behaviour among specific roles of attitudes and habit in this context. These relationships remain significant when considering socio-demographic and built environment factors. Given these findings, we support earlier conclusions suggesting that interventions focused on perceptions are equally important as built environment to support cycling (Ma et al., 2014), especially in the context where a good level of cycling infrastructure is reached. Some of the policy implications of this may include the diversification of investments to implement or expand the following strategies: cyclist groups accompanying inexperienced employees in their journeys, groups supporting and informing overseas employees, comprehensive information in multiple languages for easy access to recent migrants, alternative transport systems supporting large households with children, advertising campaigns about the opportunities to cycle in a well-connected network, emphasizing efficiency-related aspects, e.g. commuting times, cost or easiness. Conversely, campaigns aimed at informing about benefits of cycling for the environment, or individual and public health could be re-examined.

At a finer level than the above, our findings concerning the trade-off between attitudes and habit showed to be in line with the notion that travel behaviour is the result of reasoned and unreasoned influences. The implication of this complements the notion that targeted policies aimed at changing behaviour through reasoned factors (e.g., as suggested by Bamberg et al., (2003)), would not be expected to have homogenous impact on all type of commuters, e.g., potential new cyclists vs. existing bicycle users at least in this context where cycling infrastructure is satisfied. Given that in this context habit is associated with cycling, it is worthwhile considering the two techniques identified by Verplanken et al. (2019): (1) implementation intentions and (2) habit discontinuities.

There are limitations in our study. First, we cannot identify causal effects because our data is cross-sectional. Second, the sample size is limited in scope to employees of the EUR. Therefore, caution is advised in generalizing the findings. Our sample is largely composed of highly-educated participants. However, most of our results are consistent with findings from previous studies. Third, we adopted simple definitions to categorise cyclists. This is a common issue in this type of research (e.g. de Geus (2008) defined cyclists as people who cycled at least once a week, whereas Heinen (2011) used 'once during the last year' as criterion to define cyclists).

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Supplement

Table s4.
Main built environment characteristics

	Wodestein		Hoboken	
Description	*Neighborhood*	*District*	*Neighborhood*	*District*
Population density (number of inhabitants per km2)	3728	4892	1358	7548
Business density (number of businesses per km2)	532	376	310	1700
Mean distance to main road entrance (km)	1.60	1.80	3.30	2.70
Mean distance to train station (km)	2.50	1.90	1.90	0.90
Mean distance to major transfer station (km)	3.80	2.80	2.00	1.40

Source: CBS (2016). Toelichting Wijk- en Buurtkaart 2014, 2015 en 2016.
Note: Mean distance refers to the mean road network distance for all residents in the area to the nearest facility.

Table s5.
Factor analysis results

	Attitudes-efficiency	Attitudes-benefits
Environmental friendly		0.554
Healthy		0.539
Safe in traffic		
Convenient	0.897	
Time-saving	0.799	
SS loadings	1.873	0.739
Proportion of variance	0.375	0.148
Cumulative variance	0.375	0.522

Note: 1) Showing loadings ≥ 0.50 or ≤ -0.5. 2) Method: Maximum likelihood estimate.
3) Test of the hypothesis that 2 factors are sufficient. The chi square statistic is 1.33 on 1 degree of freedom. The p-value is 0.249.