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Estimating the safety benefit of separated cycling infrastructure adjusted for behavioral adaptation among drivers; an application of agent-based modelling

Jason Thompson [a,b,*], Jasper S. Wijnands [a], Giovanni Savino [b,d], Brendan Lawrence [b], Mark Stevenson [a,c]

[a] Transport, Health and Urban Design Research Hub, Melbourne School of Design, University of Melbourne, Australia
[b] Monash University Accident Research Centre, Australia
[c] Melbourne School of Engineering, University of Melbourne, Australia
[d] University of Florence, Italy

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ABSTRACT

Separated cycling infrastructure is a key strategy employed by urban and transport planners to reduce car vs cyclist crashes.

We constructed an agent-based model (ABM) to explore the potential effects of introducing progressively greater levels of saturation (e.g., more kms) of separated cycling infrastructure into a transport network in which drivers also demonstrated behavioral adaptation in response to increased exposure to cyclists as suggested by the safety in numbers (SiN) theory.

The findings highlight that if behavioral adaptation among drivers is assumed to be a strong mechanism underpinning cyclist safety, the introduction of low levels of separated cycling infrastructure across a network (e.g., few kms) may provide little or no reduction in car vs cyclist crashes. This is due to the countervailing effects that separated infrastructure may have on drivers' exposure to cyclists; a fundamental contributor to the concept of behavioral adaptation.

This study demonstrates the utility of ABMs to explicitly define and model candidate behavioral mechanisms associated with cyclist and vehicle interaction when estimating the interaction of infrastructure and behavioral mechanisms proposed to underlie cyclist safety. Practically, it suggests that greater saturation of separated cycling infrastructure across transport networks may be required to reduce overall car vs cyclist crashes in circumstances where behavioral adaptation is also a strong mechanism contributing to cyclist safety.

1. Introduction

Each year, 1.25 million people are killed and a further 50 million are injured in road crashes. Approximately half of these deaths and injuries occur among vulnerable road users such as motorcyclists, pedestrians and cyclists (World Health

* Corresponding author at: Transport, Health and Urban Design (THUD) research group Room 416, Level 4, Melbourne School of Design (Building 133) The University of Melbourne, Victoria 3010, Australia.

E-mail address: jason.thompson@unimelb.edu.au (J. Thompson).

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Organization, 2013). Evidence from studies of injured cyclists show that crashes are less likely to occur on cycling infrastructure that separates cyclists from motor vehicles (Lawrence, Stevenson, Oxley, & Logan, 2015; Teschke et al., 2012). The addition of such infrastructure is considered critical in efforts to reduce the risk exposure of vulnerable road users, and deaths and injuries associated with car vs cyclist crashes (OECD & International Transport Forum, 2013; Reynolds, Harris, Teschke, Cripton, & Winters, 2009; Wegman, Zhang, & Dijkstra, 2012).

The rate of cycling in countries such as the United States, United Kingdom, and Australia are below 2%; far below the levels of 10–30% observed in many northern European countries including Denmark, the Netherlands, and Sweden (Bassett, Pucher, Buehler, Thompson, & Crouter, 2008; Fraser & Lock, 2011; Pucher & Buehler, 2008). In cities where cycling is low, efforts to increase cycling's share of the total transport mix from health, environmental, and congestion perspectives are apparent (City of Yarra, 2010; Department for Transport Energy, 2006; NSW, 2012; OECD & International Transport Forum, 2013). However, ensuring that increased rates of cycling do not come at the expense of increased injuries and deaths through collisions with cars remains a concern. Car vs cyclist crashes not only produce severe injuries (Cripton et al., 2015; Rivara, Thompson, & Thompson, 1997; Sikic, Mikocka-Walus, Gabbe, McDermott, & Cameron, 2009) but fear of crash involvement also poses barriers to riding for both current and potential cyclists (Bauman et al., 2008; Kingham, Taylor, & Koorey, 2011). Understanding the mechanisms that underpin cyclist safety in order to reduce both the real and perceived dangers associated with cycling is a priority.

Despite the contention that separated cycling infrastructure 'benefits everyone' (Chipman, 2002), its effects on cyclist safety continue to attract debate (Phillips, Bjørnskau, Hagman, & Sagberg, 2011). Further, the simple mechanism by which infrastructure operates (i.e., by reducing opportunity for car / cyclist interactions) conflicts with alternative mechanisms proposed to underlie cyclist safety. For example, behavioral adaptation among drivers is a popularly theorised means by which per-capita risk reduces for cyclists with increasing exposure to cyclists in a road network (Jacobsen, 2003). Conceptualised as a process whereby drivers learn, over time, to detect cyclists and adapt driving styles to suit (Fyhri, Sundfor, Bjornskau, & Laureshyn, 2016; Jacobsen, Ragland, & Komanoff, 2015; Robinson, 2005), the mechanism underlying behavioral adaptation is at odds with that underlying separated infrastructure; behavioral adaptation requires exposure of drivers to cyclists in order for it to apply. In contrast, separated infrastructure is specifically designed to *reduce* exposure of cyclists to drivers by removing them from the road (Christie & Pike, 2015; OECD & International Transport Forum, 2013; Pucher, 2001) (see Fig. 1). This cycling infrastructure vs behavioral adaptation paradox is important to consider for highly motorised cities attempting to transition to new models of urban mobility (Stevenson et al., 2016; van Wee & Handy, 2016) and encourage greater levels of safe cycling from what are at present, relatively low rates (Bhatia et al., 2016; Buehler, Pucher, Merom, & Bauman, 2011; Fraser & Lock, 2011; Munro, 2011; Pucher, Buehler, & Seinen, 2011; Pucher, Dill, & Handy, 2010; Pucher, Garrard, & Greaves, 2011; Talbot, Reed, Barnes, Thomas, & Christie, 2014; Thomas & DeRobertis, 2013).

Estimating the safety benefits of separated cycling infrastructure remains difficult due to variation in infrastructure design within and between studies (Mulvaney et al., 2015; Reynolds et al., 2009). For example, in the City of Toronto, Teschke et al. (2012) identified 14 different road and path types used by cyclists, of which separated cycle tracks demonstrated the lowest risks for collision. However, improved safety for individuals traveling on a short sections of cycle track may not necessarily translate into reductions in risk for the overall cycling population of an areas if bicyclists also have to ride with traffic on other road segments. For example, if the introduction of separated cycling infrastructure encourages increased use by existing cyclists to the exclusion of roads, changes in total car vs cyclist crashes across the system should also account for the effect on safety of commensurate reductions in cyclist volume in the on-road environment, consistent with the safety in numbers hypothesis (Elvik, 2009; Jacobsen, 2003). To our knowledge, this relationship between local-level safety facilitated by separated infrastructure and overall system collision-risk adjusted for expected changes in behavioral adaptation by drivers has not been explored.

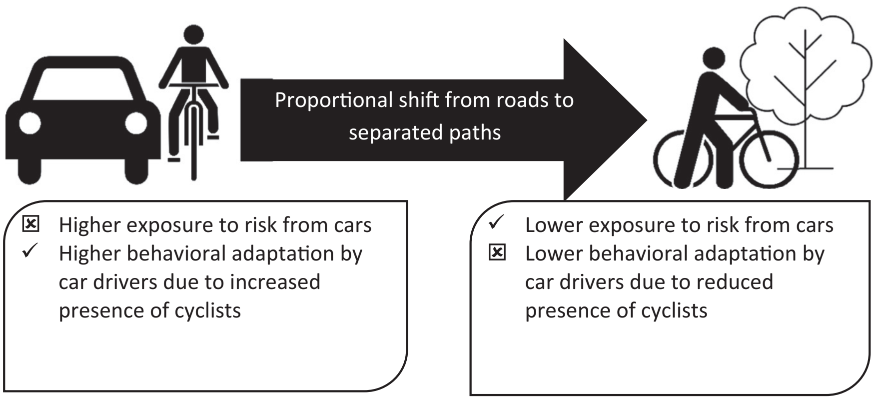

Fig. 1. A proportional shift from cyclists on road infrastructure to separated paths may present safety challenges for remaining road cyclists.