Transportation Research Part A 85 (2016) 65–75

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

A model of behavioural adaptation as a contributor to the safety-in-numbers effect for cyclists

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ARTICLE INFO

Article history:
Received 23 February 2015
Received in revised form 29 November 2015
Accepted 21 December 2015
Available online 22 January 2016

Keywords:
Cycling
Safety-in-numbers
Injury
Pedestrians
Accidents
Agent-based-modelling

ABSTRACT

The safety in numbers (SiN) effect is often invoked as a mechanism by which increasing numbers of vulnerable road users introduced into a transport network can result in reduced per-capita risk of collision resulting in injury or death. Mechanisms underlying SiN's function, however, have not been well described. Extending previous agent-based modelling work, this study explored the potential role of behavioural adaptation of drivers to the presence of cyclists that followed patterns of Rescorla–Wagner (R–W) learning models. Results indicated that SiN effects consistent with those present in real-world studies were replicable in a simulated environment, and that R–W model input settings were able to control the strength of the SiN effect in combination with the influence of increased cyclist density. The combined theoretical and simulation model presented here provides a novel means by which the potential safety effects of cycling policy settings and interventions may be academically and practically explored.

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1. Introduction

Despite the widespread adoption of Safety-in-Numbers (SiN) as a strategy for increasing cycling safety and its inclusion into many local and regional transport strategies and plans (e.g., British Medical Association, 2012; City of Yarra, 2010; Department for Transport Energy and Infrastructure, 2006), there is limited empirical investigation into the mechanisms underlying SiN and the circumstances under which it may or may not apply.

The SiN theory suggests that increasing numbers of cyclists and pedestrians results in reduced per-capita risk of collision, death, and injury for vulnerable road users. In practice, this means that, for instance, a doubling of cyclist or pedestrian activity would be expected to lead to a less-than doubling of injury. As a general rule, SiN is assumed to operate on the basis that

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http://dx.doi.org/10.1016/j.tra.2015.12.004
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an association between cyclist numbers and collision risk exists in the form of $I \propto E^b$ indicating that the road injury risk I is proportional to an exponential function of number of cyclists E, where b is estimated to average around 0.4 (Elvik, 2009).

However, recent increases in cycling deaths and injuries in London (Stordy, 2013), San Francisco (San Francisco Municipal Transportation Agency, 2012), and across Australia (Department of Infrastructure and Regional Development, 2014) point to a rise in rates of cyclist deaths and injuries that do not accord with those expected under conditions where a SiN effect in its 'averaged' form is present. This suggests a possibility that SiN may be a latent phenomenon comprised of multiple factors, the presence or absence of which in any circumstance may determine the strength of its effect. Understanding the mechanisms that underpin the SiN effect is crucial if we are to understand the circumstances in which SiN may exert influence. It is also crucial if we are to ensure that SiN is not relied upon as a mechanism for improving safety at the expense of investment in cycling infrastructure or other initiatives that may genuinely reduce risk (Bhatia and Wier, 2011).

Behavioural adaptation is the process of learning through exposure to a stimulus and has been offered by some researchers as a mechanism by which the SiN effect operates (Jacobsen, 2003). However, our recent paper, Thompson et al. (2014) demonstrated that the SiN effect can be replicated in simulated transport systems where drivers show no behavioural adaptation. Instead, the mechanism of cyclist density was identified as a possible mechanism producing reductions in cyclist vs motor vehicle collisions. This did not rule out a role for behavioural adaptation but demonstrated that it may not be necessary in order for the phenomenon to be observed.

The behavioural adaptation hypothesis requires further investigation. At face value, it appears reasonable that drivers who are increasingly exposed to cyclists on the road may become 'conditioned' to associate the act of driving with the presence of cyclists. As long as drivers exhibit an intention and capacity to drive safely around cyclists, increasing exposure to cyclists and awareness (through greater cyclist numbers) should result in reduced per-capita risk of collision.

This assumed form of association between driving and expectation of encountering cyclists on the road accords well with classic patterns of learning such as those demonstrated by Rescorla–Wagner models (Rescorla and Wagner, 1972). Rescorla–Wagner models are mathematical interpretations of classical conditioning trials; they explain the 'learning curve' associated with pairings of unconditioned and conditioned stimuli and the eventual evocation of conditioned responses in the presence of conditioned stimuli. Rescorla–Wagner models have successfully explained a range of behaviours related to learning and conditioning across numerous fields (Miller et al., 1995; Siegel and Allan, 1996). However, with few exceptions (e.g., Harrison, 2005; Vadillo et al., 2008), their application in the context of road safety is rare. This is despite the role of learning and 'behavioural adaptation' being an assumed mechanism by which the SiN effect occurs (Jacobsen et al., 2015).

1.1. Application of Rescorla–Wagner models to cyclist safety

Across the road transport system, where drivers encounter increasing numbers of cyclists, an increased association between the act of driving and the expectation of encountering cyclists on the road occurs. It is reasonable to expect that patterns of learning consistent with Rescorla–Wagner models may apply. In such models, safety can be expressed as a function of time, $S(t)$. At time t_k, safety $S(t_k)$ for a given population of N cyclists would be proportional to V, being the mean level of association drivers have between driving and an expectation of encountering cyclists in the immediate road environment. Considering a given population of n drivers, mathematically, this would take the form of:

$$V(t_k) = \frac{\sum_{i=1}^{n} V_i(t_k)}{n} \tag{1}$$

$$S(t_k) \propto V(t_k) \tag{2}$$

where

$$V_i(t_k) = V_i(t_{k-1}) + \Delta V_i(t_k) \tag{3}$$

The variation $\Delta V_i(t_k)$ in case the i-th driver at time t_k encounters one or more bicycles in their surroundings can be expressed as following:

$$\Delta V_i(t_k) = (\alpha \cdot \beta) \cdot (\lambda_1 - V_i(t_{k-1})) \tag{4}$$

In this formulation, time invariant α and β are the saliency of the road environment and the saliency of cyclists that exist in the road environment, respectively, λ_1 is the maximum possible association between driving and expectation of encountering cyclists on the road (assumed to be time invariant and driver independent), and $V_i(t_{k-1})$ is the association strength between driving and expectation of encountering cyclists for the i-th driver at the previous 'trial' or point in time (t_{k-1}).

Despite drivers being conditioned to expect a cyclist in the road environment, it is not sufficient to assume they have either the intent or capacity to drive safely around them. Indeed, cases where drivers deliberately drive unsafely around cyclists are reported (Heesch et al., 2011; Johnson et al., 2014; Johnson and Le, 2012). Therefore, any consideration of the total safety effect for cyclists of the association between driving and expectation of encountering cyclists on the road must also take into account the combined product of drivers' intention to drive safely around cyclists (ω) and the driver's capacity to do so (σ).

Added to the model, population safety for cyclists within the variation of individual drivers' association that drivers have between driving and expectation of encountering cyclists for the i-th driver at time step t_k with one or more bicycles in the

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