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Modeling the impact of traffic conditions and bicycle facilities on cyclists' on-road stress levels

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ABSTRACT

Past research efforts have shown that cyclists' safety, stress, and comfort levels greatly affect the routes chosen by cyclists and cycling frequency. Some researchers have tried to categorize cyclists' levels of traffic stress utilizing data that can be directly measured in the field, such as the number of motorized travel lanes, motorized vehicle travel speeds, and type of bicycle infrastructure. This research effort presents a novel approach: real-world, on-road measurements of physiological stress as cyclists travel across different types of bicycle facilities at peak and off-peak traffic times. By matching videos with stressful events, it was possible to observe the circumstances of those stressful events. The stress data was normalized, and the method was carefully validated by a detailed analysis of the stress measurements. Novel statistical results from a multi-subject study quantifies the impact of traffic conditions, intersections, and bicycle facilities on average stress levels.

1. Introduction

Many cities have ambitious plans to increase bicycle mode share in the short and long term. These plans motivated researchers to better understand where and what types of bicycle improvements yield the maximum net benefit in terms of increased ridership, comfort, and safety. Transportation engineers and planners have attempted to estimate cyclists' safety, comfort, stress levels, and level of service using two experimental design approaches: naturalistic and non-naturalistic studies. In a naturalistic approach, the subject is observed or analyzed in his or her natural environment (on-road) while cycling without any significant manipulation or interference. In a non-naturalistic study, the subject is analyzed in an artificial setting or provides data executing an activity that is not cycling—for example, in a laboratory or through a web-survey.

Most non-naturalistic studies have used surveys, photos, and/or films to understand cyclists' preferences. For example, the subjects evaluate different environments or facilities by looking at pictures of intersections and/or corridors. Non-naturalistic studies are useful to investigate cyclists' perceived comfort and preferences for various types of bicycle facilities. Nonetheless, this approach may result in bias due to the subjectivity of the metrics and the nature of stated versus revealed (or measured) preferences or responses. Surveys and laboratory settings do not always reflect the psychological and physiological responses that occur in a natural setting. Picard, Vyzas, and Healy (2001) suggest that when measuring human emotions and perceptions, the researcher has to be aware that questions related to a subject's personal feelings can produce

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answers which vary "according to her awareness of her feelings, her comfort in talking about feelings, her rapport with the administrator of the experiment and more."

Naturalistic studies are designed to collect data by investigating the subject in his or her natural riding environment without any significant interference. Using video, Johnson, Newstead, Charlton, and Oxley (2001) found that the main variables associated with red light infringement are a function of cyclists' safety perceptions of opposing traffic volumes. Chuang, Ksu, Lai, Doong, and Jeng (2013) collected field data using a bicycle equipped with various sensors and cameras. The authors found that cyclists' behavior changes with proximity to motorized vehicles. They also found that a demarcated bike lane generates a higher distance between the cyclist and the motor vehicle than riding on the right of the motorized vehicle lane without demarcation; more separation from motorized vehicles is perceived positively by cyclists (Carter, Hunter, Zegeer, & Stewart, 2007). The Bicycle Level of Service (BLOS) of the 2010 *Highway Capacity Manual* (*HCM*) measures the performance of bicycle users and facilities using data directly collected in the field (Transportation Research Board, 2010); however, this methodology is not based on naturalistic data as defined in this paper; users were asked to rate different types of facilities after watching video clips filmed from a bicycle. Alternately, using revealed GPS data from on-road, real-world bicycle trips, Harvey, Krizek, and Collins (2008) found that cyclists are willing to travel longer distances to their destinations in order to achieve high levels of safety and comfort. A limitation of the cited naturalistic studies is the lack of consideration of stress measurements while the subject is cycling—videos and bicycle sensors cannot measure the level of stress that a cyclist is experiencing while making a route decision or simply biking.

Summarizing, naturalistic and non-naturalistic studies have pros and cons and ideally complement each other. This research is a multi-subject research study linking real-world, on-road cyclists' stress measurements with roadway characteristics. Some researchers have previously used the term stress to characterize bicycle-riding conditions. For example, bicycle level of stress (BLS) has been described as a function of safety levels and physical/mental effort and age (Sorton & Walsh, 1994), while level of traffic stress (LTS) is a function of traffic/geometric variables and the different user groups' characteristic within the population (Mekuria, Furth, & Nixon, 2012). Despite their names, neither BLS nor LTS is based on real-world, on-road stress measurements. BLS and LTS are relatively intuitive and simple to apply, but they are not supported by real-world, on-road empirical evidence. This research is the first step to filling this research gap.

The key research questions of this study are the following: (a) what is the impact of traffic conditions (peak vs. off-peak) on cyclists' stress levels, and (b) what is the impact of different facility types (bike lane, shared road, dedicated path) on cyclists' stress levels?

2. Stress background

The term stress can be defined as "the non-specific mix of physiological and psychological responses of the body to any demand of change" (Seyle, 1956). It is a reaction from a calm state to an excited state for the purpose of being alert during a situation in which the subject feels threatened or attacked. Stressful events, such as biking too close to motorized traffic, cause dynamic changes in the autonomic nervous system (ANS); more specifically, stressful events cause an increase in sympathetic nervous system (SNS) activity (Wilfrid & McLachlan, 1992) and a decrease in parasympathetic nervous system (PNS) activity, which is evidenced by changes in heart rate, blood pressure, breathing rate, and galvanic skin response (GSR) (Sharma & Gedeon, 2012).

For nearly four decades, psychologists have studied stress levels by collecting physiological data. Various studies have found a definitive association between specific human emotions and physiological responses such as heart rate, skin conductance, blood pressure, breath rate, etc. (Boucsein, 2012). Physiological responses can also be used to predict emotional state. Friedlund and Izard (1983) were the first to recognize emotions from physiological responses, attaining rates of 38–51% accuracy using electromyogram signals (an electromyogram, or EMG, measures the electrical activity of muscles at rest and during contraction). It is possible to differentiate states of anger and fear (Ax, 1953) and states of conflict and non-conflict using GSR and heart rates (Kahneman, 1973). Ekman, Levenson, and Friesen (1983) found evidence for distinctive patterns of autonomic nervous (ANS) activity for anger, disgust, and possibly sadness. Helander (1978) found that GSR was the best predictor to measure the impact of stressful events on a subject. Labbé, Schmidt, and Babin (2007) found that when an individual is under stress, skin conductance increases due to an increase in sweat activity. Physiological responses have the potential to represent internal human states influenced by cognitive and social variables (Picard et al., 2001); some internal human emotional responses can be measured using noninvasive methods (Lanzetta & Orr, 1986).

GSR-based studies have been successfully employed for many years in the psychological field to recognize and associate emotions and behaviors to physiological responses. In previous studies, GSR yielded the most accurate data for measuring stress in human subjects compared to surveys or questionnaires (subject to cognitive biases). Skin conductance (also known as GSR) is one of the most robust, non-invasive physiological measures of ANS and electrodermal activity to investigate stress (Dawson, Schell, & Filion, 2007; Healy, 2000; Lisetti & Nasoz, 2004; Picard et al., 2001). GSR sensors measure the changes in the conductance of skin caused by ionic sweat secretion (which is related to stressful events). "The resistance of the skin is usually large; however, momentary changes in the level of the sweat gland activity causes changes in resistance that can be measured by passing a small electrical current across two electrodes placed on the surface of the skin" (Healy, 2000). Studies in other fields, mainly psychology and medicine, have demonstrated that emotional arousal (such as stress) leads to an increase in skin conductance (Healy & Picard, 2005; Labbé et al., 2007; Seyle, 1956).