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Changes in bicycling over time associated with a new bike lane: relations with kilocalories energy expenditure and body mass index

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Abstract

Although bicycling has been related to positive health indicators, few studies examine health-related measures associated with non-competitive community cycling before and after cycling infrastructure improvements. This study examined cycling changes in a neighborhood receiving a bike lane, light rail, and other "complete street" improvements. Participants wore accelerometers and global positioning system (GPS) data loggers for one week in both 2012 and 2013, pre- and post- construction completion. Participants sampled within 2 km of the complete street improvements had the following patterns of cycling: never cyclists (n=434), continuing cyclists (n= 29), former cyclists (n=33, who bicycled in 2012 but not 2013), and new cyclists (n=40, who bicycled in 2013 but not 2012). Results show that all three cycling groups, as identified by GPS/ accelerometry data, expended more estimated kilocalories (kcal) of energy per minute during the monitoring week than those who were never detected cycling, net of control variables. Similar but attenuated results emerged when cycling self-report measures were used. BMI was not related to cycling group but those who cycled longer on the new path had lower BMI. Although cyclists burn more calories than non-cyclists across the week, among cyclists, their cycling days involved more calories expended than their non-cycling days. The new cyclists account for 39% of the cyclists identified in this study and former cyclists account for 32% of cyclists. These results suggest that

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cycling is healthy, but that sustaining rates of cycling will be an important goal for future policy and research.

Keywords

cycling; cycling; body mass index; kilocalorie; bike lane; energy expenditure

1.0 Introduction

Bicycling is an uncommon but healthy mode of transportation in the United States that is growing in popularity. According to National Household Travel Survey data, small but significant increases in cycling occurred in the U.S. between 2001 and 2009, from 12.4 to 14.2 trips per year (Pucher et al., 2011). Where city officials have invested substantially in bike lanes or paths more cycling is reported, but most evidence is from cross-sectional surveys that rely on self-reports and have limited health measures (Buehler and Pucher, 2012; Cervero et al., 2013). In contrast, the present research examines how objectively-measured and self-reported cycling changes over time in association with new cycling infrastructure and how cycling relates to kcal expenditure and body mass index (BMI). The new bike lane was part of a “complete street” implementation (McCann, 2013) that improved and completed a bike lane, added a light rail transit line, and widened sidewalks in a downtown corridor in Salt Lake City, Utah.

1.1 Cycling and health

Despite historically low population participation in cycling in the U.S., cycling is associated with immediate and long-range health benefits. Areas with more cycling have lower proportions of obese adults (Pucher et al., 2010) and more self-reported physical activity (Pucher et al., 2010; Pucher et al., 2011). Cyclists in the CARDIA (Coronary Artery Risk Development in Young Adults) study had lower BMIs and lower lifetime cardiovascular risk (Boone-Heinonen et al., 2009). A recent review sought to identify causal relationships between cycling and health benefits by selecting prospective observational, case-control, or interventional studies (Oja et al., 2011). Notably, 8 of the 10 studies that examined adult cyclists and their physical activity or weight outcomes were from Western Europe (Besson et al., 2008; Bo Andersen et al., 2000; De Geus et al., 2009; De Geus et al., 2008; Hendriksen et al., 2000; Hoevenaar-Blom et al., 2011; Oja et al., 1991) or China (Matthews et al., 2007), which has higher base rates of cycling than the U.S. (Bassett Jr et al., 2008). These and other studies show cycling is associated with lower all-cause (Bo Andersen et al., 2000; Kelly et al., 2014; Matthews et al., 2007; Sahlqvist et al., 2013b) and cardiovascular disease mortality (Hoevenaar-Blom et al., 2011) and generally greater cardiovascular fitness (Oja et al., 1991). A U.S. study, the Nurses' Health Study II, showed that self-reported weight decreased for those who increased their cycling or stationary cycling and weight increased for those who decreased their cycling; however, 48% of their sample reported cycling, making this an unusual sample for the U.S. (Lusk et al., 2010). In sum, cycling is linked to greater self-reported physical activity as well as distal health outcomes such as lower BMI and cardiovascular risk, especially where cycling is common.

1.2 Cycling infrastructure and cycling

Few studies, however, examine the role of new bike lanes in facilitating cycling, either in cross-sectional or longitudinal analyses. Among cross-sectional studies, a study of a new car-free bike path in England showed 6% of journeys by bicycle among nearby residents compared to 2% of journeys by bicycle among residents of a control town where bike paths were distant; however, no comparison was available prior to path construction (Jones, 2012). Another correlational study showed that girls living in neighborhoods with bike paths had greater accelerometer-measured MVPA and lower BMI than girls in neighborhoods without bike paths, but the methodology could not tie the measures to bike path use (Evenson et al., 2007).

Studies that examine cycling before and after a trail has been constructed demonstrate mixed results. Cyclists near a new path in Sydney reported 11.4 minutes per week more cycling compared to a 14.4 minute per week decrease in cycling among distant (>1.5 km) control cyclists (Merom et al., 2003). Yet a more recent Sydney study showed no increase in cycling frequency due to a new bike path (Rissel et al., 2015). A large study of multiple UK towns showed that new training programs along with new bike paths resulted in a significant reported increase from 5.8% at baseline to 6.8% cycling after construction and training programs were implemented. It was impossible to tell whether the new path or training or other aspects of the intervention were responsible for the increase (Goodman et al., 2013a). An allied study found greater activity by year two for residents who lived close to a new path when walking and cycling data were combined. However, when cycling was analyzed separately (see their online appendix Tables S4 and S5) there was no significant increase in either leisure or transport cycling after one or two years (Goodman et al., 2014).

In contrast to some positive results from non-U.S. studies reviewed above, new U.S. bike paths have not been associated with increased ridership among nearby residents. For example, one U.S. study found only 2 bicycle trips per 386 travel diary days from 144 participants, with no effect for the new suburban bike trail (Burbidge and Goulias, 2009). Another recorded only 2 of 366 residents making any bicycle trips before a rail line was converted to a multi-use trail and a decrease in cycling time after the trail was built (Evenson et al., 2005). A pre- post study of a 1 km Santa Monica, CA complete street retrofit, which improved pre-existing sidewalks and bike paths, showed that the number of cyclists remained roughly the same but the number of pedestrians increased (Shu et al., 2014).

In sum, U.S. longitudinal studies have not shown new bicycle lanes lead to more use by nearby residents, perhaps due to low base rates of cycling, small samples, siting paths far from popular destinations, or variability of cycling over time. Indeed, only 0.6% of workers bicycled to work, according to the 2008-2012 American Community Survey (McKenzie, 2014), and cycling accounts for only 3.1% of relatively short (< 3 mile) trips (Litman, 2010). Cycling is not a consistent behavior, with the most common last bike trip being over five years ago (Schroeder and Wilbur, 2013) and many reporting that they are not “regular cyclists” (Bauman et al., 2012). These realities suggest that larger samples and more varied cycling infrastructure options should be examined.

1.3 The current study

The current study examines how changing patterns of cycling in a neighborhood receiving a “complete street” intervention relates to health indicators of calories burned from physical activity (kilocalorie expenditure) and BMI. The complete street intervention provided a new complete bike lane that paralleled a new light rail extension along a main traffic corridor that connected the Salt Lake International Airport to the downtown district. As part of a larger study that examined residents' attitudes and behaviors related to the new bike lanes, light rail line, and improved sidewalks, we focus in the current study on those who cycled at least once during the data collection weeks. We examine changes in cycling over time, before and after the complete street improvement in relation to kcal expenditure and BMI. We expect that any cycling will have beneficial results for BMI and kcal expenditure and that use of the bike lane corridor will be a significant contributor to the health outcomes. Unlike prior studies, this one focuses on physical activity and body mass health outcome as well as infrastructure use, has a larger sample size (n=536), and is sited in an urban area, which has higher population density and more diverse land uses than past studies of more suburban neighborhoods or rail-trail conversions in isolated corridors. We expect these novel features will result in a sample with sufficient power to detect activity and weight relationships with cycling, if not increases in cycling.

1.4 Objective estimates of cycling and energy expenditure

The current study provides objective measures of cycling including the duration of bike trips using the new bike lane corridor. Due to the paucity of objective measures of cycling, most studies have used self-reported cycling (Librett et al., 2006; Pucher et al., 2010; Pucher et al., 2011). Although accelerometers are frequently used to provide objective measurement of walking, they substantially underestimate the effort associated with cycling (Herman Hansen et al., 2014). Researchers have thus turned to GPS data loggers as an alternative way to assess cycling. When GPS devices are used in combination with accelerometers, researchers can assess cycling through the pattern of activity, speed, and acceleration that is typical for cycling. One study using GPS measures of cycling compared adult cyclists before and after new bike boulevards were constructed in Portland, OR. In an unexpected result, the GPS data revealed that those nearest the new facilities reduced their time cycling, despite the fact that about 40% had bicycled at least 10 minutes during the week of observation; six other physical activity measures showed no significant changes (Dill et al., 2014). Dill et al. speculated that substantial changes in cycling behaviors among both the bike boulevard exposed group and the more distant controls accounted, in part, for these results. Such surprising results underscore how little we know about cycling in the U.S. More studies utilizing GPS measures over time are needed to enhance basic understanding of spatial and temporal qualities of bike use and their relationship with new cycling infrastructure. Perhaps many U.S. cyclists simply quit cycling (Schroeder and Wilbur, 2013) or reduce their cycling (Dill et al., 2014) over time while others start cycling in response to new infrastructure (Buehler & Pucher, 2012). In this study we use both objective GPS measures of cycling along with more typical self-reports to examine cycling at two points in time.

Another advantage of utilizing GPS measures is that we can estimate kcal expenditure associated with cycling. U.S. health recommendations translate to a recommended minimum of 1000 kilocalories of energy spent in at least 150 minutes of moderately intense physical activity per week (Pate et al., 1995). The recommendations note that cycling is often a moderate activity, with estimates that it would require four to seven calories per minute while cycling (Pate et al., 1995). Although many studies are focused on the health benefits of cycling, most tests of the calories spent during cycling are conducted in the lab, which does not have stop signs and other features one would find in the community (e.g., Haakonssen et al., 2013). A study that included both lab and community measures of cycling found that cyclists tend to ride faster in the lab and when they were wearing a measuring mask than when they were keeping diary entries of cycling (De Geus et al., 2007). By unobtrusively using GPS data loggers to estimate speeds of bicycle rides in a community setting, the current study can provide field estimates of calories spent by community cyclists. In addition, by examining the calories spent by bicyclists on cycling days compared with non-cycling days, we can assess whether bicyclists are a select group who are generally more active, or whether their activity levels reflect their cycling behaviors. Past research has found that the greater levels of physical activity among transit riders are achieved only on days of using transit (Miller, et al., 2015); we provide this novel comparison for cyclists.

1.5 Summary of research questions

We ask how cycling, both GPS/accelerometry-measured and self-reported, relates to kcal expenditure and BMI. We focus on four groups defined by their patterns of cycling over two separate measurement weeks, one each in 2012 and 2013. We expect never cyclists (bicycled in neither 2012 nor 2013) to have lower kcal expenditures and higher BMIs than the three cycling groups: continuing cyclists (both 2012 and 2013), former cyclists (2012, but not 2013), and new cyclists (in 2013, but not 2012). Furthermore, we examine the total duration of cycling on and off the bike lane corridor and test whether the duration of cycle trips associated with the complete street bike lane corridor accounts for additional explanatory power in the prediction of kcal expenditure and BMI. Finally, we test how kcal expenditure varies from non-cycling days to cycling days amongst cyclists.

2.0 Method

2.1 Site

As noted, the street improvements completed an incomplete bike lane (i.e., one present for less than half the length of the corridor) and widened sections of the lane to create what is now designated a “high comfort” bike lane on the city bike map due to the presence of the bike lane and the relatively low speed along the road (30 mph). The bike lanes are painted on both sides of the street and the sidewalks were improved and widened to provide a shared bike and pedestrian path. In addition, the 2.6 mile (4.2 km) complete street improvements extended an existing light rail line (called the Green line on the local TRAX system) from downtown to the airport, reduced automotive lanes, and provided better lit sidewalks with landscaping. The bike lanes traverse a road (North Temple, between about 200 W to 2000 West) with multiple commercial areas, some multifamily and hotel lodging, and a variety of services along with the state fair park and some industrial sites. It connects to a bike lane and path going westward to the airport as well as with a pre-existing bike network downtown on the east end. There is also an older parallel bike lane three blocks north of the new lane.

2.2 Participants

Participants were drawn from the Moving Across Places Study (MAPS) that recruited adults living within 2 km of the complete street intervention, a distance within the median distance (2.8 miles) that adult bike riders have been found to ride (Dill, 2009). Participants were surveyed and wore accelerometers and GPS loggers for approximately one-week periods before (2012) and after (2013) bike lane improvements, light rail construction, and other complete street installations. The light rail and bike lane improvements were completed for a grand opening in April 2013; most follow-up data were collected from May through November, 2013 (one participant was included during late April 2013because of an impending relocation). Participants were recruited door-to-door and were asked to provide informed consent. Eligible participants were selected to be over 18, able to walk a few blocks, intending to stay in the neighborhood ≥ 1 year, not pregnant, able to speak Spanish or English, and able to wear the devices and fill out the surveys (see details in Brown et al., 2014). This study uses 536 consented participants who had at least 3 days of valid accelerometer wear in 2012, defined as ≥10 valid hours of wear time (Troiano et al., 2008). Non-wear was defined as 60 minutes of 0 counts on the accelerometer, allowing for 1-2 minutes of up to 100 counts per minute (Troiano et al., 2008). Participants also had to have GPS data and remain in the study for the 2013 follow-up.

2.3 Measures

Participants wore Actigraph GT3X+ accelerometers and GlobalSat DG-100 global positioning system data loggers, which together provide evidence of trip modes (see additional details in Miller, 2015, Appendix 1). The GPS data loggers collected data at 3-second intervals when signals were available. Participants wore the GPS units for approximately the same total times in both years: 4757 minutes in 2012 and 4772 minutes in 2013 (with a range across the four cyclist groups from 4524 for former cyclists in 2013to 4952 minutes for continuing cyclists in 2012). GPS wear time was not significantly different across groups and was not meaningfully associated with any outcome variable.

2.3.1 Bicycle trips—To assign travel mode, each trip was compared to average speeds, their standard deviations and maximums. An initial mode assignment was based on observed GPS average speed, with bike trips averaging 10.44 mph (SD 5.07 mph or M 16.80 kph and SD 8.16 kph). Experts from GeoStats (now Westat) reviewed trip stage assignments based on GIS layers, speed profiles, and physical activity data from the accelerometers. Bike mode was identified by combining the speed levels with elevated PA levels indicated by accelerometer (see Miller et al., 2015, for additional technical details). Although accelerometer counts for cycling are often not accurate, they are typically elevated beyond the low levels associated with riding in vehicles. For example, one study found cycling accelerometer counts per minute averaged 597 (Troped et al., 2008) and another reported 1157 (Herman Hansen et al., 2014). In our study, complete street corridor bicycle trips were defined as trips with GPS points indicating cycling and where some part of the trip was within a 40-meter street network buffer from the street centerline. This 40-meter distance is within the range of buffers used by others to detect cycle trips (Jarjour et al., 2013; Krenn et al., 2014).

2.3.2 Duration of cycling on complete street bicycle trips—To detect duration of cycling associated with the complete street corridor, all trips were divided into stages by mode of travel. Thus a trip might include a cycling stage, then a light rail stage, ending with another cycling stage. The duration of cycling was extracted from the entire trip associated with the complete street to test whether duration of cycling involving the new bike lane adds any explanatory power to the cycling group predictors.

2.3.3 Kilocalorie expenditure—For minutes that were identified via accelerometer and GPS recordings as walking or cycling, Ainsworth's physical activity compendium was used to convert speed of travel to METs (Metabolic Equivalents) and then used with participant weight to derive the estimated kcals per minute ((METS × 3.5 × body weight in kg)/200) (Ainsworth et al., 2011). For all non-cycling and non-walking physical activity (e.g., jogging) we used the Freedson two-part equation, available from the Actigraph web site, which is extensively used and valid for predicting moderate intensity activities from accelerometer counts per minute (Lyden et al., 2011). The equation uses the Williams Work-Energy equation (Williams, 1998) for physical activity intensities ≤1951 accelerometer counts per minute (cpm; kcals= cpm × 0.0000191 × kilograms of body weight). For physical activities with ≥ 1952 cpm, the Freedson estimation is used (.00094 × cpm + (0.1346× kilograms of body mass -7.37418)).

2.3.4 Self-report measures—The survey data provided the second dependent variable of self-reported cycling during the previous week. It also provided the control variables: gender, age, Hispanic ethnicity, household income, and automobile availability. Income was imputed by regression for cases when missing (14%; random residuals were chosen from complete cases) and other cases were dropped when data were missing (i.e., for Hispanic ethnicity n= 5 missing) so that the final sample size for the multivariate analysis of kcal was N= 531.

2.3.5 Body mass index (BMI)—Weight was obtained from measures in the participants' homes using calibrated scales in both years. BMI was calculated as weight in kilograms divided by height in meters squared (Centers for Disease Control and Prevention, 2007). For BMI analyses all underweight individuals were removed (n=9) to focus on the range from healthy weight to obese.

3.0 Statistical analyses

Separate analyses were conducted for the dependent variables of kcal expenditure and BMI. Independent variables included dummy variables representing the cyclist groups. Separately for both GPS/accelerometry-measured cyclists and self-reported cyclists, four groups were defined: never cyclists, continuing cyclists, former cyclists, and new cyclists. The three dummy variables compared each of the three cycling groups to the reference category of never cyclists. Analyses were conducted sequentially to assess the effects of 1) cycling group membership, net of control variables and 2) cycling duration for trips that included the complete street bike lane corridor. Initial descriptive statistics and univariate associations were tested with univariate ANOVAs; linear mixed models (Proc Mixed) tested multivariate effects (using SAS 9.4; Cary, NC).

4.0 Results

Table 1 demonstrates that the most consistent individual-level covariate associated with cycling is gender, with 55% females among never cyclists, and 17% to 43% females among the three cycling groups when GPS-measured groups are used; gender is similarly significant for self-reported ridership groups. Participants who had no access to a car were more likely to be continuing cyclists when GPS-measured ridership groups are used. Former bicyclists, according to self-reported cyclist group membership only, are the youngest. Of those detected as cycling by GPS measures 83% had self-reports that corroborated the GPS accounts of cycling, suggesting that the two measures are similar but worthy of separate analysis.

Like other U.S. studies, the net increase in duration of cycling on the new corridor is insignificant. Among residents who cycled in either year 2012 or 2013, (n=102) cycling duration on the corridor increased from 18.51 minutes (SD = 54.96) to 25.55 minutes (SD= 49.95; $t(203) = .99$, $p = .32$). These increases are likely insignificant due to two reasons. The loss of 33 riders in 2013 in the former rider group almost equaled the 40 new riders in 2013. There is also substantial variability in riding durations within the groups, as shown by the high standard deviations for mean cycling durations. Similarly, cycling duration off the complete street corridor increased non-significantly from 38.24 minutes (SD= 71.01) to 43.92 (SD= 81.42, $t(203) = .35$, n.s.). These results suggest that it is important to track separate groups of cyclists when assessing ridership patterns over time and associated health effects.

4.1 Kilocalorie expenditure: GPS-measured cycling groups

Model 1 in Table 2 demonstrates that any GPS-measured cycling in either or both measurement years is associated with higher estimated calories expended, compared with the calorie expenditures of never cyclists. Continuing cyclists had the highest kcal expenditures that were 2.67 calories more per minute of GPS wear time than never cyclists. However, cycling during either year also relates to significantly more kcal expenditure than for never cyclists. Among control variables, access to a car, female gender, and Hispanic ethnicity were associated with lower kcal expenditures.

4.2 Duration of GPS-identified bicycle trips, including the new bike lane corridor

In Model 2 of Table 2, the duration of GPS-identified cycling on trips that included the complete street bike lanes was shown to account for a significant amount of kcal expenditure (.03 kcals per minute cycling), after accounting for cycling group membership. The addition of the duration variable reduces the effect of all three cycling groups, demonstrating that the relationship between cycling and kcal expenditure is, as expected, partially explained by the duration of cycling on the bike lane corridor.

To examine how the use of the new bike lane corridor contributes to total cycling, the durations of cycling trips on and off the new corridor were calculated for each participant's monitoring week in each year. Former cyclists rode the least amount of total time in 2012 and utilized the pre-construction corridor the least (22/70 minutes or about 31% of their time cycling), as shown in Figure 1. Continuing cyclists rode the longest (120 and 130 minutes in 2012 and 2103, respectively) and the bike lane corridor accounted for about a third of their cycling time. New cyclists rode about 83 minutes in 2013, with the newly completed bike lane corridor accounting for about 41% of their cycling time.

4.3 Kilocalorie expenditure: Self-reported cycling groups

When the mixed model analysis is repeated, replacing GPS-measured cycling with self-reported cycling groups, results are very similar to GPS-measured cycling, except that results are somewhat attenuated for self-reported cycling groups (compare upper to lower half of Table 2). Specifically, kcal expenditure is greater for continuing and new cyclists than for never cyclists. Self-reported former cyclists no longer demonstrated significantly greater kcal expenditure than the never cyclists. Duration of cycling on the bike lane corridor again accounts for some of the effects for continuing and new cyclists, as shown by the diminished coefficients after adding the duration variable (see lower right quarter of Table 2).

The same control variables were significant for self-reported and GPS-measured cycling groups. Those with access to a car, females, Hispanic individuals, and those with lower incomes were less likely to engage in GPS/accelerometry-measured or self-reported cycling; age was not significant in either model.

4.3 Cycling vs. non-cycling day kcal expenditure: GPS-measured cycling

To address whether cyclists are generally more active on cycling days compared to non-cycling days, paired *t*-tests examined the mean kcal expenditures per minute on cycling days compared to non-cycling days. In 2012, cyclists' cycling days averaged 4.82 kcal/min, which was significantly higher than the 2.82 kcal/min of their non-cycling days (Satterthwaite $t(83.90) = -3.69$, $p = .0004$). For comparison, non-cyclists' kcal/min was 1.03 in 2012. In 2013, cyclists' cycling days averaged 4.34 kcal/min, which was significantly higher than the 2.96 kcal/min of their non-cycling days (Satterthwaite $t(105.78) = -3.43$, $p = .0009$). For non-cyclists, the kcal per minute was 1.14 in 2013. These results demonstrate that cyclists are a relatively active group, but even their levels of kcal expenditures increase on cycling days.

4.4 BMI for the four cycling groups: GPS-measured cycling

Measured BMI levels did not differ across cycling groups for the planned contrasts in a mixed model. However, the longer the duration of cycling trips along the complete street, the lower the BMI ($t(517) = -2.20$, $p = .03$). Both higher income and younger individuals had lower BMIs.

5.0 Discussion

This work adds to the small pool of research on the health-related outcomes of cycling. Results confirmed that cyclists had greater kcal expenditures than non-cyclists and that, among cyclists, their cycling days had more kcal expenditures than their non-cycling days. Furthermore, the addition of an improved and completed bike lane to this neighborhood was associated with greater kcal expenditure and lower BMI among cyclists who had longer durations of new bike lane corridor cycling trips. The complete street corridor hosted bike trips that accounted for between 31% and 41% of total cycling time of the cyclists, according to GPS measures, suggesting that the complete street route was a key contributor to participants' cycling.

In all of the bicycle use groups—continuing, former, and new—more participants reported cycling in the past week than were detected by accelerometer/GPS measures of cycling. The higher level of self-reported cycling could be due to limitations in adherence to GPS wear protocols, equipment problems, or errors in the self-report measures. The stronger relationships with kcal expenditure in the expected direction for GPS/accelerometry measures of cycling than for self-reported cycling suggest that the objective measures are useful ones. However, except for former cyclists, the same groups of cyclists were significant across both self-reported and objectively measured analyses of cycling groups, suggesting that reliance on self-reported cycling for future analyses of new bike infrastructure may still be useful. The GPS measures were least likely to converge with self-reports for the two groups who experienced changes in cycling, with 58% of GPS-identified former cyclists reporting that they had not ridden a bike that week and 65% of new cyclists reporting their cycling activity. In contrast, 86% of never cyclists and 93% of continuing cyclists had self-reports that corroborated GPS measures. Thus GPS may be especially useful in studies of changes in cycling. In this study the GPS measures also were useful in providing cycling duration measures, which we did not trust to self-reports.

Our results are consistent with a growing body of research that assesses a variety of benefits associated with cycling, although few prior studies have estimated the kilocalorie expenditures of community cycling outdoors. The kcal expenditure results demonstrate that bicyclists are a self-selected active group. Even on their non-cycling days they expend over two and one-half times the energy of non-cyclists (2.82 vs. 1.03 in 2012; 2.96 vs. 1.14 in 2013). However, a cyclists' cycling day boosts kcal expenditure by about 50% more over a non-cycling day, demonstrating the potential kcal expenditure benefits of community cycling. These immediate kilocalorie expenditure benefits may be precursors to the longer term health benefits described in other research. For example, one study has estimated that increasing daily active transportation from 4 to 22 minutes could reduce diabetes and cardiovascular disease burdens by 14% (Maizlish et al., 2013). The new riders spent an average 83 minutes cycling per week, which would be in the range needed for those health benefits. That amount of cycling also means the new riders achieve 55% of the total time needed to meet the recommended 150 minutes of moderate activity per week.

Fewer minutes of cycling on trips involving the new complete street were associated with significantly higher BMIs. Yet, perhaps surprising, the group BMIs for continuing, new, or former riders were not significantly different from those of never riders. Although continuing cyclists averaged 26.5 and 27 BMI in the two study years compared to the never cyclists' higher BMIs of 29.3 and 29.5, there was substantial variability in the BMIs, which makes it difficult to obtain significant differences (BMIs of continuing cyclists ranged from 19.7 to 41.9.) In addition, it is known that BMI as a measure does tend to overestimate weight problems of individuals who are muscular, which may be true for cyclists (Burkhauser and Cawley, 2008). Furthermore, the BMIs of new cyclists (28.6 and 28.5 from

2012 to 2013, respectively) appeared higher than the BMIs of continuing cyclists (26.5 and 27), suggesting that new cyclists might be able to reduce their BMIs if they were to continue cycling. The new bike lane may have appealed to those somewhat overweight individuals who had not cycled in the past, providing an opportunity for a new healthy behavior. Thus, to the extent that bike lanes can support longer durations of cycling, and cyclists can continue riding, they may over time be associated with healthier BMI.

Individuals cycling in the U.S. have often done so sporadically, with relatively few individuals relying on cycling as a major mode of transportation over a long time period (Schroeder and Wilbur, 2013). Even when a new bike lane was added in this study, a number of individuals who had been detected as cyclists before the lane was completed were no longer detected as cycling after the lane was completed. Specifically, 33/102 cyclists (32.35%) were former cyclists whose accelerometer/GPS data indicated cycling trips in 2012 but not 2013. This pattern is similar to data from other communities. In Cambridge England, 23% of cyclists increased but 26.4% decreased cycling to work across one year (Panter et al., 2013) and in a UK sample, 35% reduced reported active transit times and 32% increased active transit times by >15 minutes over a year (Sahlqvist et al., 2013a). When cycling rates were tracked before and after new cycling infrastructure in the UK, of those who changed cycling, 70% increased but 30% decreased their cycling (Goodman et al., 2013b). Similarly, Portland cyclists reduced cycling despite having a new greenway constructed near home (Dill et al., 2014). Given the health benefits of cycling identified in the current study and others, a new focus for future research might be the challenge of sustaining the cycling regimen over time.

This study also confirms that males are more likely to bicycle than females (McKenzie, 2014; Pucher et al., 2011) and that residents without access to cars (Lachapelle, 2015; Panter et al., 2013) are more likely to bicycle than residents who have access to cars. Exploratory post-hoc analyses of gender differences across cyclist categories revealed that there were more females among never cyclists (55%) than either continuing (17%; Games-Howells $p < .001$) or former (30%; $p = .03$) cyclists. However, the percentage of female new cyclists was substantial at 43%, which was not significantly different from the never cyclists' percentage. Thus, females were as likely to be among the never cyclists as the new cyclists. These results suggest to us that cycling has become more attractive to females in 2013 and the results of the duration analysis show that new cyclists spent the most time—41% of their cycling time—on trips involving the new bike corridor. Females have shown a preference for better quality bike lanes in past research so the completion and widening of bike lanes for this complete street project may have attracted more new female cyclists (Heesch et al., 2012; Heinen et al., 2010). Of course, our sample size of new cyclists is limited so these suggestive results warrant replication with larger samples.

This study shares the limitations of many studies of accelerometer-measured walking in community settings. Specifically, the GPS/accelerometry method of defining cycling does not address possible variations in kcal demand induced by hills, loads being carried, or wind resistance. Individuals needed to be wearing properly functioning equipment in order to be counted as cycling. These results are also limited to one set of equations for estimating kilocalorie expenditure. The setting was limited to one urban street in one city and it would be important to know if complete street improvements that provide bike lanes also work in suburban settings and other communities. The follow-up study was completed just seven months after the complete street improvements, which limited the time participants were exposed to the intervention. One UK study found that residents walked and cycled on a new bike lane two years, but not one year after implementation, suggesting that effects of new infrastructure may take time to be used by local residents (Goodman et al., 2014). Finally, the irregularity of cycling suggests that future research may need testing of longer data collection intervals; the one-week data collection per year in the current study means that those who cycle but do so less than once a week would not have been detected.

In sum, the ability to utilize GPS/accelerometry to identify cycling may be useful for a variety of public health and transportation initiatives. Cycling is relatively rare in the U.S., so it has always been difficult to identify samples of individuals likely to benefit from nearby bike lane improvements. As technological measures of cycling become more pervasive we expect increases in the number of studies that have access to good data on cycling trips (Wang et al., 2010). This will enable researchers to identify both health benefits and design requirements of good bike lanes so that cycling may become less rare and more stable in the U.S. In the current community sample we demonstrated that those who bicycled in both observed years had the greatest kcal of energy expenditure, but that any cycling was associated with greater kcal expenditure than no cycling.

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Highlights

- We tracked bicycling activity over two years using accelerometers and GPS loggers
- Any cycling relates to more calories burned but not lower BMI
- Cyclists burn more calories on their cycling days than on their non-cycling days
- Cyclists burn more calories than non-cyclists, even on non-cycling days
- Greater use of a urban bike lane related to lower BMI and more calories burned

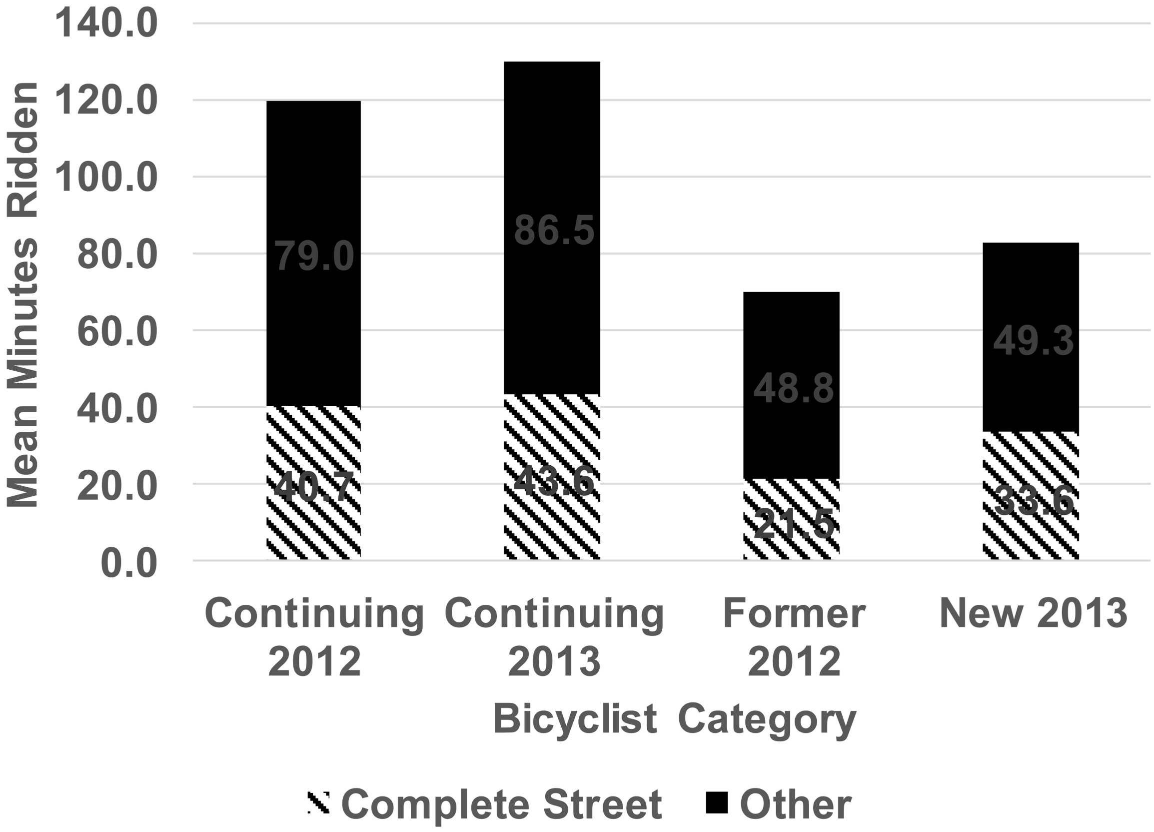

Figure 1. Minutes cycled on rides on and off the complete street bike corridor: GPS measured groups

Table 1

Four cycling groups: Descriptive statistics (proportions or means) and group differences

	Never (n=434)		Continuing (n=29)		Former (n= 33)		New (n= 40)		
	M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	***p* =**
			GPS-measured bike use						
Sociodemographic control variables									
Household income	41.03	32.14	51.35	36.20	42.33	26.83	39.60	28.43	
Age	42.54	15.28	39.69	12.13	38.09	12.10	37.25	11.44	
Female	0.55	0.50	0.17	0.38	0.30	0.47	0.43	0.50	***
Car available 2012	0.88	0.33	0.69	0.47	0.88	0.33	0.93	0.27	*
Car available 2013	0.90	0.30	0.79	0.41	1.00	--	0.95	0.22	*
Hispanic	0.26	0.44	0.10	0.31	0.16	0.37	0.28	0.46	
Weight and activity variables									
BMI 2012	29.28	7.20	26.52	5.26	27.92	5.59	28.55	6.64	
BMI 2013	29.50	7.21	26.95	5.61	28.66	5.89	28.49	6.23	
Kcal / min 2012	1.02	0.92	3.59	3.10	2.29	1.50	1.14	0.90	
Kcal / min 2013	1.12	0.79	4.43	3.99	1.37	1.08	2.76	3.51	
All minutes ridden 2012	0.00	0.00	119.66	126.66	70.24	92.71	0.00	0.00	
Complete street 2012	0.00	0.00	40.66	89.00	21.48	41.48	0.00	0.00	
All minutes ridden 2013	0.00	0.00	130.03	143.31	0.00	0.00	82.88	92.12	
Complete street 2013	0.00	0.00	43.59	63.36	0.00	0.00	33.55	52.15	
Proportion self-reported	0.86	0.35	0.93	0.26	0.58	0.50	0.65	0.48	
	Never (n=385)		Continued (n=54)		Former (n=47)		New (n=50)		
			Self-reported bike use						
Sociodemographic controlvariables									
Household income	41.26	31.76	50.31	33.82	37.13	30.75	38.62	30.17	
Age	42.88	15.50	40.89	11.15	34.98	10.76	40.02	14.00	**
Female	0.55	0.50	0.26	0.44	0.51	0.51	0.44	0.50	***
Car available 2012	0.88	0.32	0.78	0.42	0.89	0.31	0.90	0.30	

	Never (n=434)		**Continuing (n=29)**		**Former (n= 33)**		**New (n= 40)**		
	M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	***p* =**
Car available 2013	0.90	0.30	0.87	0.34	0.98	0.15	0.88	0.33	
Hispanic	0.23	0.42	0.20	0.41	0.26	0.44	0.39	0.49	
Weight and activity variables									
BMI 2012	29.32	7.24	27.50	6.17	27.31	6.36	29.64	6.19	
BMI 2013	29.55	7.28	27.94	6.32	27.73	6.37	29.66	5.79	
Kcal / min 2012	1.04	0.94	2.59	2.71	1.39	1.27	1.28	0.92	
Kcal / min 2013	1.15	0.82	3.01	3.35	0.96	0.60	2.44	3.23	

Note: Control variable differences tested by one way ANOVA.

[*] p<.05,

[**] p<.01,

[***] p<.001

Table 2

Bicycle rider groups and kilocalorie per minute energy expenditure: Linear mixed model analyses

	Model 1: Cycling group					**Model 2: Duration of cycling trip within new lane corridor**				
	B	**SE**	**95% CI**		***p* =**	**B**	**SE**	**95% CI**		***p* =**
GPS-measured cycling			Lower	Upper				Lower	Upper	
Continuing cyclists	2.67	0.23	2.23	3.11	***	1.40	0.20	1.01	1.78	***
Former cyclists	0.73	0.21	0.31	1.15	***	0.40	0.17	0.06	0.74	*
New cyclists	0.91	0.19	0.53	1.29	***	0.38	0.16	0.07	0.70	*
Minutes cycling trip, complete street corridor						0.03	0.00	0.03	0.03	***
Self-reported cycling										
Continuing cyclists	1.52	0.18	1.16	1.87	***	0.70	0.15	0.41	0.99	***
Former cyclists	0.15	0.19	-0.23	0.53		-0.01	0.15	-0.31	0.28	
New cyclists	0.81	0.19	0.44	1.17	***	0.48	0.15	0.19	0.77	**
Minutes cycling trip, complete street corridor						0.03	0.00	0.03	0.04	***

Note: Analyses controlled for gender, age, ethnicity, income and automobile ownership.
All comparisons were to never cyclists.

[*] = p<0.05,

[**] = p< 0.01,

[***] = p < 0.001