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Mary-Ellen Hammond

Rumble Strip Gaps for High Speed Bicycles on Downgrades

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Abstract: Shoulder rumble strips (SRS) are a proven safety countermeasure that reduce motor vehicle lane departures; however, they may be seen as an impediment to bicycle travel as they decrease comfort for bicyclists and can impact one's control while bicycling. Existing literature provides recommendations for the placement of regular gaps in SRS, but the testing was limited to low and moderate bicycle speeds. Roads with SRS along long, steep grades present a unique set of risks for cyclists due to the capacity for higher bicycle speeds. This study evaluates how variations in SRS gap lengths and shoulder widths affect a bicyclist's ability to maneuver through these gaps when riding at higher than average bicycling speeds. The findings suggest that as gap length increases, bicyclist comfort is maintained while downhill speed also increases, with subjects reporting fewer instances of discomfort as the gap size increased. The likelihood of a bicyclist hitting a rumble strip while crossing a gap decreased modestly as the gap size increased. Shoulder width did not appear to significantly influence a bicyclist's capability of maneuvering across different gap lengths and had only a minor effect on bicyclist speeds.

Key Words Rumble Strips, Bicycles, Steep Grades, Shoulder Width	Distribution Statement

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EXECUTIVE SUMMARY

The North Carolina Department of Transportation (NCDOT) plays a lead role in the safe and efficient travel of people throughout the state. Bicyclists represent an important mode of non-motorized transportation in the state and are a focus of many recent initiatives at NCDOT.

Some safety countermeasures designed for motor vehicles are seen as potential impediments to bicycle travel. Right-side rumble strips, or shoulder rumble strips (SRS), provide a proven motor vehicle collision reduction in areas where run-off-road crashes are common. However, rumble strips decrease comfort for bicyclists and can lead to a loss of control when bicycling over them, posing a conceivable safety risk particularly for bicyclists traveling at higher speeds on steep, downhill roadway segments.

Existing literature provides recommendations for placement of regular gaps in rumble strips for bicycle maneuvers, but the testing was limited to low and moderate bicycle speeds. NCDOT personnel in Division 14 have reported bicyclist concerns about high speed (25-40 mph) maneuverability when trying to exit or enter a paved shoulder using 12-ft gaps between SRS, despite using best known practices for rumble strip placement and gap length where bicycle use is legal (non-freeways). These concerns are important to study, particularly for roadways which experience a high volume of bicycle traffic such as routes that are designated as part of the NC bicycling highway system or a signed local route.

To promote and allow for the safety of bicyclists on state roadways, additional guidance is needed for when and how to apply SRS on roads with steep grades where bicycles are present or likely to use the facility. General direction on providing for safe bicycle travel is contained within NCDOT’s Bicycle Policy, but additional specificity is needed for the application of rumble strips.

The following report evaluates rumble strip gap lengths, in combination with varying shoulder widths, to better establish their relationship with bicycle maneuverability, bicyclist comfort, and other important indicators of cyclist safety.

TABLE OF CONTENTS

INTRODUCTION

Problem Definition and Need

The North Carolina Department of Transportation (NCDOT) plays a leading role in ensuring the safety and efficiency of travel throughout the state. In congruence with NCDOT’s commitment to environmental sensitivity, and other recent initiatives, bicyclists represent an important and growing mode of transportation in the state.

This modal inclusion poses unique infrastructural challenges, as many of North Carolina’s roads are experiencing increased use by bicyclists and motorists alike. Design elements that balance the needs of both drivers and cyclists are in demand but are also not as well understood.

Currently, some safety countermeasures designed and tested for motor vehicles can be problematic for bicycle travel. Right-side rumble strips, or shoulder rumble strips (SRS), are a type of pavement treatment used to alert motorists of potential danger through vibrations and noise when a vehicle drives over the edgeline. SRS provide a proven motor vehicle collision reduction in areas where run-off-road crashes occur. However, rumble strips can pose a safety risk and decrease comfort for bicyclists, as rumble strips may impact one’s control and handling of the bicycle *(1,2)*. This may be particularly concerning to those traveling at higher speeds on steep, downhill roadway segments.

Richard Moeur’s study conducted in 1999 provides some recommendations for placement of regular gaps in rumble strips for bicycle maneuvers, but the findings do not consider cyclists at high speeds *(3)*. For instance, Moeur evaluated the traversability of different rumble strip gap lengths, recommending the use of 12-foot gaps for roadways with cyclists (*3*). These findings only apply to bicyclists on grades of approximately 2-3% or less, which was the average grade for Moeur’s test area where the maximum speed reached by any test subject was 31 mph (*August 30, 2013 email correspondence, Richard C. Moeur, unpublished data*). Some cyclists descending steeper grades can comfortably reach up to 40 mph or more which presents a unique set of conditions and safety concerns that must be evaluated.

NCDOT personnel in Division 14 have reported concerns from some bicyclists about high speed (25+ mph) maneuverability when trying to exit or enter a paved shoulder using 12-foot gaps between SRS, despite using best known practices for rumble strip placement and gap length where bicycle use is legal (i.e. non-freeways). These concerns are important to study, particularly for roadways which experience a high likelihood of bicycle traffic and may include routes that are designated as part of the NC bicycling highway system or a signed local route.

Research Objectives

The primary goal of this research effort was to better understand how the application of rumble strip gap lengths may be adjusted so that SRS can be used as a tool to improve motor vehicle safety without unduly impacting bicyclists. Study objectives were to:

- Determine how different SRS gap lengths may impact bicyclists’ maneuverability, comfort, and speed when descending a steep grade.
- Assess what impact varying shoulder widths may have on bicyclists’ maneuverability comfort, and speed when traversing SRS gaps along a steep grade.
- Consider tradeoffs between SRS with gaps as a motor vehicle safety countermeasure and their impacts on bicycling safety.

STATE OF THE PRACTICE

To fully understand the issue, the research team examined existing rumble strip policies in North Carolina with respect to bicyclist travel, as well as national guidance and literature from other states. Particular focus was given to those policies that may identify how steep grades impact the placement of or design considerations for SRS with respect to high speed bicyclists.

NCDOT Policies and Practices

Per the Bicycle and Bikeways Act of 1974, "bicycling is a bonafide highway purpose subject to the same rights and responsibilities and eligible for the same considerations as other highway purposes." (*4*) The 2009 Bicycle Policy goes on to say that "paved shoulders … should be designed to accommodate bicycle traffic" and that "rumble strips …shall be placed in a manner as not to present hazards to bicyclists where bicycle use exists or is likely to exist. Rumble strips shall not be extended across shoulder or other areas intended for bicycle travel" (*4*).

As of 2012, it is NCDOT's standard practice to consider rumble strips or stripes along roads with a documented problem of motor vehicle lane departures (*5*). Policy R-44 indicates a desired minimum width of 12 in (30.5 cm) for SRS; they must be delineated at the beginning in accordance with Section 9C.06 of the Manual on Uniform Traffic Control Devices (MUTCD), and the Division of Bicycle and Pedestrian Transportation should have an opportunity to comment on any project where SRS are to be implemented. An effort was made through Policy R-44 to further provide guidance with consideration to bicycling traffic to ensure it did not conflict with the Bicycle Policy. The following details address considerations in applying Policy R-44 so as not to present a hazard to bicyclists:

- A minimum suggested width of 4 ft of "useable shoulder between the outside edge of the shoulder rumble strip/stripe to the edge of pavement".
- SRS may be as narrow as 8 in (20 cm).
- "Gaps in milled patterns, varying between 6 and 12 feet, may be provided to allow bicyclists to move between the through lane and the right shoulder to avoid vehicles, debris, etc., but the pattern should be a minimum of a 5:1 rumble-to-gap ratio."
- "Consideration should be given to the alignment of the roadway in the direction of travel from the perspective of bicyclists."
- "Consideration should be given to the grade and speed at which bicyclists may be traveling."(*5*)

NCDOT Division 14 took a step further to provide design and placement guidance for SRS within its region (*6*). They do not install SRS if the paved shoulder is less than 3.5 ft (1.1 m) wide even if a lane departure safety condition exists. On roads with shoulders between 3.5 and 6 ft (1.1 and 1.8 m), SRS are 12 in (30.5 cm) wide and should be placed on the edgeline (i.e. a rumble stripe), but only if a clear width of 3 ft (0.9 m) remains for use by bicycles. Roads with shoulders greater than 6 ft (1.8 m) allow the SRS to be offset from the travel lane by 6 in (15 cm). Division 14 also clarified the 5:1 rumble to gap ratio, setting a pattern of 12-foot gaps (3.7 m) after each 48-foot long (14.6 m) SRS, the maximum gap pattern allowed through Policy R-44 (*6*). The decision to use a 48-foot SRS:12-foot gap pattern is influenced largely by previous research in gap lengths lead by Richard C. Moeur.

Assessment of Moeur's Rumble Strip Gap Study

Richard C. Moeur conducted a gap study in 1999 to determine a typical skip pattern that would be suitable for typical bicyclists to traverse. In his study, he analyzed the success at which bicyclists of varying skill level could traverse different gap lengths in rumble strips. The average test speed was 23-28 mph, on downgrades approximately 2 to 3% (*August 30, 2013 email correspondence, Richard C. Moeur, unpublished data*), based on typical rural state highways found in Arizona. Moeur's study concluded that 12-foot (3.7 m) longitudinal gaps in rumble strips that are 12 in (30.5 cm) wide should be sufficient length to allow a bicyclist to cross. He additionally calculated that a 12-foot skip pattern did not interfere with the rumble strip's ability to alert motorists to roadway departure, assuming a typical 3-degree angle for a run-off-road crash (*3*).

While Moeur's study has helped to provide important guidelines, the findings do not reflect potential considerations for bicyclists traveling at high rates of speed as would be expected on steeper downgrades. The following series of figures demonstrate how steeper grades increase the acceleration of bicyclists, resulting in dramatic increases in speed over shorter distances. Using mathematical models, speeds were calculated at set distance intervals along a range of possible downhill grades. Two conditions, where a cyclist is either pedaling or coasting, are represented. Further details on the assumptions and calculations made to create these graphs are provided in Appendix A.

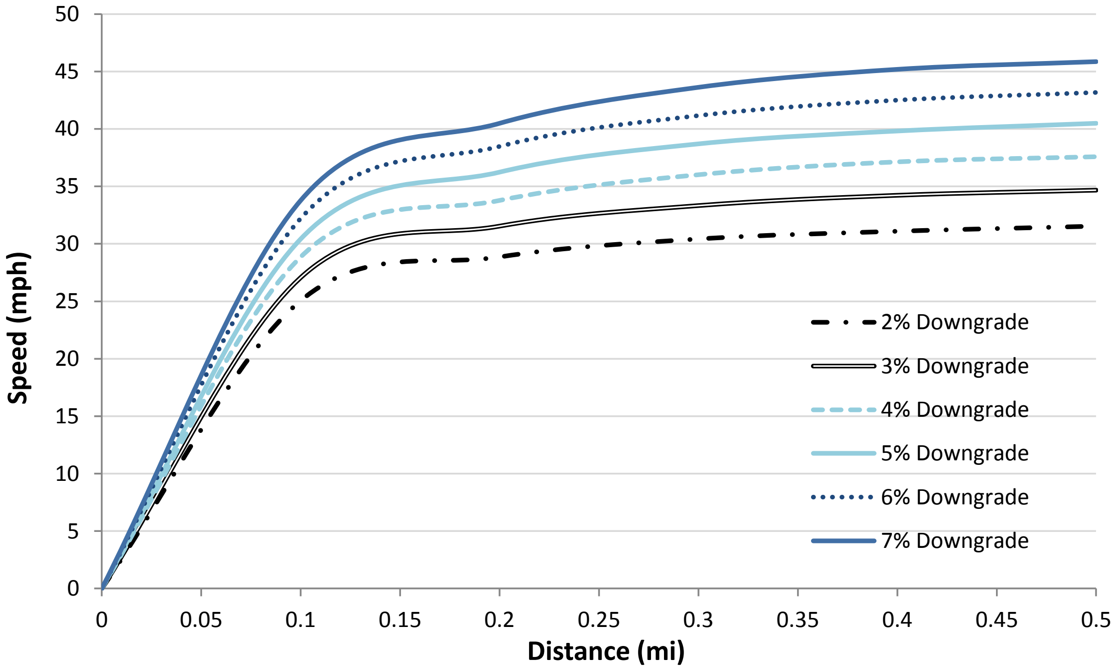

FIGURE 1 Effect of varying downgrades on speed over 0.5 mi (0.8 km), while pedaling.

For Figure 1 and Figure 2, it is assumed that the bicyclist starts at 0 mph. Figure 1 shows that as the percent downgrade increases, the maximum typical speed a bicyclist may reach while pedaling approximately 0.5 mi (0.8 km) under these conditions also increases from almost 34 mph on a 2% downgrade up to approximately 46 mph on a 7% downgrade.

At some distance on steep downgrades, most bicyclists achieve a speed where pedaling no longer assists them in further accelerating, and many bicyclists will rely on gravity to coast downhill. Therefore, Figure 2 shows the speeds achieved if a bicyclist chooses to simply roll down a 0.5 mi (0.8 km) hill. Under this assumption, bicyclists on a 2% grade will reach just over 20 mph while bicyclists on a 7% grade will almost double that speed over the same distance.

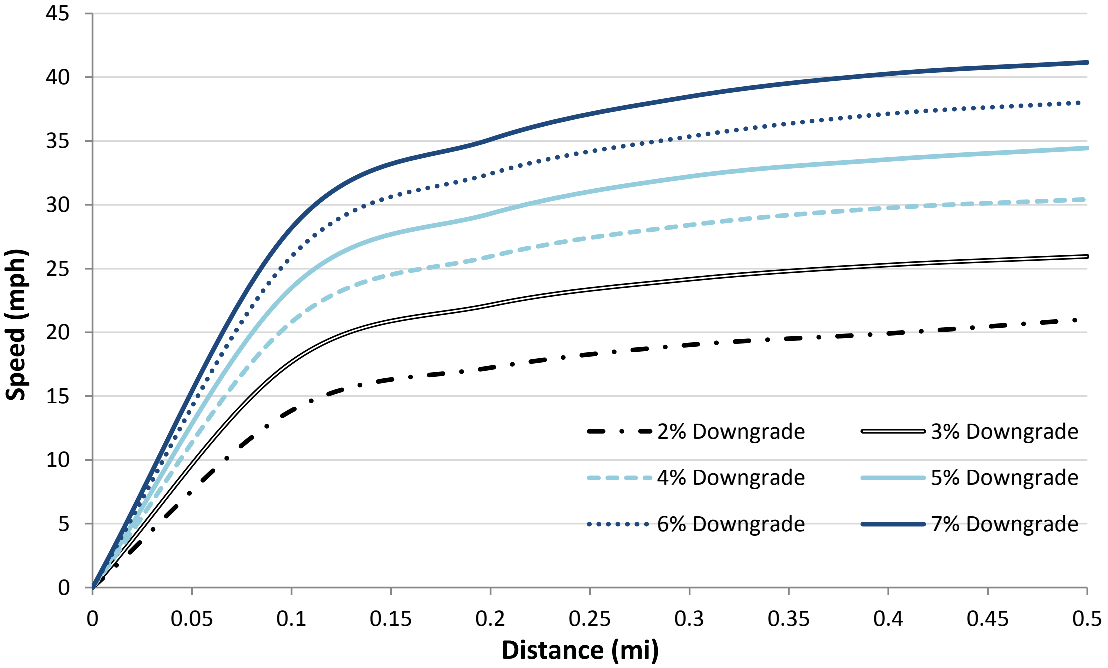

FIGURE 2 Effect of varying downgrades on speed over 0.5 mi (0.8 km), while coasting.

Comparing Figure 1 and Figure 2, it is clear that pedaling, at least on lower grades, is necessary to achieve higher speeds. Also, as is to be expected, pedaling helps bicyclists achieve higher speeds more quickly. However, as the grade increases, a bicyclist can easily reach high speeds without much additional effort.

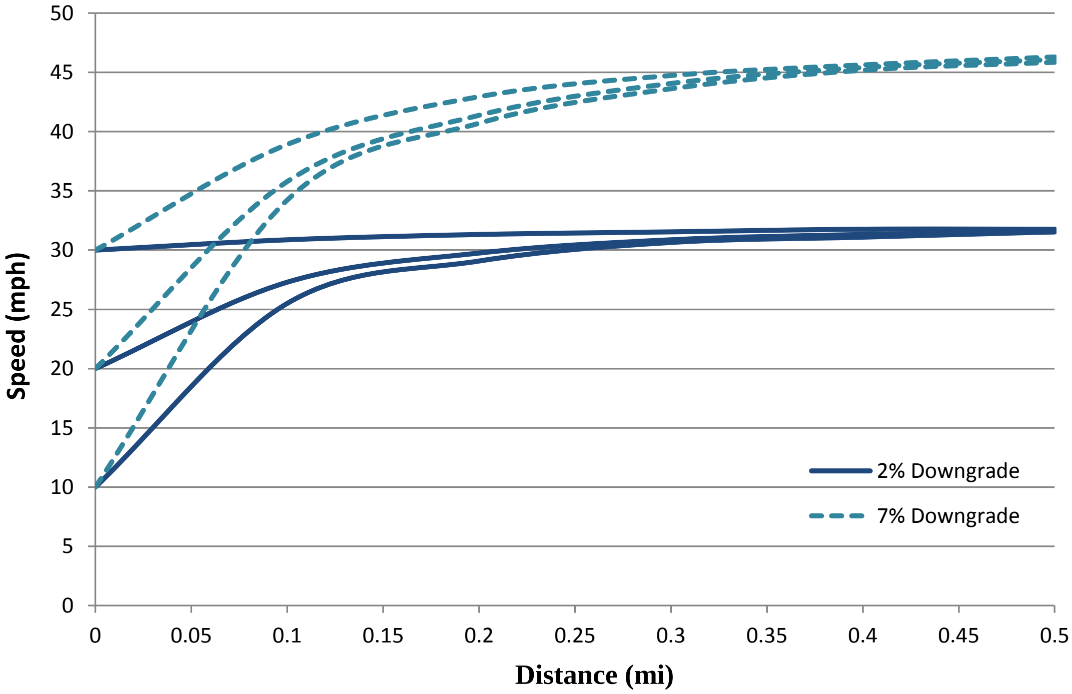

FIGURE 3 Comparison of the effect of 2% and 7% downgrades on speed over 0.5 mi (0.8km) when starting from 10, 20, or 30 mph.

It is unlikely that a bicyclist would start a descent from 0 mph on a road – it is much more likely that a bicyclist traveling along a road will approach the descent at a certain entry speed. Figure 3 displays a comparison of bicyclists entering two different downgrades (2% or 7%) from three different starting or entry speeds (10, 20, or 30 mph) and assumes the bicyclist coasts down the hill. Regardless of starting speeds, bicyclists on a 2% grade will converge over 0.5 mi (0.8 km) to a threshold speed of approximately 32 mph. Increasing the slope to 7% allows a bicyclist to quickly surpass the 2% speed threshold and converge at 46 mph over the same distance. A 5% change in slope can result in bicyclists increasing their speed by about 14 mph, without the aid of pedaling to accelerate.

Other State or Federal Guidance

In 2000, the Federal Highway Administration (FHWA) compiled a "Synthesis of Shoulder Rumble Strip Practices and Policies" which also discussed bicyclist concerns and perspectives. At that time, at least ten states used a skip pattern rather than continuous SRS to allow gaps for bicyclists to weave easily across from the shoulder to the travel lane (*7*). The FHWA study also illustrated the pros and cons of SRS placement with respect to bicyclists and the tradeoffs to motorists departing the roadway:

TABLE 1 SRS Placement Based on Drivers' and Bicyclists' Perspectives on Shoulders 4-8 ft (220 – 2440 mm) Wide[a]

Perspective	SRS Placement Near Edgeline	SRS Placement Near Edge of Shoulder
Motor Vehicle Safety Advocates	• Large recovery zone • Earliest warning for errant drivers	• Eliminates the recovery zone • Diminished early warning for drivers
Bicyclists	• Forces bicyclists to cross over the SRS • Places warning device between cars and bicycles	• Allows bicycles to cross freely into travel way • Places bicycle in sweep zone • Places bicycle closer to vehicles

a. Adapted from Table 7 in "Synthesis of Shoulder Rumble Strip Practices and Policies" (5)

The FHWA synthesis also concluded that additional skip pattern research was needed to take into "account both errant [motor] vehicle speed and trajectory as well as the speed of the bicyclists." (*7*).

Other general criteria for the location and placement of SRS that take into account bicyclist accommodations was issued by FHWA through the following Technical Advisory guidance in 2011:

> "a. Wide ***shoulders***: ... Where existing cross-section exists or paved shoulders can be added within the scope of the project, it is preferred to allow at least four feet beyond the rumble strips to the edge of the paved shoulder… FHWA design guidance…recommends states not install rumbles on *new construction* and *reconstruction* projects where shoulders are used by bicyclists unless this condition is met. Where guardrail, curb, or other continuous obstructions exist, additional width may be needed to provide adequate clearance for bicyclists (refer to current AASHTO bicycle guidance for additional information).
>
> "b. Bicycle ***gaps***: Where any width paved shoulder exists beyond the rumble strip and bicycles are allowed to ride, recurring short gaps should be designed in the continuous rumble strip pattern to allow for ease of movement of bicyclists from one side of the rumble to the other. A typical pattern is gaps of 10 to 12 feet between groups of the milled-in elements at 40 to 60 feet." (*8*)

Technical Advisory T 5040.39 also recommends using edgeline rumble strips or a smaller offset in areas where additional shoulder may be needed for bicyclists, or decreasing the rumble strip's length, width, depth, or spacing to reduce their impact to bicyclists if they are traversed.

Some states developed more detailed criteria to evaluate whether rumble strips are appropriate at all and to provide further considerations to address the needs of bicyclists in an area where SRS are needed. For example, Washington State Department of Transportation (WSDOT) installs SRS on undivided rural road highways with posted speeds of 45 mph or more only if there is at least 4 ft (1.2 m) of usable shoulder width beyond the rumble strip. WSDOT policy also states that SRS should not be placed "on downhill grades exceeding 4% for more than 500 ft (152 m) in length along routes where bicyclists are frequently present" (*9*). Through coordination with the regional Bicycle and Pedestrian Coordinator, engineers determine which of four standard rumble strip pattern types to apply, given the level of bicycle usage along a route in concert with the frequency of run-off-road crashes. The SRS pattern types vary in width (from 12 to 16 in (30.5 to 41 cm)), gap length (12 to 16 ft), and gap spacing (28 or 48 milled units) (*10*).

In 2007, FHWA released a report about SRS and bicyclists. In this report, Daniel conducted a survey in which 40 state Departments of Transportation responded, and summarized the following range of strategies to accommodate bicyclists where SRS are used:

- Do not use rumble strips if the shoulder width is less than 8 ft.
- Widen the shoulder to provide a minimum 4-ft effective width along the shoulder in which bicyclists may ride.
- Move the SRS as close to the travel lane as possible.
- Not allow SRS on roadways used by bicyclists.
- Require approval of the bicycle and pedestrian coordinator if the SRTS is to be installed on a shoulder width less than 8 ft. (*11*)

While Report 641 of the National Cooperative Highway Research Program (NCHRP), does not focus exclusively on bicycling issues regarding SRS, Torbic *et al.* does recommend that further research is needed to determine the optimal longitudinal gap needed to accommodate bicyclists while maintaining effectiveness in reducing lane departures. The report specifically notes that previous research did not vary the rumble strip patterns or the trajectories of the bicyclists (*12*). The experiment, as explained below, attempts to address some of these research needs.

EXPERIMENTAL DESIGN

Test Location

The experiment took place on a straight, half mile (0.8 km) section of NC 28 in Swain County near Almond, North Carolina, a mountainous region of the state. See Figure 4 for a map of the general area, with the town of Almond indicated by the red marker.

FIGURE 4 Location map showing test site near Almond, N.C. and surrounding area.

This section of NC 28 is a four-lane median divided highway with 3-4 ft (0.9-1.2 m) paved shoulder and no SRS and a uniform average downgrade of 6.6%. It was selected out of eight potential sites considered within NCDOT's Division 14 based on meeting the following criteria:

- Average grade of the section was within a target range of 5-7%
- Traffic volume was low (4,700 vpd), allowing for minimal traffic control disruption to motorists
- Distance was long enough with a relatively consistent grade for bicyclists to potentially achieve speeds more than 25 mph
- Pavement quality was well maintained with minimal cracks or debris
- Location was proximate to population areas with potential for test subject recruitment (i.e. within 30-60 min drive time from several towns, cities or centers with known bicycling populations.)

NCDOT supplied traffic control during the trials to direct motorists and other road users appropriately around the test area. Eastbound traffic was reduced to one inside lane with the closure of the outside lane during the four test days. During each session, the inside lane was also closed each time bicyclists conducted a run down the hill and was opened to release traffic in between runs. The inside lane was open for cars to go around the area only while the research team adjusted the configuration of the course for the next run. NCDOT's Division 14 conducted the traffic control measures for the duration of testing in coordination with signals from the research team for when to open or close access to traffic.

The test area was segmented into four primary sections, as shown in Figure 5. Participants began each run near the entry to a curve west of the scenario stations. This Bicyclist Approach segment, shown in red in Figure 5, provided approximately 2200 ft (670 m) for subjects to reach speeds exceeding 25 mph prior to entering the first scenario. The green and orange lines along the course run indicate the approximate locations for Scenario Station A and B, respectively. Subjects could then exit the course by continuing to ride over the bridge to reach the shuttle loading area just beyond. This last segment allowed ample stopping distance for subjects to slow down before exiting the roadway.

FIGURE 5 Aerial image of test area showing 4 main segments to comprise the course run from west to east – 1) Bicyclist Approach (red) , 2) Scenario Station A (green), 3) Scenario B (orange), and 4) Bicyclist Ride-out (red).

Prior to conducting the experiment, one researcher rode the full test location with a GPS unit to create a profile of the variable grade through the road segment in relation to speeds attained while riding along the segment.

Course Layout

During the experiment trials, a radar speed measurement device recorded subject bicyclist speeds and relayed those to the research team through a speed display board. To maintain the integrity of the experimental design, the display was not visible to bicyclists during the test scenarios. Researchers also recorded each trial using a video camera, filming only the rumble strip gap segments. This allowed the research team to check field technician data, and resolve any conflicting reports made by technicians or participants when processing the data.

Each participant conducted 11 runs through the course, with each run having a different combination of rumble strip gap length and shoulder width. For each run, the subject encountered two scenarios, as shown in Figure 6. Each scenario comprised two gap events to allow for testing both shoulder-to-lane maneuvers and lane-to-shoulder maneuvers across the same gap length. Therefore, subjects encountered four separate gap events for each run.

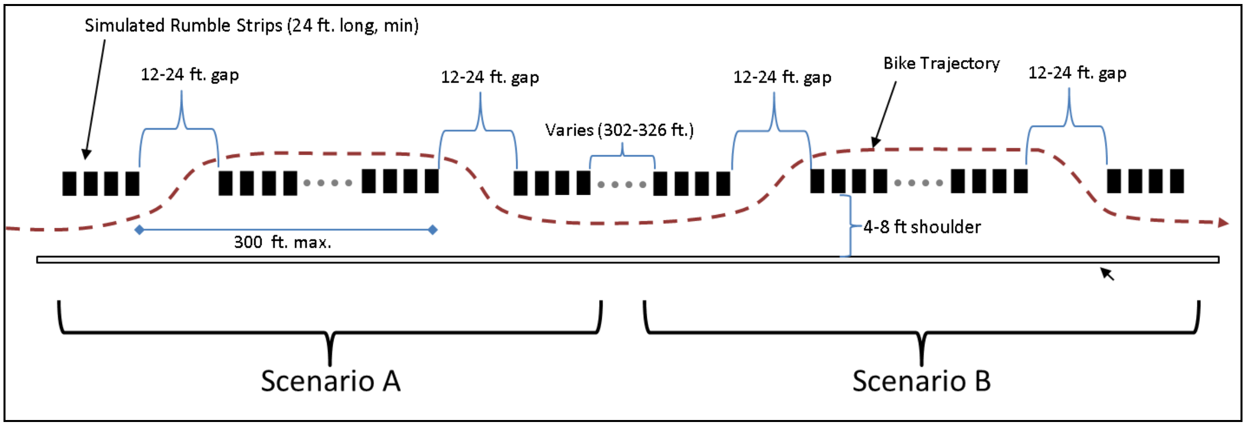

FIGURE 6 Schematic representation of the course layout. Graphic not to scale.

Rumble strips were simulated using raised pavement markers so that they could easily be reconfigured for each scenario. In between gap events, tennis ball halves were widely spaced to continue a visual demarcation of the effective line of simulated rumble strip. This ensured that participants could clearly distinguish the test gap locations from the space in between each gap event. While Moeur’s study considered whether raised pavement markers increased visibility under simulated conditions compared to an actual rumble strip, no research was found testing this concern *(3)*. Figure 7 includes an array of images to show the course setup during testing. All measurements were marked out using chalk in advance of the study sessions so that the field technicians could quickly move the raised pavement markers as needed to adjust the gap lengths and shoulder widths for each run.

Scenarios varied in the longitudinal gap spacing between the simulated rumble strip from 12 ft (3.6 m) to 24 ft (7.3m), changing by 2- or 4-ft increments for each scenario. Gaps smaller than 12 feet were not tested as they were found to be uncomfortable and “too tight” under Moeur’s test conditions *(3)*. The researchers also adjusted the lateral placement of the simulated rumble strip in relation to the edge of the pavement to vary the width of the shoulder area from 4 ft (1.2 m) to 8 ft (2.4 m). Shoulder widths were modified by two-foot increments between runs. For the purposes of the study, the existing edge line was used to define the “edge of pavement” from which shoulder widths were measured. This allowed an additional three to four feet of space as a safety precaution / recovery area to minimize the likelihood of a subject running off the road during testing.

FIGURE 7 Clockwise from top left: looking east down course showing radar gun and video camera placement; looking west uphill showing first gap subjects approach as they ride through the course; looking east down the course showing tennis ball line between scenario A and B stations; at top of course looking east showing ITRE researcher signaling to NCDOT traffic controllers upstream; close-up of subject crossing a gap while bicycling at high speed.

Table 2 illustrates the specific configurations of shoulder widths and gap length events laid out for each run.

TABLE 2 Course Layout Configurations for Each Run

Run	Scenario A Gap Event Length (ft)	Scenario B Gap Event Length (ft)	Shoulder Width (ft)
1	no gap	no gap	full lane
2	no gap	no gap	full lane
3	no gap	no gap	4
4	24	22	4
5	20	18	4
6	16	14	4
7	12	12	4
8	24	20	6
9	16	12	6
10	24	20	8
11	16	12	8

Study Protocol

The study protocol consisted of two primary phases: 1) recruitment of test subjects, and 2) conducting the test sessions.

Recruitment and Consent Process

Subjects were recruited through social media outlets, bicycle group contacts, phone calls, emails, and distributed flyers. The researchers drafted a standard email with the flyer attached to solicit subjects. The email was sent to local bicycle shops, bicycle clubs, touring directors, and known municipal and/or transportation planning organization contacts in the area to request that these entities reach out to their members, patrons, and/or constituents through their normal channels of communication, which included social media platforms like Facebook and Twitter as well as blogposts. Interested individuals were asked to contact the research team to sign up to participate. The researchers sent prospective subjects follow-up information including general information on what they would be asked to do, location and directions to the test area, and what they needed to bring with them to participate. Subjects were sent a link to a private Doodle Poll to indicate availability to participate in 16 possible study session times. These times included back-up options in case of the need to delay due to weather conditions. Researchers then organized participant appointments to cluster them into groups of 5-10 subjects per study session. An email confirmation was sent to each subject with his/her appointment time and a back-up time as well as reminder of previously sent logistical details. This confirmation email also included a copy of the consent form and the pre-test questionnaire so that subjects could familiarize themselves with each prior to arrival on-site. A copy of all recruitment materials is included in Appendix B.

Upon arrival, subjects were asked to sign the consent form and fill out the pre-test questionnaire. A sample questionnaire is provided in Appendix C. Respondent answers provided researchers with information on subjects’ level of experience as cyclists, familiarity with rumble strips, and other factors like weight and type of bicycle, which were utilized during later analysis.

Once all subjects for a study session arrived, the research team asked that they all conduct an ABC Quick Check of their bicycle to ensure it was in good working order. A bike pump and basic set of tools was available in case subjects needed to adjust their equipment. Researchers visually inspected the fit of each subject’s helmet, as well. The team did not perform any mechanics on a subject’s bicycle nor make any physical adjustments to a subject’s helmet.

Subjects were determined to be eligible for the study if they were physically capable of and comfortable exceeding 20 mph during the first test runs. This skills test was used to determine the rider’s capability (ability and comfort) of bicycling downhill at the high speeds necessary for the study. It also allowed researchers an opportunity to observe the subject’s handling skills to confirm that the subject could suitably represent the targeted bicycling population for the study. Novice or unskilled bicyclists were not targeted for this study, as it is likely they would either (a) typically avoid routes with long steep downgrades, or (b) brake frequently enough to maintain a lower speed more comfortable with their abilities and at which they 12-ft gap should be sufficient based on Moeur’s research *(3)*.

A total of 20 subjects were enrolled and participated in the study. They were divided into four 4-hr study sessions as shown in Table 3.

TABLE 3 Summary of Study Session Conditions and Participant Numbers

Date	Session (AM/PM)	Weather	Number of Participants
March 7, 2014	PM	55^{o}; overcast; low wind	3
March 8, 2014	PM	64^{o}; sunny; 5-10 mph W wind	7
March 9, 2014	AM	47 ^{o}; sunny; 5-9 mph NNW wind	2
March 9, 2014	PM	63^{o}; sunny; 9-13 mph NNW wind, with gusts	8

Test Session Process

Subjects were asked to ride as fast as comfortable through the test area, and to attempt crossing the rumble strip at each gap event only to the extent that they felt safe and in control. A total of four traversable gaps were present in each run downhill. Participants crossed each gap by moving from the shoulder area to the left of the strip as well as from the left of the strip onto the shoulder area.

The first two runs served as the eligibility skills test for the participants. The inside travel lane was blocked from traffic, and subjects were asked to ride in that full lane where no simulated rumble strips were present. This allowed subjects an opportunity to acclimate themselves with the terrain and the grade of the road within the test area before the simulated rumble strips were applied. Subjects rode as they naturally would and as fast as they felt comfortable given the conditions, terrain, and grade. Researchers noted the typical baseline speed at which each subject bicycled during these two runs. Given the study’s focus on high speed conditions, subjects who were not able to exceed 20 mph while maintaining control of their bicycle during either of these two runs would not have been eligible to continue in the study; however, no participants failed to meet this requirement.

After the two trial runs, researchers arranged a course with a 4 ft shoulder. Subjects each made a single run down the hill under this condition, serving to determine how speeds may be affected simply by narrowing the lateral road space available to the bicyclists. Then, maintaining the 4 ft shoulder, subjects ran through test scenarios beginning with a 24-ft gap event and narrowing by two-foot increments down to a 12-ft gap event for a total of 4 runs at the 4-ft shoulder width. Next, the course was modified for a 6-ft shoulder, testing four different gap length scenarios within two separate runs. This was repeated again with an 8-ft shoulder.

This design resulted in a total of 11 runs through the course for each subject testing 18 unique scenarios. Each run contained two scenario stations; the two gap events for scenario station A were always the same to allow for testing of both maneuvers from the shoulder to the lane and from the lane to the shoulder across the same gap length. Likewise, the two gap events for the second scenario station were always the same length. See Table 2 for a breakdown of the configurations for each run. Subjects who felt uncomfortable attempting to cross a rumble strip gap at any time could choose to simply continue riding straight down the hill.

After each run, test subjects were asked about their experience in order to assess their level of comfort. Participants were asked a series of four questions independently from one another so that responses were not influenced by their peers. Respondents were asked to indicate their comfort level on a scale from 1-5 with 1 being extremely uncomfortable and 5 being extremely comfortable for each separate gap event. If a subject chose to not attempt to cross a gap, the score for that gap event was recorded as a 1. Modifications to a subject’s travel path based on missing gap events was documented so that each event was correctly associated with either an ‘in’ maneuver (from the lane to the shoulder) or an ‘out’ maneuver (from the shoulder to the lane). Subjects were also prompted to provide general comments about their experience during the run. See the debriefing form in Appendix D.

Along with debriefing, two field technicians recorded speeds for each subject at each gap event during each run. The technicians also documented any event misses and any observations made of subjects hitting the simulated rumble strip or other general performance notes.

Data Analysis Process

In total, data was collected from video recordings, speed cameras, researcher observations, and participant responses. All the data collected in the field were digitized by entering records into a spreadsheet. Video recordings were used to compare with responses from participants and notes from field technicians as a way to check the data for consistent and accurate information. Potential data conflicts were identified such as where a technician noted a gap event miss that a participant did not disclose in the debriefing; in such cases, the video recording was consulted to verify its occurrence.

After cleaning the data, the researchers developed summary data and compared data from runs with different shoulder widths, gap lengths, and subjects’ level of comfort to determine the relationship between these three variables. Information on a subject’s level of experience, bicycling weight, and other factors were further applied to determine what if any influence these factors had on the average subject’ capability to maneuver across gap events.

ANALYSIS

Using established data evaluation criteria and testing protocols, field data were processed after testing.

Test Subject Profile

In total, 20 individuals participated in the study. Most subjects bicycled an average of 6-15 miles per trip and bicycled at least 1-2 times per week (50%), as shown in Figure 8. Eleven out of 19 participants reported they had previously reached bicycling speeds of more than 40 mph. However, when asked what was the highest speed at which they would feel comfortable bicycling downhill for a long stretch, responses were mixed with half of those who responded indicating they would feel comfortable riding more than 41 mph.

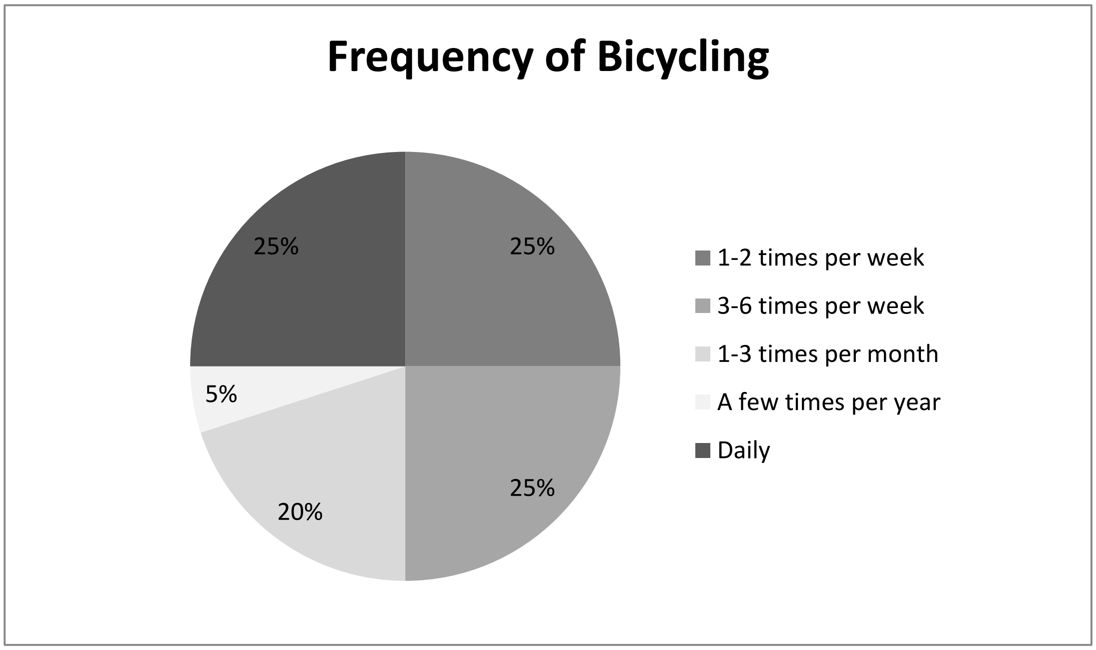

FIGURE 8 How often test subjects bicycle, as self-reported by each test subject.

For the purposes of analysis, two subjects who indicated they rode a touring bicycle were combined with those who reported riding a road bicycle. Likewise, mountain bike/cyclocross riders and hybrid/comfort riders were combined. See Figure 9 for a graphic display of the type of bicycle the subjects rode during the study, as self-reported.

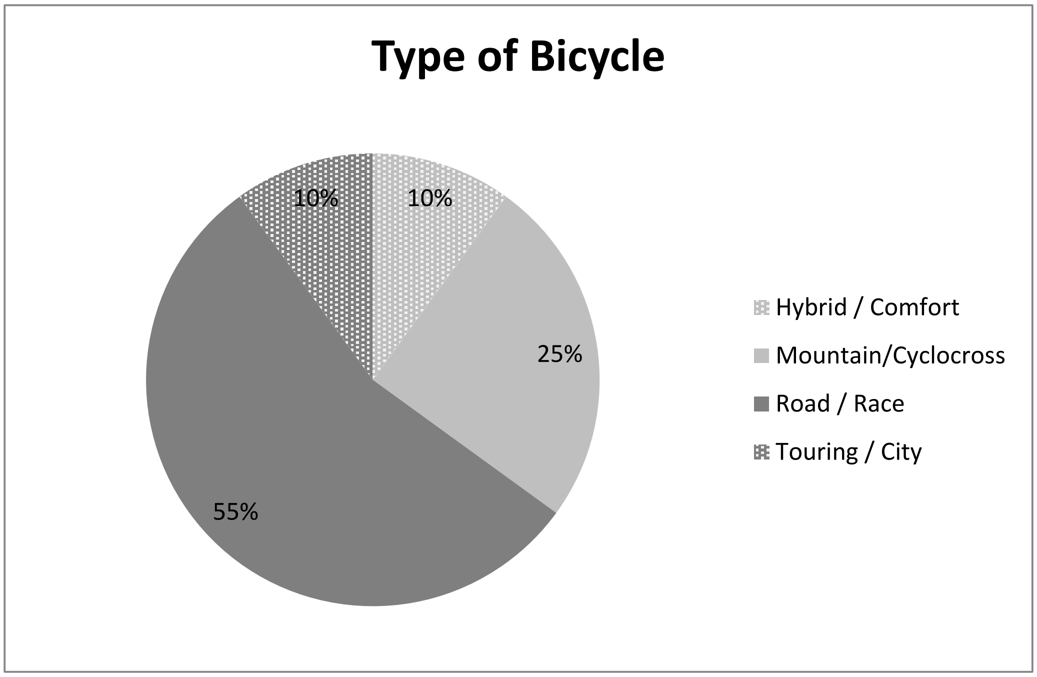

FIGURE 9 Proportion of the different types of bicycles used in the study as self-reported each test subject.

Participants were also asked to indicate the type of bicyclist they self-identify as. The majority of subjects indicated they are "enthused and confident," which is illustrated in Figure 10.

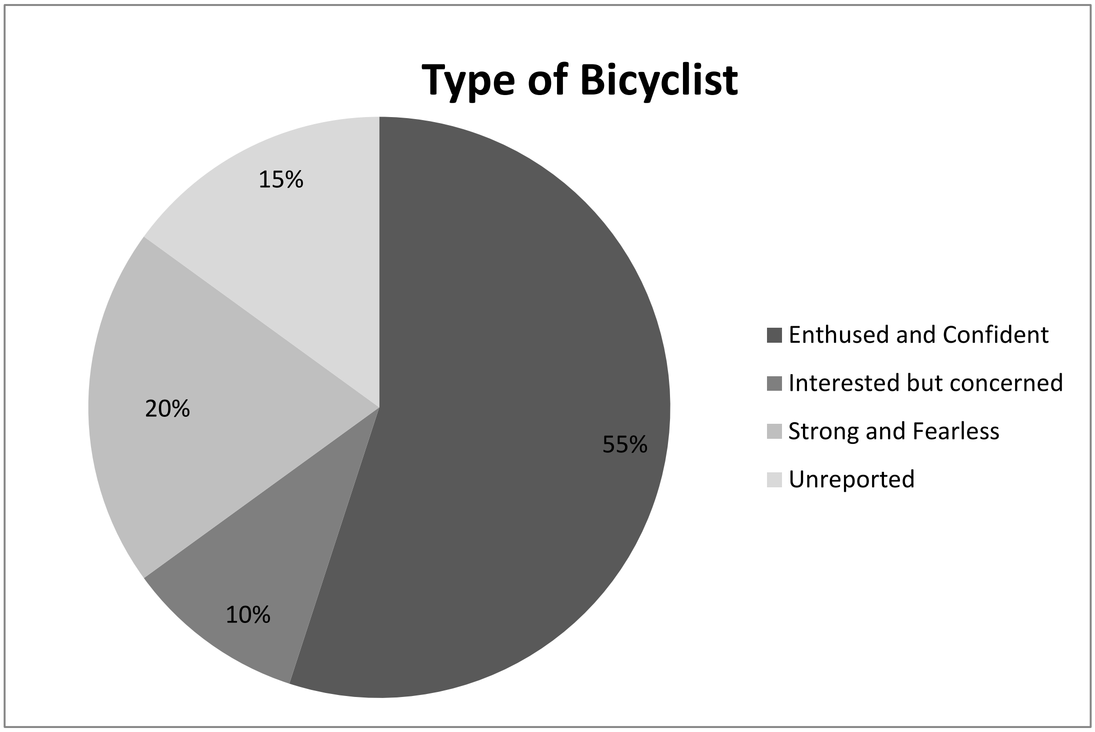

FIGURE 10 Proportion of different types of bicyclists in the study as self-reported by each subject.

When asked if they had ever ridden on a road with a SRS, 64% had done so, and, of those, only one subject had not crossed or needed to cross it. These profiles fit with the ideal test subjects the researchers targeted for the purpose of this study who were deemed to represent the type of bicyclist one would expect to be bicycling at high speeds on routes with long steep grades.

Relationships between Comfort, Gap Length and Shoulder Width

On average across all runs, bicycling speed was 32.3 mph (minimum 19 mph; maximum 50 mph). Weight of a bicyclist and bicycle can impact speeds reached, therefore, the researchers collected information on both participant weight and bicycle weights to ensure results were not skewed based on disproportionally heavier or lighter weights. The average weight of participants was 166.5 lbs with a 29.2 standard deviation, while the average weight of the bicycle was 26.0 lbs with a standard deviation of 6.1. The total weight of participants and their bicycles follows a normal distribution.

To determine if the likelihood of hitting a raised pavement marker (RPM) increased as the gap length decreased, the researchers recorded each time a subject hit the RPMs when attempting to cross a gap event, which simulated a bicyclist riding over a rumble strip. Gap events where a subject did not attempt to cross were included in the total number of events and were recorded as uncomfortable events. From Table TABLE 4, it is clear that the most RPMs were hit when testing the 12-ft gap; this represents approximately 7% of the total number of 12-ft gap events. Comparatively, RPMs were hit only three times at the 24-ft gap, representing 2.5%

of the possible events at that gap length. There was no statistically significant difference in the percentages of hits across the gap length categories which had hits.

Table 4 also shows the number of times subjects indicated that a particular gap event was uncomfortable. An event qualified as uncomfortable if the subject indicated a score of 1 (extremely uncomfortable) or 2 (uncomfortable) during the run’s debriefing. Again, the highest number of uncomfortable gap events was recorded for the 12-ft gap length, representing approximately 28% of the events for that length. Even discounting the events where a subject hit an RPM and indicated it was uncomfortable, the 12-ft gap length was deemed uncomfortable approximately 22% of the time. Using ANOVA to test for significant differences in uncomfortable events across each gap length resulted in identifying statistically significant differences between 12-ft and 16-ft or larger gaps and between 16-ft and 20-ft or larger gaps. This suggests that gap lengths of 16 ft or more may offer additional comfort to bicyclists compared to smaller gap sizes; however they may be just as likely to hit the rumble strip when attempting to cross the larger gaps.

TABLE 4 Participant-Reported Uncomfortable Events and Number of RPM Hit Events by Gap Length

Gap Length (ft)	Total Events (n)	Total RPM Hits (n)	Number of Uncomfortable Events - No RPM Hit	Number of Uncomfortable Events - RPM Hit	Uncomfortable Events Total	Uncomfortable Events (%)	RPM Hit Events (%)
12	152	11	33	9	42	27.6	7.2
14	40	2	0	2	6	15.0	5.0
16	120	6	4	6	16	13.3	5.0
18	40	2	0	0	4	10.0	5.0
20	120	0	0	0	6	5.0	0.0
22	40	2	0	2	4	10.0	5.0
24	120	3	4	2	6	5.0	2.5
Total	**632**	**26**	**41**	**21**	**84**	**13.3**	**4.1**

Table 5 conveys similar information, but it shows the comparison of uncomfortable events and frequency of RPM hits by the shoulder width. Subjects indicated at least twice as many uncomfortable events when maneuvering from and onto a 4-ft shoulder as they did a 6- or 8-ft shoulder. However, when normalized as a percentage of the total number of events per width, little distinction can be surmised between the three shoulder widths tested, and in fact, there is no statistical difference between the percentage of uncomfortable events across the three shoulder widths.

TABLE 5 Participant-Reported Uncomfortable Events and Number of RPM Hit Events by Shoulder Width

Shoulder Width (ft)	Total Events (n)	Total RPM Hits (n)	Number of Uncomfortable Events -No RPM Hit	Number of Uncomfortable Events - RPM hit	Uncomfortable Events Total	Uncomfortable Events (%)	RPM Hits Events (%)
4	320	14	36	10	46	14.4	4.4
6	152	7	12	6	18	11.8	4.6
8	160	5	15	5	20	12.5	3.1
Total	**632**	**26**	**63**	**21**	**84**	**13.3**	**4.1**

When considering RPM hits, Table 5 shows that the most hits occurred at gap events along a 4-ft shoulder. As a percentage of gap events, it appears there is no greater likelihood of hitting a rumble strip when maneuvering onto or off of a 4 ft shoulder as there is a 6- or 8-ft shoulder, and in fact, there is no statistical difference between the percentages of RPM hits across the three shoulder widths.

Relationship between Cyclists' Speed and Comfort

Figure 11 and Figure 12 represent the relationship found between bicycle speeds, comfort, and either gap length or shoulder width, respectively. Figure 11 suggests that test subjects will bicycle as fast as they feel comfortable, adjusting their speed to remain within a certain level of comfort given the conditions. When the subjects were asked to 'take the lane' and ride in the travel lane with no need to cross a rumble strip gap, they recorded their highest average speed of 35.5 mph. During Run 3, when bicyclists were constrained to the 4-ft shoulder area, the average speed decreased slightly by a 1.5 mph. While the average speed dropped to 31.2 mph and 31.0 mph when testing the 24-ft and 22-ft gap length respectively, this may be a result based on the order in which the runs of the experimental design were conducted. The first run (Run 4) in which participants were asked to attempt to cross any gap tested these two lengths, and since they were not told in advance what the gap length would be for any run, subjects may have ridden with additional caution through these initial gap event crossings. As the gap length continued to narrow, speeds continued to decrease; however, no average speeds were significantly different from one another for each gap event. At the narrowest gap event tested, the 12-ft gap length, bicyclists were on average 5.2 mph slower than their original speed using the full lane – the differences in average speed between the scenarios where subjects did not cross a gap versus where they did were statistically significant.

Examining the average comfort ratings, subjects appeared to adjust their speed to attempt to maintain an average score within the 'comfortable' to 'extremely comfortable' (4 - 5) range. The lowest level of comfort on average was observed for the 12-ft gap length with a rating of 3.4.

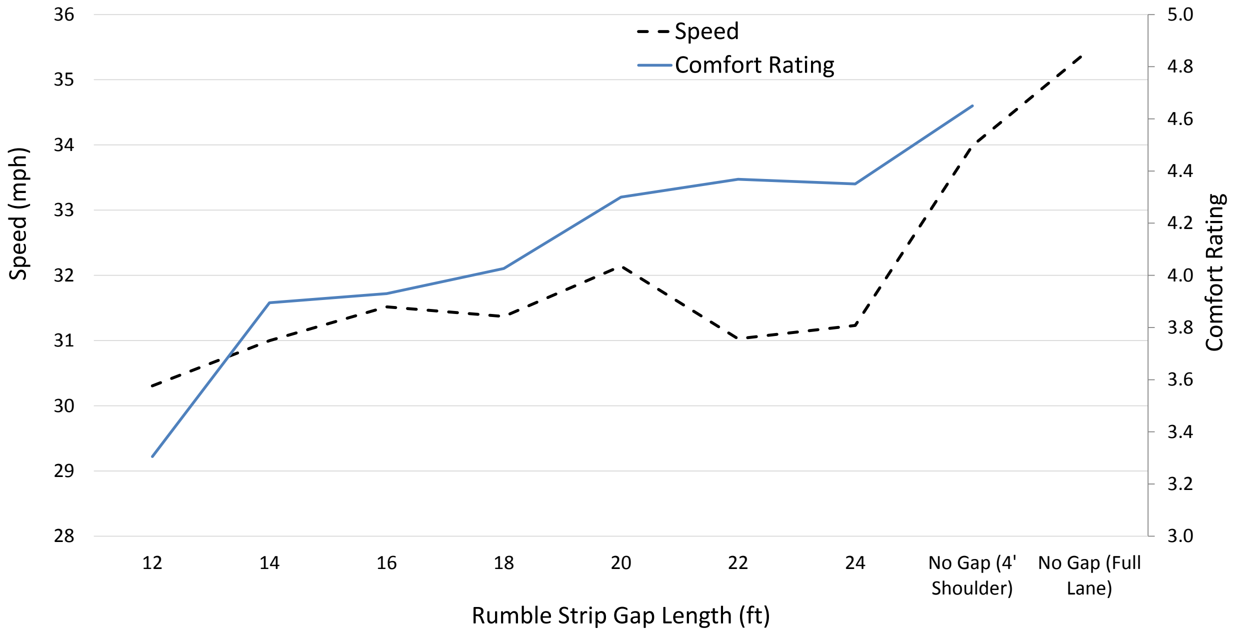

FIGURE 11 Bicyclist speed and reported comfort level by gap length.

When studying the relationship between speed, comfort, and shoulder width, the results support the previous findings that bicyclists adjust their speed to maintain a certain level of comfort. Figure 12 illustrates this relationship. Among different shoulder widths, the variation in speed was statistically significant only between 4 and 8 foot shoulders. Test subjects’ speed on average was 2.6 mph higher on runs using an 8-ft shoulder width than those using a 4-ft shoulder width.

FIGURE 12 Bicyclist speed and reported comfort level by shoulder width.

GAP LENGTH CONSIDERATIONS TO MOTOR VEHICLE IMPACTS

The provision of a sufficient width of paved shoulder benefits both cyclists and motorists, but SRS as a countermeasure to run-off-road vehicle crashes may be seen as an impediment to bicycle travel. Therefore, any changes in the design and implementation of SRS to apply them in a more bicycle-friendly way should consider how those changes on non-freeway roads may reduce their effectiveness as the countermeasure tool they are intended to be. Larger gaps in SRS can provide easier access for bicyclists to transition to the shoulder or to the lane, while the increased distance may negatively impact motorists by providing opportunities for vehicles to pass through the gap without striking the SRS and alerting the driver of the lane departure.

The following graph shows the relationship between departure angle and the maximum gap size possible for a departing vehicle to strike the rumble strips. For a three degree departure angle described by Moeur (*1*), 12-in wide rumble strips could have a maximum gap length of 19.1 ft. before the outside wheels of an errant vehicle could pass through without striking the SRS.

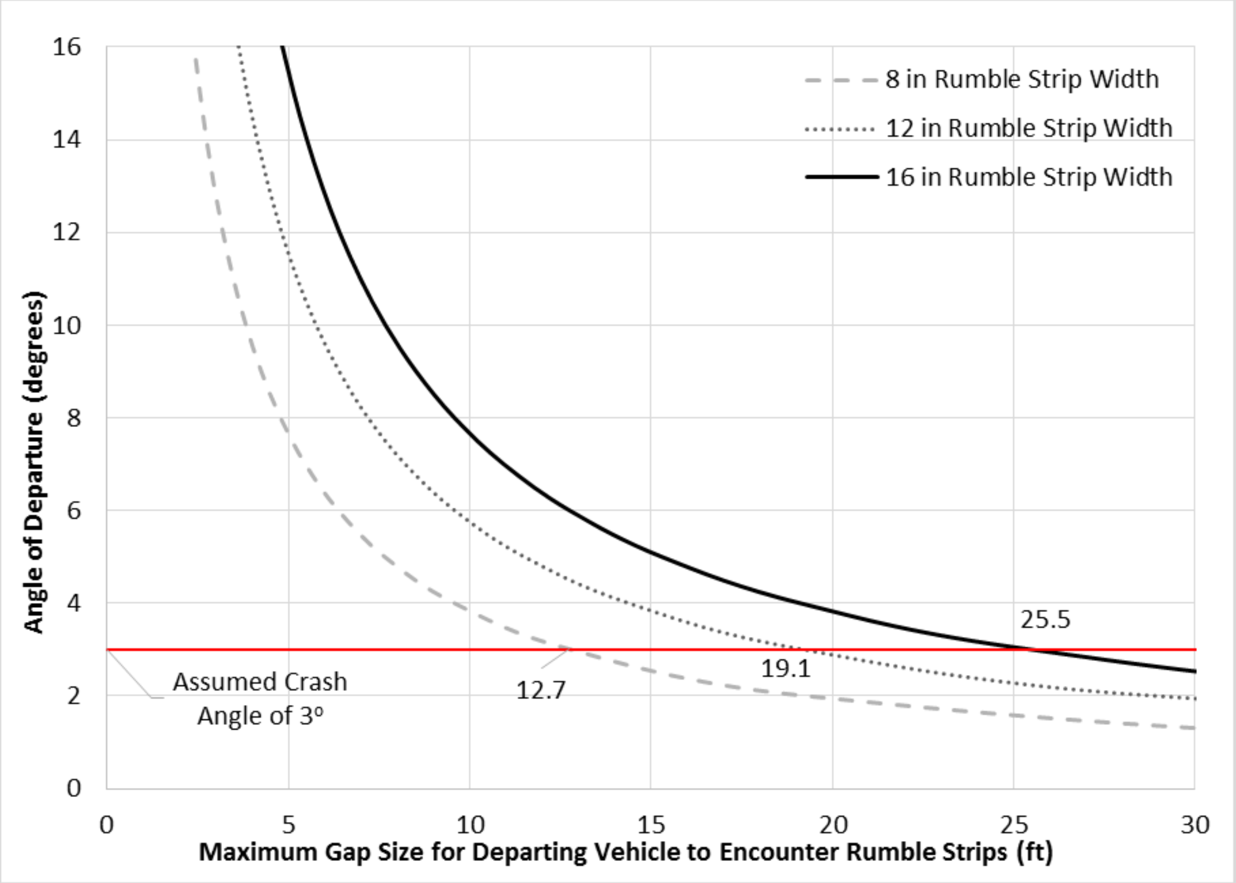

FIGURE 13 Relationship between a motor vehicle's angle of departure and the maximum gap length allowed ensuring the departing vehicle encounters the rumbles.

CONCLUSIONS

This study revealed a relationship between bicyclist comfort, speed, and rumble strip gap length when riding on steep, long downhill segments. Bicyclists are more likely to feel comfortable maintaining a naturally high speed while maneuvering through larger gap sizes between rumble strips. They are also less likely to make a maneuvering error (i.e. clip the rumbles) when given a longer gap to cross, which may reduce the potential for a bicyclist to lose control when maneuvering to or from the shoulder. Given that gap lengths of 16 to 18 feet would still be short enough for motorists to encounter a 12-in wide rumble strip assuming a lane departure of 3 degrees, consideration should be given to increasing the standard gap size on roads with authorized speed limits greater than 35 mph to allow bicyclists more comfort while maintaining their preferred speed than what they currently experience under the 12-ft gap length used in current practice.

While this study did not find a clear relationship between shoulder width and comfort for given gap lengths, the experimental design does not fully represent real-world situations. Since the experiment controlled for traffic to ensure the safety of test subjects, they did not have to consider traffic conditions before making the decision to cross any gap event. There are many reasons a bicyclist may need to cross a rumble strip – to avoid debris or poor pavement conditions in the shoulder; to ride with traffic on downhill segments where bicyclists may reach high speeds more comparable to adjacent motorist speeds, and where they may feel more comfortable with the wider lateral flexibility afforded them in the travel lane; or because they need to move left in advance of making a left-turn downstream. Depending on the reason, a bicyclist may have very little time to make the decision to cross. This study did not account for additional decision-making factors that a bicyclist would need to gather, such as shoulder-checking for traffic before merging, to form a true assessment of the level of comfort a bicyclist may feel when attempting to cross different gap lengths in prevailing traffic conditions.

In locations with adequate clear shoulder width, the likelihood that a bicyclist would need to move into the travel lane decreases. For example, wider shoulders that are routinely swept and free of surface imperfections or inlets may allow for an effective width of at least 4 ft to be maintained within the shoulder while avoiding debris or hazards in the bicyclist's travel path. Also, as the shoulder width approaches that of the adjacent travel lane, a bicyclist going higher speed downhill may feel that there is adequate space for lateral movement within the shoulder without the need to enter the travel lane. In these cases, the placement of a gap with advanced signage may be more important than the actual size of the gap itself, where gap placement may be prioritized in advance of locations where bicyclists tend to need to turn left. Strategically placing gaps near the top and bottom of a hill may also be effective where shoulder width is limited, to allow exit and entry points where bicyclists may be more inclined to ride with traffic of matching speeds on their downhill descent.

Likewise, modifications to the placement of gaps in SRS may be more important to maintaining the effectiveness of the SRS as a lane-departure countermeasure than concerns about using a gap length that may allow a vehicle to slip through, but further research is needed to substantiate this concept. Regardless of the gap length used, avoiding the placement of gaps or reducing their frequency in more hazardous spot locations, such as on the outside edge of a horizontal curve to the left in the direction of travel, where vehicles are more likely to depart the roadway towards the shoulder, may be warranted in favor of motorist safety performance. Locations of roadway less likely for lane departures, such as curves in the opposite direction or tangent roadway sections, may provide only minimally lower safety performance with elongated or more frequent gaps; however no research was found that tests this. Engineering judgment should also be used in the implementation of SRS to consider whether the road provides a critical bicycling connection, the type and quantity of traffic volumes, and speed differentials between motor vehicles and bicycles. Adverse factors for bicyclists may indicate the need for wide climbing bicycle lanes on uphill segments while encouraging cyclists to take the travel lane on steep, downhill sections where they may be traveling closer to motorist speeds.

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Roger Thomas P.E.
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John Vine-Hodge
Anthony D. Wyatt P.E.

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NCDOT Division 14, Traffic Services
Stecoah Township Rescue Squad and Fire Department

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APPENDIX A. CALCULATIONS AND ASSUMPTIONS

Speeds were calculated using an online modeling tool developed by Tom Compton. The tool is available online at www.analyticcycling.com/DiffEqMotionFunctions_Page.html. Using the calculator, the velocity (i.e. speed) of a cyclist riding down a hill of the indicated grade was modeled under two conditions: pedaling and rolling. Bicycle speed was calculated at five separate distances, at 0.1-mi increments, from 0.0 mi to 0.5 mi (0 to .8 km).

For each calculation, the percent downgrade was assumed to remain constant throughout the descent. Calculations to derive Figures 1 and 2 assume the bicyclist starts on the hill at 0 mph. Calculations to derive Figure 3 assume the bicyclist enters the percent grade in question from varying starting speeds of 10 mph, 20 mph, and 30 mph.

The only variables in the calculation were the distance at which speed was calculated and the percent slope of the road. A number of assumptions were made using the calculator:

- Total Weight (including cyclist and bicycle): 187 lbs. (85 kg)
- Air Friction Coefficient: 0.5
- Road Friction Coefficient: 0.004
- Average Power Generated When Pedaling: 0.34hp (0.25kW)
- Total Frontal Area of Cyclist and Bicycle: 5.4 ft^2 (0.5 m$^{2)}$

Total weight reflects the weight of both the cyclist and the bicycle together and is close the average combined weight of the test subjects their bicycles used in this study, providing a model that is congruent with the research content.

Both the air and road friction coefficients are unitless values that are used to account for the sources of friction slowing down a bicyclist in the modeled scenario. The air friction value above is generally applicable to most conditions, while the road friction coefficient provided is specifically applicable to losses from asphalt.

The average power generated is an approximation of the average energy output per second that a bicyclist can generate. This number is an estimate, and varies greatly from person to person. Generally speaking, the average healthy bicyclist can sustain 200 Watts when pedaling over a long period of time. A slightly higher value was chosen, since our test subjects only had to sustain their pedaling for a short duration.

The total frontal area provided is a default estimate suggested by the modeling tool. This measure factors in the air resistance on a bicyclist, and describes the exposed frontal area of the bicyclist and bicycle combined. Values can typically range from 0.4 to 0.7 m^2. A default of 0.5 m^2 is given in the calculator tool, and we felt no need to deviate from this value given our study purpose.

APPENDIX B. RECRUITMENT MATERIALS

Solicitation Recruitment Email

The following email template was sent to a list of contacts with a request to broadly distribute the email to their network of contacts. See the original list of contacts below as well as the flyer that was attached to the email.

Subject: Seeking Cyclists to Volunteer for Research Project

Hi All,

Please help us recruit participants by posting the attached flyer in your bike shop, or by distributing the information below to your members and friends through your normal channels. Feel free to contact me should you have questions.

Thanks in advance,
Sarah

We are seeking volunteer bicyclists for a research project this March! The Institute for Transportation Research and Education is conducting a study to evaluate how variations in gaps between rumble strips* affect a bicyclist’s ability to cross them when riding on roads with steep downhill grades.

If you participate in this study, you will help us test different options for gap-spacing between rumble strips by riding your bicycle through a designated test area in the mountains of western North Carolina near Almond, NC. Bicycling on downgrades of 4-8% at higher than average bicycle speeds will occur during the test scenarios.

We are holding several 4-hour study sessions in March 2014 near Almond, NC. To check available dates, or to learn more about the study, contact Sarah O’Brien at skworth@ncsu.edu or 919-515-8703.

Volunteers must meet the following eligibility criteria to participate:

- Be 18 years of age or older
- Have a properly fitted helmet
- Be able to bring to a bicycle in good working condition to the test area
- Be in good physical health
- Not be pregnant
- Be capable of safely bicycling above 20 mph

All participants will be asked to:

- Answer basic questions regarding yourself and your bicycling habits.
- Ride at higher than average bicycle speeds on downgrades of 4-8%.
- Give feedback after each test run.
- Be available for a 4-hour period on the study date.

*Rumble strips are a type of pavement treatment used to alert motorists of potential danger through vibrations and noise when a vehicle drives over them. They are often used along a road’s edge to prevent run-off-the-road crashes. Rumble strips can cause a safety concern for bicyclists attempting to cross them as doing so may cause discomfort or increase the possibility of falling or losing control of the bicycle. This is particularly true for cyclists who may be traveling downhill at higher than normal speeds.

Sarah Worth O’Brien
Bicycle and Pedestrian Program Manager
Institute for Transportation Research and Education
NC State University
919-515-8703

Recruitment Flyer

Would you like to participate in important research AND descend hills without having to climb?

We are seeking volunteer bicyclists for a research project this March! A study is being conducted to evaluate how variations in gaps between rumble strips* affect a bicyclist's ability to cross them when riding on roads with downhill grades. **A shuttle will take participants back to the top of the hill between descents.** Bicycling on downgrades of 7-8% or higher will occur during the test scenarios so a participant should be comfortable riding at higher than average bicycle speeds.

All participants will be asked to commit to one 4-hour study session in March 2014.

Weekend and weekday options are available. Research will occur near Almond, NC.

You must meet the following to be eligible to participate:

- Be 18 years of age or older
- Have a properly fitted helmet
- Be able to bring to a bicycle in good working condition to the test area
- Be in good physical health
- Not be pregnant
- Be capable of safely bicycling above 20 mph

All participants will be asked to:

- Answer basic questions about yourself and your bicycling habits.
- Ride at higher than averabe bicycle speeds on downgrades of 7-8%.
- Give feedback after each test run.
- Be available for the full 4-hour period.

To sign up, or to learn more about the study, contact Sarah O'Brien at skworth@ncsu.edu or (919) 515-8703

*Rumble strips are a type of pavement treatment used to alert motorists of potential danger through vibrations and noise when a vehicle drives over them. They are often used along a road's edge to prevent run-off-the-road crashes. Rumble strips can cause a safety concern for bicyclists attempting to cross them as doing so may cause discomfort or increase the possibility of falling or losing control of the bicycle. This is particularly true for cyclists who may be traveling downhill at higher than normal speeds.

This project is being conducted by the Institute for Transportation Research and Education at NC State University.

Outreach Contact List

Organization	Contact	Email	Secondary Email
Velo Girl Rides	Jennifer Caldwell-Billstrom	jen@velogirlrides.com	
Blue Ridge Bicycle Club	Joe Sanders	president@BlueRidgeBicycleClub.org	
Asheville Pedal Punks	Cullen Reed	cullen.reed@gmail.com	
Pisgah Area SORBA	Chris Strout	cstrout@pisgahareasorba.org	chris@pisgahareasorba.org
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Motion Makers Bicycle Shop		info@motionmakers.com	
Liberty Bicycles	Claudia Nix	claudianix@libertybikes.com	
Rolls Rite Bicycles		rollsrite@att.net	
Cane Creek (Bicycle Business)		info@canecreek.com	
Epic Cycles		epiccycles@bellsouth.net	
Beer City Bicycles		info@beercitybicycles.com	
The Bicycle Company		thebicycleco@yahoo.com	
City of Asheville	Barb Mee	bmee@ashevillenc.gov	
Tailwind Tandem Club		newsiesuziesisk@carolina.rr.com	
NC Recumbent Riders Association	Andrew Olls	getbent@jahoopa.com	fausto@vnet.net
Sycamore Cycles		wood@sycamorecycles.com	
City of Asheville	Kathy Molin	kmolin@ashevillenc.gov	
Bicycle Haywood	Cecil Yount	gr8smokieszeke@gmail.com	
Blue Ridge Bicycle Club	Jason Wilde	jasonmwilde@gmail.com	
Blood Sweat and Gears	Scott Nelson	sconelson@aol.com	
Carolina Tailwinds		Info@CarolinaTailwinds.com	
Hot Doggett 100		conmolland@frontier.com	
French Broad River MPO	Lyuba Zuyeva	lyuba@landofky.org	
Black Bear Adventures Bicycle Tours	Paul Wood	paul@blackbearadventures.com	
High Country Council of Governments	Phil Trew	ptrew@regiond.org	
Smoky Mountain Bicycles		info@smokymtnbikes.com	
Outdoor 76		info@outdoor76.com	
Nantahala Outdoor Center	Curt Roth	curt.roth@noc.com	
NCSU	George Hess	george_hess@ncsu.edu	

Follow-up Email to Prospective Test Subject

Thank you for expressing an interest in participating in this study! **Please complete item 1 below as soon as possible** so we can schedule you in this study.

General Information on the Study

We are seeking volunteer bicyclists for a research project to evaluate how variations in gaps between rumble strips affect their ability to cross them when riding on roads with downhill grades. Our study timeframe targets dates between March 7 – 16. A shuttle will take participants back to the top of the hill between descents. You should be comfortable at riding higher than average bicycle speeds, as the test area utilizes a 5-8% downgrade.

Location of the Test Area

This study is being conducted on NC 28 in Almond, NC (See a map of the general location here: http://goo.gl/maps/QqDDX). While the test area is located on a downhill segment of this public road, motor vehicle traffic will be stopped through the test area during each run. The research team will provide more details on parking, etc. when your study session is scheduled.

What You will be Asked to Do

1) Please fill out the Doodle Poll using this link (http://doodle.com/73eyfmy3ya93ckk6) to let me know for which dates and time sessions you are available during study timeframe. Only choose sessions for which you are available to participate for the full time listed. Each session is four (4) hours. You must respond to the poll by Wednesday, February 26. The research team will email you once the poll is closed to notify you of the appointment time and date for which you have been scheduled. This is to ensure we can balance the number of participants across any given study session. The poll is private, so only the poll administrator will see your responses.

2) Consent to participate. When your session time is confirmed, we will send you a consent form for you to review prior to arrival on-site. When you arrive, you will be asked to sign two copies of this form so that you can participate in the study.

3) Answer some questions. When your session time is confirmed, we will also send you a simple questionnaire to find out about you and your bicycling habits.

4) Ride your bicycle through a designated test area. The test area will be located on a downhill segment of a public road. The motor vehicle traffic on the road will be diverted from the test area through the use of standard traffic control measures.

   The first two times down the hill through the test area will allow you a chance to get acclimated to the terrain and grade of the road within the test area. You will be asked to ride as you normally would and as fast as you feel comfortable while maintaining control of your bicycle so that we can assess the typical speed you reach in the test area at your capability level based on your comfort and ability. Then, over the next several runs through the test area, the researchers will arrange a series of raised pavement markers to simulate a rumble strip with different size gaps. The gap within the simulated rumble strip will be reduced by two-foot increments, starting with a 24 foot gap. For each scenario, you will be asked to ride your bicycle as fast as you feel comfortable while maintaining control of your bicycle and attempt to cross the rumble strip at the gap by moving from the right side to the left (out of the shoulder area). You should attempt to cross the gap only to the extent that you feel comfortable and in control, and you should feel no pressure to maneuver through the gap if you feel unsafe in doing so.

The researchers will also adjust the placement of the simulated rumble strip in relation to the edge of the pavement to vary the width of the shoulder area from 4 feet to 8 feet, changing the shoulder width by two-foot increments between tests. For each scenario, you will also be asked to ride your bicycle as fast as you feel comfortable and attempt to cross the rumble strip at the gap only to the extent that you feel comfortable and in control by moving from the left side to the right (into the shoulder area).

5) Answer some more questions. At the end of each run, a researcher will ask you a few questions about your experience going through the test area.

What You Need to Bring to Participate

- A properly fitted helmet
- A bicycling in good working condition

Feel free to contact me if you have further questions.

Thank you,
Sarah

Appointment Confirmation Email to Test Subject

Hi [name],

This is to confirm your appointment to participate in the Rumble Strips and Bicycling research study for **[day], March [date], [4 hr session time].** In the event of inclement weather, your back-up appointment is [day], March [date], [4 hr session time]. See more below on inclement weather plans.

Directions and Parking
This study is being conducted on NC 28 in Almond, NC. Please use the Fingerlake Day Use parking area accessible from the eastbound side of NC 28. (See a map showing the parking location here: https://mapsengine.google.com/map/edit?mid=ze9ytX3xXXaE.kOoQAnyYMHZU.) The research team will meet you in the parking lot.

From Bryson City: Go on US-74 W/Great Smoky Mountains Expressway toward Murphy. Continue on US-74W about 8 miles to NC 28. Turn right on NC 28. After about 1 mile, make a U-turn at Watia Rd. (State Rd. 1121). Destination will be on your right.

Inclement Weather
Dress appropriately for the weather. We will be outside for the full study time. We will not conduct the study if conditions on the ground are wet. The research team will make the call on Wednesday, March 5 as to whether conditions are favorable to conduct the study over the first weekend dates (i.e. 3/7-

3/9). If, by Wednesday, March 5, it is determined that the following weekend’s conditions may be more ideal, we will follow up with you to confirm that you are still available for you scheduled back-up appointment session.

Weather can be finicky and less predictable in mountainous areas. Therefore, the research team reserves the right to cancel any individual study sessions should the weather become unsuitable due to safety concerns. If your study session is cancelled, you will be notified by phone and email. Therefore, it is important that you **send me your phone number(s)** where we can best reach you.

Consent Form
Attached is a copy of the consent form. Please review this prior to your arrival, but do not sign it. Two copies of the form will be supplied on-site for you and an authorized researcher to sign at that time. One copy will be kept by the researcher and the other copy will be yours to keep for your records.

Participant Questionnaire
Attached is a questionnaire. You may fill this out prior to your arrival, and bring a printed copy with you. We will also have copies on-hand, should you choose to fill it in on-site.

What You Need to Bring to Participate

- A properly fitted helmet
- A bicycling in good working condition
- Appropriate clothing for the temperature – layers may be key, if cold weather is forecast
- Sunscreen

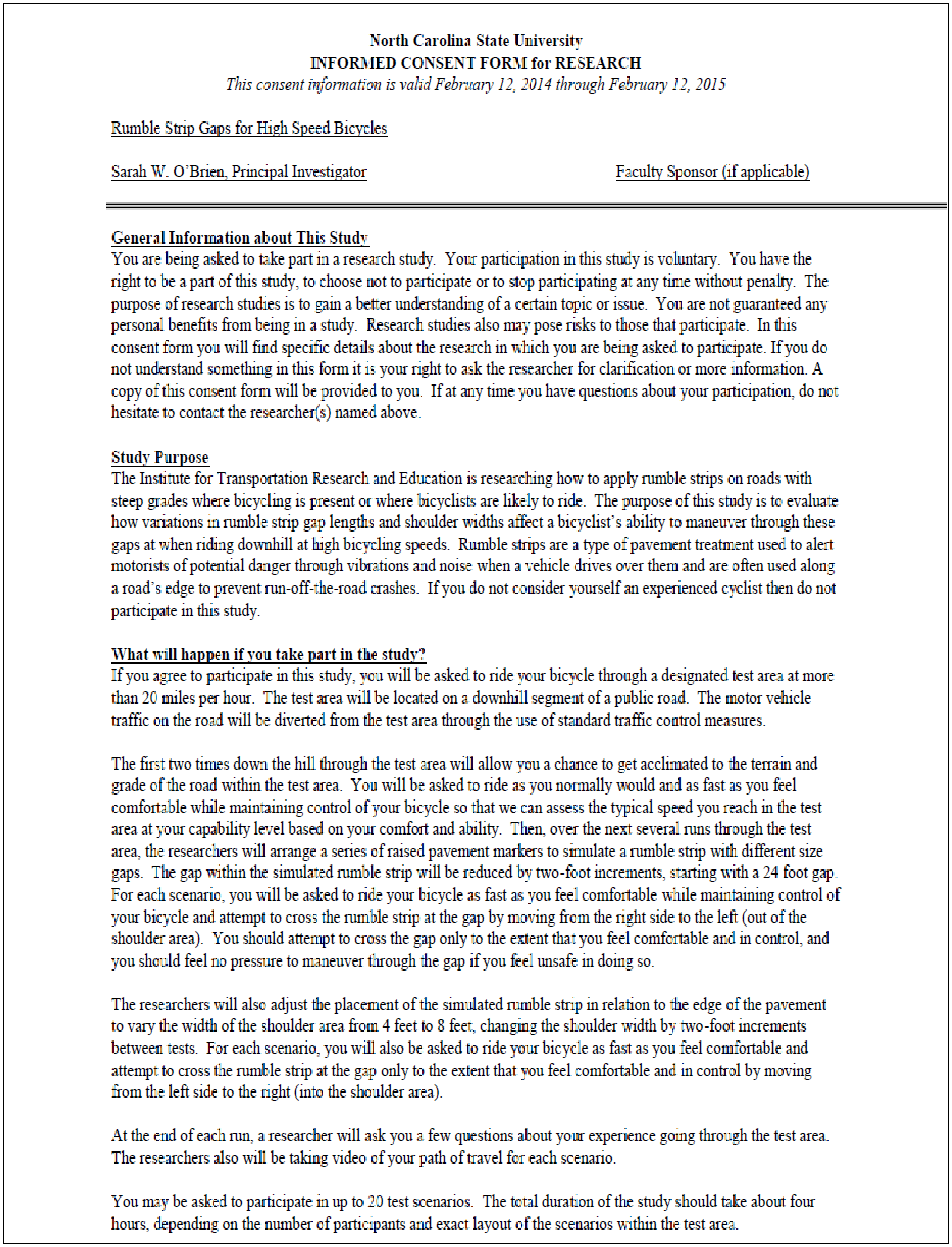
We will supply water and some snacks, but please bring your own if you have dietary restrictions or other special needs.

Feel free to contact me if you have further questions.

Thank you,
Sarah

Sarah Worth O’Brien
Bicycle and Pedestrian Program Manager
Institute for Transportation Research and Education
NC State University
919-515-8703

Consent Form



North Carolina State University
INFORMED CONSENT FORM for RESEARCH
This consent information is valid February 12, 2014 through February 12, 2015

Rumble Strip Gaps for High Speed Bicycles

Sarah W. O'Brien, Principal Investigator Faculty Sponsor (if applicable)

General Information about This Study

You are being asked to take part in a research study. Your participation in this study is voluntary. You have the right to be a part of this study, to choose not to participate or to stop participating at any time without penalty. The purpose of research studies is to gain a better understanding of a certain topic or issue. You are not guaranteed any personal benefits from being in a study. Research studies also may pose risks to those that participate. In this consent form you will find specific details about the research in which you are being asked to participate. If you do not understand something in this form it is your right to ask the researcher for clarification or more information. A copy of this consent form will be provided to you. If at any time you have questions about your participation, do not hesitate to contact the researcher(s) named above.

Study Purpose

The Institute for Transportation Research and Education is researching how to apply rumble strips on roads with steep grades where bicycling is present or where bicyclists are likely to ride. The purpose of this study is to evaluate how variations in rumble strip gap lengths and shoulder widths affect a bicyclist's ability to maneuver through these gaps at when riding downhill at high bicycling speeds. Rumble strips are a type of pavement treatment used to alert motorists of potential danger through vibrations and noise when a vehicle drives over them and are often used along a road's edge to prevent run-off-the-road crashes. If you do not consider yourself an experienced cyclist then do not participate in this study.

What will happen if you take part in the study?

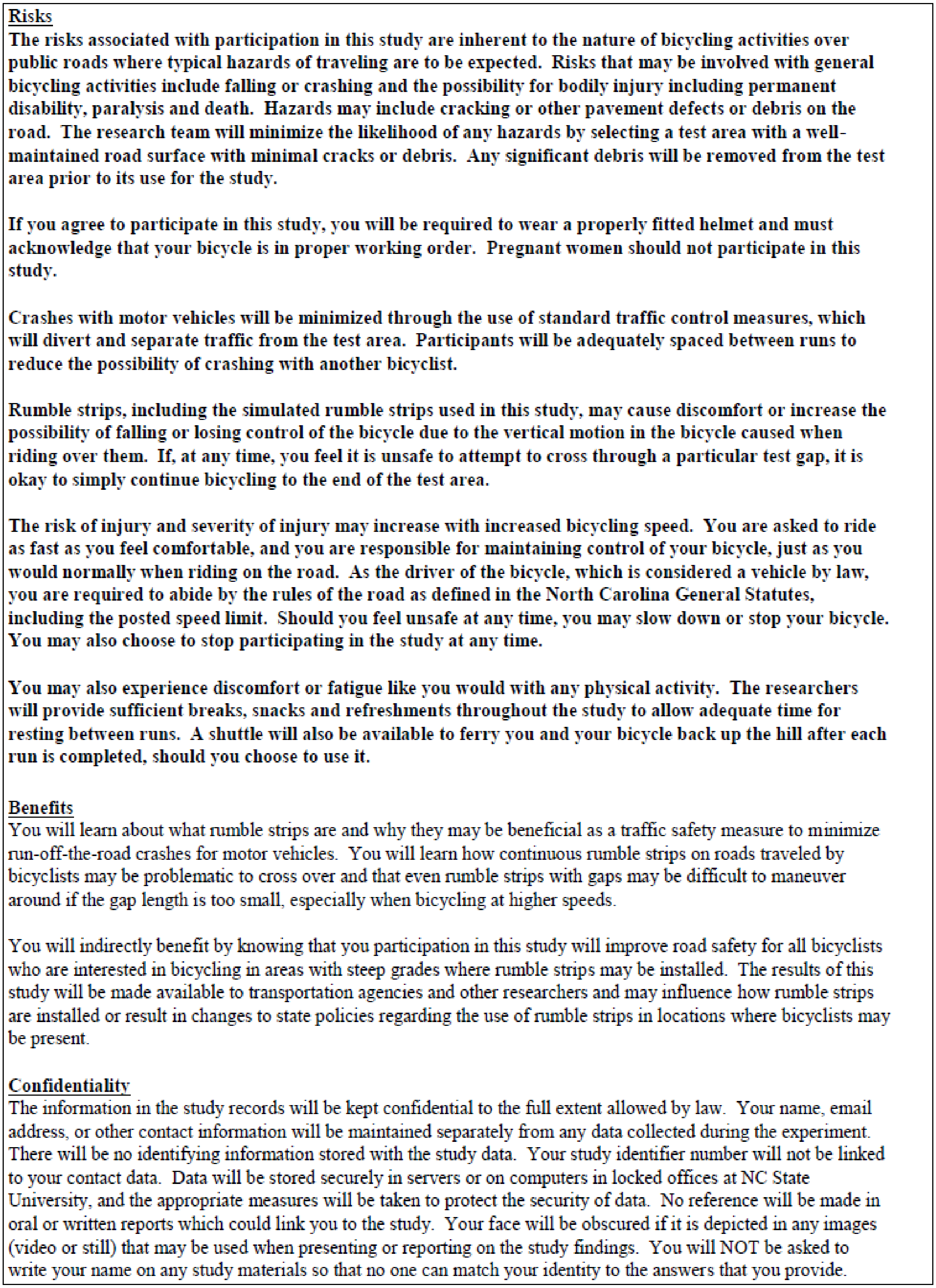
If you agree to participate in this study, you will be asked to ride your bicycle through a designated test area at more than 20 miles per hour. The test area will be located on a downhill segment of a public road. The motor vehicle traffic on the road will be diverted from the test area through the use of standard traffic control measures.

The first two times down the hill through the test area will allow you a chance to get acclimated to the terrain and grade of the road within the test area. You will be asked to ride as you normally would and as fast as you feel comfortable while maintaining control of your bicycle so that we can assess the typical speed you reach in the test area at your capability level based on your comfort and ability. Then, over the next several runs through the test area, the researchers will arrange a series of raised pavement markers to simulate a rumble strip with different size gaps. The gap within the simulated rumble strip will be reduced by two-foot increments, starting with a 24 foot gap. For each scenario, you will be asked to ride your bicycle as fast as you feel comfortable while maintaining control of your bicycle and attempt to cross the rumble strip at the gap by moving from the right side to the left (out of the shoulder area). You should attempt to cross the gap only to the extent that you feel comfortable and in control, and you should feel no pressure to maneuver through the gap if you feel unsafe in doing so.

The researchers will also adjust the placement of the simulated rumble strip in relation to the edge of the pavement to vary the width of the shoulder area from 4 feet to 8 feet, changing the shoulder width by two-foot increments between tests. For each scenario, you will also be asked to ride your bicycle as fast as you feel comfortable and attempt to cross the rumble strip at the gap only to the extent that you feel comfortable and in control by moving from the left side to the right (into the shoulder area).

At the end of each run, a researcher will ask you a few questions about your experience going through the test area. The researchers also will be taking video of your path of travel for each scenario.

You may be asked to participate in up to 20 test scenarios. The total duration of the study should take about four hours, depending on the number of participants and exact layout of the scenarios within the test area.



Risks

The risks associated with participation in this study are inherent to the nature of bicycling activities over public roads where typical hazards of traveling are to be expected. Risks that may be involved with general bicycling activities include falling or crashing and the possibility for bodily injury including permanent disability, paralysis and death. Hazards may include cracking or other pavement defects or debris on the road. The research team will minimize the likelihood of any hazards by selecting a test area with a well-maintained road surface with minimal cracks or debris. Any significant debris will be removed from the test area prior to its use for the study.

If you agree to participate in this study, you will be required to wear a properly fitted helmet and must acknowledge that your bicycle is in proper working order. Pregnant women should not participate in this study.

Crashes with motor vehicles will be minimized through the use of standard traffic control measures, which will divert and separate traffic from the test area. Participants will be adequately spaced between runs to reduce the possibility of crashing with another bicyclist.

Rumble strips, including the simulated rumble strips used in this study, may cause discomfort or increase the possibility of falling or losing control of the bicycle due to the vertical motion in the bicycle caused when riding over them. If, at any time, you feel it is unsafe to attempt to cross through a particular test gap, it is okay to simply continue bicycling to the end of the test area.

The risk of injury and severity of injury may increase with increased bicycling speed. You are asked to ride as fast as you feel comfortable, and you are responsible for maintaining control of your bicycle, just as you would normally when riding on the road. As the driver of the bicycle, which is considered a vehicle by law, you are required to abide by the rules of the road as defined in the North Carolina General Statutes, including the posted speed limit. Should you feel unsafe at any time, you may slow down or stop your bicycle. You may also choose to stop participating in the study at any time.

You may also experience discomfort or fatigue like you would with any physical activity. The researchers will provide sufficient breaks, snacks and refreshments throughout the study to allow adequate time for resting between runs. A shuttle will also be available to ferry you and your bicycle back up the hill after each run is completed, should you choose to use it.

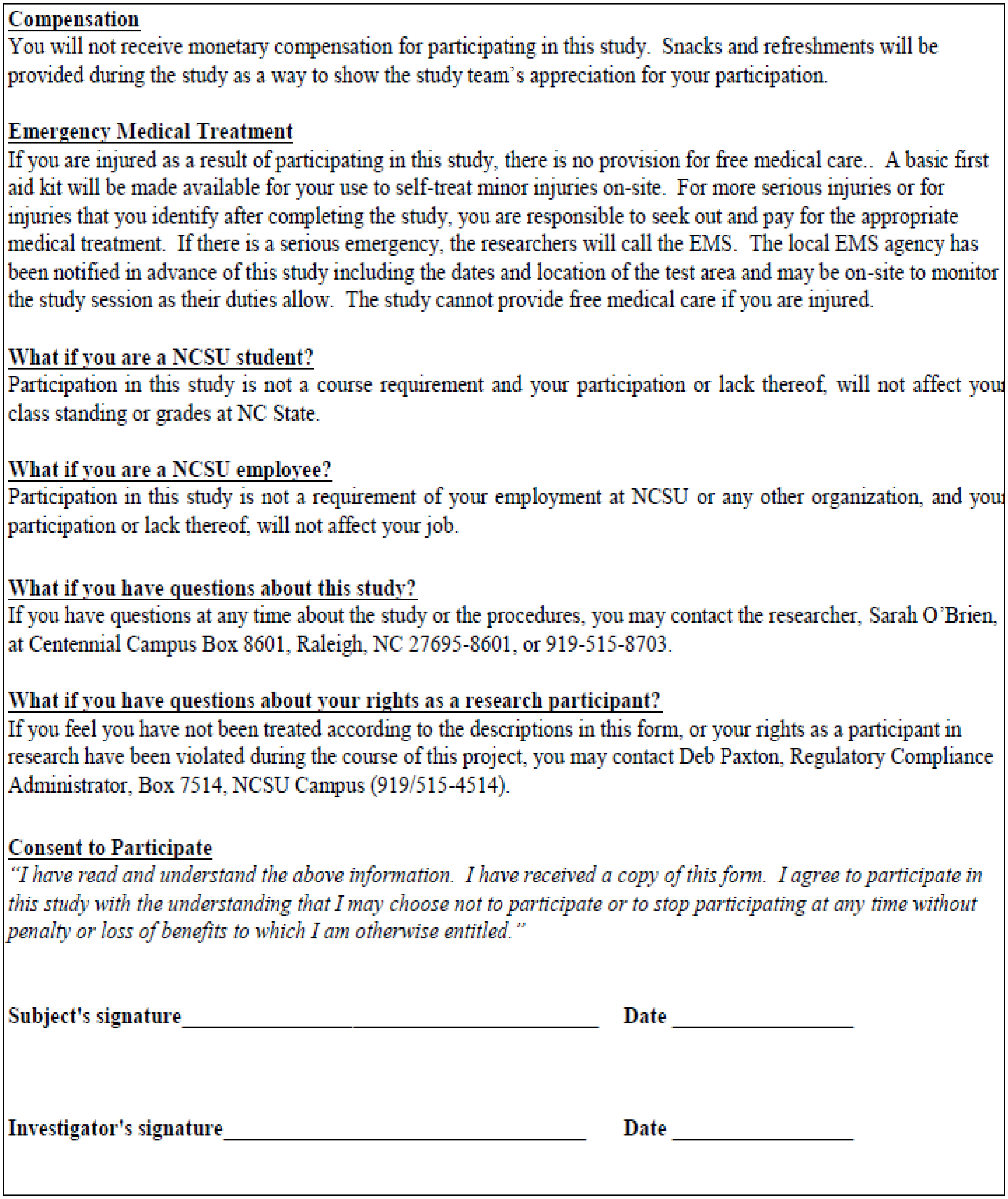
Benefits

You will learn about what rumble strips are and why they may be beneficial as a traffic safety measure to minimize run-off-the-road crashes for motor vehicles. You will learn how continuous rumble strips on roads traveled by bicyclists may be problematic to cross over and that even rumble strips with gaps may be difficult to maneuver around if the gap length is too small, especially when bicycling at higher speeds.

You will indirectly benefit by knowing that you participation in this study will improve road safety for all bicyclists who are interested in bicycling in areas with steep grades where rumble strips may be installed. The results of this study will be made available to transportation agencies and other researchers and may influence how rumble strips are installed or result in changes to state policies regarding the use of rumble strips in locations where bicyclists may be present.

Confidentiality

The information in the study records will be kept confidential to the full extent allowed by law. Your name, email address, or other contact information will be maintained separately from any data collected during the experiment. There will be no identifying information stored with the study data. Your study identifier number will not be linked to your contact data. Data will be stored securely in servers or on computers in locked offices at NC State University, and the appropriate measures will be taken to protect the security of data. No reference will be made in oral or written reports which could link you to the study. Your face will be obscured if it is depicted in any images (video or still) that may be used when presenting or reporting on the study findings. You will NOT be asked to write your name on any study materials so that no one can match your identity to the answers that you provide.



Compensation
You will not receive monetary compensation for participating in this study. Snacks and refreshments will be provided during the study as a way to show the study team’s appreciation for your participation.

Emergency Medical Treatment
If you are injured as a result of participating in this study, there is no provision for free medical care.. A basic first aid kit will be made available for your use to self-treat minor injuries on-site. For more serious injuries or for injuries that you identify after completing the study, you are responsible to seek out and pay for the appropriate medical treatment. If there is a serious emergency, the researchers will call the EMS. The local EMS agency has been notified in advance of this study including the dates and location of the test area and may be on-site to monitor the study session as their duties allow. The study cannot provide free medical care if you are injured.

What if you are a NCSU student?
Participation in this study is not a course requirement and your participation or lack thereof, will not affect your class standing or grades at NC State.

What if you are a NCSU employee?
Participation in this study is not a requirement of your employment at NCSU or any other organization, and your participation or lack thereof, will not affect your job.

What if you have questions about this study?
If you have questions at any time about the study or the procedures, you may contact the researcher, Sarah O’Brien, at Centennial Campus Box 8601, Raleigh, NC 27695-8601, or 919-515-8703.

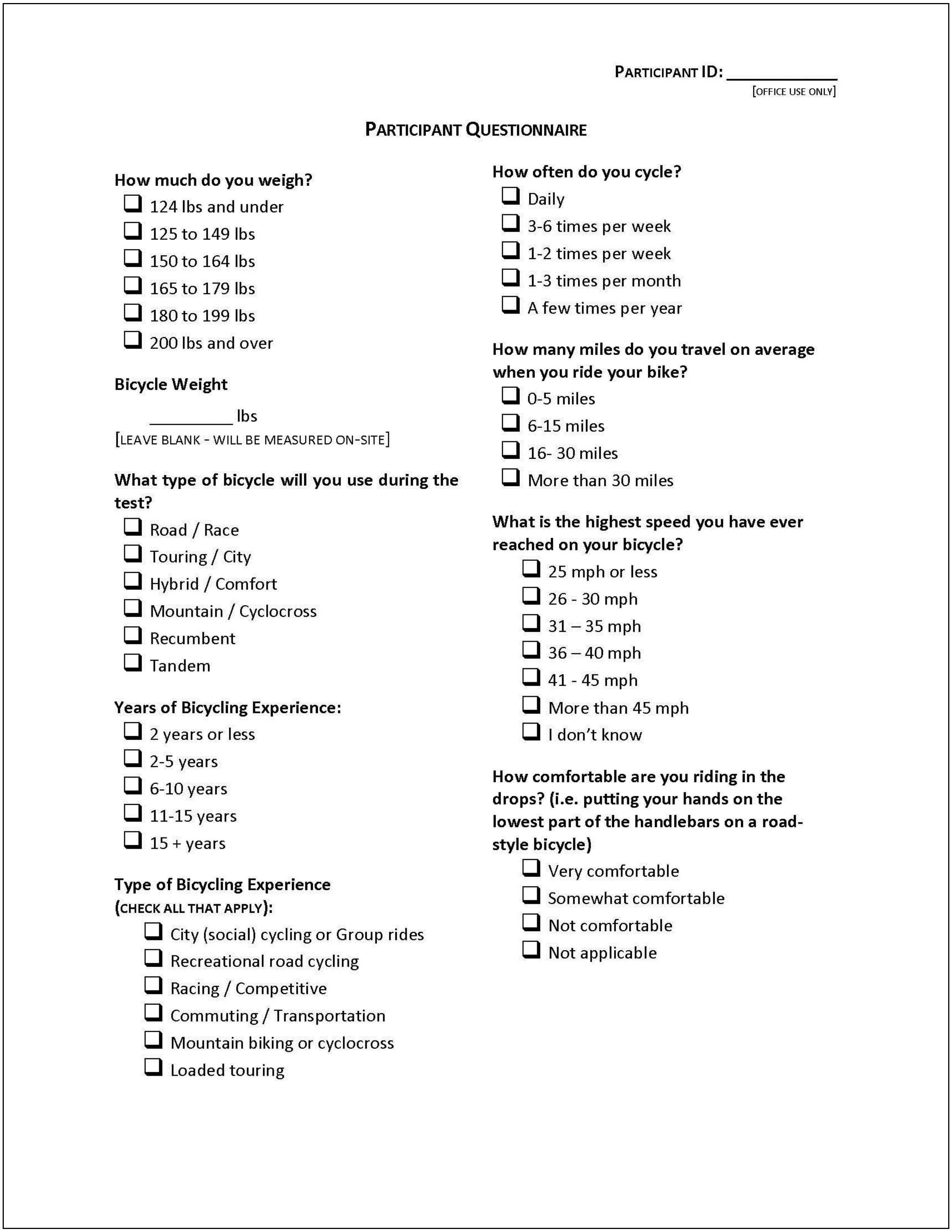
What if you have questions about your rights as a research participant?
If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Deb Paxton, Regulatory Compliance Administrator, Box 7514, NCSU Campus (919/515-4514).

Consent to Participate
“I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may choose not to participate or to stop participating at any time without penalty or loss of benefits to which I am otherwise entitled.”

Subject's signature____ **Date** ________________

Investigator's signature__________________________________ **Date** ________________

APPENDIX C. PRE-TEST QUESTIONNAIRE



PARTICIPANT ID: ____________
[OFFICE USE ONLY]

PARTICIPANT QUESTIONNAIRE

How much do you weigh?
- ☐ 124 lbs and under
- ☐ 125 to 149 lbs
- ☐ 150 to 164 lbs
- ☐ 165 to 179 lbs
- ☐ 180 to 199 lbs
- ☐ 200 lbs and over

Bicycle Weight

__________ lbs
[LEAVE BLANK - WILL BE MEASURED ON-SITE]

What type of bicycle will you use during the test?
- ☐ Road / Race
- ☐ Touring / City
- ☐ Hybrid / Comfort
- ☐ Mountain / Cyclocross
- ☐ Recumbent
- ☐ Tandem

Years of Bicycling Experience:
- ☐ 2 years or less
- ☐ 2-5 years
- ☐ 6-10 years
- ☐ 11-15 years
- ☐ 15 + years

Type of Bicycling Experience (CHECK ALL THAT APPLY):
- ☐ City (social) cycling or Group rides
- ☐ Recreational road cycling
- ☐ Racing / Competitive
- ☐ Commuting / Transportation
- ☐ Mountain biking or cyclocross
- ☐ Loaded touring

How often do you cycle?
- ☐ Daily
- ☐ 3-6 times per week
- ☐ 1-2 times per week
- ☐ 1-3 times per month
- ☐ A few times per year

How many miles do you travel on average when you ride your bike?
- ☐ 0-5 miles
- ☐ 6-15 miles
- ☐ 16- 30 miles
- ☐ More than 30 miles

What is the highest speed you have ever reached on your bicycle?
- ☐ 25 mph or less
- ☐ 26 - 30 mph
- ☐ 31 – 35 mph
- ☐ 36 – 40 mph
- ☐ 41 - 45 mph
- ☐ More than 45 mph
- ☐ I don't know

How comfortable are you riding in the drops? (i.e. putting your hands on the lowest part of the handlebars on a road-style bicycle)
- ☐ Very comfortable
- ☐ Somewhat comfortable
- ☐ Not comfortable
- ☐ Not applicable

PARTICIPANT ID: ____________
[OFFICE USE ONLY]

What is the fastest speed at which you feel you would be comfortable riding your bicycle on a long downhill stretch?

- ☐ 25 mph or less
- ☐ 26 - 30 mph
- ☐ 31 – 35 mph
- ☐ 36 – 40 mph
- ☐ 41 - 45 mph
- ☐ More than 45 mph
- ☐ I don’t know

From the following list, please indicate what type of cyclist you self-identify as:

- ☐ Interested but Concerned
- ☐ Enthused and Confident
- ☐ Strong and Fearless

Please describe any formal bicycle training you’ve received or any bicycling skills courses that you’ve taken:

____

____

____

____

Have you ever ridden your bicycle on a road with shoulder rumble strips?

- ☐ No
- ☐ Yes

If yes, did you cross, or need to cross, the rumble strip?

- ☐ No
- ☐ Yes

If yes, please describe that experience (i.e. why did you cross/need to cross; were there gaps to accommodate crossing; how easy or comfortable was it to do?)

____

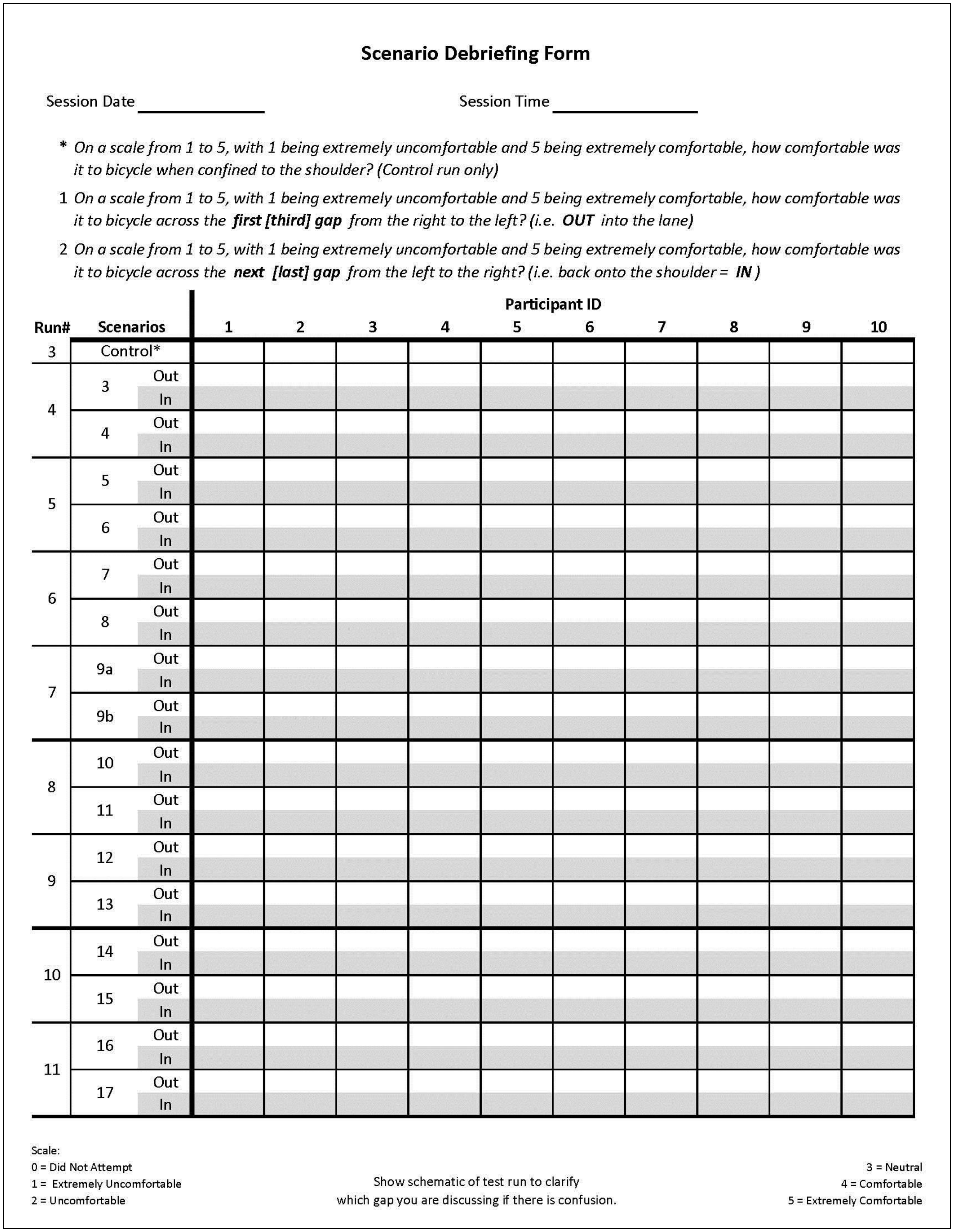
____

____

____

____

APPENDIX D. SCENARIO DEBRIEFING FORM



Scenario Debriefing Form

Session Date ______________

Session Time ________________

* *On a scale from 1 to 5, with 1 being extremely uncomfortable and 5 being extremely comfortable, how comfortable was it to bicycle when confined to the shoulder? (Control run only)*

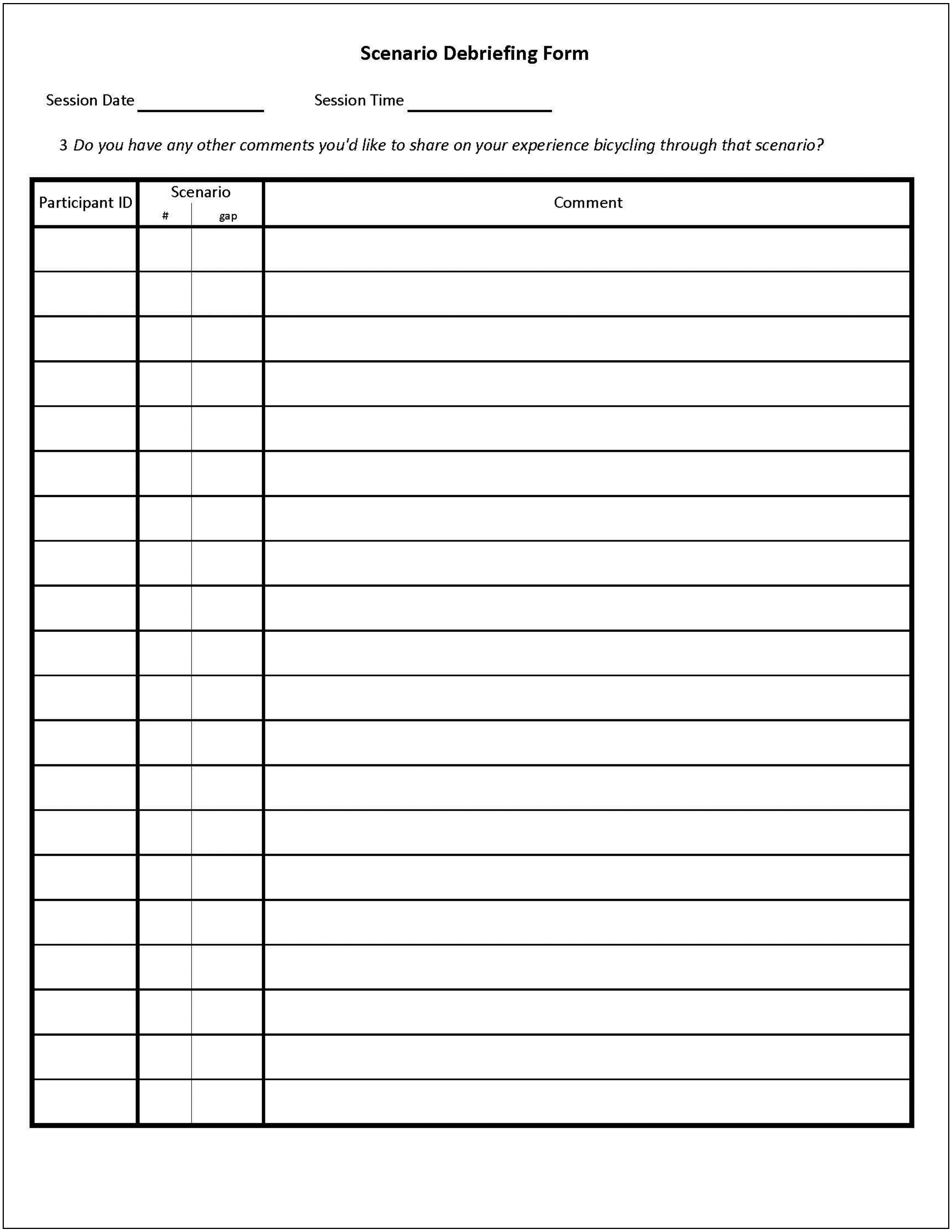
1 *On a scale from 1 to 5, with 1 being extremely uncomfortable and 5 being extremely comfortable, how comfortable was it to bicycle across the **first [third] gap** from the right to the left? (i.e. **OUT** into the lane)*

2 *On a scale from 1 to 5, with 1 being extremely uncomfortable and 5 being extremely comfortable, how comfortable was it to bicycle across the **next [last] gap** from the left to the right? (i.e. back onto the shoulder = **IN**)*

			Participant ID									
Run#	**Scenarios**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
3	Control*											
4	3	Out										
		In										
	4	Out										
		In										
5	5	Out										
		In										
	6	Out										
		In										
6	7	Out										
		In										
	8	Out										
		In										
7	9a	Out										
		In										
	9b	Out										
		In										
8	10	Out										
		In										
	11	Out										
		In										
9	12	Out										
		In										
	13	Out										
		In										
10	14	Out										
		In										
	15	Out										
		In										
11	16	Out										
		In										
	17	Out										
		In										

Scale:
0 = Did Not Attempt
1 = Extremely Uncomfortable
2 = Uncomfortable
3 = Neutral
4 = Comfortable
5 = Extremely Comfortable

Show schematic of test run to clarify which gap you are discussing if there is confusion.



Scenario Debriefing Form

Session Date ______________ Session Time ________________

3 *Do you have any other comments you'd like to share on your experience bicycling through that scenario?*

Participant ID	Scenario		Comment
	#	gap	