The Road Environment and Bicyclists' Psychophysiological Stress

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MOTIVATION

What makes a safe bicycling environment? People may disagree on an answer to this question, but it is clear that a perceived safe bicycling environment is a necessary condition for bicycling to thrive as a normal mode of travel. Although it is not the only important factor (Black & Street, 2014), safety is often seen as the largest impediment to bicycling (Sallis et al., 2013; Sanders, 2015). Common explanatory measurements used to define safe bicycling environments include the physical road (e.g. lane widths, types of bicycling infrastructure, road slope, etc.), and car driver behavior (e.g. speed, volume, etc.). However, outcome measures of safety are much more limited; they include bicyclists preferences (e.g. survey responses of perceived safety), and injuries (e.g. collision data, hospital records). We propose another measure, intrinsically linked to the concept of safety, bicyclists' acute psychological stress.

We are not the first to propose that acute stress may be an important measure of the bicycling experience (Caviedes & Figliozzi, 2016; Doorley et al., 2015; Vieira, Costeira, Brand, & Marques, 2016). Indeed, the term stress has been used loosely in bicycling research for some time (Sorton & Walsh, 1994). We have a more narrow focus, the examination of bicyclists' acute psychological stress from the road environment through physiologic data using wearable technology. The connection between safety, stress, and physiology is clear; if safety is uncertain, stress is the default neurobiological response (Brosschot, Verkuil, & Thayer, 2016). Our focus on the relationship between the road environment and stress is an example of the overarching concept of *environmental stress*: environmental characteristics that lead to psychological discomfort (Evans & Cohen, 1987). In the case of day to day bicycling, the road environment may only have a small direct influence on bicyclists' stress (e.g. pavement roughness can make bicyclists worry about crashing their bike). However, the road indirectly controls driver behavior (e.g. wide lanes lead drivers to increase their speed), which has a direct relationship with bicyclists' stress. With a better understanding of how the road environment influences bicyclists' stress, we can provide better guidance to planners and engineers about how to design roads that increase safety and encourage bicycling.

OBJECTIVE

Our overarching goal is to improve our understanding of what makes for safe and comfortable bicycling environments. We do this by considering the bicycling experience, specifically focusing on the acute psychological stress of bicycling in different road environments. We also examine the relationship between survey measures of bicycling comfort and physiological responses to validate both measurement types.

DATA AND METHODS

We designed a within-subject (i.e. cross-over or repeated measures) experiment to examine real world bicycling experiences across numerous road conditions in Davis, California. We collected data in the spring and fall of 2016. Our experiment includes an all-female college undergraduate cohort ($n \approx 20$) where we measure subjects' acute stress physiologically through a heart beat-to-beat measuring device (an approach often labeled heart rate variability (HRV) analysis), and subject anxiety and comfort through questionnaires. We consider five primary experimental conditions (varying road environments), three speed trials, and one computer-based psychological stress test (dual 2-back) to examine the relationship between the road environment and bicyclist acute psychological stress.

We define stress through the high frequency (spontaneous breathing range) variation of heart beat-to-beat intervals. This measure most closely aligns with vagal tone (activity of the vagus nerve) which represents the functional state of the parasympathetic nervous system (Porges, 2007). Following normal preprocessing steps for beat-to-beat data (e.g. outlier removal, resampling), we extract the high frequency variation of the beat-to-beat signal using the so-called Maximal Overlap Discrete Wavelet Transform (MODWT). This method decomposes the non-stationary (mean and variance vary over time during bouts of moderate exercise) beat-to-beat signal into frequency components associated with spontaneous breathing.

We model the variance of the high frequency beat-to-beat signal (high variance is associated with low stress, and low variance with high stress) as a dependent variable in a series of multi-level regression models. These models help us evaluate the influence of experimental road conditions (Table 1) on stress, conditional on speed (indicator of physical exertion) and other "control" variables thought to influence heart beats (e.g. individual, state anxiety, BMI, bicycling experience, vehicle volume, pavement condition, wind, etc.).

Table 1. Observed Road Characteristics and Experimental Conditions

Road Characteristics

- Number of vehicular lanes
- Outside lane width
- Presence of median
- Presence and width of bike lane
- Bike lane configuration (e.g. buffer, etc.)
- Presence and width of on-street parking
- Posted speed limit
- Intersection configurations (e.g. pocket lanes, turn lane designs)

Experimental Condition Summary

	ADT	*Speed (mph)*	*Lanes*	*Parking*	*Bike Lane*
Local	NA	NA	2 (no centerline)	Yes	No
Collector #1	~2,000	NA	2	Yes	Conventional
Collector #2	~6,000	22-33	2	No	Buffered
Collector #3 (minor arterial)	~10,000	25-36	2	Yes	Conventional
Arterial	~20,000	27-36	4 (median)	Varies	No

CONTRIBUTION

Preliminary results suggest that stress (as we've defined it) is associated with the road environment. Intra-subject stress differences between experimental conditions are considerable for the more extreme cases (i.e. local road and arterial), but more equivocal for the less extreme cases (i.e. different configurations of collectors). However, the magnitudes of differences by condition between subjects show large variation. Preliminary results also clearly point to bicyclists' speed change as a key explanation to changing heart beats (reduction of variance). This is likely due to both changes in physical exertion (acceleration and deceleration) and psychological stress, especially near intersections. Because of this, our study may be limited to evaluating stress where speed is more constant such as road segments. Our ongoing analysis will examine the interactions between different road characteristics and their influence on stress. This is especially important because road characteristics are not independent from each other and must be considered jointly to inform improved road designs to increase bicycling safety and encourage normal day-to-day bicycling.

Our research into bicyclist acute psychological stress provides a clear advancement in the identification of a safe bicycling environment. Acute stress measured through physiology is a potential safety measure with fine temporal resolution, one dimension currently lacking in bicycling safety measures. Importantly, our goal of connecting stress to survey questionnaires may provide a way to model expected stress from simple stated preference questionnaires. Finally, because this is one of the first attempts to measure the bicycling experience through physiology, we suggest this research has a much broader scientific impact. This type of measurement could be extended to other travel research (e.g. walking, transit), and possibly other realms of urban planning (e.g. architecture).

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