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Impact of COVID-19 on adolescent travel behavior

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ABSTRACT

Introduction: The outbreak of COVID-19 has significantly impacted travel behavior. However, few studies have analyzed the impact of COVID-19 on adolescent travel behavior. This article analyzed the impact of COVID-19 on adolescent travel behavior using questionnaire survey data.
Methods: This paper first used confirmatory factor analysis (CFA) to explore the psychological factors related to the adolescents' perceptions about the severity of COVID-19. The study then established a logit model to study the effects of COVID-19 in different phases (before, during, and after the epidemic peak), demographic characteristics, and the role of psychological factors on their travel behavior.
Results: The results show that the phase of COVID-19 did not significantly impact the adolescents' choice of short-distance travel. The frequency of outings per week, the number of exercise sessions per week, and willingness to travel by public transportation decreased significantly in the outbreak phase. Meanwhile, the perception of the severity of COVID-19 significantly impacted adolescent travel behavior.
Conclusion: This research demonstrates that COVID-19 has led adolescents to reduce their frequency of outings, and they try not to use public transportation. Adolescents appear to be traveling more cautiously in the outbreak phase and the post-epidemic phase.

1. Introduction

1.1. Impact of COVID-19 on travel behavior

Due to the high infectious power and fatality rate, the World Health Organization (WHO) set the risk level of the coronavirus (COVID-19) as "very high" in 2020 (WHO, 2020). According to the S.I.R. model (Susceptible Infectious Recovered Model), the epidemic includes 5 phases: the normal phase, the incubation phase of the epidemic, the outbreak phase, the post-epidemic phase, and the recovery and improvement phase (Ye et al., 2020). The normal phase is a phase when there is no pandemic to create interference; during these normal times, people in the cities of China usually travel by public transit. During the incubation phase, a small number of infected people appear, but the infection has not spread. During the outbreak phase, the number of infected people increases rapidly, and the risk of cross-infection increases rapidly. In the post-epidemic phase, the number of newly infected people gradually decrease, and the number of existing infected people declines. In the recovery and improvement phase, the epidemic is controlled, but it is difficult to determine whether there are still asymptomatic infections. The epidemic outbreak phase in China ranged from December 2019 to March 2020. China has gradually entered and sustained the post-epidemic phase since March 2020.

The sudden epidemic disrupted people's lives and significantly impacted the transportation industry and urban transportation systems (Fatmi, 2020). According to the Ministry of Transport of China, only 283 million passengers used the transportation system from January 25 to February 14, 2020. This was an average of 13.49 million passengers per day, representing a year-on-year decrease of 82.3%.[1]

Traffic flow has been restored gradually in different places; however, people's travel behavior is still affected by traffic control measures to different degrees (Shengyu, 2020). Shengyu (2020) found that 75.1% of the people surveyed went out during the outbreak phase. Nan et al. (2020) found that only a small number of residents went out multiple times during the outbreak phase. An analysis of online car-hailing data showed that the volume and intensity of ordered rides dropped sharply during the outbreak phase, and people only used online car-hailing for critical needs (medical treatment, for example) (Yong et al., 2020).

Travel modes have also been affected by COVID-19. Dan and Longfei (2020) investigated urban traffic conditions in February 2020 and found a significant increase in bicycle use and a significant decrease in online car-hailing use. Zheng et al. (2020) found that shared bike use in Wuhan increased from 5 min to 10–20 min, and long-distance riding orders (over 3 km) increased threefold.

1.2. Travel behavior of adolescents

People's travel needs drive transportation, and adolescents are part of the traveling public (Siiba, 2020). Adolescents have little travel autonomy; as such, their travel patterns share characteristics with ordinary commuter travel, while also retaining some patterns similar to children (Shuhong et al., 2016). This makes adolescents a special kind of commuter, whose travel behavior depends in part on family characteristics (Copperman and Bhat, 2017).

The active travel behavior of adolescents has been a research focus for many scholars. The primary purpose of adolescents' travel is to commute to school (Liu and Ying, 2011), and most teenagers rely on their parents' cars. A small proportion of adolescents independently travel using public transportation (Yang et al., 2019). Consistent with the global trend of decreasing physical activity, today's adolescents' school trips are usually made by driving, rather than by walking or cycling (Santos et al., 2019). There are also significant differences between age groups. Younger children prefer to use an active mode to travel to school, while older children have more positive attitudes towards traveling by car (Stark et al., 2019). Studies have shown public transportation and active transportation by adolescents during school trips have decreased over time, and the use of private vehicles has increased (Sá et al., 2015).

Many factors affect adolescents' choice of travel behavior (Leslie et al., 2010). The main obstacles preventing adolescents from going to school by bus include the distance to the school, cost, parental travel behavior, indoor environment characteristics, weather, convenience, and the safety of traveling by car (Mindell et al., 2020). Adolescents' active travel patterns vary widely across countries (Pizarro et al., 2016). For adolescents living in rural areas, those attending schools in dense neighborhoods with sidewalks are most likely to be active travelers (Dalton et al., 2011). The choice to use active travel relates to after-school sports activities and transportation; transportation options are vital for those who do not use an active travel mode (Stewart et al., 2017). Positive perceptions of school travel were found to be positively correlated with children's psychological well-being, and travel-related attitudes were found to be significantly correlated with happiness (Stark et al., 2018b). Adolescents' selection of active travel patterns was also found to be associated with Body Mass Index (B.M.I.) and fat mass (Falconer et al., 2015).

1.3. Research goals

Previous studies focusing on COVID-19 have focused on the travel behavior of adults; few studies have explored the impact of COVID-19 on the travel behavior of adolescents. Further, existing studies have mainly considered the impact of the epidemic on travel behavior during the outbreak phase. Few studies have examined the effects of COVID-19 on travel behavior in the post-epidemic phase.

Given the background above, this study examined the impact of COVID-19 on adolescents' travel behavior. The research considered demographic characteristics and psychological factors, focusing on adolescents' travel behavior in different epidemic phases. Section 2 describes the survey design. Section 3 presents the results. Section 4 discusses the results and policy implications.

2. Data sources

2.1. Theory perspective and hypothesis

The logit model is used to analyze the impact of the COVID-19 phase. The dependent variable in this study was adolescent travel behavior, while the independent factors were epidemic phases, demographic features, and a factor derived from CFA. This paper assumed that the random utility gained by adolescents choosing a travel plan is shown in formula (1):

$$U = c + \alpha_1 d_{\text{outbreak}} + \alpha_2 d_{\text{post}} + \delta^T z + \gamma L + \varepsilon \tag{1}$$

In which: U is the utility of adolescents choosing a specific travel plan; d_{outbreak}, d_{post} are dummy variables indicate that it is in the outbreak phase and the post-epidemic phase or not, respectively; z is a vector of adolescents' demographic characteristics; L is the psychological factor assessing adolescents' perceptions about the severity of COVID-19; c, α_1, α_2 and δ are parameters to be estimated, ε

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is the error term.

We hypothesized that the epidemic's consequences vary depending on the phase of the epidemic. Two hypotheses were proposed: 1) $d_{outbreak}$ and d_{post} are significantly less than zero, that is, the epidemic phases have a significant impact on adolescents' travel behaviors; 2) $d_{outbreak}$ are significantly less than d_{post}, that is, the travel behavior of adolescents in the post-epidemic phase somewhat recovered, but had not returned to the normal phase.

The utility structure is shown in Fig. 1.

2.2. Survey design

The survey was conducted in April 2020 in Panyu District, Guangzhou, China. We focused on junior high school students. All surveys were completed in a face-to-face setting and generated 315 valid responses.

The survey had three parts: demographic characteristics, latent psychological variables, and travel behavior. The travel options that adolescents have, relate significantly to whether people pick them up or drop them off, and whether the family owns a private car (Shouyu and Zuopeng, 2017). As such, the study's demographic data include adolescents' age, gender, household information, and travel characteristics. Three family-related variables were added to the personal statistical characteristics of surveyed adolescents: whether the family has a car, whether the family has a motorbike and the monthly household income. The travel characteristics also assessed behavior related to mask-wearing in the current environment.

Latent psychological variables were characterized and collected using manifest variables. The key variable in this study focused on the adolescents' assessment of the severity of COVID-19 and the impact of that assessment on their travel behavior. Psychological factors were measured using a five-point Likert scale, with responses of 1, 2, 3, 4, and 5 representing "strongly disagree," "somewhat disagree," "uncertain," "basically agree," and "completely agree," respectively (Huo et al., 2020).

Studies have found that adolescents' travel activities are mainly for school and family travel, and autonomous travel by adolescents is somewhat restricted by age, ability, and other factors. Therefore, the travel distance is short, at usually no more than 5 km (Rodríguez-López et al., 2017). Furthermore, a survey in the United Kingdom showed that the distance threshold that determines whether adolescents walk to school and actively commute is 1.4 km. Another study showed that adolescents who live 800 m away or more from school in urban areas are less likely to use an active method to travel to school (Jurak et al., 2021). Therefore, this article defined travel distances of 1 km, 3 km, and 5 km as short-distance travel, medium-distance travel, and long-distance travel, respectively. The travel behavior survey focused on the adolescents' choices to travel these different distances: 1 km, 3 km, and 5 km.

This paper also considered the frequency of weekly outing activities for young people in different periods. This study mainly investigated adolescent travel behaviors in three distinct periods: the normal phase, the outbreak phase, and the post-epidemic phase. This paper defined the outbreak phase as Period1 and defined the post-epidemic phase as Period2. This study was conducted in April 2020, when China had entered the post-epidemic phase.

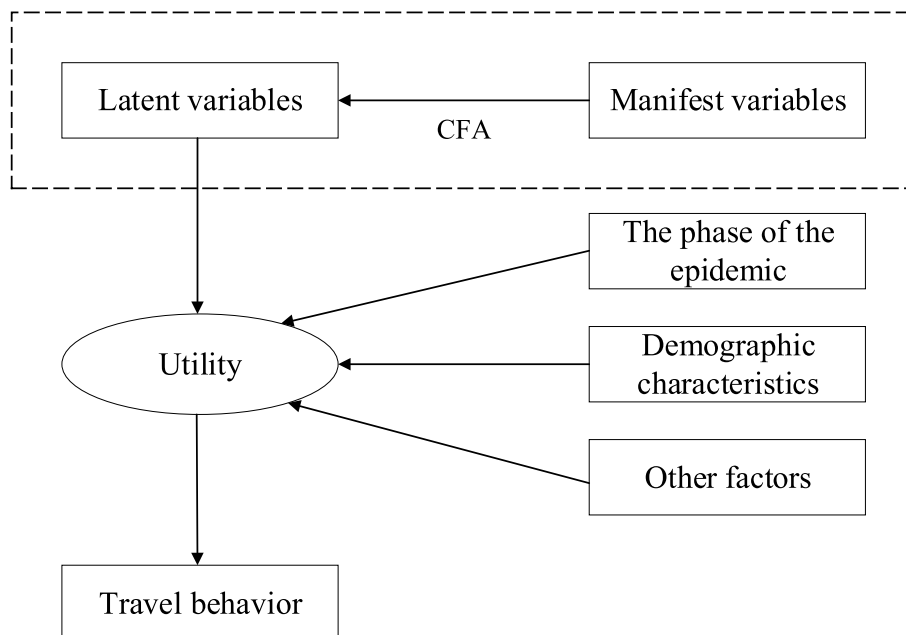The specific survey content is shown in Appendix A.

Fig. 1. Utility structure.

2.3. Statistical results

Table 1 shows the statistical results of demographic characteristics. There is a representative proportion of men and women among respondents. Most adolescents' families own cars, and more than half of the families have motorbikes. A total of 88.57% of adolescents reported still wearing masks when going out. Adolescents reported that 42.86% of families have a monthly income exceeding 10,000 yuan. The statistical results related to demographic characteristics indicate that the survey data are valid and reasonable.

Psychological factors were analyzed using the average and the standard deviation of each survey item's ratings to assess the rationality of the data. An average score of 3 is considered uncertain. A score below 3 indicates disagreement, and a score higher than 3 indicates agreement with respect to that factor. Table 2 shows the statistical results. It shows that the average value of the answers to each question exceeds 4, indicating that most adolescents classify the severity of COVID-19 as high. The standard deviation for most items is close to 1, indicating that different adolescents answer the same questions somewhat differently.

3. Results

3.1. Confirmatory factor analysis

Latent variables cannot be directly measured; rather, they are quantified and obtained using related manifest variables. Confirmatory factor analysis is conducted to obtain the latent variables shown in Table 2. This model fitness is assessed with the Root Mean Square Error of Approximation (RSMEA), the Comparative Fit Index (CFI), and the Tucker Lewis Index (TLI) (Rahman et al., 2019).

Table 3 shows the reliability and convergence validity of the model. Each parameter index of the CFA model is within the standard range (RMSEA≤0.08, SRMR≤0.08, CFI ≥0.9, and TLI ≥0.9) after filtering the manifested variables. This also indicates that the model has good reliability and convergence validity. In other words, it is acceptable if the SMC is larger than 0.36; it is acceptable if the CR is greater than 0.7 (Hair et al., 1998); and it is acceptable if the AVE is greater than 0.5 (Fornell and Larker, 1981).

Moreover, this correlation is statistically significant, allowing the manifest variable to be used to effectively characterize the latent variable.

3.2. Short-distance travel behavior

In this section, we analyze adolescents' short-distance travel choices and compare the results from adolescents with the results from adults. We investigate different factors for adolescents and commuters regarding travelers' demographic characteristics, so the section below focuses only on the factors that are the same.

Adolescents usually choose to walk when faced with a short distance of 1 km. This study assesses how COVID-19 influenced that choice. Table 4 shows the regression fitting results and indicates that adolescents' age, gender, the presence of a car or motorbike in the family, and perceptions of the severity of COVID-19 yield statistically significant differences at different confidence levels. The commuters' age, the presence of a motorbike in the family, the mask-wearing situation, and income (high) are statistically significant. The post-epidemic phase and the presence of a car have the same effect (positive effect) on both groups; however, other variables show opposite effects.

The p-values associated with statistical results for Period1 and Period2 exceed a 0.05 significance level, indicating that the COVID-19 phase does not significantly impact the choice of short-distance travel mode for adolescents. The same is true for commuters. The adolescents' choice of travel mode to travel 1 km in the outbreak phase does not change significantly compared to the normal phase, and there is no significant difference in the choice of travel mode when traveling 1 km between the post-epidemic phase and the

Table 1
Statistical results of demographic characteristics.

Variables	N = 315	
	Percentage (%)	Mean
Age	/	13.5
Gender indicator		
female	55.24	/
male	44.76	/
Whether the family has a car		
yes	75.24	/
no	24.76	/
Whether the family has a motorbike		
yes	59.05	/
no	40.95	/
Whether you wear a mask when you go out now		
yes	88.57	/
no	11.43	/
Whether the family's monthly income exceeds 10,000 yuan		
yes	42.86	/
no	57.14	/

Table 2
Descriptive statistics of the observed values assessing latent variables.

Manifest variables	Perception of the severity of COVID-19		
	Item	Average	Std. Err
I think the epidemic is still serious	Q_1	4.200	0.697
I try to avoid going to crowded places	Q_2	4.429	0.743
I try to avoid eating outside	Q_3	4.162	1.036
I try to avoid shopping	Q_4	4.162	0.949
When going out, I try to avoid taking the bus or subway	Q_5	4.248	0.945

Table 3
Reliability and convergence validity.

Dim	Item	Parameters of significant test			Item Reliability	Composite Reliability	Convergence Validity
		Estimate	S.E.	Est./S.E.	SMC	CR	AVE
L_1	Q_2	0.753	0.030	25.286	0.567	0.866	0.684
	Q_4	0.859	0.024	35.175	0.738		
	Q_5	0.865	0.024	35.741	0.748		

Table 4
Result of whether walking is chosen as a travel mode when the distance is 1 km.

Variables	Adolescents		Commuters	
	Coef.	Odds ratio	Coef.	Odds ratio
Period1 (1 if it is in the outbreak phase, 0 otherwise)	−0.086 (−0.51)	0.917		
Period2 (1 if it is in the post-epidemic phase, 0 otherwise)	0.208 (1.25)	1.231	0.187 (1.96)	1.206
Age	**−0.226***** (−3.91)	0.798	**0.010*** (2.17)	1.010
Gender indicator (1 if female, 0 if male)	**0.549***** (3.69)	1.731	−0.077 (−0.80)	0.925
Whether the family has a car (1 if true, 0 otherwise)	**−0.667***** (−3.61)	0.513	−0.002 (−0.02)	0.997
Whether the family has a motorbike (1 if true, 0 otherwise)	**0.328*** (2.21)	1.388	**−0.732***** (−7.34)	0.481
Whether you wear a mask when you go out now (1 if true, 0 otherwise)	−0.414 (−1.83)	0.661	**0.505***** (3.82)	1.655
Whether the family's monthly income exceeds 10,000 yuan (1 if true, 0 otherwise)	0.095 (0.87)	1.099	**−0.230*** (−2.00)	0.794
Perception of the severity of COVID-19	**0.302*** (2.09)	1.352	−0.012 (−0.19)	0.987
Constant	**3.382***** (3.10)	29.417	**−1.263***** (−5.57)	0.283

t statistics in parentheses.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

normal phase. Therefore, hypothesis 1 and hypothesis don't hold.

The perception of the severity of COVID-19 significantly affects adolescents' choice of short-distance travel. When this variable increases by 1 unit, the probability that adolescents choose to walk is multiplied by 1.352, which is an increase of 35.2%. However, the perception of the severity of COVID-19 does not significantly impact the choice of the short-distance travel mode of commuters. The primary activities of adolescents include short-distance travel to school (Loureiro et al., 2021). If the epidemic is severe, and there are also traffic control measures, adolescents may reduce traveling by public transportation and choose to travel by walking.

The regression results indicate that the number of adolescents choosing walking for short-distance travel decreases with age. Car ownership has a negative impact on adolescents' walking choices. Female adolescents prefer walking more than male adolescents for short-distance travel.

3.3. Frequency of outing activities

This part focuses on adolescents' activities frequency on weekends: the frequency of going out and the frequency of exercise outings.

3.3.1. The frequency of going out

This paper defines 'more than one outing' per weekend to be frequent outings. Therefore, this study assesses whether adolescents report taking frequent outings on weekends, and the influence of COVID-19 on that choice. Table 5 shows the regression fitting results. Period1, Period2, adolescents' age, having a car in the family, and the perception of the severity of COVID-19 are all statistically significant factors at different confidence levels. The perception of the severity of COVID-19 also significantly negatively impact the frequency that the subjects reported going out on weekends. The correlation coefficient is −0.786, and the odds ratio is 0.456. For each 1-unit increase in this variable, the probability of frequent outings on weekends for adolescents is multiplied by 0.456, that is, a

Table 5
Result of doing weekly outing activities frequently.

Variables	Adolescents				commuters			
	outings		going out for exercise		outings		going out for exercise	
	Coef.	Odds ratio	Coef.	Odds ratio	Coef.	Odds ratio	Coef.	Odds ratio
Period1 (1 if it is in the outbreak phase, 0 otherwise)	−1.029*** (−6.07)	0.357	−1.092*** (−6.22)	0.336	/	/	/	/
Period2 (1 if it is in the post-epidemic phase, 0 otherwise)	−0.416* (−2.49)	0.659	−0.041 (−0.25)	0.959	−0.861*** (−8.86)	0.423	−0.107 (−1.01)	0.898
Age	0.126* (2.27)	1.135	0.086 (1.54)	1.090	−0.007 (−1.64)	0.992	−0.003 (−0.63)	0.996
Gender indicator (1 if female, 0 if male)	0.249 (1.71)	1.283	−0.676*** (−4.49)	0.509	−0.025 (−0.27)	0.975	−0.201 (−1.85)	0.818
Whether the family has a car (1 if true, 0 otherwise)	0.385* (2.09)	1.470	0.691*** (3.61)	1.996	0.386*** (3.83)	1.471	0.201 (1.81)	1.223
Whether the family has a motorbike (1 if true, 0 otherwise)	0.288 (1.95)	1.334	0.519*** (3.44)	1.681	−0.056 (−0.51)	0.946	0.117 (1.06)	1.124
Whether you wear a mask when you go out now (1 if true, 0 otherwise)	0.055 (0.24)	1.056	0.648** (2.66)	1.911	−0.055 (−0.35)	0.947	0.284* (2.16)	1.328
Whether the family's monthly income exceeds 10,000 yuan (1 if true, 0 otherwise)	−0.093 (−0.86)	0.912	0.213 (1.94)	1.237	0.720*** (5.79)	2.054	0.051 (0.42)	1.052
Perception of the severity of COVID-19	−0.786*** (−5.20)	0.456	0.369** (2.21)	1.447	−0.248** (−3.65)	0.780	0.262*** (3.89)	1.299
Constant	−2.783** (−2.63)	0.062	−3.973** (−3.67)	0.019	1.535*** (6.62)	4.644	1.209*** (4.90)	3.349

t statistics in parentheses.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

decrease of 54.4%. The results clearly show that adolescents who remain pessimistic about the epidemic situation reduce their frequency of going out.

The p-values associated with Period1 and Period2 are less than 0.05, with odds ratios of 0.357 and 0.659, respectively (which are both less than 1). This indicates that the epidemic phase significantly impacts the frequency of adolescents' weekend outings, with adolescents going out significantly less during the outbreak phase compared to the normal phase (the coefficient of Period1 is −1.029 and is significantly less than 0). The same is true with respect to going out in the post-epidemic phase. Therefore, hypothesis 1 holds. We further analyze whether there is a significant difference between the coefficient of Period1 (−1.029) and the coefficient of Period2 (−0.416). Table 5 shows there is a significant difference between the two coefficients (Prob > chi2 = 0.000). The frequency at which adolescents go out in the post-epidemic phase somewhat recovers compared to the outbreak phase, but the frequency does not return to the normal phase level.

For commuters, certain variables (e.g., age, gender, the presence of a family motorbike, mask-wearing, and income) have an opposite impact on the frequency of weekly outings compared to adolescents. What is similar is that if the family has a car, adolescents and commuters both will increase the frequency of weekly outings. This is logical, as people still have travel needs, regardless of whether it is the epidemic or post-epidemic phases. If the family has a car, it can meet travel needs while still implementing epidemic prevention measures to minimize contact with others (Abdullah et al., 2020). The perception of the severity of COVID-19 also significantly negatively impacts the frequency of weekly outings for commuters. The correlation coefficient is −0.248, and the odds ratio is 0.780. For each 1-unit increase in this variable, the probability of frequent outings on weekends for commuters decreases by 22% (1–0.780). Both adolescents and commuters reduce the frequency of outings when they think that the epidemic is in a severe state. Adolescents report being more sensitive to that factor, with a lower possibility of going out.

3.3.2. The frequency of exercise outings

Regular exercise outing is defined as going out for exercise more than once per weekend. Table 5 shows that the coefficients Period1, gender, the presence of a family car or motorbike, mask-wearing, and the perception of the severity of COVID-19 are statistically significant at different confidence levels (adolescents).

For adolescents, the p-value associated with Period1 is less than 0.001, and the odds ratio is 0.336. This indicates that the outbreak of COVID-19 significantly impacts the adolescents' frequency of exercise outings per weekend. Adolescents' frequency of exercise outings in the outbreak phase is significantly less than during the normal phase. The coefficient of Period2 isn't significant. Adolescents' frequency of exercise outings in the post-epidemic phase does not significantly differ from during the normal phase. Therefore, hypothesis 1 doesn't hold. We further analyze whether there is a statistically significant difference between the coefficient of Period1 (−1.092) and the coefficient of Period2 (−0.041). The result shows there is a significant difference between the two coefficients (Prob > chi2 = 0.000). Therefore, the frequency of exercise outings for adolescents in the post-epidemic phase returns to the normal phase.

The perception of the severity of COVID-19 significantly and positively impacts the frequency of exercise per week for adolescents and commuters. This may be because they believe that if the epidemic remains in a serious state, they should exercise to improve their

immunity. For adolescents and commuters, if they report continuing to wear masks when they go out, it increases the possibility of them going out more frequently (coef. = 0.691 and coef. = 0.284, respectively). This result is consistent with the results discussed above. When adolescents/commuters continue to wear masks to travel, they likely perceive the epidemic as continuing to be difficult. They may be able to strengthen their immunity and prevent infection by increasing their frequency of exercise.

3.4. The choice of traveling by bus

Past studies have shown that travel distance influences adolescent travel behavior (McDonald, 2007). This section analyzes the travel distance and the epidemic phases on adolescents' choice of taking the bus. The results are shown in Table 6. Except for the variable denoting the presence of a car in the family, the remaining explanatory variables are all significant at different confidence levels.

The p-values of Period1 and Period2 are less than 0.05, and the odds ratios are 0.334 and 0.642, respectively. This indicates that the epidemic phase significantly impacts the adolescents' choice to travel by bus. The willingness to travel by bus during the outbreak phase is significantly smaller compared to the normal phase. This is similar to the adolescents' willingness to travel by bus in the post-epidemic phase. We further analyze whether there is a significant difference between the coefficient of Period1 (-1.095) and the coefficient of Period2 (-0.443). Table 6 shows there is a significant difference between the two coefficients (Prob > chi2 = 0.000). The adolescents' willingness to travel by bus in the post-epidemic phase somewhat recovers compared to the outbreak phase but does not return to the level of the normal phase.

The perception of the severity of COVID-19 also significantly and negatively impacts the adolescents' likelihood of using public transportation, with a correlation coefficient of -0.359 and an odds ratio of 0.698. When the assessment of COVID-19 severity increases by 1-unit, the probability that adolescents use public transit is multiplied by 0.698 (a decrease of 30.2%). Travel distance also impacts the probability that adolescents will use public transportation. As the travel distance increases, adolescents' willingness to choose public transit increases.

Household income significantly and negatively impacts the adolescents' choice of public transportation: the probability of selecting public transportation decreases when the family's monthly income is reported to exceed 10,000 yuan (the correlation coefficient is -0.205).

There is a difference between adolescents and commuters with respect to bus traveling. Table 6 shows that all the explanatory variables are significant at different confidence levels (commuters). The p-value of Period2 is less than 0.001, and the odds ratio is 0.726. The result also indicates that COVID-19 has a significant impact on commuters' probability of traveling by public transportation, which commuters report a reduction in its use. The perception of the severity of COVID-19 also significantly and negatively impacts the likelihood of commuters to use public transportation, with a correlation coefficient of -0.288. This psychological factor has the same influence on the willingness to travel by bus for adolescents and commuters. Some studies have noted that buses expose passengers to a relatively closed environment, which may increase the risk of spreading infectious diseases (Edelson and Phypers, 2011). During the post-epidemic period, the government's control measures are relatively loose, that is, the government requires travelers to wear masks when traveling by public transit. It is impossible to provide a completely risk-free environment; however, when adolescents/commuters report continuing to wear masks, the possibility of using public transport increases.

Table 6
Results related to whether respondents reported traveling by bus.

Variables	adolescents		commuters	
	Coef.	Odds ratio	Coef.	Odds ratio
Period1 (1 if it is in the outbreak phase, 0 otherwise)	**−1.095***** (−8.28)	0.334	/	/
Period2 (1 if it is in the post-epidemic phase, 0 otherwise)	**−0.443***** (−3.79)	0.642	**−0.319***** (-3.85)	0.726
Age	**0.111**** (2.92)	1.117	−0.003 (-0.95)	0.996
Gender indicator (1 if female, 0 if male)	**0.401***** (3.68)	1.493	**0.235**** (2.76)	1.264
Whether the family has a car (1 if true, 0 otherwise)	−0.140 (−1.05)	0.869	**−0.968***** (-11.077)	0.379
Whether the family has a motorbike (1 if true, 0 otherwise)	**0.649***** (5.72)	1.914	**−0.316**** (-3.71)	0.729
Whether you wear a mask when you go out now (1 if true, 0 otherwise)	**0.984***** (5.02)	2.676	**0.599***** (5.01)	1.820
Whether the family's monthly income exceeds 10,000 yuan (1 if true, 0 otherwise)	**−0.205*** (−3.49)	0.815	−0.380 (−3.60)	0.684
Perception of the severity of COVID-19	**−0.359***** (−3.94)	0.698	**−0.288***** (−5.52)	0.750
Travel distance	**0.286***** (8.84)	1.331	**0.163***** (7.77)	1.177
Constant	**−6.569***** (−8.48)	0.001	**−1.797***** (−8.71)	0.166

t statistics in parentheses.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

4. Discussion

This study showed that a logit method with latent variables achieved an order-of-magnitude acceleration in studying the impact of COVID-19 on adolescents' travel behavior. Applying a CFA and logit model to study adolescents' travel behavior among different periods revealed that the method was both sensitive and reliable. This was demonstrated at the individual participant level. Our results found that adolescents' travel behavior is significantly affected by COVID-19. There are differences in travel behavior between the epidemic's outbreak phase and post-epidemic phase, compared with the normal phase. For example, if adolescents report perceiving the severity of COVID-19 as high, there is a 35.2% increase in the chance that adolescents travel by foot for a short distance trip. The selection of public transportation by adolescents traveling long-distance is 33.4% and 64.2% for the outbreak-phase and post-epidemic phase, respectively, compared to the normal phase.

Consistent with other studies, our results found that the epidemic has an important impact on adolescents' travel behavior (Munasinghe et al., 2020). This paper also differed from another previous study (Stavrinos et al., 2020) that explored the effects of COVID-19 on adolescents' driving behavior. Another paper (Beck and Hensher, 2020) analyzed household travel behavior under the impact of COVID-19, finding that adolescents' travel behavior was affected by household behavior. The epidemic significantly impacted travelers (Tan and Ma, 2021).

Some papers have argued that latent variables (such as psychological factors) have significant impacts on people's behavioral choices, and adding latent variables to the model can increase the explanatory power of the model (Galdames et al., 2011; Stark et al., 2018a). This paper supports that thesis, as we found that adolescents' psychological factors impact the choice of travel mode.

5. Conclusion

This research studied the demographic characteristics of adolescents and latent psychological variables to assess the impact of COVID-19 on the travel behavior of adolescents. The study resulted in the following conclusions.

The phase of COVID-19 does not significantly impact the choice of travel mode for adolescents traveling within a short distance of 1 km. During short-distance travel, walking and other non-motorized travel modes have advantages over motorized travel modes, due to their high levels of convenience and flexibility (Mitra and Buliung, 2015).

The phase of COVID-19 significantly and negatively impacts the frequency of adolescents' weekend outings. In the post-epidemic phase, adolescents' exercise outings frequency returned to normal. Adolescents' perception of the severity of COVID-19 significantly increases the frequency of going out for exercise. It highlights the relevance of daily exercise activities in maintaining or improving the physical function of adolescents. Measures should be taken by relevant departments to encourage adolescents' engagement in sports. More fitness facilities near residential areas could be installed by urban operators. Schools could increase the hours of physical education. More stadiums and parks could be built. The dangers of sedentary behavior should be widely publicized by relevant departments.

The phase of COVID-19 and the adolescents' perception of the severity of COVID-19 significantly and negatively impact the adolescents' willingness to travel by bus. Due to safety and health concerns during the outbreak phase of the epidemic, adolescents are reluctant to travel by public transit. Some adolescents may switch from public transportation to private automobiles, which is environmentally unfriendly. Therefore, public transportation and stations might offer disinfection services to give passengers a sense of security. Transportation operators can increase the number and frequency of buses, or deploy larger buses to minimize passenger density.

Also, some adolescents may switch from public transportation to active modes. These modes would aid in enhancing physical activities, maintaining the health and wellbeing of people during the epidemic (De Vos, 2020). Urban and transportation planners could make use of this chance to promote active modes of transportation. More bicycle lanes could be built by government agencies to make cycling easier for people. More sidewalk amenities could be installed alongside the sidewalk. More trees could be planted alongside the sidewalk to offer shade for pedestrians.

The findings of the study will assist the Transportation Bureau and transportation management agencies in developing appropriate policies for post-epidemic transportation recovery and reconstruction. It will help the transportation business grow in a healthy way.

Author statement

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Declaration of competing interest

There is no conflict of interest.

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Appendix A. Survey of adolescents' travel behavior

Variables	
Age	Demographic characteristics
Whether the respondent is female	
Whether the family has a car	
Whether the family has a motorbike	
Whether the family's monthly income is above 10,000 yuan	
Whether you wear a mask when you go out now	
I think the epidemic is still serious	Perception of the severity of COVID-19
I try to avoid going to crowded places	
I try to avoid eating outside	
I try to avoid shopping	
When going out, I try to avoid taking the bus or subway	
Before the outbreak, whether respondent walked when the distance was 1 km	Travel behavior
During the outbreak, whether respondent walked when the distance was 1 km	
After the outbreak, whether respondent walked when the distance was 1 km	
Before the outbreak, whether respondent traveled by bus when the distance was 1 km	
During the outbreak, whether respondent traveled by bus when the distance was 1 km	
After the outbreak, whether respondent traveled by bus when the distance was 1 km	
Before the outbreak, whether respondent traveled by bus when the distance was 3 km	
During the outbreak, whether respondent traveled by bus when the distance was 3 km	
After the outbreak, whether respondent traveled by bus when the distance was 3 km	
Before the outbreak, whether respondent traveled by bus when the distance was 5 km	
During the outbreak, whether respondent traveled by bus when the distance was 5 km	
After the outbreak, whether respondent traveled by bus when the distance was 5 km	
Before the outbreak, whether adolescents were going out frequently on weekend	
During the outbreak, whether adolescents were going out frequently on weekend	
After the outbreak, whether adolescents were going out frequently on weekend	
Before the outbreak, whether adolescents were going out for exercise frequently on weekend	
During the outbreak, whether adolescents were going out for exercise frequently on weekend	
After the outbreak, whether adolescents were going out for exercise frequently on weekend	

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