Transportation Research Part A 84 (2016) 4–17

Contents lists available at ScienceDirect

Transportation Research Part A

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

Transition to a cyclable city: Latent variables affecting bicycle commuting

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ARTICLE INFO

Article history:
Available online 20 November 2015

Keywords:
Bicycle commuting
In transition to a cyclable city
Latent variables
Psychometric indicators
Theory of planned behaviour
Factor analysis

ABSTRACT

An understanding of the key factors influencing bicycle commuting is essential for developing effective policies towards a cyclable city. This paper contributes to this line of research by proposing a methodology for including cycling-related indicators in mobility surveys based on the Theory of Planned Behaviour (TPB), and applying an exploratory factor analysis (EFA) to evaluate the structure of latent variables associated with bicycle commuting. The EFA identified six cycling latent variables: *Lifestyle*, *Safety and comfort*, *Awareness*, *Direct disadvantages*, *Subjective norm*, and *Individual capabilities*. These were complemented with a latent variable related to habit: *Non-commuting cycling habit*. Statistical differences and regression analysis were applied with the cycling latent variables. The study also includes the relationship between objective factors and bicycle commuting, which reveals minor associations. This methodology was applied to the "starter cycling city" of Vitoria-Gasteiz (Spain). The results confirm that in this context – in transition to a cyclable city – safety and comfort issues are not the main barriers for all commuters, although more progress needs to be made to normalise cycling. A set of customised policy initiatives is recommended in the light of the research findings, including marketing campaigns to encourage non-commuting cycling trips, bicycle measures to target social groups as opposed to individuals, bicycle-specific programs such as "Bike-to-work Days", and cycling courses.

1. Introduction

Problems of sustainability in urban transport are well known and very common in developed countries. The public policies enacted to tackle them have focused mainly on promoting public transport and non-motorised commuting modes – including cycling – through policy documents such as the Green Paper on Urban Mobility (European Commission, 2007). In the last decade many cities in Spain have developed bicycle mobility plans aimed at increasing bicycle share, and the corresponding measures are already underway. Recent increases in cycling demand (Monzon and Rondinella, 2010) indicate that Spanish cycling levels are progressing adequately, although still in the early stages. One indication of this is the lack of information on cycling, as this is not generally included in household mobility surveys.

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http://dx.doi.org/10.1016/j.tra.2015.10.006
0965-8564/

In order to develop effective cycling policies it is essential to understand the key factors influencing bicycle commuting. Increased efforts have been made in both policy-making and academic research. Variables such as time and cost are not sufficient to explain why cyclists choose this mode of transport, and a wide array of variables – including latent variables – are currently under study using a variety of methodologies. Latent variables are not observed by the researcher and must be inferred from other observable variables called indicators – usually responses to attitudinal or perceptual survey questions – and require specific analysis techniques. Previous studies using a range of methodologies have identified cycling latent variables as influential in the decision to choose cycling. This is an active research field due to the complexity of latent variables.

This paper contributes to this line of research by focusing on commuting, and proposing cycling-related indicators based on the Theory of Planned Behaviour (TPB) (Ajzen, 1991) for their inclusion in mobility surveys. It also evaluates the structure of the latent variables that influence bicycle commuting using exploratory factor analysis (EFA). Statistical differences for cycling latent variables were determined between bicycle commuters and other modes, showing medium and high associations. These variables were also used in a regression analysis to explain bicycle commuting choice. The study also defined the bicycle commuter profile by analysing the relationship between certain objective factors and bicycle commuting. This methodology was applied to Vitoria-Gasteiz (Spain). According to Dufour (2010) this is a "starter cycling city" with a bicycle share of 6.9% (Council of Vitoria-Gasteiz, 2015) – the highest in Spain in 2011– and with moderate cycling conditions due to a favourable transport policy over the last decade. However, it has continued working to improve its bicycle use. Vitoria-Gasteiz can therefore be said to be in transition to a cycling city. The results confirm that safety and comfort issues are not the main barriers for all commuters, but more progress needs to be made to normalise cycling. The results also support the recommendation of a wide array of policy initiatives.

The paper is organised as follows. The conceptual model and literature review are presented in the next section. The methodology of the paper is described in the third section. The fourth section contains a description of the context and the data collection process. The empirical application is described in the fifth section, which is further divided into two subsections. The first contains the analyses of a number of traditional objective factors (socio-economic and household characteristics, mode availability, and trip characteristics). The second determines the cycling latent variables, analyses their differences among different types of commuters and shows the regression analysis. The last section contains some policy recommendations and conclusions.

2. Conceptual model and literature review

This study focuses on commuting trips and applies the Theory of Planned Behaviour (TPB) (Ajzen, 1991) as the conceptual framework for measuring cycling indicators – defined here as perceptions of cycling characteristics – in order to extract the latent variables for the study. This is a well-known and widely supported psychological attitudinal theory in studies relating to behavioural decisions. The TPB states that attitudes towards a behaviour, subjective and descriptive norms, and perceived behavioural control (PBC) combine to shape an individual's behavioural intention and final behaviour. According to the TPB, attitude towards a behaviour is "the degree to which performance of the behaviour is positively or negatively valued"; subjective norm refers to "the perceived social pressure to engage or not to engage in a behaviour"; descriptive norm is related to "perceptions of what others are doing"; and the PBC is considered as "people's perceptions of their ability to perform a given behaviour".

This study is part of a research work using the TPB, as it analyses how changes to infrastructures and transport policies may affect attitudes and other psychological constructs, and how these may in turn affect the decision to begin commuting by bicycle. The TPB has also been successfully applied in a number of studies on bicycle use during the last decade and more recently. However, taking into account criticisms of this theory – namely that strong habit reduces the influence of TPB constructs – we have extended its application by including habit. Previous studies have shown that habit has a significant impact on bicycle use (Forward, 2004; de Bruijn et al., 2009; Heinen et al., 2011; Muñoz et al., 2013).

Most of the studies on cycling using the TPB focused on modelling applications. Some used the "intention" to choose the bicycle as the dependent variable. In studies using regression analysis, the extended version of the TPB in Forward (2004) explained between 47% and 78% of variance in intention to bike in four different cities with different levels of cycling. The TPB regression model in Eriksson and Forward (2011) explained 45% of variance in intention to use a bicycle for daily trips. Sigurdardottir et al. (2013) used a structural equation model and found that adolescents' cycling intention to commute by bicycle as adults was related to a positive cycling experience, willingness to accept car restrictions, negative attitudes towards cars, and a bicycle-oriented future vision; and was negatively related to car ownership norms. Lois et al. (2015) recently extended the TPB model to predict cycling commuting intention by including social identity, and their logistic regression model revealed that the psychosocial variables alone predicted 32% of the variance in car users' intention to start commuting by bicycle.

Other studies predicted the behaviour rather than the intention in the TPB framework. The binary logistic regression in de Bruijn et al. (2005) showed that the TPB elements had the highest odds ratios after some distal factors such as ethnicity or school type. Heinen et al. (2011) and Muñoz et al. (2013) explored statistical differences in cycling indicators among commuter modes, and developed binary bicycle mode choice models including cycling latent variables based on the extended version of TPB (including habit). They applied this methodology in two completely different cycling environments.

Regardless of the differences in context, both studies identified the importance of attitudes and other psychological factors in the choice to commute by bicycle. Analysing the environment both objectively and subjectively with structural equation modelling, Ma et al. (2014) concluded that the objective environment may affect bicycling behaviour only indirectly by influencing perceptions.

Other types of analysis also based on the TPB framework can be seen in Gatersleben and Uzzell (2007) and in Heinen and Handy (2012). The first centred on discriminant analysis and included statistical differences of perceptions among commuters using different modes. The second was a qualitative study based on in-depth interviews which analysed the similarities and differences in attitudes and norms affecting the decision to commute to work by bicycle in two cycling-oriented cities.

Other than the TPB, in earlier research on bicycle commuting only Dill and Voros (2007) studied statistical differences in cycling indicators among different groups based on cycling frequency and purpose. Cycling indicators have also been directly used in some modelling studies (Wardman et al., 2007; Akar et al., 2013; Muhs and Clifton, 2014). Many authors use a reduced number of cycling indicators to avoid problems of multicollinearity when modelling. Some use summated scales – average or sum – (de Bruijn et al., 2005; de Geus et al., 2008; Handy and Xing, 2010; Panter et al., 2010; Emond and Handy, 2012; Heinen et al., 2012), while others apply Principal Component Analysis (PCA) (Moudon et al., 2005; Titze et al., 2007, 2008; Akar and Clifton, 2009; Lee et al., 2011; Maldonado-Hinarejos et al., 2014). PCA has also been used in other cycling experiences such as association studies (Whannell et al., 2012) and market segmentation studies (Damant-Sirois et al., 2014).

Another technique is exploratory factor analysis (EFA), which is applied when both indicators and expected latent variables are metrical. This method conveys the information contained in the interrelationships of the indicators, to a good approximation, in a much smaller set of latent variables. It thus reduces the dimensionality of the indicators and improves the understanding of their structure (Bartholomew et al., 2011). This technique has recently been applied to some cycling studies using different methodologies such as descriptive analysis (Winters et al., 2011), modelling (Ma and Dill, 2015), and market segmentation (Li et al., 2013). EFA has been also applied in TPB studies using statistical differences in cycling indicators and modelling (Heinen et al., 2011; Muñoz et al., 2013). A confirmatory extension of EFA, including explanatory variables for the estimation of the latent variables – multiple indicators multiple causes (MIMIC) model – is also possible in more advanced research with discrete choice models (Kamargianni and Polydoropoulou, 2013; Fernández-Heredia et al., 2014; Habib et al., 2014). Other methodologies such as the Rasch model have been applied by Cheng and Liu (2012) to study bicycle-transit users' latent inconvenience.

3. Methodological approach

This study focuses on commuting trips. The commuting mode is considered as any mode used three or more times a week to go to a place of work/study: bicycle (B), walking (W), public transport (PT) and car (C).

The factors identified in the literature as influential in bicycle use are numerous and very diverse (Heinen et al., 2010). In the present study they have been divided according to the way they are measured into "objective" and "subjective". We denote as "objective" the factors that can be directly observed. Three types of objective factors have been considered here: socio-economic and household characteristics, mode availability, and trip characteristics. In addition, there are "subjective" factors which must be measured through interaction with the person. In the subjective part of this study we have considered the latent variables, which in most cases do not have an equivalent objective variable. The paper's methodology is summarised in Fig. 1, and comprises three parts: one on objective factors, another on subjective factors, and a final one on policy recommendations. SPSS®v20 has been used as the statistical tool for the analyses.

We first investigate the objective factors, starting with a sample distribution analysis according to the objective factors specified for bicycle and non-bicycle commuters. Categorical techniques (e.g. Pearson's chi-square test) are applied to find the relationships between the objective factors and commuting by bicycle or by other modes. The commuting modal share is also analysed, especially for the bicycle, comparing each specific value in the various categories in each objective factor.

We then investigate the structure of cycling latent variables extracted with an explanatory factor analysis (EFA) and applied to indicators of attitudes, subjective norm, descriptive norm and PBC (through the two elements of controllability and self-efficacy). The habit latent variable is obtained through the self-reported frequency of past behaviour (Verplanken et al., 2005). The assumptions underlying the factor analysis (Hair, 2009) are checked previously, and are: minimum sample size ($654 > 5 * 14$ indicators of attitude; $654 > 5 * 3$ indicators of subjective norm; $654 > 5 * 5$ indicators of descriptive norm; $654 > 5 * 4$ indicators of controllability; $654 > 5 * 6$ indicators of self-efficacy); and multicollinearity (Bartlett test: Sig = 0.00; MSA > 0.5). Among the various "common factor analysis" extraction methods, the principal factor analysis (Principal Axis Factoring[1] in SPSS) is applied following the recommendation of Fabrigar et al. (1999), as the indicators violated multivariate normality. A rotational method is used to achieve a simpler and theoretically more meaningful solution to the latent variables. The oblique Oblimin rotation (with delta zero) is applied to allow the latent variables to correlate. The names of the latent

[1] A method of extracting factors from the original correlation matrix, with squared multiple correlation coefficients placed in the diagonal as initial estimates of the communalities. Iterations continue until the changes in the communalities from one iteration to the next satisfy the convergence criterion for extraction (SPSS®v20).

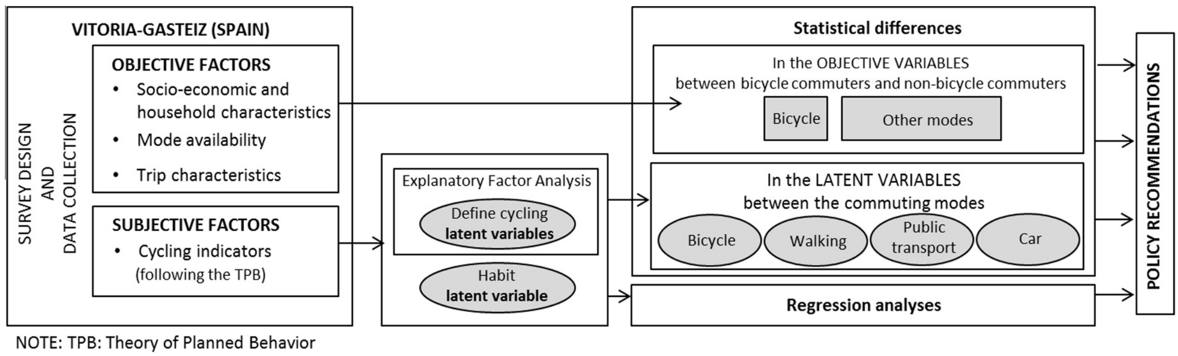

Fig. 1. Methodological process.

variables are assigned according to their constituent indicators, and by taking into consideration previous works mentioned in Section 2 that identified cycling latent variables through principal component analysis and explanatory factor analysis. Factor scores representing each individual's placement in the latent variable(s) for use in the follow-up analyses are calculated with the Bartlett method to obtain unbiased estimates of the true factor scores (DiStefano et al., 2009). The factor scores are then standardised to make the mean equal to zero and the standard deviation equal to one to allow comparison with the other latent variables.

We also examine any associations between these cycling latent variables and the commuting mode by determining statistical differences in the cycling latent variables between commuters by bicycle or by other modes. Non-parametric techniques are used, as the latent variables violate the normality distribution in the groups. A multivariate regression analysis with cycling latent variables is used to explain the bicycle commuting choice. Finally, the analysis of the two types of factors allows us to identify some policy recommendations to reinforce bicycle use.

This research follows the course initiated by Heinen et al. (2011) and Muñoz et al. (2013) in analysing the relationship between psychological factors and bicycle commuting, but contributes two additional aspects. First, the questionnaire was designed by a multidisciplinary research team of transportation planners, geographers and psychologists. This well-executed TPB survey included not only questions related to beliefs but also to importances, in order to measure attitudes and subjective norms more accurately. The second value of the questionnaire is that the PBC is addressed both by controllability and self-efficacy indicators (only for beliefs). A further difference between this and previous works is that this study has been applied in a city where cycling has only recently become the subject of promotion. The results highlight the differences with cities with other levels of cycling use – either advanced such as Dutch cities (Heinen et al., 2011) or in the early stages such as Madrid (Muñoz et al., 2013).

4. Context and data collection

Vitoria-Gasteiz is a dense, medium-size city (243,298 inhabitants in 2012) in northern Spain. It has a flat topography and a climate with moderately cold, damp winters (8 °C average temp) and cool summers (20 °C average temp). Bicycle use in Vitoria-Gasteiz is the highest of any city in Spain, and increased sharply from 3.3% in 2006 to 6.9% in 2011, and to 12.3% in 2014 (Council of Vitoria-Gasteiz, 2015). New cycling infrastructures and services are continuously being implemented. These measures receive strong support from the local authorities, and are developed within the framework of the Mobility and Public Space Plan (Council of Vitoria-Gasteiz, 2007) and the city's Cycling Mobility Master Plan (Council of Vitoria-Gasteiz, 2010). Thanks to this sustainable transport policy – among other reasons – Vitoria-Gasteiz was awarded the title European Green Capital in 2012 (European Commission, 2011).

This work uses data obtained from an ad-hoc telephone mobility survey, the first wave of a panel mobility survey on commuting trips conducted in Vitoria-Gasteiz among a sample of 736 employees and students in April 2012. The sample distribution was designed to be representative of commuting mobility, in terms of the modal share for the group "bicycle + walking + public transport" (58%), and for the group "car + motorbike + other modes" (42%). In 2011, the modal split for commuting trips in the city was: 11% bicycle, 38% walking, 9% public transport, 37% car, and 5% other modes (Council of Vitoria-Gasteiz, 2015). Specific sampling procedures were also conducted in order to guarantee a realistic distribution of gender, age, activity sector and location of place of work/study (Fig. 2). The survey included objective factors such as socio-economic and household data, availability of transport modes, commuting trip characteristics and detailed origin–destination trip data for each of the respondents. Minimum network distance was determined by entering the origin–destination information into a geographic information system (ESRI® ArcMap™ 10.0).

The subjective part was measured by indicators – perceptions of cycling characteristics – and designed based on the results of a qualitative study on attitudes towards bicycle use in Vitoria-Gasteiz, consisting of 15 in-depth interviews with commuters by different transport modes (Lois et al., unpublished results).

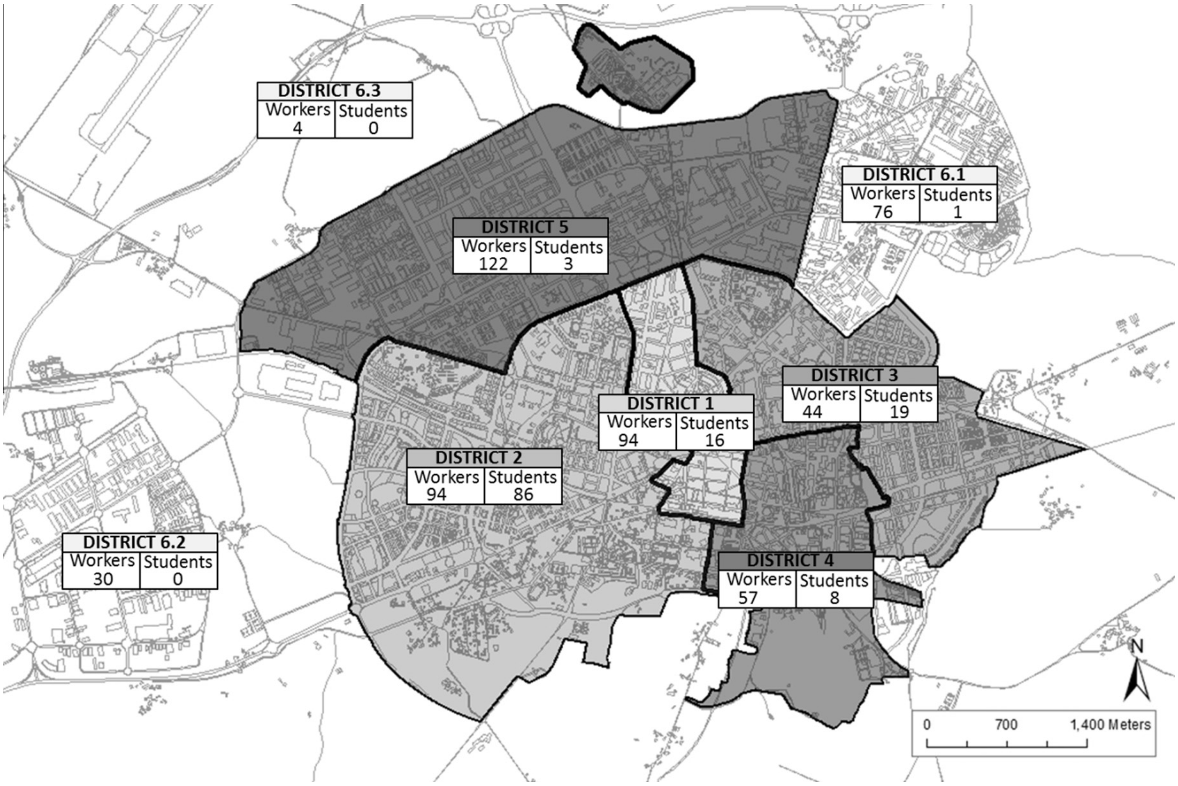

Fig. 2. Sample distribution of workers and students in the city.

Following the TPB, each element is calculated by multiplying the beliefs linking the behaviour (commuting by bicycle in our case) with their corresponding importances. We applied this method to calculate attitudes and subjective norm. Indicators related to descriptive norm and PBC (controllability and self-efficacy) were only measured through beliefs. All indicators (beliefs and importances) were measured using a 7-point Likert scale ranging from completely disagree-unimportant (+1) to completely agree-important (+7). The question on the frequency of bicycle use for non-commuting purposes (excluding sport) used the following scale: never, occasionally, almost always or always. The exact questions and indicators are summarised in Table 1.

5. Empirical application

The valid final sample consisted of 654 respondents, as the motorbike sample (6 respondents) was discarded due to its low percentage in the sample population; and because only direct trips from home to the place of work/study were considered. In the final sample, the distribution of commuters was as follows: 13% by bicycle, 27% by walking, 17% by public transport, and 41% by car.

5.1. Objective factors

Table 2 shows the sample distribution according to objective factors, specified for bicycle and non-bicycle commuters. The column proportions are compared between cycling and other commuting modes. Table 3 presents the commuting modal share – bicycle (B), walking (W), public transport (PT), car (C) – for the different categories of objective factors. Specific modal shares are compared between the categories in each objective factor.

Table 2 reveals that the majority of cyclists are men (72%); this proportion is significantly greater than for other modes (46%). Bicycle share is significantly more important among men (19%) than women (7%). In contrast, public transport is more preferred by women (26%) than men (10%). For groups aged 25–54, there is no difference in column proportions between cyclists and other commuters. However, the proportion of cyclists aged 16–24 (47%) is significantly higher than for other modes (19%). Among cyclists, 27% of the share for the 16–24 age group is statistically higher than for the other age groups. This group mainly comprises students, who are more limited in terms of driving. Car share increases significantly over age 25, while bicycle share decreases to 8% (on average). Almost half the cyclists (45%) are children (both male and female) aged >16 years, still living with their parents. This proportion is significantly higher than for the other modes (21%). This family

Table 1
Summary of perceptual questions and cycling indicators.

Attitudes towards bicycle commuting characteristics	
Belief question: "Considering your (possible) commuting trip by bicycle to the place of work/study, to what extent do you agree with the following statements...?"	Importance question: "And how important are the following things to you as a commuter...?"
I (would) commute quickly	Commuting quickly
I (would) know how long it (would) take(s) me to get to my destination	Knowing how long I'm going to take to reach my destination
It (would be)/is difficult for me to transport people	Being able to transport people
It (would be)/is difficult for me to transport objects	Being able to transport objects
I (would be)/am free because I (would)/do not depend on any other transport mode	Being free, not having to depend on any mode of transport
I (would) save money compared to other transport modes	Saving money compared to other modes of transport
I (would be)/am at high risk of having an accident	Reducing the risk of having an accident
I (would) get some physical exercise	Doing physical exercise
I (would be)/am able to park easily	Being able to park easily
There (would be)/is a high risk that my bike (would be)/is stolen or damaged	Reducing the risk of having my mode of transport stolen or damaged
I (would) pollute the environment less	Causing less environmental pollution
I (would be)/am breathing polluted air	Not breathing polluted air
I (would be)/am a nuisance to pedestrians	Not being a nuisance to pedestrians
I (would be)/am very dependent on the weather	Not being dependent on the weather
I (would) wear the proper clothes for my activities	Wearing proper clothes for my activities
I (would) make a good impression on others	Making a good impression on others
I (would be)/am stressed when I arrive(d) at my destination	Not being stressed when I arrive at my destination
I (would) enjoy the ride	Enjoying my ride
I (would be)/am sweaty when I arrived at my destination	Not being sweaty when I arrive at my destination
I (would) relax during the trip	Relaxing during the trip
Subjective norms towards bicycle commuting characteristics	
Belief question: "Considering your (possible) commuting trip by bicycle to the place of work/study, to what extent (would) the following groups of people approve?"	Importance question: "And how important to you is the opinion of the following groups of people with regard to your (possible) commuting by bicycle?"
My family	My family
My friends	My friends
My co-workers or classmates	My co-workers or classmates
Descriptive norms towards bicycle commuting characteristics	
Belief question: "How much do you think the following groups of people use the bicycle to get to their place of work/study?"	
Young people	
My family	
My friends	
My co-workers or classmates	
Immigrants	
Controllability towards bicycle commuting characteristics	
Belief question: "To what extent do you agree with the following statements...?"	
The infrastructures along my route to my place of work/study (cycle lanes, cycleways, and cycle pavements) (would) make it easier for me to move around by bike	
I could/can park my bike securely in my place of work or study	
I could/can park my bike securely at home	
Along my route to my place of work/study there are hills, changes in level and slopes which (would) hinder routine use of a bicycle	
The distance I (would) have to travel on my route to my place of work/study is suitable for travel by bicycle	
The traffic along my route to my place of work/study would allow(s) me to travel by bicycle on the road alongside the cars	
Self-efficacy towards bicycle commuting characteristics	
Belief question: Indicate how far you (would) consider yourself capable of performing the following tasks	
Riding your bicycle through traffic	
Parking your bicycle safely to avoid theft	
Regularly checking your bicycle to keep it in good condition	
Fixing a puncture on a bicycle wheel	
Using personal protection elements	
Safely performing manoeuvres on the bicycle	
Going up hills or changes in level on the bicycle	
Planning the route before you travel	
Interpreting the traffic signals and the road safety regulations	

Table 1 (*continued*)

Non-commuting cycling habit
Question: "Thinking of activities other than your usual journey to your place of work/study, how often have you used the bicycle in the last year to...?"
Going to the doctor, shopping, to visit people, for administrative purposes, etc.
For leisure (meeting friends, going to the cinema, having lunch or dinner out...)

Table 2
Distribution of the sample according to objective factors.

Variables	Total		Commuting mode	
	Frequency	%	Bicycle (%)	Other modes (%)
Gender[*,a]	654	100	100	100
Male	325	50	**72**	**46**
Female	329	50	**28**	**54**
Age group[*,a]	654	100	100	100
16–24	149	23	**47**	**19**
25–34	197	27	21	28
35–44	204	25	20	25
45–54	128	18	11	19
55–64	52	7	**1**	**8**
Family status[*,a]	654	100	100	100
Father/mother	264	40	**28**	**42**
Son/daughter	157	24	**45**	**21**
Couple no children	132	20	16	21
Without family ties	101	15	11	16
Professional situation[*,a]	654	100	100	100
Employed	521	80	**58**	**83**
Student	133	20	**42**	**17**
Car licence[*,a]	654	100	100	100
Yes	503	77	**66**	**79**
No	151	23	**34**	**21**
Car availability	654	100	100	100
Yes	550	84	80	85
No	104	16	20	15
Know how to ride	654	100	100	100
Yes	618	94	100[b]	94
No	36	6	0[b]	6
Bicycle availability[*,a]	654	100	100	100
Yes	479	73	100[b]	69
No	175	27	0[b]	31
Bicycle parking at home[*,a]	479	100	100	100
Inside home	128	27	**39**	**24**
In storeroom/warehouse/street	351	73	**61**	**74**
Travel time[*,a]	654	100	100	100
<10 min	64	10	8	10
10–30 min	448	69	**80**	**67**
>30 min	142	22	**12**	**23**
Travel distance[*,a]	654	100	100	100
<1 km	83	13	**1**	**14**
1–5 km	472	72	**98**	**68**
5–10 km	67	10	**1**	**12**
>10 km	32	5	0[b]	6

Bold values in the same row and sub-table are significantly different at $p < 0.05$ in the two-sided test of equality for column proportions.
[*] The Chi-square statistic is significant at 0.05 level for bicycle commuting.
[a] Small size association.
[b] This category is not used in comparisons as its column proportion is equal to zero or one.

Table 3
Commuting modal share according to objective factors.

Variables	Commuting mode				Total
	Bicycle (B) 13%	Walking (W) 27%	Public transport (PT) 18%	Car (C) 41%	
Gender					
Male	**19%**	27%	**10%**	44%	100%
Female	**7%**	28%	**26%**	39%	100%
Age group					
16–24	**27%**	**45%**	19%	**9%**	100%
25–34	**10%**	**18%**	16%	**56%**	100%
35–44	**11%**	**19%**	22%	**48%**	100%
45–54	**8%**	**27%**	17%	**48%**	100%
55–64	**2%**	**35%**	19%	**44%**	100%
Family status					
Father/mother	**9%**	**23%**	**15%**	**50%**	100%
Son/daughter	**24%**	**34%**	**21%**	**20%**	100%
Couple no children	**11%**	**15%**	**25%**	**49%**	100%
Without family ties	**9%**	**43%**	**9%**	**40%**	100%
Professional situation					
Employed	**9%**	**22%**	19%	**49%**	100%
Student	**27%**	**48%**	14%	**11%**	100%
Car licence					
Yes	**11%**	**22%**	**15%**	**52%**	100%
No	**19%**	**44%**	**31%**	**5%**	100%
Car availability					
Yes	12%	**23%**	**15%**	49%	100%
No	16%	**50%**	**34%**	0%[a]	100%
Know how to ride					
Yes	14%	27%	**17%**	42%	100%
No	0%[a]	36%	**36%**	28%	100%
Bicycle availability					
Yes	18%	**25%**	**16%**	41%	100%
No	0%[a]	**33%**	**23%**	43%	100%
Bicycle parking at home					
Inside home	**26%**	28%	14%	32%	100%
In storeroom/warehouse/street	**15%**	24%	17%	44%	100%
Travel time					
<10 min	**11%**	**50%**	0%[a]	**25%**	100%
10–30 min	**15%**	**27%**	**12%**	**45%**	100%
>30 min	**7%**	**17%**	**46%**	**30%**	100%
Travel distance					
<1 km	**1%**	**94%**	0%[a]	**5%**	100%
1–5 km	**18%**	**21%**	21%	**40%**	100%
5–10 km	**1%**	**1%**	22%	**75%**	100%
>10 km	0%[a]	0%[a]	13%	**88%**	100%

Bold values in the same column and sub-table are significantly different at $p < 0.05$ in the two-sided test of equality for row proportions.
[a] This category is not used in comparisons as its row proportion is equal to zero or one.

status has a significantly higher bicycle share (24%) than the others. With regard to professional status, Table 3 shows that students use the bicycle for commuting three times more (27%) than workers (9%). Significantly more students (48%) prefer walking than workers (22%), who choose the car in a significantly higher percentage (49%). *Gender*, *Age group*, *Family status* and *Professional situation* are associated at a level of 0.05 with the *Bicycle commuting* (yes/no) variable with small size effects (Cramer's statistics < 0.30) (Field, 2009).

Considering mode availability variables, Table 2 shows that most respondents have a driving licence (77%) and a car available to commute (84%). *Car licence* shows statistically significant differences in column proportions between bicycle commuters and other modes, and also in bicycle share. These results are in line with the association between *Car licence* and *Bicycle commuting*, but with a small size effect. In contrast, *Car availability* shows no statistically different proportion relating to the bicycle, and this variable is therefore not significantly associated with bicycle commuting. Almost all respondents can ride a bicycle (94%) and the majority have a bicycle available for their commuting trips (73%). However, only 18% of this last group (13% of all respondents) choose the bicycle for commuting. A storeroom, warehouse or parking space in the building of their place of residence is the preferred place to keep the bicycle at night (73%). Pearson's chi-square test for the variables *Know how to ride a bicycle* and *Bicycle commuting* may be invalid because it does not fulfil the assumption of expected frequencies >5 (Field, 2009). *Bicycle availability* and *Bicycle parking at home* also have a small association with the variable *Bicycle commuting* (yes/no) at the level of 0.05.

Characteristics such as *Travel time* and *Travel distance* are both statistically associated at the level of 0.05 with bicycle commuting, with a small size effect. Most trips have a duration of between 10 and 30 min (69%). Bicycle trips of 10–30 min (80%) are significantly higher than those for other modes (67%), and the opposite is true when the trip duration is over 30 min. Vitoria-Gasteiz is a medium-size and compact city; and most bicycle commuters therefore ride a distance of between 1 and 5 km (98%). The bicycle share for this distance (18%) is statistically higher than for other distances. The variables *Nationality*, *Family size*, *Children* < 12, *Level of studies*, *Car parking at home* and *Schedule type* are not included in the results as they are not associated with bicycle commuting, and show no statistically significant differences.

5.2. Subjective factors

5.2.1. Exploratory factor analysis

Tables 4–6 show the association of indicators and the definition of latent variables, along with the total proportion of the common variance explained in the indicators. These tables contain factor loadings from the pattern matrix (weights determining the effect of each latent variable on a particular indicator), and Cronbach's alpha coefficients for each latent variable, as a measure of internal consistency or reliability. All Cronbach's alpha coefficients are equal to or greater than the suggested minimum acceptable level of 0.7 (Hair, 2009), indicating that internal consistencies are acceptable, and it is therefore acceptable to use each latent variable instead of the original indicators.

The characteristics *Theft safe*, *Weather independent*, *Easy to park*, *Easy to carry objects*, *Easy to carry people* and *Independent* were removed from the attitudinal indicators due to their low communality[2] (<0.20). Table 4 shows the four attitudinal latent variables defined: *Lifestyle*, *Safety and comfort*, *Awareness* and *Direct disadvantages*. The larger the factor loadings, the more a particular indicator is said to load on the corresponding latent variable. The importance of ***Lifestyle*** is therefore derived from the bicycle characteristics *Fun*, *Relaxing*, and – to a lesser extent – *Good image* and *Daily clothing*. The latent variable ***Safety and comfort*** combines safety issues (*Safe for pedestrians*, *Low accident risk*, *Pollution safe*) with comfort issues (*No sweat*, *No stress*). The latent variable ***Awareness*** explains the long-term benefits of commuting by bicycle, such as *Environmentally friendly*, *Healthy*, and *Cheap*. Finally more immediate indicators such as *Quick* and *Time reliable* are explained by a latent variable. Their factor loadings are all negative, which means that indicators are negatively correlated to the latent variable. We therefore call this latent variable ***Direct disadvantages***, to express the opposite of the *Quick* and *Time reliable* indicators. These attitudinal latent variables correlate moderately (between 0.27 and 0.42).

The latent variable for psychological support for bicycle commuting was defined and is shown in Table 5. The ***Subjective norm*** latent variable is mainly explained by the *My friends* indicator, and – to a lesser extent – *My co-workers or classmates* and *My family*. Table 6 summarises the latent variable identified for self-efficacy indicators: ***Individual capabilities***. It reflects respondents' ability to deal with certain cycling circumstances such as going up hills, safely manoeuvring the bicycle, fixing a puncture, riding in traffic, planning a bicycle route, and making frequent bicycle repairs. *Park safely*, *Interpreting road signs*, and *Using safety elements* were removed due to low communality (<0.20).

The corresponding latent variables were extracted from the indicators of descriptive norm and controllability. However, they could not take the place of the original indicators due to the very low variance they explained, and to their unacceptable measure of internal consistency. They were not therefore used in subsequent analyses. Among the six latent variables identified, it is worth noting the high factor loadings of the indicators in the ***Subjective norm*** latent variable (from 0.79 to 0.97), and the high percentage of the common variance of the indicators explained (75%).

5.2.2. Differences in latent variables between groups

Six cycling latent variables were identified by EFA. A seventh latent variable for the habit of using the bicycle for non-commuting trips – *Non-commuting cycling habit* – was also calculated from the self-reported frequency of past behaviour (Verplanken et al., 2005). We investigated the possible associations between these seven cycling latent variables and the commuting mode using non-parametric techniques, due to the fact that latent variables violated the normality distribution in the groups. A Bonferroni correction (adjusted-p) was applied to control the overall Type I error rate, as multiple significance tests were done (Field, 2009). Table 7 shows that all the means of the latent variables significantly differ among the commuting modes (all $H(3) > 7.82$; adjusted-$p < [0.05/7 = 0.071]$). Mann–Whitney tests (U) between cyclists and other groups were used to follow up these findings. These effects are reported at $[0.05/(7 * 3) = 0.0024]$ the adjusted level of significance. The size effects, measured by the Pearson's correlation coefficient (r) (Field, 2009), are also reported.

The results confirm that the values of the cycling latent variables in the present sample are more positive (in absolute value) for bicycle commuters (B) than non-bicycle commuters. The most important latent variables for B are *Non-commuting cycling habit* (1.06) and *Individual capabilities* (0.53), while the latent variables *Lifestyle* (0.31) and *Awareness* (0.27) score lowest. The negative value for *Direct disadvantages* in B and walking commuters (W) means that both groups perceive the speed and time reliability of the bicycle commuting trip as a benefit, as opposed to public transport (PT) and

[2] Total amount of variance each indicator shares with all the indicators included in the analysis (Hair, 2009).

Table 4
Factor loadings of attitudes towards bicycle commuting characteristics.

Latent variables	Attitudinal indicators	Latent variables			
		Lifestyle	Safety and comfort	Awareness	Direct disadvantages
Lifestyle	Fun	0.80			
α: 0.74	Relaxing	0.75			
	Good image	0.52			
	Daily clothing	0.42			
Safety and comfort	No sweat		0.58		
α: 0.67	Safe for pedestrians		0.55		
	Stress-free		0.53		
	Low accident risk		0.51		
	Pollution safe		0.47		
Awareness	Environmentally friendly			0.81	
α: 0.84	Healthy			0.75	
	Cheap			0.74	
Direct disadvantages	Quick				−0.76
α: 0.72	Time reliable				−0.70

% Of indicators' common variance explained: 46%.
Values below 0.4 are not reported. α = Cronbach's alpha coefficient.

Table 5
Factor loadings of subjective norm towards bicycle commuting characteristics.

Latent variable	Subjective norm indicators	Latent variable Subjective norm
Subjective norm	My friends	0.97
α: 0.89	My co-workers or classmates	0.82
	My family	0.79

% Of indicators' common variance explained: 75%.
Values below 0.4 are not reported. α = Cronbach's alpha coefficient.

Table 6
Factor loadings of self-efficacy towards bicycle commuting characteristics.

Latent variable	Self-efficacy indicators	Latent variable Individual capabilities
Individual capabilities	Hills	0.77
α: 0.80	Manoeuvring	0.76
	Fixing a puncture	0.67
	Riding in traffic	0.65
	Planning a route	0.49
	Repairs	0.48

% Of indicators' common variance explained: 42%.
Values below 0.4 are not reported. α = Cronbach's alpha coefficient.

car (C) users. W has the highest values almost equal to the aspects of *Direct disadvantages* (−0.23) and *Awareness* (0.21). PT users score more positively in the *Lifestyle* latent variable (0.22), while C users score higher in *Individual capabilities* (−0.03).

Lifestyle, *Safety and comfort*, *Awareness* and *Subjective norm* show no differences between B and W, or between B and PT users. *Direct disadvantages* show no difference between B and W; although they do between B and PT users, with a medium size effect ($r = -0.27 \approx -0.30$). The only latent variables where all comparisons differ are *Individual capabilities* and *Non-commuting cycling habit*, with medium and large size effect differences respectively. This result reveals that B users significantly see themselves as more prepared than other commuters to cope with certain cycling-related circumstances; and they also use the bicycle for daily non-commuting trips more frequently than others.

The study confirms that C commuters are very strongly in opposition to B commuters, with the highest difference (Muñoz et al., 2013). All latent variables are significantly higher for B than for C users, but *Direct disadvantages* – where the cyclists' mean is significantly more negative – are less important for B than for C users. *Non-commuting cycling habit* has the greatest difference (1.21) with a large size effect ($r = -0.47$), followed by *Direct benefits* (0.75) and *Safety and comfort* (0.73) with medium size effects (−0.32 and −0.31 respectively). Although the rest of the latent variables are significantly associated with the commuting mode choice, their size effects are small ($r < 0.3$).

Table 7
Differences in means of cycling latent variables between commuting modes.

Cycling latent variables	B	W	PT	C	H_{test}	U_{test}: B-W		U_{test}: B-PT		U_{test}: B-C	
	Mean	Mean	Mean	Mean	Sig.	Sig.	S.E. (r)	Sig.	S.E. (r)	Sig.	S.E. (r)
Lifestyle	0.31	−0.02	0.22	−0.18	0.00*	0.00	−0.17	0.46	−0.05	0.00**	−0.20
Safety and comfort	0.45	0.14	0.10	−0.28	0.00*	0.00	−0.16	0.01	−0.16	0.00**	-0.31_m
Awareness	0.27	0.21	0.15	−0.29	0.00*	0.00	0.00	0.71	−0.02	0.00**	−0.20
Direct disadvantages	−0.49	−0.23	0.10	0.26	0.00*	0.00	−0.16	0.00**	-0.27_m	0.00**	-0.32_m
Subjective norm	0.40	0.04	0.04	−0.17	0.00*	0.00	−0.18	0.02	−0.15	0.00**	−0.25
Individual capabilities	0.53	−0.11	−0.15	−0.03	0.00*	0.00**	-0.36_m	0.00**	-0.33_m	0.00**	−0.23
Non-commuting cycling habit	1.06	−0.19	−0.15	−0.14	0.00*	0.00**	-0.61_l	0.00**	-0.47_l	0.00**	-0.47_l

B: Bicycle; W: Walking; PT: Public transport; C: Car.
H_{test}: Kruskal–Wallis test when there are three or more groups; U_{test}: Mann–Whitney test when there are two groups.
S.E.: size effect; $_l$: Large size effect; $_m$: Medium size effect (medium and large size effects in grey).
*Significance at adjusted level: $p < (0.05/7) = 0.0071$.
**Significance at adjusted level: $p < (0.05/(3 * 7)) = 0.0024$.

Table 8
Logistic regression results.

Variables	β	Sig.	Exp(β)
Lifestyle	−0.17	0.26	0.84
Safety and comfort	0.28	0.04	1.32
Awareness	0.26	0.11	1.29
Direct disadvantages	−0.42	0.01	0.66
Subjective norm	0.30	0.04	1.35
Individual capabilities	0.19	0.30	1.21
Non-commuting cycling habit	1.07	0.00	2.93
Constant	−2.62	0.00	0.07

$n = 654$; χ^2 (7) = 131.96; $R^2 = 0.34$ (Nagelkerke).
Significance level: $p = .05$. Significant variables shown in grey.

5.2.3. Regression analysis

A regression analysis was carried out with the cycling latent variables to complement the bivariate analyses. Table 8 shows the results of the binary logistic regression model, where the dependent variable was "Bicycle commuter" (1 if the commuting mode is the bicycle and 0 otherwise) and the independent variables were the identified cycling latent variables.

Respondents with a ***Non-commuting cycling habit*** have the greatest likelihood of commuting by bicycle (2.93). The influence of friends, family and co-workers/classmates (***Subjective norm***) also fosters the decision to cycle for commuting purposes ($\beta = 0.30$). The ***Safety and comfort*** latent variable also has a positive effect on the decision to commute by bicycle ($\beta = 0.28$). This result may be influenced by the low value of this latent variable from car commuters, who account for 41% of the total sample. In fact, the model for a subsample of non-car commuters confirms that this variable is not significant for them. The constructed attitude ***Direct disadvantages*** is statistically significant with a negative sign, confirming that a positive perception of the speed and time reliability of the bicycle increases the likelihood of choosing it for commuting.

6. Conclusions and policy recommendations

This paper proposes a number of cycling indicators based on the Theory of Planned Behaviour (TPB) (Ajzen, 1991) for their inclusion in mobility surveys, and contributes to a deeper understanding of the structure of cycling latent variables, using exploratory factor analysis (EFA). We examine both objective and latent variables and their association with, and influence on, bicycle commuting.

The results for the objective factors showed that socioeconomic and household characteristics (*Gender*, *Age group*, *Family status* and *Professional situation*), mode availability (*Car licence*, *Bicycle availability*, and *Bicycle parking at home*) and trip characteristics (*Travel time* and *Travel distance*) were associated with bicycle commuting, albeit all with minor size effects. However, this analysis allowed the bicycle commuter profile to be identified.

The TPB survey developed in this study included not only questions related to beliefs but also importances, and therefore provided a more accurate measurement of attitudes and subjective norm. As a consequence the association and regression analysis of the six cycling latent variables identified have a sound basis. The EFA identified four attitudinal latent variables – ***Lifestyle***, ***Safety and comfort***, ***Awareness***, and ***Direct disadvantages***; another – ***Subjective norm*** – related to psychological support for using the bicycle to commute; and a final variable – ***Individual capabilities*** – referring to respondents' ability to cope with certain cycling circumstances. The study also calculated a seventh latent variable – ***Non-commuting cycling habit***

– for the habit of using the bicycle for non-commuting trips. All these cycling latent variables were significantly associated with the commuting mode, with medium and large effects, unlike the objective factors. The results showed the performance of the city of Vitoria-Gasteiz (Spain), which is currently in the process of using the bicycle as a viable transport mode.

Although the present study is cross-sectional, the findings allow the selection of certain policy recommendations, as suggested by Handy et al. (2014). The results for ***Non-commuting cycling habit*** show the greatest difference between bicycle and non-bicycle commuters. This latent variable appears to be the strongest latent predictor of bicycle commuting. One potential strategy to change this that could be considered by the city authorities is the launch of *marketing campaigns* to encourage non-bicycle commuters to increase their bicycle use for going out, shopping, running errands and so on. It should however be noted that habit may not be easy to change. For this reason, and because ***Subjective Norm*** is another latent variable influencing bicycle commuting, it may be more positive to target bicycle measures to social groups rather than individuals. We suggest prioritising marketing campaigns and other infrastructure investments (cycleways and bicycle parks) around leisure zones and social and cultural centres/associations to maximise the significant influence of friends on bicycle commuter behaviour. The second most important social group to target is co-workers and classmates, suggesting measures in work/study environments.

Further efforts could also be made to foster the speed and time reliability of the bicycle (***Direct advantages*** for bicycle commuters) – especially in the case of public transport or car users – through policies aimed at encouraging people to experience the cycling trip. Some 59% of these commuters have never tried commuting by bicycle, and 67% of them make trips of less than five km. A lack of experience in this area may impact the results of this latent variable (Rondinella et al., 2012). One positive measure would be to launch bicycle-specific programmes such as *Bike-to-work days*. There is encouraging evidence from other places of the effect of this type of programmes on cycling (Pucher et al., 2010; Yang et al., 2010). ***Safety and comfort*** is another important predictor for bicycle commuting, although only for car commuters, for whom this is probably seen as a deterrent due to their lack of experience. Safety and comfort issues are not major barriers to bicycle commuting for non-car commuters. Therefore the recent policy in Vitoria-Gasteiz of providing cycleways and improving bicycle network connectivity appears to be effective. With regard to the latent variable ***Individual capabilities***, the extension of measures such as cycling courses (how to ride safely on the proper infrastructures and near cars, how to fix a puncture and repair/maintain the bicycle and so forth) would benefit non-bicycle commuters, and especially pedestrians and public transport users.

These results differ from those in cities with less bicycle use such as Madrid, where safety is a clear barrier for all commuters, and social pressure is not an influential factor (Muñoz et al., 2013). Vitoria-Gasteiz shares with Madrid the importance of the latent variable ***Non-commuting cycling habit***, and more progress is thus needed to normalise the bicycle as a mode of transport. The importance of habit diminishes the influence of other latent variables such as ***Individual capabilities*** (PBC), which appears to be significant in more cyclable contexts such as the Netherlands (Heinen et al., 2011).

The results of this study correspond to an intermediate stage, and could help shed light on the process of so-called cities in transition towards a cyclable city. The cycling latent variables extracted can serve as the starting point for more sophisticated modelling schemes such as structural equation models (Golob, 2003) and hybrid choice models (Ben-Akiva et al., 2002a, 2002b; Walker and Ben-Akiva, 2002).

Acknowledgements

The authors gratefully acknowledge the funding awarded to Begoña Muñoz by the Spanish Science and Innovation Ministry under Grant BES-2011-049533 associated with the National Research Project: "TRANSBICI–Travel behaviour analysis for modelling the potential use of bicycle: transition to a cycling city". We would also like to thank Manuel Loro (TRANSyT – Universidad Politécnica de Madrid) for his help with the distance calculations.

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