HHS Public Access
Author manuscript
Accid Anal Prev. Author manuscript; available in PMC 2022 January 25.

Published in final edited form as:
Accid Anal Prev. 2017 May ; 102: 1–11. doi:10.1016/j.aap.2017.02.017.

Examination of adult and child bicyclist safety-relevant events using naturalistic bicycling methodology

Cara J. Hamann[a], **Corinne Peek-Asa**[b]

[a]Injury Prevention Research Center, University of Iowa College of Public Health, 200 Newton Rd, 2186 WL, Iowa City, IA, USA

[b]Injury Prevention Research Center, University of Iowa College of Public Health, 145 N Riverside Dr, S160 CPHB, Iowa City, IA, USA

Abstract

Among roadway users, bicyclists are considered vulnerable due to their high risk for injury when involved in a crash. Little is known about the circumstances leading to near crashes, crashes, and related injuries or how these vary by age and gender. The purpose of this study was to examine the rates and characteristics of safety-relevant events (crashes, near crashes, errors, and traffic violations) among adult and child bicyclists. Bicyclist trips were captured using Pedal Portal, a data acquisition and coding system which includes a GPS-enabled video camera and graphical user interface. A total of 179 safety-relevant events were manually coded from trip videos. Overall, child errors and traffic violations occurred at a rate of 1.9 per 100 minutes of riding, compared to 6.3 for adults. However, children rode on the sidewalk 56.4% of the time, compared with 12.7% for adults. For both adults and children, the highest safety-relevant event rates occurred on paved roadways with no bicycle facilities present (Adults = 8.6 and Children = 7.2, per 100 minutes of riding). Our study, the first naturalistic study to compare safety-relevant events among adults and children, indicates large variation in riding behavior and exposure between child and adult bicyclists. The majority of identified events were traffic violations and we were not able to code all risk-relevant data (e.g., subtle avoidance behaviors, failure to check for traffic, probability of collision). Future naturalistic cycling studies would benefit from enhanced instrumentation (e.g., additional camera views) and coding protocols able to fill these gaps.

Keywords

naturalistic bicycling; safety; children; safety-critical events

1. Introduction

There has been an increase in bicycling in the United States in recent years, for all ages and for multiple purposes (e.g. recreational and utilitarian) [1]. However, riding a bicycle comes with inherent risks, including those related to exposure to motor vehicle traffic, and injuries can be severe due to the low protection of the cyclist's body to impact. These increases in

Corresponding Author Injury Prevention Research Center, University of Iowa College of Public Health, 200 Newton Rd, 2186 WL, Iowa City, IA, USA, cara-hamann@uiowa.edu.

Author Manuscript
Author Manuscript
Author Manuscript
Author Manuscript

Author Manuscript
Author Manuscript
Author Manuscript
Author Manuscript

bicycle riding and the burden of bicycle-related injuries have been recognized by the US Department of Transportation and the Secretary of Transportation, Anthony Foxx, who in 2014 released an action plan for addressing bicyclist and pedestrian safety [2]. This plan identifies bicyclists and pedestrians as elements of the larger transport system and prioritizes their safety [2]. This action plan calls for improved data describing risks for bicycling.[2].

Identifying common environmental and behavioral risks among bicyclists during rides is useful for informing injury prevention approaches and identifying the needs for education and infrastructure improvements. This is especially true among children once they reach an age when they are riding independently, and therefore no longer receiving feedback from an accompanying adult. In order to fill this knowledge gap, we developed Pedal PORTAL (Portable Video and Data System for Assessing Rider Locomotion), which is a system to naturalistically capture and code bicycling exposure data using a GPS-enabled helmet camera and graphical user interface.

There is a growing body of literature related to bicycling and bicycle crashes, which has identified some key risk factors and characteristics. For example, it has been established that bicycling is generally beneficial to health, bicyclist safety is related to bicyclist density on the roadway (safety in numbers effect), crashes are underreported and are more prevalent in urban areas, yet rural crashes are typically more severe [3]. However, to date, bicycling risk factors have primarily been determined through use of limited data from police crash reports, self-reports, or hospital data. Police crash reports typically include only crashes involving motor vehicles occurring on roadways; self-reported surveys or interviews suffer from recall bias and often do not have sufficient samples to describe crashes; hospital data include only the more severe cases and sometimes misclassify bicyclists as motor vehicle occupants or unknown injured party in a motor vehicle collision[4].There are also an unquantifiable number of bicycle crashes and injuries that are never reported. These limitations yield a body of research with an incomplete picture of the cycling experience, and in particular with little information about the incidence and circumstances associated with behaviors that could lead to crashes. Existing data also fail to capture bicycling riding exposure.

Naturalistic research, which has been used frequently in driving studies [9-11], offers an approach to study bicycle riding behaviors and exposure. Naturalistic methodology, which collects information about exposure and behavior, has been used to identify the frequency and types of unsafe driving that lead to crashes and near crashes. These type of data are important, given that driver error has been found to be a contributor in over 90% of all vehicle crashes [5]. These provide the often missing information from the bottom of the Heinrich Triangle and Injury Pyramid (adapted from Heinrich Triangle), which include unsafe behaviors, near crashes, and injuries treated outside the health care system or not reported (Figure 1). At the top of these models are well documented fatalities and severe injuries, which are captured in various datasets, including vital statistics (death reports), crash reports, and hospital records. The bottom of the models consist of much larger numbers than the top and include minor injuries that do not receive care from a healthcare institution and near crashes as well as risky or unsafe behaviors and are not included in traditional datasets[6,7], but can be captured from naturalistic data.

Author Manuscript
Author Manuscript
Author Manuscript
Author Manuscript

Naturalistic bicycling studies, collecting both GPS and video data, are very new and have largely been adapted from naturalistic driving methods. The majority of these naturalistic bicycling studies have been done in Western Europe and Australia thus far [8-18]. No naturalistic studies using both GPS and video have yet been conducted in the United States, and because bicycling cultures vary by country, more is needed to understand safety risks in the United States and how they align or differ from other countries [19,20]. Furthermore, no studies have naturalistically examined bicycle riding of children.

Among the published Australian and European studies, the main measurements have focused on general trip characteristics, crashes and near crashes[8,11,13,15], conflict partners[13], infrastructure[13,16], e-bicycle trip characteristics[9,17], or study of specific commuting routes[10]. In the Australian studies[11,14], a helmet-mounted camera was used and they were able to code cyclist head checks left and right, cyclist steering and braking reaction, and incidents involving crash avoidance[11]. Several of the existing naturalistic cycling studies have also cited use of a coding schemes adapted from naturalistic driving methodologies [21,22].

Naturalistic cycling instrumentation has been quite varied from study to study, ranging from simple ‘off-the-shelf’ GPS-enabled action cameras[11,16] to multi-camera systems with additional sensors for speed or braking[9,18], one requiring participants to use specially equipped study bicycles, rather than their own [18]. The majority of studies also required participants to complete written trip diaries to complement the video and GPS data collected.

Key issues and limitations from previous naturalistic studies have included GPS inaccuracies[9] or signal difficulties[15], technical difficulties with chosen instrumentation (e.g., participant error related to starting/stopping the system[9,13,15], limited battery life[13], poor video quality in dim lighting[11], etc.), and general challenges related to processing and coding the large volume of data that are produced. There are also no established definitions among naturalistic cycling studies in terms of definitions and coding protocols.

The purpose of this study was to better understand the circumstances and behaviors surrounding safety-relevant events (SREs; i.e., crashes, near crashes, errors involving evasive action, and traffic violations) among both adult and child bicyclists in the United States and how they compare or contrast to previous naturalistic cycling findings. A secondary aim of this study was to evaluate the strengths and limitations of our chosen instrumentation (GPS-enabled helmet camera) and data collection and coding framework, which were adapted from previous naturalistic cycling studies and general observational study practices.

2. Materials and Methods

2.1 Participants: eligibility, recruitment, and enrollment

Twenty bicyclists were recruited via word-of-mouth and flyers hung at popular bicycling destinations in Johnson, County, Iowa. The cycling community is strong in numbers and enthusiasm in Johnson County, compared to the majority of the state. Johnson County

Author Manuscript

contains three of only eight League of American Bicyclist Bicycle Friendly Communities in the state, and includes the highest ranking among those, Iowa City, which is at the Silver level[23]. The University of Iowa also holds a Silver level Bicycle Friendly University status, the only bicycle friendly university in the state. These rankings are determined by a set of key outcomes (ridership, crashes, and fatalities) and indicators in the following categories: enforcement, education, engineering, evaluation, and encouragement.

For all participants, study inclusion criteria included residence within Johnson County, fluency in spoken and written English, and average bicycling of at least four days per week at time of enrollment. The inclusion criteria for average riding at least four days per week was chosen to maximize the number of trips captured within this small pilot study sample. An equal distribution of children and adults and male and female were enrolled, balanced by enrolling the first 10 males and 10 females who indicated interest in the study. Adult participants were those aged 18 or older. For children, recruitment targeted ages 10 to 14, the ages most likely when children are riding independently from their parents, but before they begin driving. Final enrollment only included 11- to 13-year-olds. The number of participants enrolled was capped to 20 due to time and budget restraints.

Participants completed baseline demographic and riding experience surveys during enrollment. A GPS-enabled camera was mounted on each bicyclist's helmet (Figure 2) and they were asked to ride 'as usual' and record all of their trips for consecutive seven days. Participants were trained on the use and care of the camera during enrollment and practiced riding with the camera, which provided the opportunity for familiarization with the system and verification that the camera angle was appropriately adjusted to capture the cyclist's field of view.

The system collected the GPS trace, forward-facing video, and audio for each trip. These data were used as inputs for the graphical user interface and GIS during the data reduction and coding process (Figure 3). A total of $150 USD compensation was provided to each participant.

2.2 Data collection

Participants recorded all of their bicycling trips (each origin to destination was considered a trip) for one week and were specifically instructed to not bike more or less or change how they typically ride during the study data collection. Each participant was also asked to keep a trip diary to record trip details (date, time of day, weather, type of bicycle ridden) and indication of any safety-relevant events. A safety-relevant event was defined as an incident involving one or more of the following characteristics: crash, near crash, cyclist, pedestrian, or motorist errors, or traffic violations.

Crashes and near crashes were documented by participants in their respective trip diaries and/or were identified by data coders during manual review of each trip video. Participants also indicated any dangerous circumstances, anything that occurred during a bicyclist trip that made the participant feel unsafe (e.g., car passing too closely to bicyclist). These were then categorized, if appropriate, into one of the safety-relevant event categories (crash, near crash, error, traffic violation). Crashes were defined as a collision with the ground, person, or

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

object. A near crash was an event in which a bicyclist or other road user (pedestrian or motor vehicle) were required to take evasive action (e.g., jump out of the way, swerve) to avoid a collision. Bicyclist errors included reckless riding toward a pedestrian or another bicyclist and riding against traffic. Bicyclist traffic violations included incomplete stop (yielded when should have stopped) and complete failure to stop or yield.

The safety-relevant events we coded did not include all potentially unsafe behaviors, leaving out those that we were unable to code consistently and objectively, such as instances of failure-to-yield or failure-to-stop when it was not clear there was a legal obligation for the rider to do so (e.g., uncontrolled intersections or riding on the sidewalk) and failure to check for traffic at an intersection. Therefore, we chose to remain more conservative and code traffic violations (failure to stop or yield, incomplete stop) and risk-related errors (wrong way riding or recklessness toward another pedestrian or bicyclist, requiring evasive action), things which could be coded clearly and objectively. For the traffic violations, we specifically focused on those that were clear and generalizable to other jurisdictions—failure to stop or yield and incomplete stop.

Motorist errors that could be clearly seen as directly impacting the bicyclist (e.g., cutting in front of a bicyclist when making a turn and bicyclist braking or swerving to avoid collision) were also coded. Overall, our data collection and coding protocol was designed to capture bicyclist behaviors and, therefore, did not capture details of motor vehicle behavior. Ultimately, our coding scheme for safety-relevant events captured a set, but not all potentially unsafe behaviors. However, it represents events that could be coded consistently and objectively for all riders.

Our use of the term safety-relevant events varies from that of existing naturalistic bicycling studies, which have typically used the term safety-critical events. Although our term differs, the definition of safety-critical events also varies among naturalistic cycling studies. For example, Dozza and Werneke (2014) defined safety-critical events as “a point in time when the cyclist experienced a situation which made him/her feel uncomfortable”. Conversely, the Schleinitz, Petzoldt, Franke-Bartholdt, Krems, & Gehlert (2015) definition of safety-critical events focused on interactions with other road users, consistent with the definition of a conflict: “…one of the parties has to change speed or direction to avoid a collision”[24]. This latter definition is akin to definitions commonly used in naturalistic driving studies, which primarily identify events using kinematic triggers [e.g.,25,26,27]. The instrumentation for the current study did not have kinematic trigger capability, therefore we relied on participant self-reports combined with events that we could identify from video review, which relied heavily on visible errors and traffic violations.

We chose a more inclusive term and definition, safety-relevant events, to include errors and traffic violations, as they are valid measures of risk. Errors and traffic violations also fit into “unsafe acts” at the bottom of the Heinrich Triangle, which is an important part of understanding bicycling risk. We examined safety-relevant events separately by age (adult vs. children) and type of roadway infrastructure on which they were riding.

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

2.3 Data reduction

Each recorded trip (video and GPS data) and trip diary was manually reviewed. Safety-relevant events that were noted in trip diaries were searched for in the corresponding trip videos for further coding. SREs were also found through the video manual review and the graphical user interface was designed to mark location and type of events in a database. Events were visually identified by trained raters.

Once the safety-relevant events were identified, they were validated by a second rater. A second set of raters observed and coded the details of the SREs. In the event of discrepancies between raters, videos were reviewed by a third rater or reviewed by both raters simultaneously until they reached a consensus. For both the identification of SREs and the detailed coding, raters coded the participant videos in random order to reduce any bias that may have been introduced by getting to know a particular rider's riding style or risk tendencies. They were also blind to the rider characteristics (age, gender, etc.), unless it was apparent from the video footage they were coding. For all raters, inter-rater reliability was assessed, and re-training on how identify and code desired events and variables was conducted where necessary to attain at least 95% reliability.

Event time points were visually coded for the following: roadway infrastructure (no bicycle facility, on-street painted bicycle facility—bicycle lane or shared lane marking, sidewalk or side path, off-street bicycle facility--bicycle path, gravel road, other) and configuration (4-way, T, non-intersection, other), visual obstructions (Yes or No), traffic controls (stop sign, traffic light, unregulated, other), land use (education, agriculture, residential, recreation, commercial, other), bicyclist lane position (left, right, center, sidewalk/side path), parking (same and opposite side as bicyclist, same side as bicyclist, opposite side of bicyclist, none), and bicyclist, pedestrian, and motorist actions relative to each other. Driveway frequency and traffic volumes (bicycle, pedestrian, and motor vehicle) were also coded for the 15 second window leading up to the time of event.

Miles and minutes were accrued from the GPS data and corresponding time stamps. These total minutes and miles and totals for subgroups were imported and generated using SAS, Version 9.4.

2.4 Data analysis

Frequencies and rates (per 100 miles and per 100 minutes) of crashes, near crashes, errors, and traffic violations were tabulated and stratified by age (adult or child) and gender. Frequencies and proportions of safety-relevant events were tabulated by environmental (e.g., visual obstructions, on-street parked vehicles), trip (e.g., time of day, trip purpose), and behavioral characteristics (e.g., bicyclist lane positioning) and stratified by age (children, ages 11-13 vs adults, aged 18 or older).

Rates of safety-relevant events were calculated for each infrastructure type and trip purpose overall, then stratified for children and adults. To account for exposure, rates per 100 minutes of bicycling were calculated, which allowed for better comparison between adults and children, since adults rode many more miles. Calculation by minutes instead of miles also gave a better indicator of exposure, as it takes into account variations in speed between

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

riders. However, rates per 100 miles were included in Table 2, for comparison purposes to other naturalistic bicycling studies, which have included distance-based rates (e.g., [13]).

Means and standard deviations for traffic volumes (motor vehicles, bicycles, and pedestrians) and number of driveways encountered were tabulated for the 15 seconds leading up to each event. Statistical testing of the variation in event frequencies and rates was not conducted due to small cell sizes for many of the variables, therefore we used a descriptive analytic approach.

3. Results

3.1 Safety-relevant events: Crashes, near crashes, errors, and traffic violations

A total of 185 independent safety-relevant events were recorded, from 261 adult and child (ages 11 – 13) bicycling trips, which included 2 crashes, 10 near crashes, and 178 errors or traffic violations (Tables 1 & 2). Five of the 185 SREs included more than one category (crashes, near crashes, errors, or traffic violations), such as a motorist error and near crash occurring together. Within those 185 events, 3 occurred in conditions too dark to code the video, and we could not locate three events identified through the rider trip diaries in the video/GPS data. Thus, six (3.2%) events were excluded (Figure 4). Tables 3 through 6 include data from the 179 independent events that could be coded in detail.

The number of SREs per participant ranged from 0 to 6 among children and 4 to 38 among adults, during their respective one week recording periods. These event counts did not universally correlate with participant mileage. In other words, participants who rode more did not necessarily have more SREs. For example, the child with the most SREs (n=6) only rode 5.1 miles during the week, which means they had a rate of 117.7 per 100 miles. Comparatively, the child with the most miles for the week (31.9) only had 2 SREs, for a rate of 6.3 per 100 miles.

Figures 5 and 6 show the geographic boundary of the child and adult trips and the geographic distributions of the safety-relevant events. From these figures it is easy to see that adults rode more varied and longer routes throughout the county. The figures also show that for both children and adults, SREs occurred more frequently in the more urban parts of the county, specifically in the cities of Iowa City, Coralville, and North Liberty.

Of the 20 participants, 100% of adults and 70% of children had at least one safety-relevant event during their week of coded rides. Among children, the number of SREs per person ranged from zero to six and 60% had three or less. Adults had far more SREs per person, with 50% having 13 or more SREs each and only one (10%) had three or less.

Two crashes were observed; one adult and one child, which were both due to bicyclist handling errors and did not involve motor vehicles (Table 2). Ten near crashes were captured, three among children and seven among adults. Although adults had a higher total of crashes and near-crashes, the rate per mile of both crashes and near crashes was lower among adults, given their higher volume of miles ridden.

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Errors or traffic violations were the most common safety-relevant event types for both children and adults. Incomplete stops (yielding when they should have stopped) were the most common traffic violation type for all ages and both genders. The rate of incomplete stops per 100 miles was higher for female than male children (10.3 for girls and 7.2 for boys) and for female than male adults (38.2 for females and 11.5 for males). Two motorist errors were identified during adult participant trips and both were instances of the motorist 'cutting off' the bicyclist. We did not code motorist errors that did not directly impact the bicyclist (e.g. if a car ran a stop sign as a bicyclist was approaching an intersection and there was no impact on the bicyclist).

3.2 Safety-relevant events: Trip and environmental characteristics

Among the 179 events that could be coded in detail (Table 3), the majority (79.9%) occurred on paved streets with no bicycle facilities, followed by sidewalk or side path (8.4%), bicycle/ multi-use path (8.4%), and paved street with on-street painted bicycle facility (1.7%; bicycle lane, shared lane marking). The majority of events occurred at intersections for both children (77.7%) and adults (84.5%), but for children these were more frequently T-intersections (44.4%) while for adults they occurred more often at 4-way intersections (53.4%). However, it should be noted that the inclusion of traffic violations in our SRE coding framework favored intersections, given that incomplete stops and failure to stop or yield only apply to intersection locations and there is high exposure to intersections during riding. Therefore, results should be interpreted with this information mind.

The vast majority of adult events occurred near stop sign locations (88.8%), while for children most events occurred near a stop sign (66.7%) or unregulated (no traffic controls) locations (27.8%). The majority of SCEs did not involve visual obstructions (90.5%). For both adults and children, over one third of their SCEs occurred on recreational or social trips (Adults: 31.7%; Children: 38.9%).

For both children and adults, residential areas, locations with no on-street parked vehicles, and commuting trips were the most prominent characteristics of SREs. For children, no SREs were recorded for errand (non-commute utilitarian) trips compared to 13.7% of adult safety-critical events.

Mornings, 08:00-10:59 a.m. were the most common time period for safety-relevant events for both children (41.2%) and adults (30.4%). Time of day for adult events were spread out more than children, including nearly 10% of their events occurring in late night and early morning hours between 23:00 and 07:59.

3.3 Safety-relevant events: Behavioral characteristics

Nearly three quarters of all participant safety-relevant events occurred while riding on the right hand side of the lane (Table 4). Children had a higher proportion of events occur on sidewalks or non-road locations (33.3%), compared to adults (7.5%), but they also rode on sidewalks more frequently.

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Distributions of bicyclist actions during safety-relevant events were similar between children and adults, with most occurring when the bicyclist was traveling forward, with traffic (45.8%), followed by turning right (31.3%), and turning left (21.8%).

No motor vehicles were present in the 15 seconds leading up to any of the child safety-relevant events, compared to 15.1% (N = 27) of adult events. Ten adult SREs involved interaction with motor vehicles in the 15 seconds leading up to the event. However, only two (1.2%) of adult SREs involved motorist errors that required the bicyclist to take evasive action (Table 2).

Safety-relevant events by exposure: Rates per 100 minutes of bicycling

Among adults, paved streets with no bicycle facilities were the most problematic, while the lowest rates were on paved streets with on-street bicycle facilities (8.6 versus 1.7 per 100 minutes), suggesting bicycle facilities are protective against safety-relevant events (Table 5). Among children paved streets were also the most problematic, followed by sidewalk/sidepaths (7.2 versus 1.9 per 100 minutes). No child events occurred while they were riding in on-street bicycle facilities. However, they only used on-street bicycle facilities an average of 1.3% of the time during trips, compared to adults who used on-street bicycle facilities and average of 10.6% of each trip time.

Rates were also calculated by trip purpose (Table 5). For both children and adults, the highest rates were found on commute trips, although adult rates (8.7 per 100 minutes) were much higher than children (2.4 per 100 minutes), likely due to child preference for riding on the sidewalk, where they were largely immune to making traffic violations. Adult safety-relevant event rates were lowest on recreation/social trips (4.1 per 100 minutes). Children had no events on non-commute utilitarian trips and slightly lower rates on recreation/social trips compared to commutes (2.2 vs 2.4 per 100 minutes).

3.4 Safety-relevant events: Traffic volumes and frequency of driveways

Because safety-relevant events could be associated with increased traffic volume (increased number of threats), we approximated traffic and driveway density surrounding the safety-relevant events by counting driveways, bicycles, pedestrians, and motor vehicles present in the 15 seconds leading up to each event. We stratified categories of traffic and driveway density by trip purpose.

Traffic volumes and driveway frequencies did not vary considerably across safety-relevant event trip purposes for adults, with one exception (Table 6). Adult SREs occurring on errand trips had higher motor vehicle volumes in the in the 15 seconds leading up to the event (1.6) compared to commute (0.6) and recreation/social SCEs (0.7). For all trip purposes, adult SREs occurred in situations with low bicycle and pedestrian traffic volumes.

Conversely, for children, these values were not consistent across trip purpose. For example, child SREs had a higher average driveway exposure and pedestrian volumes when they occurred on commuting trips (to/from school), compared to recreation/social trips (Mean Driveways: 1.5 vs. 0.3; Mean Pedestrians: 0.8 vs. 0) which had lower average motor vehicle (Recreation: 0.1 vs. Commute: 1.3) and bicycle counts (Recreation: 0.4 vs. Commute: 1.9).

Author Manuscript
Author Manuscript
Author Manuscript
Author Manuscript

Compared to adults, children had higher average driveway, bicycle, and pedestrian counts for safety-relevant events that occurred on commute trips, and higher bicycle and motor vehicle counts than adults for safety-relevant events occurring on recreation/social trips.

4. Discussion

This paper is the first to describe safety-relevant events captured naturalistically from adult and child bicyclists in the United States. From 261 trips and 57 hours of bicycling, 179 independent safety-relevant events were coded. These data provide a first glimpse into risk exposure and bicycling behavior beyond what is reported in crash and hospital data or self-reported surveys in the United States. These additional data, which include unsafe behaviors, are important and valid risk measures that help to clarify our understanding of bicycling risk exposure. The naturalistic methodology used in this study, in terms of the data acquisition, was successful and the viability of the system was high—only 2.7% of safety-relevant events were removed due to incomplete or missing data.

However, not all safety-relevant events were captured within our minimalist instrumentation and limited data coding framework. For example, we were not able to reliably code failure to look for traffic, darting, or subtle avoidance behaviors. Our coding protocol focused on traffic violations and events requiring obvious evasive action, which we could easily observe and objectively code from the data captured.

We were not able to compare our findings to other North American data, because there are not any published naturalistic bicycling studies in North America, to date. There have also been no other naturalistic bicycling studies published with children as participants. Therefore, the following discussion focuses on comparison to the available adult naturalistic data and methods, which are from European and Australian studies.

Only 15.1% of all the SREs identified in our data (adults and children) had motor vehicles present in the video of the 15 seconds leading up to the event. This demonstrates the unique nature of the data, which focused on capturing bicycling behavior. This differs dramatically from existing data sets (e.g., hospital data, police reports, crash data), which tend to capture only the most serious crashes and injuries. For example, inpatient hospitalization records report approximately one-third of bicycle-related hospitalizations are motor vehicle related [28]. It is likely that the extent of motor vehicle involvement in the SCEs in our study were undercounted because the data collection system was not designed to capture details of the motor vehicles (e.g., braking, steering) and were limited to only the most clearly visible motor vehicle errors that involved bicyclist evasive action (e.g., cutting in front of a bicyclist, requiring bicyclist to brake). In particular, behavior of vehicles driving in the same direction as the bicyclist were not well captured (e.g., passing too close or ‘buzzing’ the bicyclist).

We found rates of safety-relevant events varied by infrastructure type. Paved streets without bicycle facilities were the most problematic for both children and adults. These rates were much higher and opposite than what was found in a German study, which found higher safety-critical event rates occurring at locations with bicycle infrastructure (2.06 per 100km compared to regular roads, no bike facility (0.89 per 100km)[13]. In our study, both child

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

and adult results indicated that safety-relevant events were least likely to occur in on-street bicycle facilities compared to other infrastructure types. Our findings are consistent with the general literature regarding safety of on-road bicycle facilities, which have suggested they are protective in against crashes [24,29-31].

We also found variation in safety-relevant event characteristics (driveway frequency and bicycle and pedestrian counts) among children by trip purpose, but not adults. These results suggest that children have less experience with the roadway environment in terms of route selection and comfort navigating traffic, given the variability in the traffic volumes and driveway frequency by trip purpose. Adult consistency in these variables may, conversely, demonstrate their experience in choosing low traffic routes and/or increased knowledge and comfort in interacting with motor vehicles and other road users, given that their SREs occurred in low traffic volume areas, overall. A total of 4.2% of our 261 recorded trips had a crash or near crash. This was very similar to the German study which found 4.6% of trips had SCEs [13]. Their definition of safety-critical event included only conflicts between the bicyclist and another road user that required one to change speed or direction to avoid a collision, in other words, crashes and near crashes.

An Australian study used a similar definition of safety-relevant event as the German study[13], by including crashes, near crashes, and incidents that involved collision avoidance[11]. We found a higher rate of crashes and near crashes to that study (0.19 vs. 0.06 per hour). Their data were drawn from nearly 128 hours of bicycling—number of individual trips were not provided. From these data, they found 2 collisions, 6 near-collisions, 46 incidents.

More than 80% of all the SREs we captured occurred at intersections. This finding is consistent with a study conducted in Sweden, where they found bicycling through intersections increased risk of safety-critical event occurrence (OR: 4.4, 95% CI 2.3-8.6) compared to non-intersection locations[18]. Their study included 114hrs of data and 63 safety-critical events. Their safety-critical event definition included anytime the "cyclist experienced a situation which made him/her feel uncomfortable"[8]. This difference in definition makes it difficult to compare to our numbers or rates of SREs meaningfully.

Results from this and other naturalistic bicycling studies would benefit from consistency in definitions and coding, to allow for comparison across studies. The field of naturalistic driving has begun to embrace this concept of uniform coding and definitions by publishing techniques, such as that found in the Handbook of Traffic Psychology [22]. Much of the definitions and coding techniques utilized in naturalistic driving are applicable to naturalistic bicycling, but not all. Therefore, it would be useful for researchers in this field to come together to determine a common approach.

4.1 Limitations

The majority of safety-relevant events we identified occurred on paved streets with no bicycle facilities among both children and adults. However, our coding scheme for safety-relevant events in this study limited the comparison between children and adults, as we focused on events that could be objectively coded (crashes, near crashes, traffic violations,

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

and errors that lead to evasive action). We were not able to objectively code instances where legal obligation to stop or yield right-of-way was not clear (e.g., when riding on the sidewalk or through an uncontrolled intersection). This resulted in a discrepancy between children and adults in the number of safety-relevant events, with children having far fewer because they spent more time in areas where there was no legal obligation to stop or yield (i.e., on sidewalks or areas other than in the roadway). The coding scheme also resulted in a dominance of traffic violations, given the rarity of crashes, near crashes, and evasive action-related errors, compared to the high frequency of traffic violations (incomplete stops and failure to stop or yield) and high exposure to intersections during riding.

Our instrumentation also led to some limitations. We were not able to reliably code lapses, such as failure to check for traffic at an intersection. Although the cameras were helmet-mounted, cyclists were inconsistent in how much they turned their head when checking for traffic and this tended to vary by the visual openness or traffic volume of an intersection. Therefore, we could not be certain that they really failed to look, versus instance where visually scanning an open intersection required minimal head movement. The camera's wide angle (270 degrees) was also a factor, as it made head movements less obvious.

Future naturalistic bicycling studies would benefit from developing more sophisticated instrumentation with objective kinematic triggers or additional camera views (especially a camera view of the rider's head and upper body).

Additional instrumentation would allow for an enhanced video coding scheme that could better capture the subtle negotiated behaviors between bicyclists and other road users (motorists, pedestrians, other cyclists), bicyclist avoiding behaviors (e.g., braking), and bicycling failure to check for traffic at an intersection. Johnson et al. (2013) [32] were able to code some of these useful measures of avoidance behavior in cyclist-car door events from their naturalistic cycling data, including cyclist reaction (veered wide, stopped) and cyclist head checks.

Additional camera views would also allow for measurement of time-to-collision (TTC) or post-encroachment time (PET), measures of probability of a collision. The Dutch Objective Conflict Technique for Operation and Research (DOCTOR) method[33] might be a useful framework for coding cycling conflicts from naturalistic data. This method has been successfully used for site-based observational studies of conflicts on bicycle paths to examine probability of collision and severity[34]. It would also be beneficial to develop objective coding protocols to capture additional unsafe behaviors that relate to risk, but which do not require evasive action, such as dart outs into the roadway, unintentional swerving, or riding up the right side of cars in the same lane.

The generalizability of results is limited, given that this is a small sample of participants (n=20), in a limited geographical area, and all participants were frequent bicyclists (typically ride at least four times per week). This small sample size also limited us to a descriptive analysis, without statistical testing. The high individual variation in event rates from our sample does suggest, however, that future studies should adjust for clustering at the person level. Nevertheless, these data and protocol for collection and coding provide unique

Author Manuscript

information, not captured in previous studies, and a basis for future naturalistic bicycling data collection and use. Collecting further data and combining these data with that from other geographic areas within North America would be beneficial for betting understanding cycling safety and developing appropriate countermeasures.

5. Conclusions

This study provides the first naturalistic bicycling data comparing children and adults in the United States. Results reveal interesting differences between children and adults in terms of safety-relevant events and warrant expanded exploration, particularly among the understudied child population. Children had more handling-related errors, while adults had more traffic violations. On-street bicycling facilities had low rates of safety-relevant events, supporting their use as effective countermeasures. Intersections were problematic for both children and adults, indicating an area of high potential for impact and need of countermeasures.

Overall, results from this study support the future expansion of naturalistic bicycling research in the United States and worldwide, given the unique and useful risk exposure and risky behavior data it provides, which are not readily available in existing datasets. As the field continues to grow, larger datasets and refined instrumentation and coding definitions and protocols will allow for examination of trends, behavior, risk exposure, and how these vary by person, traffic environment, and geographic subgroups. This study, in particular, demonstrates the importance of looking at age differences in bicycling behavior and risk exposures. Naturalistic bicycling research has great potential for understanding behavior and use of infrastructure, developing interventions, and supporting policy change.

Acknowledgements

We would like to thank Zach Noonan, Rohith Mohan, and Morgan Price for initial graphical user interface and instrumentation development for this project. Additional thanks go to Zach for the development, refinement, and coding of the graphical user interface. We would also like to thank Daniel McGehee for initial project concept assistance, and Mark Pooley, Morgan Price, Clara Keum, and Omotoyosi Soniyi for data reduction and coding. Funding for this project was provided, in part, by grant #1R49CE002108-01 of the National Center for Injury Prevention and Control/CDC.

References

1. Alliance for Biking & Walking. Bicycling and Walking in the United States 2014 Benchmarking Report. 2014; http://www.bikewalkalliance.org/resources/benchmarking. Accessed August 13, 2014.
2. US DOT. Safer People, Safer Streets: Summary of U.S. Department of Transportation Action Plan to Increase Walking and Biking and Reduce Pedestrian and Bicyclist Fatalities. 2014. http://www.transportation.gov/office-policy/transportation-policy/secretary's-action-plan-bike-and-pedestrian-safety. Accessed September 14, 2015.
3. OECD/International Transport Forum. Cycling, Health and Safety. 2013: 10.1787/9789282105955-en.
4. Karkhaneh M, Hagel BE, Couperthwaite A, Saunders LD, Voaklander DC, Rowe BH. Emergency department coding of bicycle and pedestrian injuries during the transition from ICD-9 to ICD-10. Injury Prev. 2011.
5. NHTSA. Critical reasons for crashes investigated in the national motor vehicle crash causation survey. Washington, D.C.: NHTSA National Center for Statistics and Analysis; 2015.

Author Manuscript
Author Manuscript
Author Manuscript
Author Manuscript

6. Heinrich HW. Industrial accident prevention; a scientific approach. 3d ed. New York,: McGraw-Hill; 1950.
7. World Health Organization. Injuries and violence: the facts. Geneva2010.
8. Dozza M, Werneke J. Introducing naturalistic cycling data: What factors influence bicyclists' safety in the real world? Transportation Research Part F: Traffic Psychology and Behaviour. 2014;24:83–91.
9. Gehlert T, Kuhn M, Schleinitz K, Petzoldt T, Schwanitz S, Gerike R. The German pedelec naturalistic cycling study- Study design and first experiences. International Cycling Safety Conference; November 7-8, 2012, 2012; Helmond, The Netherlands.
10. Gustafsson L, Archer J. A naturalistic study of commuter cyclists in the greater Stockholm area. Accident Anal Prev. 2013;58:286–298.
11. Johnson M, Charlton J, Oxley J, Newstead S. Naturalistic cycling study: identifying risk factors for on-road commuter cyclists. Annals of advances in automotive medicine / Annual Scientific Conference … Association for the Advancement of Automotive Medicine. Association for the Advancement of Automotive Medicine. Scientific Conference. 2010;54:275–283.
12. Mohanty S, Lee A, Carvalho T, Dias L, Lovegrove G. A global review of current instrumented probe bicycle technology and research. Paper presented at: International Cycling Safety Conference; November 18-19, 2014; Gothenburg, Sweden.
13. Schleinitz K, Petzoldt T, Franke-Bartholdt L, Krems JF, Gehlert T. Conflict partners and infrastructure use in safety critical events in cycling – Results from a naturalistic cycling study. Transportation Research Part F: Traffic Psychology and Behaviour. 2015;31:99–111.
14. Johnson M, Chong D, Carroll J, Katz R, Oxley J, Charlton J. Naturalistic cycling study: Identifying risk factors for cyclists in the Australian Capital Territory. Canberra, ACT, Australia: Monash University Accident Research Centre;2015.
15. Dozza M, Werneke J, Fernandez A. Piloting the naturalistic methodology on bicycles. Paper presented at: International Cycling Safety Conference2012; Helmond, The Netherlands.
16. de Waard D, Westerhuis F, Morsink P. Towards a "forgiving" cycle path. Paper presented at: International Cycling Safety Conference2013; Helmond, The Netherlands.
17. Dozza M, Bianchi Piccinini GF, Werneke J. Using naturalistic data to assess e-cyclist behavior. Transportation Research Part F: Traffic Psychology and Behaviour. 2016;41, Part B:217–226.
18. Dozza M, Fernandez A. Understanding Bicycle Dynamics and Cyclist Behavior From Naturalistic Field Data (November 2012). IEEE Transactions on Intelligent Transportation Systems,. 2014;15(1):376–384.
19. Pucher J, Buehler R. Why Canadians cycle more than Americans: A comparative analysis of bicycling trends and policies. Transport Policy. 2006;13(3):265–279.
20. Pucher J, Dijkstra L. Making walking and cycling safer: Lessons from Europe. Transport Q. 2000;54(3):25–50.
21. Neale VL, Klauer SG, Knipling RR, Dingus TA, Holbrook GT, Petersen A. The 100 car naturalistic driving study, Phase 1-- Experimental Design. Blacksburg, Virginia: Virginia Tech Transportation Institute;2002.
22. Klauer SG, Perez M, McClafferty J. Naturalisitic driving studies and data coding and analysis techniques. In: Porter BE, ed. Handbook of Traffic Psychology. Amsterdam: Elsevier; 2011.
23. League of American Bicyclists. Bicycle Friendly America: Award Database. 2016; http://www.bikeleague.org/bfa/awards#state. Accessed January 21, 2016.
24. Reynolds CC, Harris MA, Teschke K, Cripton PA, Winters M. The impact of transportation infrastructure on bicycling injuries and crashes: a review of the literature. Environ Health. 2009;8(1):47. [PubMed: 19845962]
25. Bagdadi O. Assessing safety critical braking events in naturalistic driving studies. Transportation Research Part F: Traffic Psychology and Behaviour. 2013;16:117–126.
26. Fitch GM, Hanowski RJ, Guo F. The risk of a safety-critical event associated with mobile device use in specific driving contexts. Traffic Inj Prev. 2015;16(2):124–132. [PubMed: 24896192]
27. Dingus TA, Klauer SG, Neale VL, Lee SE, Sudweeks JD, Perez MA. The 100-Car Naturalistic Driving Study, Phase II - Results of the 100-Car Field Experiment. National Highway Traffic Safety Administration; US DOT; 2006.

28. Hamann C, Peek-Asa C, Lynch CF, Ramirez M, Torner J. Burden of hospitalizations for bicycling injuries by motor vehicle involvement: United States, 2002 to 2009. J Trauma Acute Care. 2013;75(5):870–876.

29. Hamann C, Peek-Asa C. On-road bicycle facilities and bicycle crashes in Iowa, 2007-2010. Accident; analysis and prevention. 2013.

30. Alta Planning. San Francisco's Shared Lane Pavement Markings: Improving Bicycle Safety. 2004; http://www.sfmta.com/cms/uploadedfiles/dpt/bike/Bike_Plan/Shared%20Lane%20Marking%20Full%20Report-052404.pdf. Accessed 8/15/2012, 2012.

31. Harris MA, Reynolds CCO, Winters M, et al. Comparing the effects of infrastructure on bicycling injury at intersections and non-intersections using a case-crossover design. Injury Prev. 2013;19(5):303–310.

32. Johnson M, Newstead S, Oxley J, Charlton J. Cyclists and open vehicle doors: Crash characteristics and risk factors. Safety Sci. 2013;59(0):135–140.

33. Grayson GBE. The Malmö Study: A calibration of traffic conflict techniques. A study organized by the International committee on traffic conflict techniques. Leidschendam: Institute of Road Safety Research SWOV;1984. R-084-12.

34. Van der Horst ARA, de Goede M, de Hair-Buijssen S, Methorst R. Traffic conflicts on bicycle paths: A systematic observation of behavior from video. Accident Analysis & Prevention. 2014;62:358–368. [PubMed: 23642307]

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Author Manuscript
Author Manuscript
Author Manuscript
Author Manuscript

Highlights

- First naturalistic bicycling study in North America with children and adults
- Most safety-relevant events occurred on roads without bicycle facilities present
- There were large variations in adult and child bicycling behaviors and exposure
- Additional risk-relevant data could be captured with enhanced instrumentation
- Naturalistic cycling studies would benefit from standard coding and definitions

Author Manuscript
Author Manuscript
Author Manuscript
Author Manuscript

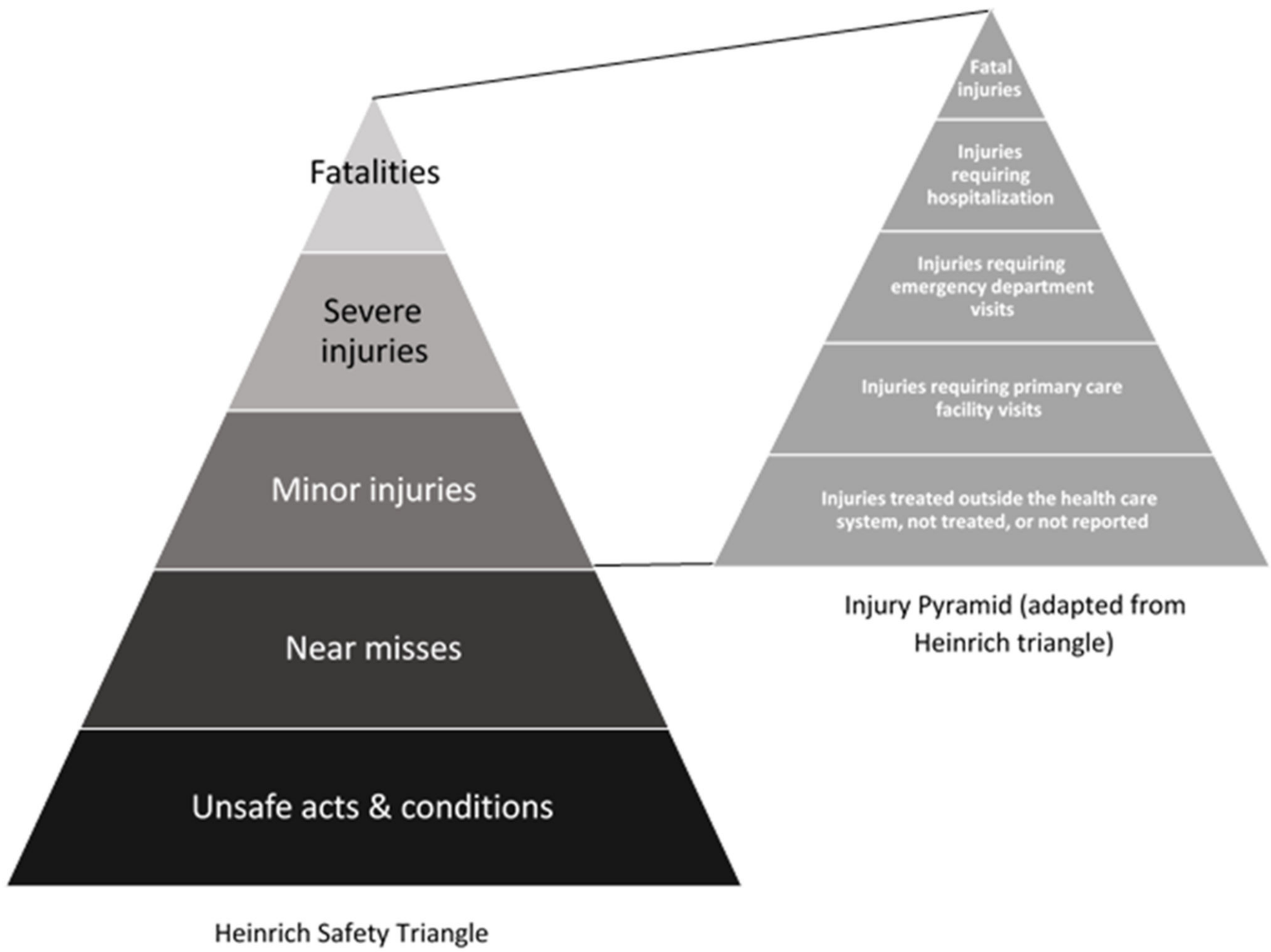

Figure 1.
Heinrich Triangle and Injury Pyramid

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Figure 2.
GPS-enabled camera mounted on helmet for data collection

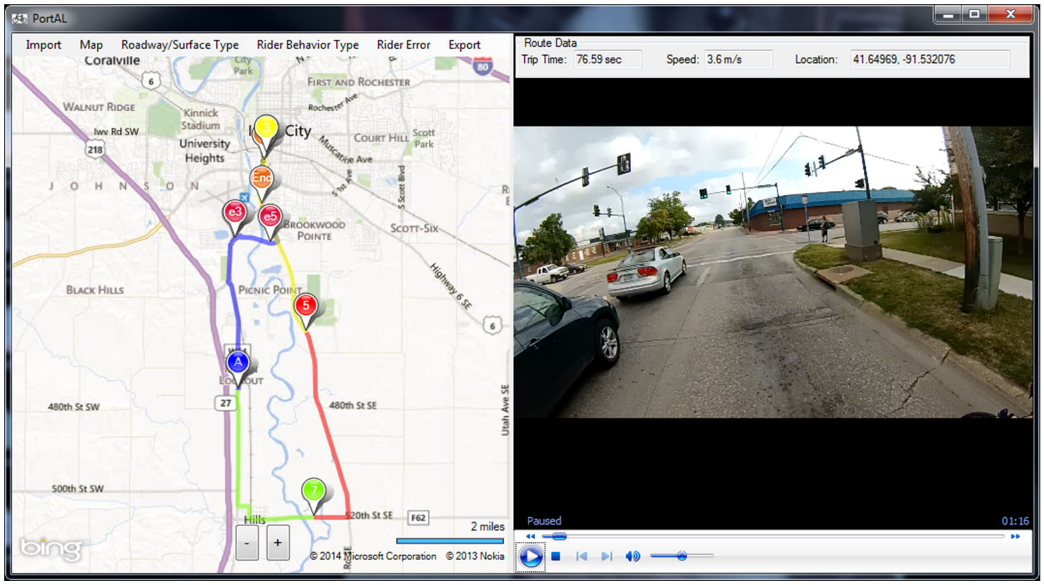

Figure 3.

Graphical user interface used for data coding with example trip and typical camera view

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Author Manuscript
Author Manuscript
Author Manuscript
Author Manuscript

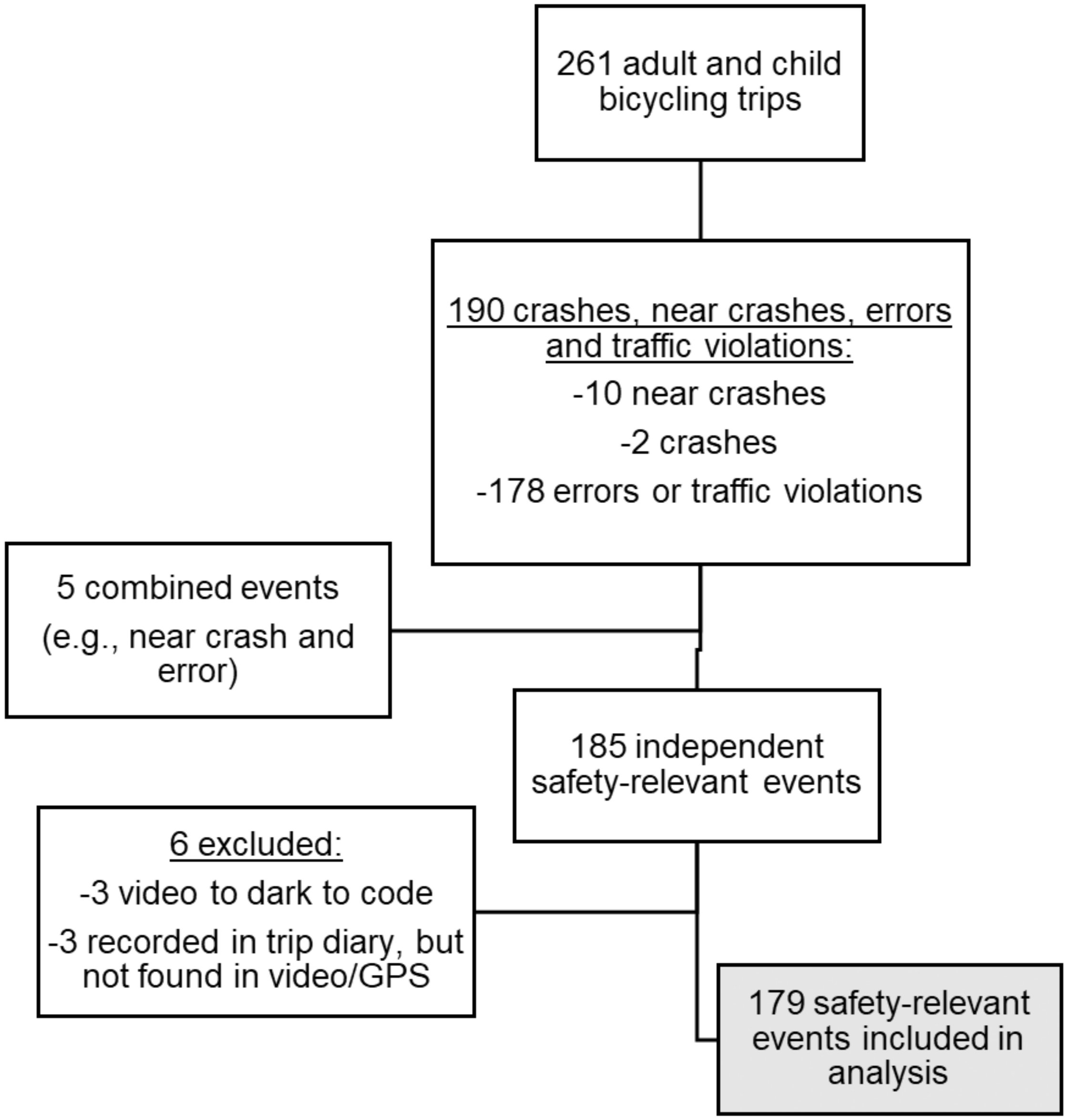

Figure 4.
Flow chart of safety-relevant events included in analysis

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

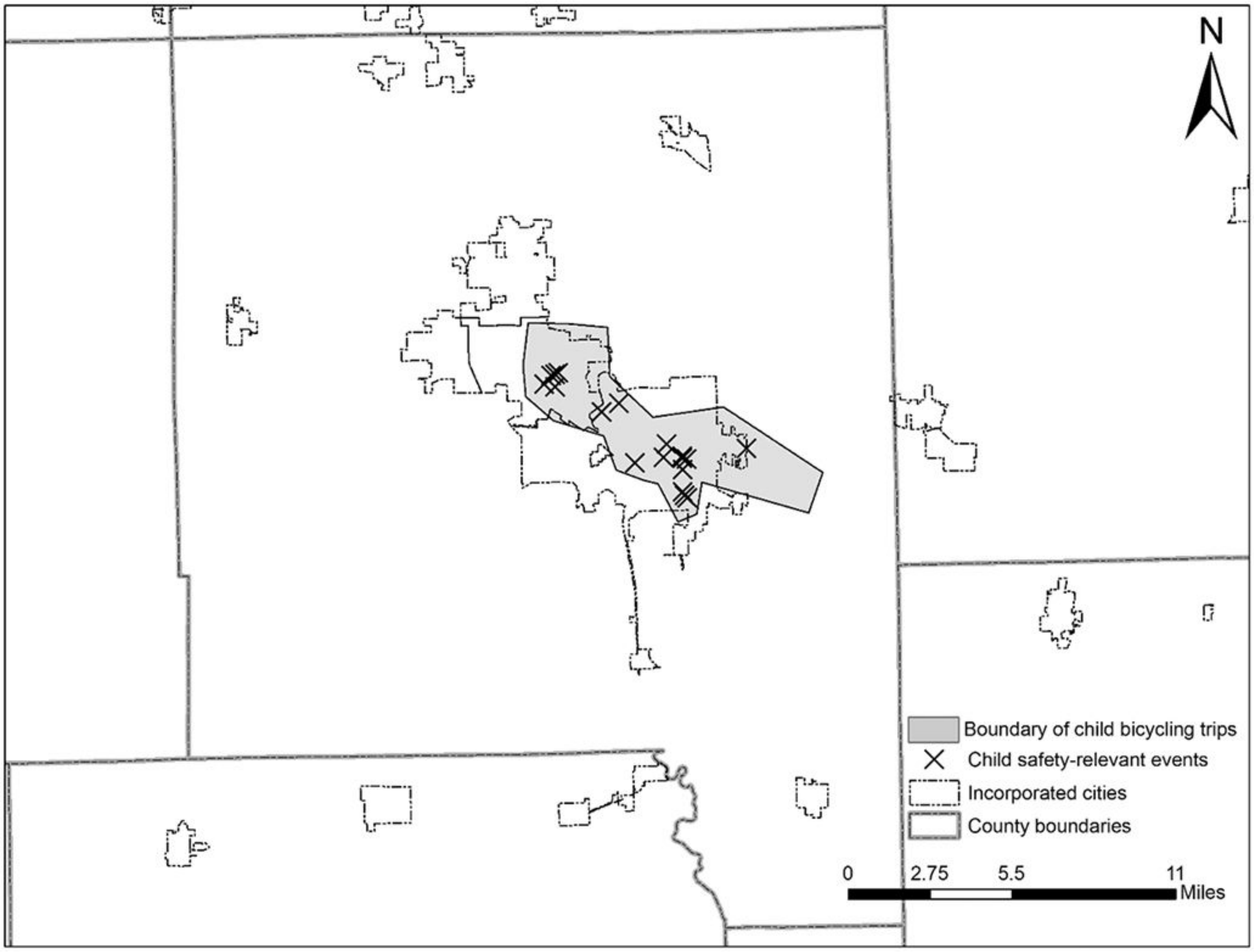

Figure 5.
Child participant (N=10) bicycle trips geographic boundary and event distribution, Johnson County, Iowa

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Figure 6.
Adult participant (N=10) bicycle trip geographic boundary and event distribution, Johnson County, Iowa

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Table 1.

Participant characteristics

Children (N=10)	
Age, Mean(SD)	12.0 (0.8)
Sex, N(%)	
Male	5 (50.0)
Female	5 (50.0)
Taken a bicycle riding class, N(%)	
Yes	2 (20.0)
No	8 (80.0)
Ride Bike to School, N(%)	
Yes	8 (80.0)
No	2 (20.0)
Miles of recorded riding, 1 week, Mean (SD)	12.8 (7.5)
Hours of recorded riding, 1 week, Mean (SD)	1.5 (0.6)
Safety-relevant events, 1 week, Mean (SD)	2.1 (1.8)
Adults (N=10)	
Age, Mean (SD)	38.4 (13.6)
Sex, N(%)	
Male	5 (50.0)
Female	5 (50.0)
Education, N(%)	
Post high school	2 (20.0)
4-year college degree	7 (70.0)
Master's or doctorate	1 (10.0)
Marital Status, N(%)	
Married	2 (20.0)
Single, Never Married	7 (70.0)
Widowed	1 (10.0)
Annual Household Gross Income (before taxes), N(%)	
< $20,000	2 (20.0)
$20,000 to $39,999	3 (30.0)
$40,000 to $59,999	1 (10.0)
>$59,999	3 (30.0)
Refused	1 (10.0)
Taken a bicycle riding class, N(%)	
Yes	4 (40.0)
No	6 (60.0)
Ride bike to work, N(%)	
Yes	8 (80.0)
No	2 (20.0)
Miles of recorded riding, 1 week, Mean (SD)	54.1 (29.9)

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Children (N=10)	
Hours of recorded riding, 1 week, Mean (SD)	4.2 (1.6)
Safety-relevant events, 1 week, Mean (SD)	16.9 (11.7)

Author Manuscript
Author Manuscript
Author Manuscript
Author Manuscript

Table 2.

Safety-relevant event (crash, near crash, error, and traffic violation) rates by age and gender

	Children									Adults								
	Total (N=10)			Male (N=5)			Female (N=5)			Total (N=10)			Male (N=5)			Female (N=5)		
Safety-relevant events	**n**	**Rate per 100 miles**	**Rate per 100 min**	**n**	**Rate per 100 miles**	**Rate per 100 miles**	**n**	**Rate per 100 miles**	**Rate per 100 miles**	**n**	**Rate per 100 miles**	**Rate per 100 miles**	**n**	**Rate per 100 miles**	**Rate per 100 miles**	**n**	**Rate per 100 miles**	**Rate per 100 miles**
Crash	1	0.8	0.1	1	1.4	0.2	0	0	0	1	0.2	0.03	0	0	0	1	0.6	0.1
Near crash/dangerous circumstance	3	2.3	0.3	2	2.9	0.5	1	1.7	0.2	7	1.3	0.3	6	1.6	0.4	1	0.6	0.1
Traffic violations	12	9.4	1.4	5	7.2	1.1	7	12.0	1.6	159	29.4	6.2	79	20.7	5.0	80	50.1	8.4
Incomplete stop/Yielded when should have stopped	11	8.6	1.3	5	7.2	1.1	6	10.3	1.4	105	19.4	4.1	44	11.5	2.8	61	38.2	6.4
Complete failure to stop or yield	1	0.8	0.1	0	0	0	1	1.7	0.2	54	10.0	2.1	35	9.2	2.2	19	11.9	2.0
Errors	5	4.0	0.5	2	2.8	0.4	3	5.1	0.7	2	0.4	0.1	1	0.3	0.1	1	0.6	0.1
Reckless toward pedestrian[a]	1	0.8	0.1	1	1.4	0.2	0	0	0	0	0	0	0	0	0	0	0	0
Reckless toward bicyclist[b]	2	1.6	0.2	1	1.4	0.2	1	1.7	0.2	0	0	0	0	0	0	0	0	0
Riding against traffic	2	1.6	0.2	0	0	0	2	3.4	0.5	0	0	0	0	0	0	0	0	0
Motorist error	0	0	0	0	0	0	0	0	0	2	0.4	0.1	1	0.3	0.1	1	0.6	0.1
Total (all safety-relevant events)	21	16.4	2.4	10	14.3	2.3	11	18.9	2.5	169	31.2	6.6	85	22.3	5.3	82	51.4	8.6

[a] Any action by participant bicyclist that impeded or endangered pedestrian

[b] Any action by participant bicyclist that impeded or endangered another bicyclist

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Table 3.

Safety-relevant event trip and environmental characteristics by age (N=179)

	Total		Children		Adults	
	# SREs	%	# SREs	%	# SREs	%
Infrastructure type						
Paved street, no bicycle facility	143	79.9	12	66.7	131	81.4
Paved street, with on-street painted bicycle facility	3	1.7	0	0	3	1.9
Sidewalk or side path	15	8.4	5	27.8	10	6.2
Off-street bicycle path	15	8.4	0	0	15	9.3
Gravel road	0	0	0	0	0	0
Other (parking lot, grass, dirt, etc.)	3	1.7	1	5.6	2	1.2
Site configuration						
4-way intersection	92	51.4	6	33.3	86	53.4
T-intersection	58	32.4	8	44.4	50	31.1
Non-intersection	27	15.1	2	11.1	24	14.9
Other	2	1.1	2	11.1	1	0.6
Visual obstruction						
No	162	90.5	17	94.4	145	90.1
Yes	17	9.5	1	5.6	16	9.9
Traffic controls present						
Stop sign	155	86.6	12	66.7	143	88.8
Traffic light	8	4.5	0	0	8	5.0
Unregulated/no traffic controls	12	6.7	5	27.8	6	3.7
Other	4	2.2	1	5.6	4	2.5
Primary land use in area						
Education	10	5.6	0	0	10	6.2
Farmland/Agriculture	5	2.8	0	0	5	3.1
Residential/Housing	115	64.2	17	94.4	98	60.9
Recreation	16	8.9	0	0	16	9.9
Commercial	28	15.6	1	5.6	27	16.8
Other	5	2.8	0	0	5	3.1
On-street parked vehicles						
Same and opposite side as bicyclist	11	6.2	2	11.1	9	5.6
Same side as bicyclist	19	10.6	2	11.1	17	10.6
Opposite side of bicyclist	13	7.3	3	16.7	10	6.2
None or Not applicable	136	76.0	11	61.1	125	77.6
Trip Purpose						
Commute	99	55.3	11	61.1	88	54.7
Errand (Non-commute utilitarian)	22	12.3	0	0	22	13.7
Recreation/Social	58	32.4	7	38.9	51	31.7
Time of Day						
05:00-07:59	11	6.2	0	0	11	6.8

Author Manuscript

	Total		Children		Adults	
	# SREs	**%**	**# SREs**	**%**	**# SREs**	**%**
08:00-10:59	56	31.3	7	38.9	49	30.4
11:00-13:59	27	15.1	3	16.7	24	14.9
14:00-16:59	34	19.0	4	22.2	30	18.6
17:00-19:59	35	19.6	4	22.2	31	19.3
20:00-22:59	11	6.2	0	0	11	6.8
23:00-4:59	5	2.8	0	0	5	3.1

SRE = safety-relevant event

Author Manuscript Author Manuscript Author Manuscript Author Manuscript

Table 4.

Bicyclist, motorist, and pedestrian lane position and actions at safety-relevant events

	Total		Children		Adults	
Characteristic	**#**	**%**	**#**	**%**	**#**	**%**
Bicyclist lane position/location						
left	3	1.7	0	0	3	1.9
Center	26	14.5	0	0	26	16.2
Right	132	73.7	12	66.7	120	74.5
Sidewalk/sidepath/not applicable	18	10.1	6	33.3	12	7.5
Bicyclist Action						
Forward, with traffic	82	45.8	9	50.0	73	45.3
Forward, against traffic	2	1.1	2	11.1	0	0
Turning right	56	31.3	3	16.7	53	32.9
Turning left	39	21.8	4	22.2	35	21.7
Motorist Action						
Forward, with bicyclist	2	1.1	0	0	2	1.2
Forward, against bicyclist	3	1.7	0	0	3	1.9
Turning left, opposite bicyclist	1	0.6	0	0	1	0.6
Stopping, right and perpendicular to bicyclist	2	1.1	0	0	2	1.2
Stopping, center and perpendicular to bicyclist	2	1.1	0	0	2	1.2
Motorist present, no interaction with bicyclist	17	9.5	0	0	17	10.6
Not applicable, no cars present	152	84.9	18	100.0	134	83.2
Pedestrian Action						
Forward, against bicyclist riding on sidewalk	1	0.6	1	5.6	0	0
Crossing perpendicular in front of bicyclist	1	0.6	0	0	1	0.6
Pedestrian present, no interaction with bicyclist	4	2.2	1	5.6	3	1.9
No pedestrian present	173	96.6	16	83.3	157	97.5

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Table 5.

Safety-relevant event rates per 100 minutes of bicycling by infrastructure and trip purpose*

	Total	Children	Adults
Infrastructure Type			
Paved street, no bicycle facility	7.8	7.2	8.6
Paved street, with on-street painted bicycle facility	1.6	0	1.7
Sidewalk or side path	1.9	1.9	3.9
Off-street bicycle path	3.9	0	4.9
Gravel road	0	0	0
Other (parking lot, grass, dirt, etc.)	1.8	1.1	2.2
Trip Purpose			
Commute	6.7	2.4	8.7
Errand (Non-commute utilitarian)	5.6	0	7.5
Recreation/Social	3.7	2.2	4.1

*Rates were calculated using denominator time totals separately tabulated for each infrastructure type and trip purpose

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Table 6.

Traffic volumes and driveway exposure prior to safety-relevant event occurrence by trip purpose

	Commute				Errands				Recreation/Social			
	Children		Adults		Children		Adults		Children		Adults	
Characteristic	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Number of driveways passed	1.5	1.0	1.1	1.4	--	--	1.1	1.1	0.3	0.5	1.1	1.3
Bicycle volume	0.4	0.7	0.2	0.9	--	--	0.1	0.4	1.9	2.3	0.3	0.9
Pedestrian volume	0.8	2.7	0.3	1.6	--	--	0.5	1.1	0	0	0.1	0.3
Motor vehicle volume	0.1	0.3	0.6	1.1	--	--	1.6	2.8	1.3	3.4	0.7	1.3

Counts taken for the 15 seconds leading up to the event.