



# Joint consideration of energy expenditure, air quality, and safety by cyclists

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## ARTICLE INFO

### Article history:

Received 5 August 2017

Received in revised form 28 June 2018

Accepted 3 July 2018

### Keywords:

Bicycles  
Travel behaviour  
Energy expenditure  
Air quality  
Safety

## ABSTRACT

Public health benefits are an important motivator and justification for urban cycling promotion. The health impacts of cycling are typically evaluated using three main effect pathways: physical activity (exercise), air pollution exposure, and safety (crashes). Effects of safety on cycling behaviour have been investigated, but little is known about how energy expenditure and air quality concerns influence cycling decisions. Understanding cyclist perceptions and preferences is important for planning and designing sustainable and healthy transportation networks. As such, research providing insights into the heterogeneity of these concerns is needed to inform models of behavioural change with evolving vehicles, technology, and infrastructure. The objective of this paper is to investigate the joint consideration of energy expenditure, air quality, and safety concerns by cyclists, and their relationships with cycling frequency. A structural equation model is developed based on data from a survey of 625 intercepted real-world cyclists. Air quality and energy expenditure were considered in routing decisions by 51% and 73% of the cyclists, respectively. Model results show that traffic safety and air pollution risks are perceived differently by cyclists, which has implications for modeling urban cycling behaviour in the context of evolving motor vehicle fleets. Safety concerns were associated with less frequent cycling, but not air quality concerns. Consideration of energy expenditure varies significantly among individuals and trip types, which will emerge with different preferences related to hills, stops, speeds, and electric-assistance. Energy and air quality concerns were significantly associated, suggesting health-conscious cyclists who tended to be older, have higher educational attainment, be more physically active, and cycle more recreationally. Utilitarian and recreational cycling trips had different relationships with health-related considerations and with weekly physical activity.

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## 1. Introduction

Urban cycling has been increasing in many cities, promoted by targeted policies and programs (Pucher, Buehler, & Seinen, 2011). Still, cycling has only a small mode share in North America, and the question of how to further motivate urban cycling is relevant and important for many cities. Provision of attractive cycling routes is a key mechanism through which cities can

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impact cycling rates (Pucher et al., 2011), and traffic calming and separated bicycle facilities are two prominent cycling promotion policies (Pucher & Buehler, 2008).

Cyclist preferences have been investigated in stated and revealed preference studies, demonstrating that cyclists perceive and value myriad factors about their trips, including distance and duration, proximity to motor vehicles of varying speeds and types, presence of hills, weather, and more (Broach, Dill, & Gliebe, 2012; Chataway, Kaplan, Nielsen, & Prato, 2014; Fraser & Lock, 2011; Motoaki & Daziano, 2015; Sener, Eluru, & Bhat, 2009; Stinson & Bhat, 2003; Tilahun, Levinson, & Krizek, 2007; Vedel, Jacobsen, & Skov-Petersen, 2017; Winters & Teschke, 2010). Cyclist preferences are typically assessed in regard to observable trip attributes, and so the current evidence base is largely oriented around proxy variables such as facility class and road grade, rather than more intangible but fundamental motivating factors such as risk and effort. Better knowledge of these fundamental influences can improve understanding of heterogeneity in cycling preferences and behaviour, and inform models of how behaviour may change with evolving vehicle fleets, technology, and infrastructure.

An important motivator and justification for cycling promotion is the potential public health benefits. A growing body of literature examines the health effects of cycling with three main effect pathways: physical activity, air pollution, and crashes (Buekers, Dons, Elen, & Int Panis, 2015; de Hartog, Boogaard, Nijland, & Hoek, 2010; de Nazelle & Nieuwenhuijsen, 2009; Deenihan & Caulfield, 2014; Fraser & Lock, 2011; Götschi, Garrard, & Giles-Corti, 2016; Int Panis, 2011; Macmillan et al., 2014; Oja et al., 2011; Tainio et al., 2016; Teschke et al., 2012; Winters, Brauer, Setton, & Teschke, 2010). This literature focuses on objective health impacts, and less is known about how energy expenditure, air quality, and safety affect decisions about whether, where, and how to cycle. The objective of this paper is to investigate urban cyclists' joint consideration of these three factors, and how they relate to cycling frequency.

### 1.1. Literature review

Safety perceptions and concerns of cyclists have been studied much more extensively than energy expenditure or air quality concerns. Perceived and objective cyclist safety often align, but it is perceived safety that is more relevant for modeling cyclist decision-making (Chataway et al., 2014; Heinen, van Wee, & Maat, 2010; McNeil, Monsere, & Dill, 2015; Sanders, 2015). Safety is a dominant concern of many cyclists, evinced in direct questioning and by avoidance of facilities perceived as more dangerous because of exposure to motor vehicle traffic (Chataway et al., 2014; Heinen, Maat, & van Wee, 2011, 2010; Willis, Manaugh, & El-Geneidy, 2015; Winters, Davidson, Kao, & Teschke, 2011). Perceived safety is often a major factor in decisions about whether to cycle and which routes to use, but not always the primary factor, and perceptions of safety are highly heterogeneous (Hatfield & Prabhakaran, 2016; Piatkowski & Marshall, 2015; Sanders, 2015; Winters & Teschke, 2010).

Physical effort and energy expenditure appear in various indirect forms in cycling behaviour research, but have rarely been directly assessed. Energy expenditure was explicitly included in a cycling speed choice model and found to have a marginal disutility at typical riding speeds (Bigazzi & Lindsey, 2018). Perspiration or sweat, a physiological response to cycling effort mediated by environmental conditions and clothing, is a concern for many utilitarian cyclists and has a negative influence on cycling activity (Dill & Rose, 2012; Piatkowski & Marshall, 2015). Cyclists generally avoid large hills (Broach et al., 2012; Fraser & Lock, 2011; Heinen et al., 2010; Winters et al., 2011, 2010), although at least two stated-preference studies found a preference (stronger in males) for moderate hills compared to flat terrain (Sener et al., 2009; Stinson & Bhat, 2003). Avoidance of hills is generally assumed to be due to a preference for less effort, but the effect could be conflated with slower cycling speed on hills (Heinen et al., 2010; Parkin & Rotheram, 2010). Similarly, the observed negative effects of distance and stops on cycling could be a conflation of travel time and effort because of the mediating effects of speed (Heinen et al., 2010). Overall, the role of physical effort and energy expenditure in motivating cycling decisions is still unclear. Some physical activity is likely desired by cyclists, motivated by the enjoyment of movement and exercise or by expected health benefits from physical activity (Götschi et al., 2016; Mokhtarian, Salomon, & Singer, 2015). However, at the margin, cyclists seem to avoid excess physical effort.

The influence of air pollution on cycling decisions remains unclear. Air pollution exposure for cyclists has been studied primarily through the lens of objective risk (Bigazzi & Figliozzi, 2014). Cyclists have high breathing rates that elevate pollutant inhalation, but exposure concentrations and inhalation doses can be reduced by traveling on low-traffic routes (Bigazzi, Figliozzi, Luo, & Pankow, 2016; Bigazzi & Figliozzi, 2014; Broach & Bigazzi, 2017; MacNaughton, Melly, Vallarino, Adamkiewicz, & Spengler, 2014). Travellers' consideration of air pollution is less clear than their actual exposure risk. The public has a general awareness that outdoor urban air pollution affects human health (Bianco, Nobile, Gnisci, & Pavia, 2008; Day, 2006), and some people perceive negative health effects from exposure during travel specifically (Badland & Duncan, 2009; Cole-Hunter, Morawska, & Solomon, 2015). Numerous studies in environmental economics have evaluated the public's positive valuation of urban air quality, typically in the context of willingness to make trade-offs in residential property attributes (Bayer, Keohane, & Timmins, 2009; Levinson, 2012; MacKerron & Mourato, 2009). Several empirical studies have looked at cyclist routing behaviour and pollution exposure, finding that cyclists generally choose low-exposure routes when available (Bigazzi, Broach, & Dill, 2016; Broach & Bigazzi, 2017), although cycling volumes can be positively related to pollution levels (Hankey, Lindsey, & Marshall, 2017; Strauss et al., 2012). These studies do not identify air pollution as a specific motivator for the observed cycling behaviour.

A few studies have included air quality as a factor influencing cycling decisions (Anowar, Eluru, & Hatzopoulou, 2017; Badland & Duncan, 2009; Cole-Hunter et al., 2015; Winters et al., 2011). In stated preference research in Vancouver, Canada,

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