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A cohort study examining individual factors influencing cycling as a transportation mode in São Paulo, Brazil

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ABSTRACT

The aim of this study is to explore the relationship between individual-level factors and cycling for transportation in a cohort of participants living in São Paulo city, Brazil. The same participants (n = 1,431 adults) were interviewed in 2014/2015 (Wave 1) and 2020/2021 (Wave 2) as part of the 'São Paulo Health Survey-ISA: Physical Activity and Environment'. For the longitudinal transport cycling binary outcome, participants who reported cycling at both time-points and those who were cycling at Wave 2 only were coded as a positive longitudinal pattern for cycling. Those who were not cycling at either Waves, and those who were cycling at Wave 1 only, were grouped into a negative pattern for cycling. The relationship between the longitudinal patterns for transport cycling and sociodemographics, health characteristics, and behaviors at Wave 1 were tested using bivariate analysis, and the significant individual-level factors were then examined in a multivariable binary logistic regression model. The odds of being classified in the positive cycling pattern were lower for women [OR = 0.09; 95 % CI = 0.04—0.19], and higher for persons aged 30 – 39 [OR = 3.25; 95 % CI = 1.38—7.66], those who owned a bicycle [OR = 2.00; 95 % CI = 1.13—3.54], and those who engaged in ≥ 120 min/week of transport walking [OR = 2.07; 95 % CI = 1.24—3.47] or leisure-time physical activity [OR = 1.77; 95 % CI = 1.02—3.06]. Cycling interventions and promotion should target women, the mid-aged and involve facilitating bicycle access. Advocacy for physical activity interventions is needed to influence transport cycling.

1. Introduction

Increasing cycling is an important investment in accordance with humanity's goals proposed by the "Global Action Plan on Physical Activity 2018–2030", the "Convergent Agenda for Sustainable Mobility and Health", and the United Nations Sustainable Development Goals (Pan American Health Organization, 2022; United Nations, 2015; World Health Organization, 2018). Cycling stimulates public health and gender equality; gives people access to services, goods, and facilities in the community; and creates jobs (European Cyclists'Federation, 2015; Götschi et al., 2016; Oja et al., 2011; Pan American Health Organization, 2022; United Nations, 2015; World Health Organization, 2018). It is also an energy-efficient mode of commuting and is instrumental for decarbonizing air (European Cyclists'Federation, 2015; Pan American Health Organization, 2022; United Nations, 2015; World Health Organization, 2018). Moreover, cycling protects against cardiovascular diseases and increases physical fitness (Oja et al., 2011). However, cycling development seems to compete against a car-centric way of living (Mattioli et al., 2020). In low-to-middle-income countries, the social and physical environments do not seem to be very attractive for women and older

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adults (Goel et al., 2022; Reis et al., 2013; Sá et al., 2017). The prevalence ratios indicate a consistent pattern wherein women and older people commute less by bicycle compared to their male and younger counterparts (Sá et al., 2017). This inequitable bicycling in low-to-middle-income countries is persisting as the lack of safety, access to bicycles, and negative attitudes towards bicycling remains (Mogaji & Uzondu, 2022). The Brazilian trend demonstrates that the overall frequency of active transportation to work/school decreased by 0.32 % on average per year between 2010 (17.9 %) and 2019 (14.1 %) (Bastone et al., 2022). In Brazil, the Master Plans, the Urban Mobility Plans, and the Bicicleta Brasil Program (Law number 13,724 of October 4th, 2018) aim to advance regulations and encourage the use of bicycles (City Hall of São Paulo, 2015, 2014; Presidency of the Republic - Brazil, 2018, 2012). Despite these regulatory plans, the recent Brazilian physical activity (PA) profile by the World Health Organization shows that such a documentation cannot be considered as "best practice", and there are no street design standards for implementing separate cycling infrastructure (World Health Organization, 2022).

In the city of São Paulo, the prevalence of cycling for transportation was 5.1 % in 2015 (Florindo et al., 2018), measured utilizing the International Physical Activity Questionnaire (IPAQ). Between 2015 and 2020, there was an increase in bike paths (67.7 %) in São Paulo (Teixeira et al., 2022); however, in 2017, bicycle trips accounted for only 0.9 % of total trips in the metropolitan area of São Paulo. Conversely, the private car fleet increased by 22.8 % between 2007 and 2017 in the same area, which was more than three times the increase in population size (São Paulo Metropolitan Company, 2019). Apparently, other determinants may be preventing people from cycling in São Paulo.

Multiple determinants of cycling may interact in a complex socio-ecological system, ranging from intrapersonal characteristics to policy and governance commitment (Götschi et al., 2016; Heesch et al., 2012; Piatkowski and Bopp, 2021). However, a systematic review found no study that used a longitudinal design to measure cycling for transportation out of 45 records on Latin American countries and the Caribbean (Sá et al., 2017). According to the literature, some intrapersonal factors are more consistently linked to bicycling than others (Heinen et al., 2010). Leisure-time PA or regular PA has been shown to increase the likelihood of transport cycling (Evans et al., 2022; Gómez et al., 2005; Menai et al., 2015), and this finding represents an opportunity to integrate discretionary PA domains and promote an active lifestyle. Cars in households (Cervero et al., 2009; Heesch et al., 2014; Heinen et al., 2010) and female sex (Cervero et al., 2009; Reis et al., 2013; Sá et al., 2017) were inversely associated with transport cycling. However, the relationship between life course and cycling seems ambiguous (Heinen et al., 2010) and varies according to geography and local cycling levels (Goel et al., 2022). Cross-sectional studies from South American countries have demonstrated that young respondents are more likely to cycle than older respondents (Cervero et al., 2009; Reis et al., 2013). By contrast, a three-year follow-up of older Belgian adults (>65 years) found an increase in the chance of engaging in transport cycling over time (Mertens et al., 2019). This study also found that educational level did not predict changes in transport cycling (Mertens et al., 2019), and this finding contrasts with the inverse cross-sectional associations found in low-to-middle-income countries in South America (Cervero et al., 2009; Reis et al., 2013).

To better clarify these individual-level issues in low-to-middle-income countries, it is necessary to follow people over time and observe changes in their cycling behavior. In addition, tracking individual variables that explain cycling behavior is paramount for identifying groups that are susceptible to health inequities. This study aimed to explore the relationship between individual-level factors and cycling for transportation in a cohort of participants living in the city of São Paulo, Brazil.

2. Methods

2.1. Ethics

All procedures involving human participants were approved by the Ethics Committee of the School of Arts, Sciences and Humanities of the University of Sao Paulo (protocol number: 10396919.0.0000.5390 on April 08, 2019). All participants were protected by the ethical principles of Resolution No. 466/2012 of the Brazilian Health Council, which is in accordance with the ethical standards of the Declaration of Helsinki.

2.2. Setting

São Paulo is the capital city of São Paulo state and is the most populated megacity in the world outside Asia (World Population Review, 2023). It is a car-oriented megacity with 212 private vehicles per 1000 inhabitants (São Paulo Metropolitan Company, 2019). Regarding cycling promotion, the existing policy includes measurable targets, but it lacks alignment with health and sustainability promotion (Global Observatory for Healthy and Sustainable Cities, 2023; Lowe et al., 2022). São Paulo has 722.1 km of permanent cycling infrastructure, including 690 km of cycle lanes and bike paths and 32.1 km of cycle routes. There are 7,192 public bike parking spaces distributed across 72 bicycle parking facilities integrated into the transportation system (CETSP, 2023). Yet, it represents approximately 80.6 public bike parking spaces per 100,000 inhabitants aged 15 or older. Accordingly, bicycle riders mostly opt for private parking in the city of São Paulo (Sao Paulo State Government, 2017). In 2017, daily trips by bicycle, as the main mode, were 0.9 % of the total trips in the city of São Paulo, of which the main purpose was to cover shorter distances and get to work (Sao Paulo State Government, 2017).

2.3. Sample design and data collection

This study shows the results of the cohort study 'São Paulo Health Survey-ISA: Physical Activity and Environment' (São Paulo, SP, Brazil) (Florindo et al., 2021). Its primary objective was to investigate associations between built environment features and PA (Florindo et al., 2021). Participants ≥12 years old were interviewed in 2014/2015 (Wave 1) and in 2020/2021 (Wave 2) when they were ≥ 18 years old. The study protocol has been described elsewhere (Florindo et al., 2021). In short, between August 2014 and December 2015, participants answered the study's questionnaire on a domiciliary interview at Wave 1; however, at Wave 2, participants were interviewed by phone between October 2020 and February 2021 because of the physical distancing measures of the COVID-19 pandemic. The Wave 1 sample consisted of 4,042 participants, but only 35.5 % (n = 1,431) of them remained in Wave 2. Not locating the participants through their cellphone numbers or landlines was the main source of Wave 2 losses (1,567 of 2,608 participants; 60.1 % of the total losses).

2.4. Variables

2.4.1. Dependent variable: Longitudinal patterns for transport bicycling

Data on PA were assessed using the long version of the IPAQ in both waves (Craig et al., 2003). Participants reported the frequency of bicycling for transportation during a typical week. For each wave, a binary variable was operationalized: no cycling activity in a typical week was coded as "none" and cycling for 1 to 7 days was coded as "some." Therefore, participants who had some cycling activities in Wave 2 were coded as the positive pattern for cycling (score = 1, n = 67) because it grouped those participants who reported cycling in both waves with those who were not cycling in Wave 1 but were cycling in Wave 2. Conversely, participants who had no cycling activity in Wave 2 were coded as the negative pattern for cycling (score = 0, n = 1,364) because they were the participants who had no cycling activity in any wave or who were cycling in Wave 1 but not in Wave 2.

2.4.2. Independent variables

The independent variables for Wave 1 were sex, skin color, age groups, marital status, bicycle ownership, car ownership, education groups (in years of study), employment, smoking, diagnosed with hypertension, self-rated health, categorical weighted sitting time (<2 or ≥ 2 h per day), categorical weighted TV time (<2 or ≥ 2 h per day). These weighted sitting and TV time variables were calculated as follows: [(weekday × 5 days) + (weekend day × 2 days)] / 7 days. These variables were then categorized. Categorical transport walking and leisure-time PA variables were grouped into three different cutoffs as < 10 min/week or ≥ 10 min/week, <120 min/week or ≥ 120 min/week, and < 150 min/week or ≥ 150 min/week.

2.5. Data analysis

A description of the analytical sample and comparisons between waves 1 and 2 was performed. Bivariate associations between individual-level factors and longitudinal patterns for transport cycling were tested, and precision of the obtained parameters were expressed using 95 % confidence intervals (CIs) to assess for significant differences. Individual-level factors that were significantly associated with a positive longitudinal pattern for transport cycling in bivariate analyses were included in a multivariable binary logistic regression model with the estimation of cluster-robust standard errors, where participants were clustered within census tracts. Findings are presented as odds ratios and 95 % CI, and the data were analyzed using Stata version 16 (StataCorp LLC, College Station, Texas, USA).

3. Results

The analytical sample with complete data regarding transport cycling comprised 1,431 participants who were retained. These participants were older (mean = 44.0 years old; 95 % CI, 43.0–45.0) than participants not retained (mean = 41.3 years old; 95 % CI, 40.5–42.2) in Wave 1. However, no differences between the retained (5.7 %; 95 % CI, 4.6 %–7.0 %) and not retained (6.7 %; 95 % CI, 5.8 %–7.8 %) were found for transport cycling behavior, or other sociodemographic factors in Wave 1.

In Wave 1, the prevalence of transport cycling was 5.7 % (95 % CI, 4.6 %–7.1 %) among 1,431 participants. As shown in Fig. 1, 91.0 % (n = 1,302) of the participants did not use a bicycle for transportation during any wave of the study. Participants who were cycling in Wave 1 but not in Wave 2 comprised 4.3 % (n = 62). By contrast, 3.3 % (n = 47) of participants were not cycling in Wave 1 but were bicycling in Wave 2. Finally, only 1.4 % (n = 20) of participants were cycling for transportation in both waves. Accordingly, the positive longitudinal pattern for transport cycling comprised 4.7 % (n = 67) of the analytical sample.

In Wave 1, there were more participants aged up to 39 years old compared to Wave 2; conversely, there were more participants aged 50 years or older in Wave 2 than in Wave 1. In Wave 2, there was an increase in the proportion of participants who had studied for 12 years or more. The sample's sex distribution was similar to that of the target population aged ≥ 15 years old (data from the Census 2010) (IBGE, 2010); however, the study's sample predominantly consisted of individuals aged 50 years or older, which does not align with the overall population (Table 1).

Bivariate associations showed that being classified in the positive cycling pattern was highest for persons aged 30 – 39 years, intermediate for those aged up to 29 years (6.5 %), and lowest for those aged 50 years or older (2.3 %). In addition, participants with a positive pattern for transport cycling were mostly men (9.8 %), had a bicycle (8.0 %), were engaged in transport walking for at least 120 weekly minutes (7.6 %), and were engaged in leisure-time PA for at least 120 weekly minutes (8.6 %) in Wave 1 (Tables 2 and 3).

Table 4 presents results from the unadjusted and adjusted regression models. The multivariable model included sex, age, bicycle ownership, transport walking, and leisure-time PA with < 120 or ≥ 120 min/week cutoff. Women were less likely than men to be classified in a positive longitudinal pattern for transport cycling in both the crude and multivariable models. Owning a bicycle was associated with a positive longitudinal pattern in both the crude and multivariable models. Only in the crude model were younger age groups more likely to be in the positive longitudinal pattern than the group aged 50 years or older. In the multivariable model, only participants aged 30–39 years old were more likely to be classified in a positive longitudinal pattern than the group aged 50 years or older. Participants who engaged in either transport walking or leisure-time PA for at least 120 min per week were more likely to be classified in a positive longitudinal pattern for transport cycling in both the crude and multivariable models.

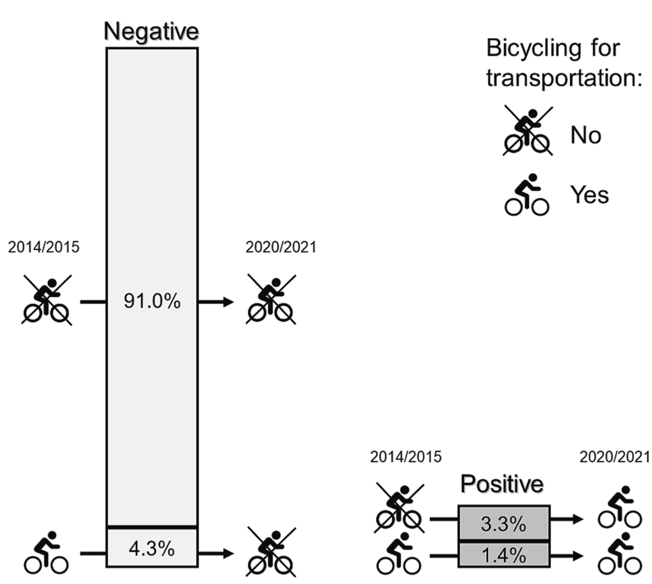

Fig. 1. Proportional description of the participants' cycling behavior on the formation of the negative and positive longitudinal pattern for transport bicycling, n = 1,431 (São Paulo, Brazil).

4. Discussion

The results indicated that participants in the positive longitudinal pattern for transport bicycling were more likely to be men, aged 30–39 years old, owned a bicycle, and practiced at least 120 weekly minutes of either transport walking or leisure-time PA in Wave 1. Cross-sectional studies demonstrate that bicycling prevalence at various sites in Brazil is low (Goel et al., 2022; Reis et al., 2013). However, the present study is pioneering, as it has prospectively observed bicycling behavior within the context of active transportation. This study design allowed the evaluation of cycling participation over time and the factors influencing it.

Few participants were classified as having a positive longitudinal pattern for transport cycling in the city of São Paulo; however, the prevalence of transport cycling remained stable comparing Waves 1 and 2. This maintenance was based on a similar proportion of participants who initiated bicycling in Wave 2 (3.3 %) and those who had bicycled in Wave 1 but discontinued in Wave 2 (4.3 %). In the city of São Paulo, the COVID-19 pandemic may have stimulated the adoption of bicycles among specific groups when authorities were massively advising to avoid public transportation. Data from bike-counters displayed in the city support this possibility because there was a peak in July 2020 of over 100,000 bike passages contrasting with 57,977 in July 2019 or 75,371 in July 2021 (Eco-Counter, 2019). Furthermore, the increase of cycle lanes observed between the study's waves may have contributed to

Table 1
Population and participant characteristics in each wave (São Paulo, Brazil).

	Sample n = 1,431 Wave 1			Sample n = 1,431 Wave 2			Population[a] N = 8,916,867
	n (%)	95 % CI Lower	Upper	n (%)	95 % CI Lower	Upper	n (%)
Sex							
Male	591 (41.3)	38.8	43.9				4,142,895 (46.5)
Female	840 (58.7)	56.1	61.2				4,773,972 (53.5)
Skin color							
Non-white	668 (48.5)	45.9	51.2				
White	708 (51.5)	48.8	54.1				
Age group							
Up to 29 y	**400 (28.0)**	**25.7**	**30.3**	**323 (22.6)**	**20.5**	**24.8**	2,908,498 (32.7)
30–39 y	**221 (15.4)**	**13.7**	**17.4**	**166 (11.6)**	**10.0**	**13.4**	1,898,761 (21.3)
40–49 y	208 (14.5)	12.8	16.5	237 (16.6)	14.7	18.6	1,555,699 (17.4)
50 y or more	**602 (42.1)**	**39.5**	**44.6**	**705 (49.2)**	**46.7**	**51.9**	2,553,909 (28.6)
Marital status							
Living with a partner-married	701 (50.7)	48.0	53.3	726 (51.0)	48.4	53.6	
Single-divorced-widowed	682 (49.3)	46.7	52.0	698 (49.0)	46.4	51.6	
Bicycle ownership (yes)	463 (33.7)	31.2	36.2				
Car ownership (yes)	818 (59.5)	56.9	62.1				
Education							
≤ 5 y	309 (21.6)	19.6	23.8	255 (17.9)	16.0	19.9	
6–11 y	**465 (32.5)**	**30.2**	**35.0**	**285 (20.0)**	**18.0**	**22.1**	
12 y	**371 (26.0)**	**23.8**	**28.3**	**498 (34.8)**	**32.4**	**37.4**	
>12 y	**284 (19.9)**	**17.9**	**22.0**	**390 (27.3)**	**25.1**	**29.7**	
Employment (yes)	746 (52.2)	49.6	54.7	743 (52.2)	49.6	54.8	

Bold font denotes a difference in the parameters. y = years. CI = confidence interval. [a]Population aged ≥ 15 years old; Census 2010 (IBGE, 2010).

Table 2
Bivariate associations between sociodemographic characteristics at Wave 1 and the positive longitudinal pattern for transport bicycling (São Paulo, Brazil).

	Total	Positive pattern for transport bicycling		
	n = 1,431	n (%)	95 % CI Lower	Upper
		67 (4.7)	3.7	5.9
Wave 1 variables				
Sex				
Male	591	**58 (9.8)**	**7.7**	**12.5**
Female	840	**9 (1.1)**	**0.6**	**2.0**
Skin color (55 miss.)				
Non-white	668	35 (5.2)	3.8	7.2
White	708	30 (4.2)	3.0	6.0
Age group				
Up to 29 y	400	**26 (6.5)**	**4.5**	**9.4**[a]
30–39 y	221	**17 (7.7)**	**4.8**	**12.0**[a]
40–49 y	208	**10 (4.8)**	**2.6**	**8.7**[ab]
50 y or more	602	**14 (2.3)**	**1.4**	**3.9**[b]
Marital status (48 miss.)				
Living with a partner-married	701	32 (4.6)	3.2	6.4
Single-divorced-widowed	682	34 (5.0)	3.6	6.9
Bicycle ownership (57 miss.)				
no	911	**27 (3.0)**	**2.0**	**4.3**
yes	463	**37 (8.0)**	**5.8**	**10.8**
Car ownership (56 miss.)				
no	557	28 (5.0)	3.5	7.2
yes	818	36 (4.4)	3.2	6.0
Education (2 miss.)				
≤ 5 y	309	8 (2.6)	1.3	5.1
6–11 y	465	26 (5.6)	3.8	8.1
12 y	371	21 (5.7)	3.7	8.5
>12 y	284	12 (4.2)	2.4	7.3
Employment (1 miss.)				
no	684	24 (3.5)	2.4	5.2
yes	746	43 (5.8)	4.3	7.7

Bold font denotes a difference in the parameters. Parameters followed by a common letter are not different. y = years. miss = missing observations. CI = confidence interval.

Table 3
Bivariate associations between health-related variables at Wave 1 and the positive longitudinal pattern for transport bicycling (São Paulo, Brazil).

	Total	Positive pattern for transport bicycling		
	n = 1,431	n (%)	95 % CI Lower	Upper
Wave 1 variables				
		67 (4.7)	3.7	5.9
Smoking				
no	1,024	52 (5.1)	3.9	6.6
yes	407	15 (3.7)	2.2	6.0
Hypertension (2 miss.)				
no	1,054	57 (5.4)	4.2	6.9
yes	375	10 (2.7)	1.4	4.9
Self-rated health (4 miss.)				
Fair-Poor-Very Poor	413	18 (4.4)	2.8	6.8
Good-Excellent	1,014	49 (4.8)	3.7	6.3
Sitting time				
< 2 h/day	265	9 (3.4)	1.8	6.4
≥ 2 h/day	1,166	58 (5.0)	3.9	6.4
TV time				
< 2 h/day	630	29 (4.6)	3.2	6.5
≥ 2 h/day	801	38 (4.7)	3.5	6.4
Transport walking (5 miss.)				
< 10 min/week	568	21 (3.7)	2.4	5.6
≥ 10 min/week	858	46 (5.4)	4.0	7.1
Transport walking (5 miss.)				
< 120 min/week	1,059	**39 (3.7)**	**2.7**	**5.0**
≥ 120 min/week	367	**28 (7.6)**	**5.3**	**10.8**
Transport walking (5 miss.)				
< 150 min/week	1,144	49 (4.3)	3.2	5.6
≥ 150 min/week	282	18 (6.4)	4.0	9.9
Leisure-time PA				
< 10 min/week	913	33 (3.6)	2.6	5.0
≥ 10 min/week	518	34 (6.6)	4.7	9.0
Leisure-time PA				
< 120 min/week	1,058	**35 (3.3)**	**2.4**	**4.6**
≥ 120 min/week	373	**32 (8.6)**	**6.1**	**11.9**
Leisure-time PA				
< 150 min/week	1,107	43 (3.9)	2.9	5.2
≥ 150 min/week	324	24 (7.4)	5.0	10.8

Bold font denotes a difference in the parameters. miss = missing observations. h = hours. min = minutes. CI = confidence interval.

Table 4
Crude and multivariable models of individual-level factors associated with a positive longitudinal pattern for transport bicycling; n = 1,374 (São Paulo, Brazil).

Wave 1 variables	Crude OR	CI 95 % Lower	Upper	Multivariable OR	CI 95 % Lower	Upper
Sex						
Male	1.00			1.00		
Female	**0.08**	**0.04**	**0.17**	**0.09**	**0.04**	**0.19**
Age group						
50 y or more	1.00			1.00		
40–49 y	**2.25**	**1.04**	**4.88**	2.05	0.91	4.63
30–39 y	**3.84**	**1.77**	**8.34**	**3.25**	**1.38**	**7.66**
Up to 29 y	**3.00**	**1.42**	**6.31**	1.95	0.83	4.59
Bicycle ownership						
no	1.00			1.00		
yes	**2.84**	**1.73**	**4.67**	**2.00**	**1.13**	**3.54**
Transport walking						
< 120 min/week	1.00			1.00		
≥ 120 min /week	**2.30**	**1.42**	**3.73**	**2.07**	**1.24**	**3.47**
Leisure-time PA						
< 120 min /week	1.00			1.00		
≥ 120 min /week	**2.68**	**1.68**	**4.29**	**1.77**	**1.02**	**3.06**

OR = odds ratio. CI = confidence interval. y = years. h = hours. min = minutes. Bold font denotes that the 95 % CI does not include 1.00.

the adoption of cycling (Teixeira et al., 2022). Nevertheless, this increase was unevenly implemented throughout the city (Teixeira et al., 2022). Further analyses are needed to address the relationship between positive cycling change and the built environment in São Paulo. On the other hand, some participants were at greater risk of having COVID-19, and the social isolation during the study Wave 2 may explain the proportion of participants who stopped cycling between waves.

Male sex was associated with a positive longitudinal pattern of transport cycling, which is consistent (Goel et al., 2022; Heesch et al., 2012; Sá et al., 2017). To date, low-to-middle-income countries have struggled to make cities sufficiently bikeable to attract women (Goel et al., 2022). By contrast, high-income and high-cycling countries, such as the Netherlands (Engbers and Hendriksen, 2010) and Germany (Buehler, 2011), show no or low sex differences (Goel et al., 2022). Women's travel decisions are based on their perceptions of accessibility and safety (Heesch et al., 2012; Pearson et al., 2023). Even barriers simultaneously perceived by women and men have different backgrounds about why they are difficulties (Pearson et al., 2023). Studies have shown that women prefer to cycle on off-road paths separate from motorists because, otherwise, they fear being hit by a car, and the exposure on the road alongside motor traffic is stressful (Heesch et al., 2012; Pearson et al., 2023; Russell et al., 2021; Twaddle et al., 2010). A qualitative study also revealed that women are convinced that they can be a victim of an unfortunate accident while riding a bicycle on the road that was explained as a consequence of "the car versus cycle feeling", where female cyclists are deeply concerned about the violent behavior of vehicle drivers (Pearson et al., 2023). Lack of confidence has been proved to be an important barrier for women using a bicycle in qualitative and quantitative research (Heesch et al., 2012; Pearson et al., 2023). Women also need to make safer choices when they ride bicycles with their children, thus preferring protected cycle paths and streets with low traffic and speed (Pearson et al., 2023). Safety constraints for women also include falling off a bicycle and being injured, riding in high-speed roads, and breathing polluted air when bicycling; important accessibility constraints include disconnects between pathways, poor quality cycling infrastructure, riding on badly lit places, and perceived inability to repair a bicycle and to take public transport with a bicycle (Heesch et al., 2012; Pearson et al., 2023).

Older participants were less likely to use a bicycle for transportation, and this finding has been reported previously (Butler et al., 2007; Hino et al., 2013; Porter et al., 2018; Reis et al., 2013; Sá et al., 2017). Low stimulation, perceived physical incapacity, and high perceived insecurity are key barriers to the lack of cycling activities of the older adults (Aldred et al., 2016; Goel et al., 2022; Heinen et al., 2010). However, designing safe and green environments with a mix of nearby destinations would encourage cycling (Böcker et al., 2017; Kemperman and Timmermans, 2014) and indirectly help prevent all-cause mortality in the older adults (Kelly et al., 2014).

In Brazil, transportation is a social right highlighted in the Constitution (Brazil, 2015). Therefore, enhancing bicycling rates among women and older individuals is not just a matter of encouraging a healthier lifestyle; it is a commitment to upholding basic human rights. Moreover, most of the UN Sustainable Development Goals are in line with the promotion of physical activity (Salvo et al., 2021), and bicycling stands out for improving mobility, public health, and mitigating carbon emissions in the atmosphere (Pan American Health Organization, 2022). Furthermore, by ensuring equal opportunities for women and girls to ride a bicycle, society acts toward achieving the Sustainable Development Goal 5 'Achieve gender equality and empower all women and girls' (United Nations, 2015).

Other sociodemographic variables from this study, such as educational level and employment status, did not show an association with longitudinal patterns for transport cycling. This finding was also seen in the study by Gómez et al., where occupational activity was not associated with bicycle use (Gómez et al., 2005). Although studies have demonstrated that bicycling and walking as a means of transportation in low-to middle-income countries is more common in the poorest strata (Bacchieri et al., 2005; Cervero et al., 2009), the prevalence of highly educated people with greater income who prefer a non-motorized mode of transportation (either walking or cycling) has increased in the metropolitan region of São Paulo (São Paulo Metropolitan Company, 2019). This may be related to the fact that the more affluent areas of the city of São Paulo have had more bicycle lanes in recent years (Teixeira et al., 2022).

Owning a bicycle is a determining factor of cycling, as supported by previous studies (Florindo et al., 2018; Kienteka et al., 2014; Ogilvie et al., 2008; Stahley et al., 2022). Notably, people without cars but have access to bicycles are more likely to have increased cycling activity; however, among those who own cars, such associations are not significant (Ogilvie et al., 2008). In Brazil, little has been done at the government and private levels so that people are encouraged to own bicycles. The high costs and low tax exemptions on imported parts, particularly from China, Taiwan, and Indonesia, still inhibit mass acquisition (Brazilian Association of the Bicycle Sector, 2021a). A key strategy for stimulating bicycle ownership is to make bicycles affordable for everyone. Although the state of São Paulo leads the Brazilian ranking in terms of the number of bicycle shops, 68 % of the bicycles sold in the country cost 2,000 BRL or more (Brazilian Association of the Bicycle Sector, 2021b); therefore, most people cannot afford a bicycle without compromising their entire monthly income, and this inequality increases when bicycles are affordable only to a few people. Free bike-sharing systems accounted for only 31 % of the total systems operating in Latin America in 2019 (Binatti et al., 2020; Duran et al., 2018). In 2018, the Brazilian government enacted legislation mandating the implementation of low-cost, though not cost-free, bicycle rental systems at public transportation terminals and commercial hubs (Presidency of the Republic - Brazil, 2018). In the city of São Paulo, a bike-sharing system is ensured within the Master Plan via law, but it is still a fee-for-service system which would be prohibitive for some (City Hall of São Paulo, 2014). Moreover, similar to the built environment (Teixeira et al., 2022), the bike-sharing system is unevenly distributed, with the main concentrations in the western zone and presenting poor coverage throughout the city of São Paulo. Communication between the third social sector (e.g., non-profit organizations), the private sector, and decision-makers from the first sector remains difficult. To promote massive accessibility, financial public initiatives and investments are needed to increase coverage and broadly exempt the population from payments for using bike-share systems.

This study showed that at least 120 weekly minutes of leisure-time PA was prospectively associated with transport cycling. However, most studies with similar results used cross-sectional designs (Gómez et al., 2005; Heesch et al., 2012; Menai et al., 2015). For example, in Australia, cyclists from Queensland were physically active (at least 150 min/week of moderate PA) and fitness improvement or maintenance was the main reason for using a bicycle for transportation (Heesch et al., 2012). Menai et al. observed adults from France and found a progressive increase in the likelihood of transport cycling when participants were exposed to either 60–150 min/week and > 150 min/week of leisure-time PA (Menai et al., 2015). Remarkably, the 'São Paulo Health Survey-ISA: Physical Activity and Environment' data indicated a significant association exclusively in the group distribution of < 120 or ≥ 120 min per week. In Bogotá (Colombia), Gómez et al. found that regular leisure-time PA increased the likelihood of cycling for transportation in a sample of adults aged 18–29 years (Gómez et al., 2005). A longitudinal study investigating other causal directions (cycling for transport predicting recreational PA) found that a decrease in cycling was associated with a decrease in recreational PA (Sahlqvist et al., 2013). PA practice was the second main reason for cycling, and this motive increased in 10 years from 6.6 % (2007) to 18.0 % (2017) among citizens who answered the 2017 São Paulo Origin-Destination survey, which encompasses the São Paulo metropolitan area (São Paulo Metropolitan Company, 2019).

This study also demonstrated that engaging in 120 or more minutes of transport walking weekly increases the likelihood of adopting a positive longitudinal pattern. By contrast, walking for transport was not prospectively associated with cycling for transport among adults participating in the iConnect study (United Kingdom) (Sahlqvist et al., 2013) or cross-sectionally among French adults (Menai et al., 2015). The need to commute and the lack of options/accessibility in the context of the city of São Paulo may explain the association between walking and cycling in transport. The built and social environment of São Paulo is uneven (Teixeira et al., 2022), the city is car-oriented (São Paulo Metropolitan Company, 2019), and many people live in neighborhoods that are not serviced by public transport (Sá et al., 2016); thus, they have to actively commute from home to the next bus stop/train station or to their destination, particularly citizens belonging to the poorest social strata.

The use of bicycles for commuting needs to be improved in Brazilian cities. Campaigns that encourage a culture that normalizes, prefers, and understands the importance of cycling are needed. Since 2020, in the city of São Paulo, new goals and indicators have linked bicycle use to the United Nations Sustainable Development Goals, which could promote cycling in the coming years (City Hall of São Paulo, 2020). Education, incentives, and information from the early years in family and school programs that include bicycling in mass events and increasing awareness of bicycling benefits and opportunities can be effective in strengthening a cycling culture. These goals can be explored via an intersectoral approach involving all social sectors in convergent areas such as health, leisure, and mobility. Systematically, in Brazil, the third social sector works hard to build cycling cities; however, it does not receive sufficient support from government (Institute for Transportation and Development Policy, 2021). Furthermore, it is imperative to address the integration of marginalized populations. By actively considering the needs of disadvantaged groups such as women, older adults, and individuals without access to bicycles, there exists an opportunity to empower them with the choice to engage in cycling. Facilitating bicycle usage in already privileged areas, rather than in areas where people lack interventions, hinders the promotion of widespread bicycle use. Therefore, there is a need for targeted initiatives and infrastructure development in underserved communities. However, in recent years, São Paulo has experienced an uneven and disconnected expansion in bicycle paths, mostly in high-income neighborhoods (Teixeira et al., 2022), consequently limiting cycling opportunities in peripheral and poor neighborhoods.

The strengths and limitations of this study must be acknowledged. Tracking participants by phone in Wave 2 led to sample losses because landlines have become less common over time, and the phone numbers collected in Wave 1 would likely become obsolete. Changing the data collection method has important implications. However, the loss of participants did not introduce bias in the outcome of bicycling for transportation. By grouping the sample into those who continued into Wave 2 and the participants who were lost, we observed that during Wave 1, both groups exhibited a similar prevalence of bicycle usage. Also bicycling for transportation was measured using IPAQ, which is valid and reliable for phone administration (Hallal et al., 2010). Another limitation was the small proportion of participants who used bicycles for transportation; thus, stratified analyses or interactions between exposure factors were not able to be investigated. The number of participants who were cycling for transportation corresponds to other similar settings, such as in Belo Horizonte (Brazil), Santiago (Chile), and Buenos Aires (Argentina) (Goel et al., 2022). The small proportion of participants classified in the positive longitudinal pattern for transport bicycling may have compromised the statistical power of the analyses and increased the Type II error risk, which may have overestimated the true effects. To minimize this limitation, 95 % CIs were used to interpret the results.

The strengths of this study include its longitudinal design that supports cause-and-effect results. Moreover, this study is of interest to decision-makers because it followed a sample of the megacity of São Paulo that demonstrated maintenance of low bicycling despite significant change in the built environment (Teixeira et al., 2022). Other barriers, particularly those experienced by women and older adults, must be addressed through inclusive policies. In São Paulo, the evidence clearly indicates that increasing the use of bicycles is not solely a matter of increasing cycle paths. In addition, transport cycling assessment using the long IPAQ increases sensitivity and specificity. The participants were asked about bicycling for transportation regardless of the destination in a typical week (Hallal et al., 2010). This study recognized the different characteristics and overall research implications of leisure and transportation cycling. The current study is a pioneering study that addresses the determining factors of transport cycling in populations from low-to-middle-income countries. Longitudinal studies investigating this subject have to date only been conducted in high-income countries (Evans et al., 2022).

5. Conclusion

Sex, age, bicycle ownership, transport walking, and leisure-time PA were individual-level factors associated with transport cycling among participants of the 'São Paulo Health Survey-ISA: Physical Activity and Environment'. Thus, making spaces bikeable, safe, and attractive for disadvantaged groups is important to achieve the widespread use of bicycles in megacities. Furthermore, additional subsidies should be given to people to encourage bicycle ownership. The right and access to active transport and leisure options should be better supported by local policies.

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CRediT authorship contribution statement

Margarethe Thaisi Garro Knebel: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft. **Gavin Turrell:** Formal analysis, Writing – review & editing. **Rildo de Souza**

Wanderley Júnior: Data curation, Investigation, Writing – review & editing. **Inaian Pignatti Teixeira:** Data curation, Investigation, Writing – review & editing. **Elaynne Silva de Oliveira:** Data curation, Writing – review & editing. **Adriano Akira Hino:** Writing – review & editing. **Douglas Roque Andrade:** Investigation, Writing – review & editing. **Alex Antonio Florindo:** Funding acquisition, Investigation, Project administration, Resources, Supervision, Writing – review & editing.

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.

Data availability

Data will be made available on request.

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