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Gender differences in bicycle sharing system usage in the city of Valencia

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ABSTRACT

Bicycle sharing systems (BSS) in cities are an environmentally friendly alternative to fossil-fuel-based transport. Among the different factors that influence its use, the scientific literature points out that there are gender differences in the frequency of trips made. The present study analysed the movements of men and women who use the BSS in the city of Valencia during weekdays. Our database contained a total of 5,300,328 trips by users over a period of 4 years. Ridership networks were constructed through user's trips (arcs) between the bicycle exchange stations (nodes). Different parameters of centrality and density of the generated networks were calculated, and the Voronoi spaces of each of the vertices were calculated to establish the spaces covered by users throughout the day. Our results show that women use the BSS less than men in all the tested time slots. We also observed different network density and centrality for men and women. Finally, we found that women do not use the peripheral areas of the city at night. The gender inequality patterns of use and space occupation observed offer useful information for the operating company and city transport policy-makers. This study also contributes to putting gender differences at the forefront of future interventions.

1. Introduction

Bicycle sharing systems (BSS) are now popular in many cities around the world (Bonham & Johnson, 2015; DeMaio, 2009; Goodman, Green, & Woodcock, 2014; Midgley, 2011; Shaheen, Guzman, & Zhang, 2010), in line with the growth of environmental consciousness among younger generations (Dutzik & Baxandall, 2013). Sustainable forms of transport policies contributed to its popularization by extending cycling infrastructures and related services (Dickinson, Kingham, Copsey, & Hougie, 2003; Fishman, 2016; O'Brien, Cheshire, & Batty, 2014; Pucher, Dill, & Handy, 2010). These systems brought new costs and benefits for citizens' transport and urban organization. The costs have been mainly due to traffic disruption, safety and the problems in managing these systems (Fishman & Schepers, 2018; Saberi, Ghamami, Gu, Shojaei, & Fishman, 2018; Shaheen et al., 2010). The benefits have been linked to economic, environmental and health issues since they reduce the number of motorised vehicles and sanitary costs associated with air quality, as well as general energy consumption (Bullock, Brereton, & Bailey, 2017; DeMaio, 2009). Air pollution, excessive use of fossil fuels and general environmental deterioration are concerns that stimulate the use of more sustainable transport systems, especially in cities (Cao & Shen, 2019; Otero, Nieuwenhuijsen, & Rojas-Rueda, 2018). Cycling and particularly BSS also offer multiple benefits to their users such as individual health improvement, more recreational opportunities, better access to public transport nodes, and diversification of city transport (Goodman et al., 2014; Molina-García, Castillo, Queralt, & Sallis, 2015; Mueller et al., 2015; Oja et al., 2011; Wen & Rissel, 2008). BSS are thus active and clean alternatives to motorised transport, urban mobility and inactivity-related health problems, as they allow cycling in the city even if you do not own a bicycle.

The factors that influence the BSS usage are multiple and varied (Eren & Uz, 2019), according to several studies. For instance, the quality and extension of transport networks (the number of stations and capacity) increase BSS usage (Faghih-Imani, Eluru, El-Geneidy, Rabbat, & Haq, 2014; R. Wang & Liu, 2013). Land-use and urban-form issues, such as population density, job density and the distance from home to a station, also affect its usage (Bachand-Marleau, Lee, & El-Geneidy, 2012; Faghih-Imani et al., 2014; Fuller, Sahlqvist, Cummins, & Ogilvie, 2012; Rixey, 2013). The number of points of interest near BSS stations, such as restaurants, retail stores and universities increase the number of bicycle users (Faghih-Imani et al., 2014; Rixey, 2013). BSS usage, and cycling in general are also affected by temporary characteristics, since more

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cyclists are active in evening peak hours and weekdays than at weekends (Faghih-Imani & Eluru, 2015; Faghih-Imani et al., 2014; McBain & Caulfield, 2018; Zhao, Wang, & Deng, 2015). Certain weather conditions such as rain, extreme temperatures, high wind speeds and high humidity contribute to using BSS for shorter trips and either taking another type of transport or foregoing longer trips in these conditions (Gebhart & Noland, 2014; Kim, 2018; Kull, Ferri, & Martínez-Usó, 2015). Daylight hours also affect riding bicycles on BSS since there is less usage and trips are shorter when it is dark, regardless of any temperature effects (Gebhart & Noland, 2014).

However, all groups and populations do not have similar programs and systems to promote bicycle use. For instance, in many countries regular cycling is more associated with the young and predominantly male population (Aldred, Woodcock, & Goodman, 2016), especially young, male, white, highly educated and affluent persons (Fishman, 2016; McNeil, Broach, & Dill, 2018). As this paper is focused on the gender role in BSS, a review of the factors that affect men and women's use is emphasised.

It is important to start by identifying gender differences in general cycling for a wider understanding of the gender factors that affect the use of BSS. Studies from the EU, the USA, Canada and Australia highlight that women use bicycles less than men in a ratio of two to one (Aldred et al., 2016; Pucher & Buehler, 2008). Similar gender differences were also observed among children in the USA when commuting to school, since boys cycle 2–3 times more than their girl counterparts (McDonald, 2012) and this proportion is maintained in college education (Abasahl, Kelarestaghi, & Ermagun, 2018; Akar, Fischer, & Namgung, 2013). These differences are similar in Spain, where bicycle participation has increased and the users are mainly young people, with 58.9 % men and 42.8 % women (GESOP, 2019). In a study carried out in the city of Sevilla, women users made up 33 % (Marqués, Calvo-Salazar, & Hernandez-Herrador, 2016) of the cyclists and in another one Valencia they were 39 % (Anaya-Boig, 2019).

Gender differences in the bicycle use depend on the cycling cultures in which every cycling system is embedded. This explains why in certain cities such as Ghent, with a high-cycling prevalence, women cycle more than men (Witlox & Tindemans, 2004) or different local and national importance of cycling help us to understand differences in cycling practices (Aldred & Jungnickel, 2014). It also explains the gender differences between the high and low bicycle-use countries, since as many women as men use bicycles in northern European countries, while only a quarter of the cyclists in English-speaking countries are women (Pucher & Buehler, 2008). However, many other psychological and socio-environmental factors are behind the gender differences in cycling. For instance, many womens' trips are for recreational purposes and those of men are for commuting (Handy, 2011; Krizek, 2006). Perceptions of safety and risk, such as injuries, accidents and moving between cars also show acute gender differences, which make women's cycle less than men (Aldred et al., 2016; Kaplan, Vavatsoulas, & Prato, 2014; Steinbach, Green, Datta, & Edwards, 2011). These perceptions also affect women's preferences for using better facilities and off-street bicycle lanes separated from motor traffic than men (Aldred, Elliott, Woodcock, & Goodman, 2017; Garrard, Rose, & Lo, 2008; Heesch, Sahlqvist, & Garrard, 2012). Safety and risk seem to play a significant role in females' bicycling choice, and fear of crime and violence is supposed to influence women cycling (Emond, Tang, & Handy, 2009; Steinbach et al., 2011). Moreover, females show greater preference than males for greenways and cycling around parks while job density is negatively associated with females' share of trips (Brick, McCarthy, & Caulfield, 2012; Heesch et al., 2012). Finally, the unequal sexual division of labour and time between men and women (e.g. household chores and childcare responsibilities) also prevent women from cycling (Aldred et al., 2016; Prati, 2018).

Fewer BSS studies focus on gender differences than those on general cycling, but they are considered strongly skewed by gender, women being substantially under-represented. For instance, less than 20 % of all trips by London BSS users are made by women (Goodman et al., 2014). In Melbourne and Brisbane only 23 % and 40 % of the total accounts belong to women (Fishman, Washington, & Haworth, 2014), and less than one third of the trips are made by women in the New York BSS (K. Wang & Akar, 2019).In the Spanish town of Vilagarcía de Arousa, women make 29.7 % of the total trips (Sanmiguel-Rodríguez, 2019) while in Palma de Mallorca they make 40 % (Pons, Lladó, Pérez, & Reynés, 2016). According to a recent Spanish barometer survey, BSS is used by 23.4 % of men and 19.1 % of women (GESOP, 2019). Commuting patterns also differ by gender since males have shorter trip durations than females and females have longer trips with more cycle chains than males (J. Wang & Lindsey, 2019; Zhao et al., 2015). Women's predominant behaviours for non-utilitarian cycling purposes over men's instrumental commuting are found in the use of many BSS (Beecham & Wood, 2014; Goodman & Cheshire, 2014;).Perceptions of safety and risk affect women BSS users by choosing off-street lanes and paths through parks and greenways, and out of job-dense areas (Beecham & Wood, 2014; K. Wang & Akar, 2019).

These data on gender differences in BSS use suggest similar differences as in general bicycling behaviour. In fact, women have been referred to as an 'indicator species' for bicycle-friendly environments due to their risk aversion (Baker, 2009; K. Wang & Akar, 2019). An 'indicator species' is originally used in ecology to refer to a species or group that can be used as an indicator of community types or environments due to their niche preferences (Cáceres, Legendre, & Moretti, 2010). Women can thus be considered as a diagnostic indicator for the general quality and equal services offered by BSS and an instrument for future improvements. However, it should be noted that research focused on gender differences in urban cycling is not plentiful, especially as regards certain understudied variables which emerge in the previous review, such as daily time slots, daylight, density of use and city zones.

Against this backdrop, the purpose of this study is twofold. First, to identify patterns in Valencia BSS usage by gender, and secondly to analyse the use of space by men and women Valencia BSS users according to ridership networks and cycling zones during the three daylight time slots.

2. Data and methods

2.1. Area of study and data

The study presented in this paper was carried out in the city of Valencia, which has around 800,000 inhabitants and is located in the East of Spain (see Fig. 1). Including its metropolitan area, Valencia reaches a total population of 1.5 million people. It is the third largest city in the country after Madrid and Barcelona. The population density is around 5900 inhabitants/km^2. Tourism is one of the main economic activities, partly due to its mild Mediterranean climate and a set of infrastructures focused on cultural tourism and entertainment. Valencia economy is predominantly sustained by small businesses and small and medium sized industries. It has two public universities (University of Valencia and the Polytechnic University of Valencia) with 80,000 students and is especially attractive for exchange students, mainly from Europe. Valencia also has four large public hospitals. For a more detailed description of the city see the work of Prytherch and Boira Maiques (2009).

With regard to transport, Valencia has a railway network connected to both the largest cities in Spain and to nearby towns. It has an airport very close to the city that can be accessed directly through by underground. There is also an urban and suburban bus network with a total of 60 lines and more than 1101 stops. There are also 9 underground lines that cross the city and go to nearby towns. In spite of the transport infrastructure, Valencia receives an average of 40,000 motor vehicles daily. With regard to bicycle transport, in 2018 an average traffic intensity of over 1300 bicycles was recorded on the city's cycle lanes. This means that about 1.8 % of the total trips are made by bicycle (Oficina de

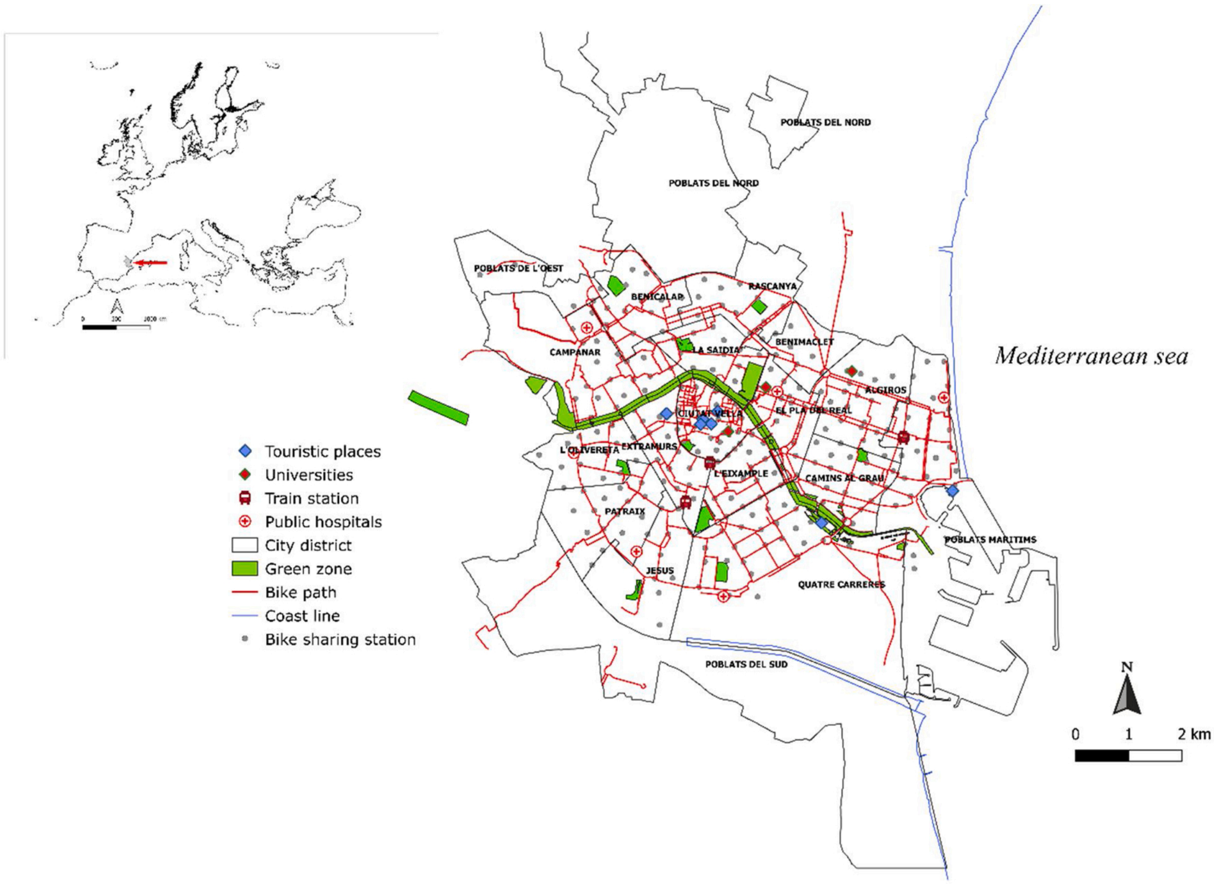

Fig. 1. Map of the studied area. Upper left, location of the province of Valencia in Europe. The red arrow points to the city of Valencia. Right, map of the city of Valencia and its main infrastructures. The red lines indicate the structure of the bicycle lane network in 2018. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

Estadística. Ayuntamiento de Valencia, n.d.). This percentage is slightly higher than the 1.3 % for the whole of Spain. Bicycle use has also increased in recent years and most of the new users are women (GESOP, 2019). The bicycle lane network in Valencia expanded from 83 km in 2008 to more than 148 km in 2018 (Oficina de Estadística. Ayuntamiento de Valencia, n.d.).

Since 2010 Valencia has had a public bicycle sharing service under the commercial name of *Valenbisi*. This service is managed indirectly by the company JCDecaux and has a total of 276 stations and 2,750 bicycles. People can use this service through different types of contracts. There are 5 types of membership, two of which have annual fees ranging from €26 to €29.21, the latter including a card for the Valencia public transport system. Citizens older than 55 years of age get a special price of €24. The other 2 types are weekly cards at a price of around €13. All the types have free access to the *Valenbisi* system for a maximum of 30 min per trip. If they want to use it longer they have to either change the bicycle or pay an extra €0.50 for between 30 min and 1 h or €2.08 for each extra hour. The present study is based on the membership database provided by the company.

The database used in this work was composed of the movement records of all users of the Valencia BSS from January 2015 to July 2018. These displacements were stored in 43 Excel files. The files had 12 columns describing each one, with the number of rows varying according to the number of users each month (usually over 500,000 trips per month). Only the following columns were used for the analyses: member code (numerical), departure station (text), return station (text), departure and arrival date (text: DD/MM/YYYY HH:MM:SS) and travel time (numerical). An estimate of the minimum distance between stations was calculated (i.e. shortest distance between stations) using the Distance Matrix API (Google Maps Platform).

On the other hand, the socio-demographic data of each of the users were stored in a duly anonymised separate file. Only two fields were extracted from this socio-demographic data file, namely: member code (numerical) and gender (numerical: male/female). This file basically contained two types of subscribers: annual (≈40,000) and weekly (≈11,000). Only the data of long-term subscribers who made at least one trip during the 4 years of the study (i.e. 25,360) were selected for analysis, 60.19 % of whom were men and 39.81 % women. The 18–25 years-old group (≈30 %) had most users, followed by 26–35 years old (≈26 %) (see Fig. 2 for comparison with the population of Valencia). Various analyses were carried out on the trips of these members over the following years to establish differences in men and women's behaviour.

2.2. Data pre-processing

Several routines were written into the Matlab programming environment for the pre-processing of the data and the subsequent analyses. As the first step, the stations where users picked up and dropped off their bicycles were geolocated. Through the member code field each of the journeys was labelled as male or female taking into account the socio-demographic data file. Those trips that took place on weekends (Saturday and Sunday), official holidays or school holidays were deleted in order to focus the analysis on weekdays. The trips made by users who had a short-term membership were also eliminated, as well as those that had the same departure and arrival station or showed anomalous journeys (e.g. when the bicycle did not reach its destination). Once the data had been cleaned and the trips segmented by gender, the matrices were saved for subsequent analyses. An example of the monthly trips,

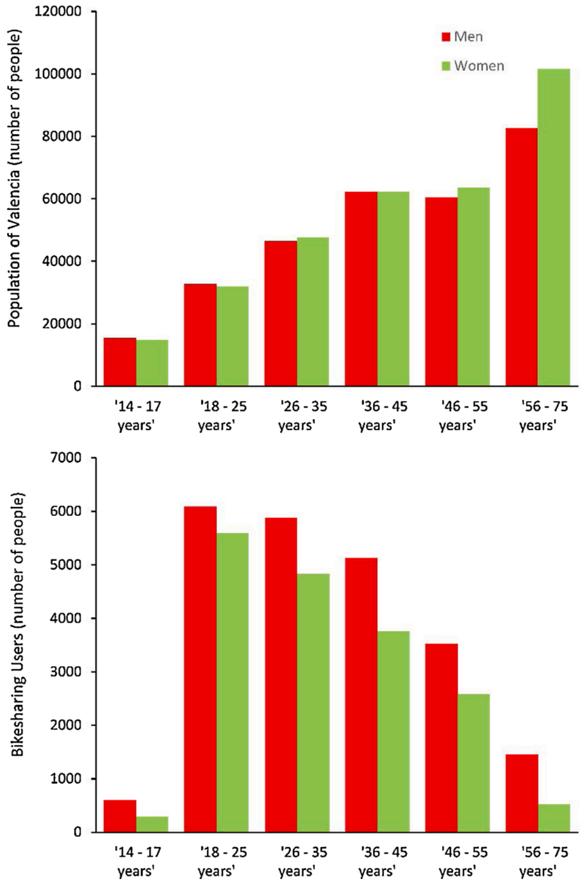

Fig. 2. Population of Valencia and BSS users age-group distribution. Upper panel, data of the population of Valencia (Oficina de Estadística. Ayuntamiento de Valencia, n.d.). Lower panel, data of the Valencia bicycle sharing system users with annual subscription.

separated by gender, can be seen in a video included in Supplementary Material V1.

2.3. Analysis of the trips made during the day

Daylight was used as a criterion to establish the three daily time slots. Night was defined as one hour after sunset to one hour before sunrise. Morning was defined as one hour before sunrise to 12 o'clock. Afternoon was established as the time between morning and evening. These time slots were therefore flexible and depended on the daily variations in sunset and sunrise. This was a culturally-based decision, since morning, afternoon and night are flexible terms in Spain, and everyday life is strongly conditioned by daylight variations during the year.

Once the time slots were established, the journey averages and the standard deviation of each hour of the day and time slot were calculated. The same calculations were also carried out, but the number of trips was previously normalised according to the number of potential users in each group (women and men).

2.4. Construction and analysis of the directed graphs (ridership networks)

A graph (G) is described as a nonempty set of vertices (V) and a set of edges (E), where each edge determines a set of two vertices called the endpoints of the edge. In the case where the connection between the two vertices has a direction (i.e. initial vertex and terminating vertex) the network is called a directed network and is defined as follows:

$$G = (V, A)$$

Where V is a finite and nonempty set of vertices or nodes, A being a series of ordered pairs of vertices (u,v) called arcs.

The non-symmetric adjacency matrices were built with the journey data and a resolution of 1 h. It is a square matrix with an equal number of rows and columns corresponding to each of the network's nodes (in our case each node is a *Valenbisi* station; 276×276). The elements of the matrix indicate the relation between the connected pairs of nodes (i.e. adjacent to each other) in the network.

The weighted all degree was calculated for each of the nodes. This parameter indicates the number of times a node is used by riders and is the sum of the inputs and outputs of a node in the network (Rodrigue, Comtois, & Slack, 2013; Taczanowska, Bielański, Gonzalez, Garcia-Massó, & Toca-Herrera, 2017). As with the total trips, the weighted all degree was also normalized according to the number of potential users. All the analyses were segmented according to gender in a similar way to trips made. The 100 most usual trips between nodes were represented, differentiating between men and women. For this, the complete sample of trips was used and the most frequently repeated connections between nodes were considered to be the most common trips.

To compare the men and women's networks, two different parameters were calculated; the density of each network and the degree of similarity between both networks. To calculate the first parameter, the following equation was used (Otte & Rousseau, 2002):

$$Density = \frac{2 \cdot m}{n(n-1)}$$

Where m is the number of direct lines and n is the number of vertices in the network. Density varies from 0 (no connection in the network) to 1 (every vertex is interrelated).

Regarding the second parameter, degree of similarity, the algorithm described by Blondel and colleagues was used (Blondel, Gajardo, Heymans, Senellart, & Van Dooren, 2004). This was done using the graph similarity function in Matlab Tools for Network Analysis of MIT (MIT Strategic Engineering Research Group: Olivier L. de Weck, n.d.). Basically, this algorithm calculates the similarity between the vertices of two directed networks. High similarity scores mean that the cyclist's behaviour between both vertices is very similar and low scores mean the opposite. The latter parameter was therefore used to represent the differences between male and female ridership networks traced by their trips.

2.5. Voronoi spatial analysis

The percentage of journeys in each of the nodes was calculated for the spatial analysis of the trips. The percentages were also obtained for each of the time slots (i.e. morning, afternoon and night). With these percentages three clusters were calculated through an iterative k-means algorithm. The resulting clusters were called low frequency, medium frequency and high frequency visits.

To represent these clusters, the Voronoi spaces were calculated for each of the nodes. The Voronoi spaces are based on Delaunay's triangulation and their main property is that once the spaces are established, any point within a space is always closer to its reference node than to any other node (Erwig, 2000). These spaces were used to calculate the area of each of the clusters. Because the calculation of Voronoi's spaces leaves some areas open, the external areas were bounded by the city limits.

The intention of this analysis was to establish the area in km^2 cyclists use or stop using when they reach a certain node. When a user returns his or her bicycle, he or she normally chooses the node closest to his or her destination. In this way, when calculating the Voronoi spaces around each of the nodes, we can establish the most logical space used by the rider.

2.6. Statistical analysis

All the statistical analyses were performed with IBM SPSS software (Version 26). The assumption of normality was tested prior to the analyses by a Kolmogorov-Smirnov test. Since some of the variables did not meet the assumption of normality it was chosen to perform non-parametric tests. A Wilcoxon signed-rank test was used to establish differences between the male and female network nodes. For each of the comparisons, the effect size was calculated according to the following equation (Fritz, Morris, & Richler, 2012):

$$r = \frac{Z}{\sqrt{n}}$$

Where n is the total number of observations on which the Z value is based.

Since the number of comparisons is high because the file is segmented into different time slots, to avoid an α type error a Bonferroni correction setting was used, so that the value $\alpha = 0.05$ was divided by the total number of comparisons made.

3. Results

3.1. Overall usage values

Valencia BSS users made a total of 5,300,328 trips during weekdays in 1212. Men made approximately 67 % (3,535,930) of the trips and women 33 % (1,764,398) with an average of 12 min per trip (11.84 min for men and 12.13 min for women).

According to estimates, if users took the shortest path between the nodes, men rode an average distance of 3389 m and women 3369 m per trip, suggesting that women's trips were ridden at a slightly lower speed than men's. The distribution of time and distance between men and women can be seen in the Supplementary Material F1.

3.2. Bicycle trips in a weekday and daily time slots

As shown in Fig. 3, there were two clear peaks of activity during weekdays at around 9 a.m. and at 3 p.m. for both men and women, and a third peak around 8 p.m.

We can also observe that when the day was divided into three time slots (i.e. night, morning and afternoon) significant differences were established between men and women ($p < 0.05$) at all three times. These differences also appeared when the average movement was normalized by the number of potential users tracked. Men rode a higher number of trips than women in each daily time slot and every variable under study. However, the difference effect size (r value) was higher during the night than the morning and afternoon (see Table 1).

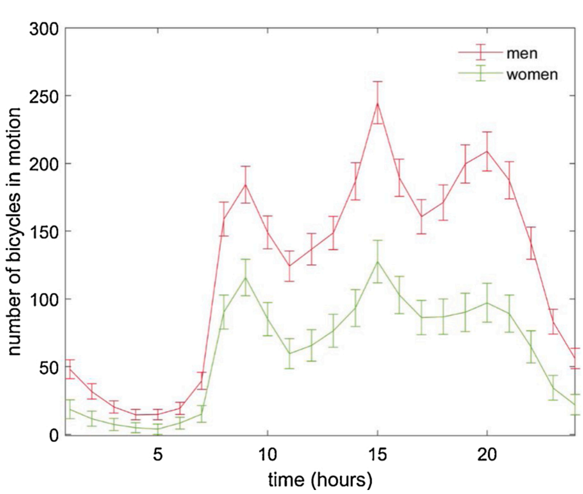

Fig. 3. Dynamics of weekday trips by gender. The lines express the average value of trips over the four years tested. The error bars indicate the standard deviation.

3.3. Ridership networks

The trips made during the 1212 tested weekdays traced the ridership networks generated by gender. The men's network had a higher density than the women's (0.78 men vs. 0.66 women). The average all-degree parameter for the men's network was 433.08 and 367.42 for the women. This indicates that the men's network had a greater number of connections with other nodes than the women's network, reinforcing the idea that the men's network was denser than the women's.

In Fig. 4, the upper and middle panels show the ridership networks traced by men and women, respectively. In order to compare both networks, the degree of similarity of the Valencia BSS nodes was calculated and is represented in the lower panel. As can be seen, the greatest similarity was in the city centre and the east-central Valencia, with the least in the suburbs.

3.4. Space occupation during time slots on a weekday

The space occupied by men and women's journeys was drawn from the Voronoi spatial analysis in the three daily time slots and identifying three clusters with similar trip patterns. Fig. 4 shows the area with the greatest number of trips (high frequency visits, shown in yellow), the area with an intermediate number of trips (medium frequency visits, shown in green) and the area with fewest trips (low frequency visits, shown in blue). The area covered by each of the clusters depended on the time of day. The maximum difference between men and women occurred during the night, and as can be seen in Fig. 4, the least used area (low frequency visits shown in blue) is 8 km^2 larger in women than men. In other words, women only used the most central areas of the city at night. At the other times of the day the differences between men and women were less than 3 km^2 (see Fig. 5).

4. Discussion

This paper analysed the use patterns of the Valencia BSS, the use of space by cyclists and identified different cycling men and women's behaviours. The results show a gender-unequal pattern and certain gender differences in space occupation. This was possible after exploring more than 5 million trips made by the 25,360 members during a three-and-a-half-year period.

One of the main results of the analysis is that males made many more trips than females during the whole period analysed. This higher male

Table 1
Gender differences in the number of trips according to daily time slots.

	Men	Women	Wilcoxon signed-rank test
Night ($trips \cdot hour^{-1}$)	71.89 (47.61)	29.84 (21.29)	$Z = -25.53$ $p <$ 0.001*, $r = -0.84$
Morning ($trips \cdot hour^{-1}$)	132.21 (122.32)	70.01 (70.12)	$Z = -29.375$ $p <$ 0.001*, $r = -0.57$
Afternoon ($trips \cdot hour^{-1}$)	185.88 (164.45)	89.58 (84.44)	$Z = -21.662$ $p <$ 0.001*, $r = -0.62$
Night ($trips \cdot hour^{-1} \cdot users^{-1}$)	0.005 (0.003)	0.003 (0.002)	$Z = -18.405$ $p <$ 0.001*, $r = -0.53$
Morning ($trips \cdot hour^{-1} \cdot users^{-1}$)	0.009 (0.008)	0.007 (0.007)	$Z = -7.429$ $p <$ 0.001*, $r = -0.21$
Afternoon ($trips \cdot hour^{-1} \cdot users^{-1}$)	0.012 (0.011)	0.009 (0.008)	$Z = -9.447$ $p <$ 0.001*, $r = -0.27$

Data are expressed in median (interquartile range). The * indicates a significant difference after applying Bonferroni' adjustment (α/no. of comparisons). Users indicate the number of people who have used the service at least once during the days tested.

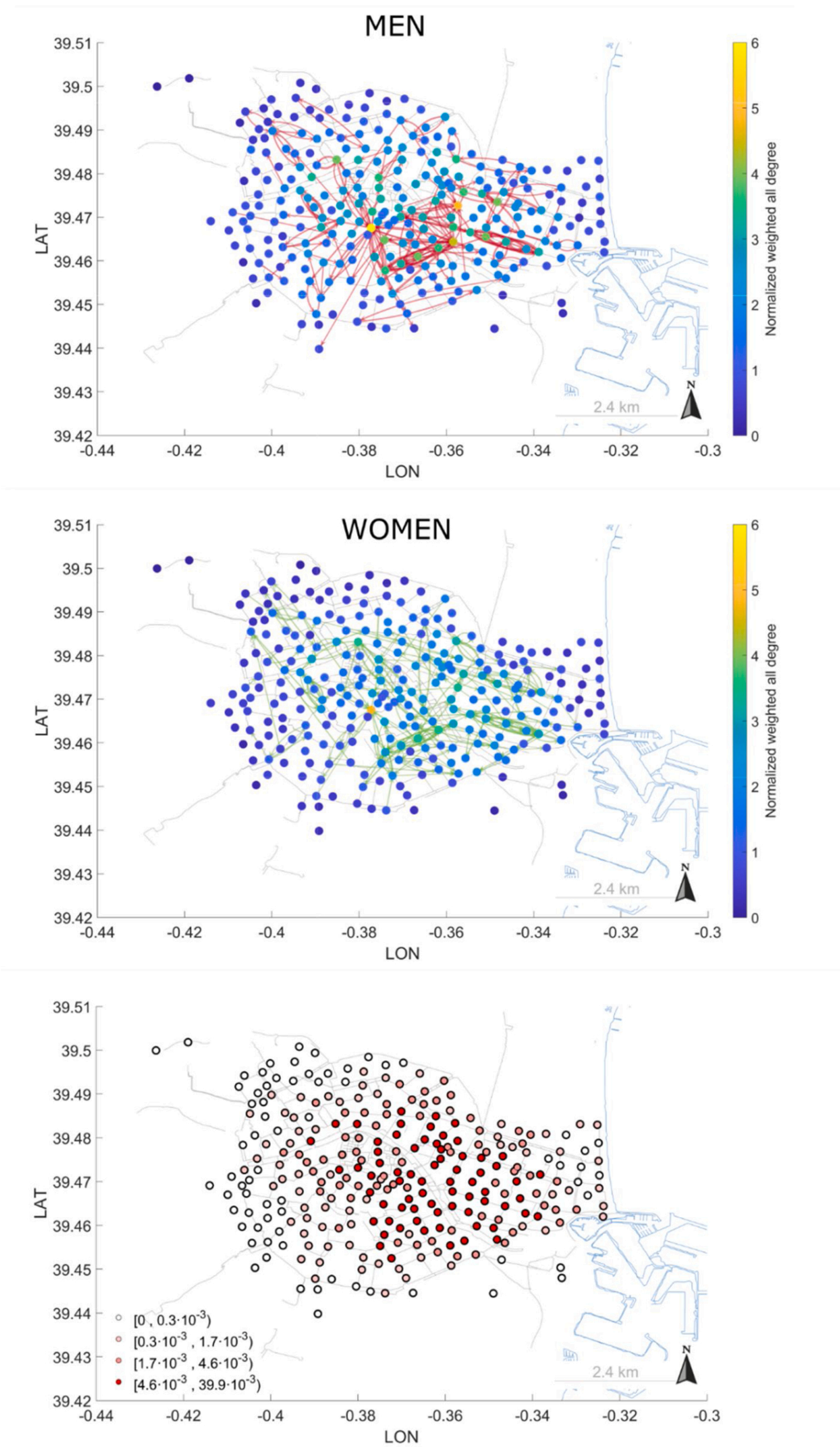

Fig. 4. Men and women's ridership networks and their comparison by degree of similarity. The top and middle panels show the 100 most common trips by men (red lines) and women (green lines), respectively. The width of the arcs indicates the number of journeys between nodes, a wider width indicates a greater number of trips. The colour of the nodes indicates the standardized weighted all degree of each of the nodes. The bottom panel indicates the degree of similarity between the male and female networks. Values close to 0 mean low similarity and high values high similarity. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

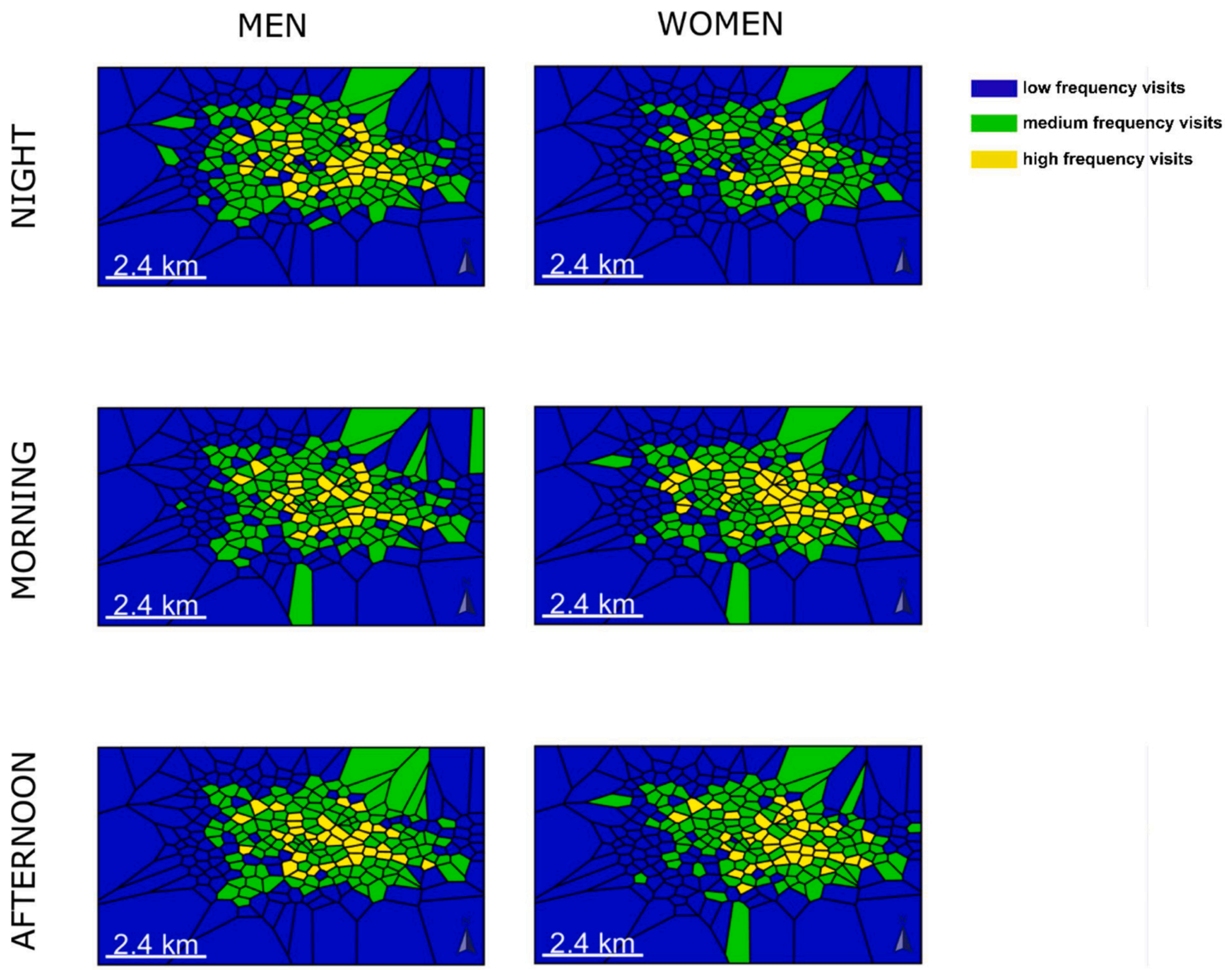

Fig. 5. Voronoi spaces used by men and women throughout the day according to the cluster to which they belong. Low, medium and high frequency visits are the three clusters calculated for each time slot and gender. Low frequency area groups little-used spaces, medium frequency, intermediate use and high frequency, intensive use. The area of the three zones during the morning and evening was similar for men and women. The night-time low frequency visited area is 8 km^2 larger for women than men.

participation is similar to the results obtained in other studies focused on BSS and the cycling transport in many cities around the world (Beecham & Wood, 2014; Fishman, 2016; Murphy & Usher, 2015; Zhao et al., 2015). Women users in the Valencia BSS make 10 % more trips than women in other cities such as London BSS (Goodman & Cheshire, 2014), but it is still strongly biased by gender. In fact, the percentage of men's trips (67 %) in Valencia is double that of women (33 %), in agreement with the cycling differences by gender found in other studies (Aldred et al., 2016; Heesch et al., 2012). This difference is lower than in Chicago, where 79 % of the trips are made by males and 21 % by females (Faghih-Imani & Eluru, 2015). However, the values of our study are closer to low-cycling prevalent cities, mainly in English speaking countries, than to the high-cycling prevalent cities in the North of Europe (Pucher & Buehler, 2008). This is probably due to the relatively recent inclusion of urban cycling infrastructures in Spanish cities such as Valencia or Seville (Marqués, Hernández-Herrador, Calvo-Salazar, & García-Cebrián, 2015). The percentage of trips made by women in Valencia BSS (33 %) is slightly lower than the percentage found in other studies on general cycling conducted in the city of Valencia and in Spain (≈39 %) (Anaya-Boig, 2019; GESOP, 2019), possibly because of methodological differences (BSS versus general cycling and data mining versus questionnaires).

In terms of time, Valencia BSS users spent an average of 12 min per trip during weekdays, close to the 14.6 min spent in Minneapolis (J. Wang & Lindsey, 2019). However, it is substantially less than the 18.3 min in Washington (Gebhart & Noland, 2014) and even shorter than the 21.8 min spent by users in Seville, although in both cities the average time also includes weekends and in the case of Seville, it also refers to all bicycle transport (Marqués et al., 2015). The average time per trip is also skewed by gender, since men spent an average of 11.8 min for 12.1 min by women, reinforcing the gender differences found in the ridership prevalence in the Valencia BSS. Also, women are likely to move at a slightly slower speed than men.

The dynamics of trips throughout a weekday indicates three peaks of activity at 9 h, 15 h and 20 h. These peaks are shown by the small number of bicycles available in the stations in the Barcelona BSS, only 350 km to the North of Valencia, during a weekday (Kaltenbrunner, Meza, Grivolla, Codina, & Banchs, 2010). The first two peaks seem to be connected with the school timetable, while the third, at 20 h, seems to be connected with shop and office closing times in Valencia. The third peak is lower among women than men, probably due to the different perception of safety at late hours, since women are more risk averse than men (Akar et al., 2013; Garrard et al., 2008). The highest usage peak is at 15 h, while in other studies this peak occurs three hours later or more (Faghih-Imani et al., 2014; Gebhart & Noland, 2014; Kaltenbrunner et al., 2010; Reiss, Paul, & Bogenberger, 2015), likely because of different job cultures and working schedules. Nevertheless, the BSS is used more in the morning than evening, which is a similar pattern to that of Montreal BSS (Faghih-Imani et al., 2014). The daily trips dynamic and peaks of activity in Valencia BSS may be connected with an instrumental usage for commuting purposes, as in the Chicago BSS (Faghih-Imani & Eluru, 2015). More important for the purposes of this paper are the significant gender differences in the trips in each daily time slot (morning, afternoon and night) since more were made by males than females, the afternoon being the period when most trips are made both by women and men.

One of the original contributions of this paper is the identification of ridership networks to observe gender differences in the use of space. Although most trips are observed in both networks, the men's network presents higher ridership density than the women's. The analysis of the degree of similarity between these networks shows comparable cyclist behaviour in the city centre and east of the city, where motor vehicle speeds are lower (based on speed limits), injuries are less severe and there are more bike lanes (Fishman & Schepers, 2018; Kaplan et al., 2014). However, these behaviours vary widely around the 69 stations in the outer areas of the city, which show a predominance of men over women's trips. The confluence of major roads with intense motor traffic and fewer cycle lanes could explain the different pattern of behaviour, since women are more risk averse than men and have an unsafe perception of the cycling infrastructure (Aldred et al., 2016; Fishman & Schepers, 2018; Krizek, 2006; Steinbach et al., 2011). In fact, the study by Beecham and Wood (2014), which used a similar methodology, revealed that the different gender behaviour is a consequence of women's greater preference to cycle in areas with less traffic and routes off main roads.

The results of the Voronoi analysis of space by daily time slots also reinforce the results from the comparison of the ridership networks. The amount of space covered by each of the three zones under study was different in each time slot. Cycling mobility in the city is similar in women and men during the morning and afternoon, although always slightly more extended among men than women. Most trips are made downtown and to universities and transport hubs, both by women and men, as found in other studies (Beecham & Wood, 2014; El-Assi, Salah Mahmoud, & Nurul Habib, 2017; Faghih-Imani & Eluru, 2015). However, women use substantially less space in the outer districts of Valencia during the night. The spaces that are self-constrained by women during the night are in an area of 8 km^2, most of which is in the suburbs. As in other studies (Beecham & Wood, 2014; Gebhart & Noland, 2014; Fishman & Schepers, 2018; Steinbach et al., 2011), darkness and risks affect women's cycling behaviour in Valencia.

In general, gender differences in the preference of cycling and perceptions of safety and risk, as well as wider sociocultural differences in the division of labour and time seem to be behind women's lower use of the bicycle service in Valencia.

The present study has two main limitations. Firstly, the results are based on the data given by the users when they open an account in the Valencia BSS, and we cannot guarantee that it is always correct as cards may be used by a non-registered person. However, the great amount of data gathered in this study minimizes the effect of potentially fraudulent card use. Secondly, this study only uses the stations at which the users picked up and left their bicycles. Geolocalization of all the trips could offer new information different from the results obtained here. Future studies should test the trip estimation algorithm and use GPS devices to improve research reliability.

5. Conclusions

This study was carried out using a data mining perspective on large numbers of anonymous members of the Valencia BSS, focusing on certain variables of interest concerning gender and cycling behaviour. The benefits of the sample size and non-behavioural biases by observation or non-errors by remembering activities in a questionnaire make this a powerful perspective in this type of study. Only detailed, subjective and cultural types of information seem to be neglected and this can only be overcome by qualitative studies that can complement big data.

However, this paper is one of the few contributions that emphasises the role women play as an 'indicator species', which allows the assessment of the quality and equality of services offered by the BSS. In fact, our results indicate that women make less use of the Valencia BSS than men and substantially reduce the space used in the city's outskirts during the night in comparison with the other two time slots.

The gender unequal patterns of use and space occupation found in this study offer useful information for the BSS company and city transport policy-makers to adopt appropriate changes to improve the city's cycling services. They also contribute to widening the knowledge on gender differences in cycling and put this issue at the forefront of future interventions.

Declaration of Competing Interest

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

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.scs.2020.102556.

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