Do cyclists make better drivers? Associations between cycling experience and change detection in road scenes

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Abstract

Efficient processing of visual information is crucial to safe driving. Previous research has demonstrated that driving experience strongly affects attentional allocation, with large differences between novice and experienced drivers. Expanding on this, we explored the influence of non-driving experiences on attentional allocation by comparing drivers with and without cycling experience. Based on situation awareness field studies, we predicted cyclist-drivers would demonstrate superior performance. Participants were 42 experienced drivers (17 female, 25 male) aged 30-50 years ($M = 39.8$): 20 drivers and 22 cyclist-drivers. The experiment used a change detection flicker task, in which participants must determine whether two alternating images are identical (change-absent) or differ in a single detail (change-present). The changed object was either a road sign, car, pedestrian, or bicycle. Change target significantly affected both accuracy and response time: all participants were slower and less accurate at detecting changes to road signs, compared with when the change was a moving road user (i.e., car, pedestrian, bicycle). Accuracy did not differ significantly between groups, but cyclist-drivers were significantly faster than drivers at identifying changes, with the effect being largest for bicycle and sign changes. The results suggest that cycling experience is associated with more efficient attentional processing for road scenes.

Keywords: change detection; change blindness; cyclists; drivers; situation awareness

1. Introduction

Driving is a visually demanding task (Lee, 2005; Sivak, 1996). In order to drive safely we must efficiently process a range of visual cues, which alert us to attributes such as where we need to go, how fast we should travel, and whether hazards are present. Failure to search for and/or detect hazards has been identified as a contributing factor in 9–12% of serious injury crashes (Beanland et al., 2013) and hazard perception ability is negatively correlated with crash involvement (Boufous et al., 2011; Horswill et al., 2010, 2015). As such, it is vital to identify factors that are associated with superior processing of visual information when driving.

There is considerable evidence demonstrating that our experiences and pre-existing knowledge shape the way we process visual information. Even under basic experimental conditions, visual search performance in a given trial is likely to be influenced by experience on previous trials (Chun and Jiang, 1998; Chun and Wolfe, 1996). Within the driving context, research findings from a diverse range of methods, from naturalistic field observations to controlled laboratory experiments, have supported the notion that drivers' schema (i.e., mental models of the world) shape what they search for and notice, and ultimately how they interact with others on the road (Bellet et al., 2009). These schema are formed iteratively through experience: situations we have encountered in the past determine what we expect to see and therefore what we will look for, which in turn influences the information we pick up, which is then fed back to update relevant schema (Neisser, 1976).

Research examining the effects of experience on visual information processing has predominantly focused on comparing novice drivers (i.e., < 2-3 years' driving experience) with more experienced drivers (Underwood, 2007). Novice drivers primarily focus on the road directly in front of their vehicle, whereas experienced drivers demonstrate more extensive horizontal scanning and better adapt their scanning strategies when the environment changes (Chapman and Underwood, 1998; Crundall et al., 2003; Falkmer and Gregersen, 2005; Underwood, 2007; Underwood et al., 2002). Consequently, novice drivers are less likely to notice peripheral events, such as vehicles approaching an intersection (Underwood et al., 2003). Similarly, a recent study found that frequent cyclists anticipate and detect more hazards than infrequent cyclists when viewing videos of bicycle paths and sidewalks (Lehtonen et al., 2016); however, the same study found that frequent cyclists rode at faster speeds, meaning they may genuinely encounter more hazards (i.e., it is more dangerous if a pedestrian suddenly steps out in front of a bicycle that is travelling faster vs. slower).

Differences between novice and experienced drivers have been observed during passive viewing of traffic scenes (Underwood et al., 2002), driving-related video games (Ciceri and Ruscio, 2014) and real driving (Crundall and Underwood, 1998; Falkmer and

Gregersen, 2005). This suggests differences between novice and experienced drivers are not simply the result of novices finding the driving task more demanding; rather, it implies accumulated driving experience fundamentally alters the manner in which drivers allocate their visual attention.

Although there is considerable evidence exploring how one's *level* of experience influences visual attention, there is relatively little research examining whether relevant *cross-modal* experiences also play a role. All drivers experience the road using other transport modes, such as walking, cycling or motorcycling. Several recent studies have compared real-world behavior of drivers, pedestrians, cyclists and motorcyclists, and have demonstrated fundamental differences in how and where road users allocate their attention (e.g., Salmon et al., 2013, 2014; Walker et al., 2011). When negotiating an urban intersection, for example, car drivers mostly focus on traffic lights and areas where other cars might appear, whereas motorcyclists search for a broader range of potential hazards and cyclists focus on seeking safe travel routes (Salmon et al., 2013, 2014). These studies were undertaken in the field, while participants were using the specified transport mode, which meant participants in different modalities experienced varying goals and task demands that influenced their behavior (Cornelissen et al., 2012, 2013; Salmon et al., 2013, 2014; Walker et al., 2011). This raises the question of whether differences in attentional allocation between road users persist when they are given identical tasks. If this were the case, then experience using multiple transportation modes could potentially improve hazard perception. Previous research has revealed that drivers' tendency to focus on searching for other cars can lead them to overlook other hazards, such as cyclists (Summala et al., 1996), highlighting the need to broaden drivers' expectations of what they will encounter on the road.

One method that can be used to explore attentional allocation is change detection paradigms, in which observers must report whether two temporally-separated displays are identical or different. If visual input is interrupted during the change period, then the observer may experience *change blindness* and fail to detect the change (Rensink et al., 1997). Visual interruptions can result from an eye blink or saccade (Grimes, 1996; O'Regan et al., 2000; Velichkovsky et al., 2002), or from an artificial disruption such as a blank screen or scene cut (Rensink et al., 1997; Simons and Levin, 1997; Velichkovsky et al., 2002), occlusion of the change target (Simons and Levin, 1998), or occlusion of nearby regions (Bahrami, 2003; O'Regan et al., 1999). Change blindness is strongly influenced by top-down processes: observers are more likely to detect changes to objects that have greater task relevance (Galpin et al., 2009; Lee et al., 2007; Pearson and Schaefer, 2005; Shinoda et al., 2001; Velichkovsky et al., 2002), personal relevance (Jones et al., 2003; Humphreys et al., 2005; Marchetti et al., 2006), or are central to understanding the scene (Rensink et al., 1997). Observers with domain expertise are more efficient than domain-novices at detecting changes, but only when the changes are relevant to their expertise (Feil and Mestre, 2010; Reingold et al., 2001; Werner and Thies, 2000). In contrast, bottom-up salience and physical size do not influence change detection in real-world contexts, including driving-related tasks (Caird et al., 2005; Mueller and Trick, 2013; Richard et al., 2002; Stirk and Underwood, 2007).

Change detection paradigms have demonstrated utility for revealing which aspects of the scene attract drivers' attention. Drivers are more efficient at detecting changes with greater safety relevance, such as vehicles changing position, compared with changes that have less safety relevance or changes that are irrelevant to driving (Beanland et al., 2017; Galpin et al., 2009; Lee et al., 2007; Mueller and Trick, 2013; Shinoda et al., 2001; Zhao et al., 2014). Drivers are comparatively poor at detecting changes to road signs (Beanland et al., 2017; Metz and Krüger, 2014) and increasing familiarity with the driving route further exacerbates change blindness to road signs (Charlton and Starkey, 2011, 2013; Harms and Brookhuis, 2016; Martens, 2011; Martens and Fox, 2007). Research examining change blindness during simulated driving has found a correlation with safe decision-making: drivers who accurately detect changes are more likely to make safe decisions at road intersections (Caird et al., 2005).

Building on previous research, the current study used a driving-related change detection task to explore the effect of cycling experience on drivers' attentional allocation. All participants were experienced drivers, but half also cycled regularly on public roads. Past research has found that drivers who also hold a motorcycle license are more efficient at detecting and responding to motorcycles (Crundall et al., 2012) and less likely to collide with motorcycles when driving a car (Magazzù et al., 2006), compared with drivers who hold only a car license. These studies demonstrate multi-modal experience can benefit aspects of hazard perception directly related to the other transport mode. Similarly, cyclist-drivers self-reported safer driving behavior around cyclists, compared with drivers who never or rarely ride a bicycle; however, these behavioral differences could be attributable to the fact that cyclist-drivers hold more positive attitudes towards cyclists (Johnson et al., 2014). The current study therefore assessed whether cyclist-drivers differ from non-cycling drivers in terms of their attentional allocation, and whether any observed differences are mode-specific (i.e., an attentional bias towards other cyclists) or more general (i.e., generic hazard perception benefits arising from multi-modal experience).

We systematically manipulated the change target so that it was either a road sign, car, pedestrian, or bicycle. This allowed us to compare both overall driving-related change detection ability and ability to detect specific targets between drivers and cyclist-drivers. If cyclist-drivers experience similar multi-modal benefits to motorcyclist-drivers, then cyclist-drivers should be more efficient at change detection when the change target is a bicycle rider. This result would be consistent with change blindness research on expertise and personal relevance (e.g., Feil and Mestre, 2010; Jones et al., 2003; Marchetti et al., 2006; Reingold et al., 2001; Werner and Thies, 2000). In other words, target-specific effects would show simply that cycling experience makes drivers more attentive to bicycles, just as motorcycling experience makes drivers more attentive to motorcycles. If the effects generalize more broadly then we would predict an overall effect whereby cyclist-drivers are more efficient at change detection than drivers without cycling experience, which would imply that cycling experience helps drivers develop better situation awareness in general, consistent with findings from field studies which suggest that travelling in different transport modes differentially develops situation awareness (Salmon et al., 2013, 2014; Walker et al., 2011).

2. Method

2.1. Participants

Forty-two fully-licensed drivers (17 female, 25 male) aged 30-50 years (*M* = 39.8, *SD* = 5.3) provided written informed consent and were offered AUD$10 compensation. All drove at least weekly and had normal or corrected-to-normal visual acuity as measured using a near vision chart. Twenty-two participants were *cyclist-drivers* who rode a bicycle on public roads at least weekly, and twenty were *drivers* who did not use any other road vehicles (e.g., bicycles or powered two-wheelers). Participants in the cyclist-driver group were recruited through ads seeking individuals who regularly used both road bicycles and cars, whereas participants in the driver group were recruited for a "driver attention study" and were asked to report which transport modes they used, in order to exclude regular cyclists. Ethical aspects of the research were approved by the Australian National University Human Research Ethics Committee (protocol 2013/064).

2.2. Apparatus

Visual stimuli were presented on a 15″ HP Pavilion Laptop with an AMD A6-4400M processor, 1366 × 768 screen resolution and 60Hz refresh rate. Stimulus presentation and data acquisition were controlled via PsychoPy (Peirce, 2007). Viewing distance was approximately 65cm, yielding a display area of 29.9° × 17.1° of visual angle.

2.3. Change Detection Task

Stimuli comprised 60 photograph pairs (each image subtending 29.6° × 17.1° of visual angle) depicting road scenes within the Australian Capital Territory (ACT) from the driver's perspective. Image pairs were either identical (change-absent trials; *n* = 20) or differed in one detail (change-present trials; *n* = 40). Change-present images were edited using Adobe Photoshop to alter a single, driving-relevant target. Targets were cars, bicycles, pedestrians or road signs, which were either moved to another part of the scene (*target-moved* trials; *n* = 20) or removed completely (*target-removed* trials; *n* = 20). Example stimuli are shown in Figure 1. Thus target characteristics were manipulated within-subjects using a 4 (change target: road sign, car, pedestrian, bicycle) × 2 (change type: moved, removed) design, with five trials per condition.

Sign moved

Car removed

Figure 1. Examples of stimuli with the change target moved (upper panel) and removed (lower panel). Note yellow ellipses are used to highlight the location of change targets for illustrative purposes only; these were not included in the experimental stimuli.

Image pairs were presented using a "flicker" paradigm (Rensink et al., 1997), in which two alternating images were displayed for 500ms each separated by a 500ms blank grey screen.[1] As shown in Figure 2, this sequence continued for 30s or until the participant responded, whichever occurred first. Participants were instructed to monitor the images carefully and press the space bar as soon as they had determined whether the alternating images were identical or differed in one detail. They were then prompted to report whether the image was changing (yes/no). If they indicated a change occurred, they were prompted to indicate the change target by selecting the appropriate option from a list of alternatives, which included several objects (e.g., animal, tree, building) that were present but never changed. If the participant failed to respond within 30s the program automatically proceeded to the screen prompting them to report whether there was a change (this occurred on only two trials [0.08%], both change-absent trials).

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[1] Presentation duration was based on Rensink et al.'s (2000) finding that longer blanks are optimal to induce change blindness, which we confirmed through pilot testing. Previous research has used the same 500ms duration, including Werner and Thies's (2000) study comparing change detection abilities of American football experts and non-experts.

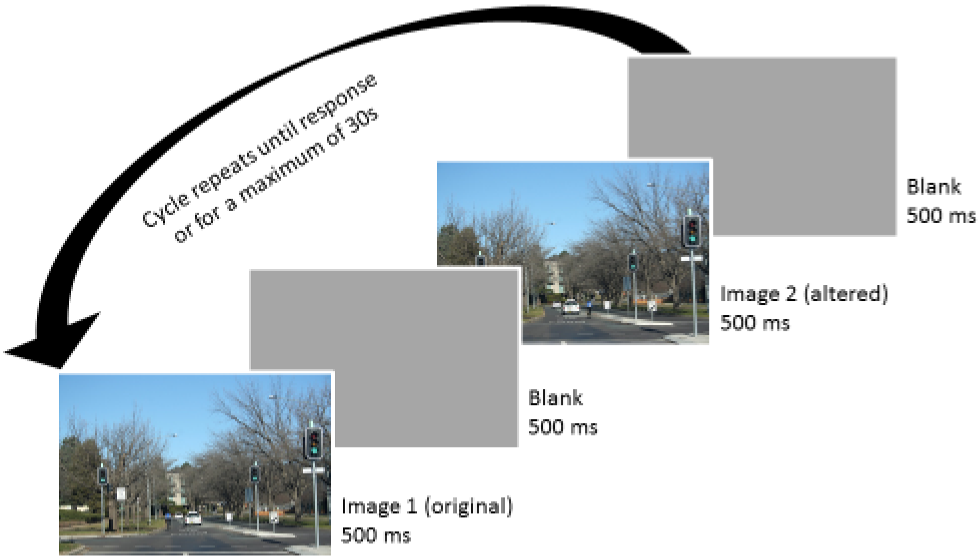

Figure 2. Standard sequence of events for a single trial in the change detection task. The original and altered images were presented for 500ms each, separated by a 500ms blank grey screen, which served to mask visual transients. Change targets were either road signs, cars, pedestrians, or bicycles, and they were either moved within (i.e., changed position) or removed from the scene (i.e., disappeared completely). This example shows a bicycle moving position.

2.4. *Procedure*

Participants completed the experiment individually, or in pairs on separate workstations, in a quiet environment. Initially participants viewed a short demonstration with example stimuli to ensure they understood the task and response requirements. Following this they completed the change detection task, during which they were instructed to imagine that they were driving while viewing each road scene. Finally, participants completed a brief demographic questionnaire that solicited information regarding their driving and cycling experience and frequency.

2.5. *Data Analysis*

Accuracy and response time (RT) were analyzed. Responses to change-absent trials were deemed “correct” if the observer reported no change. Responses to change-present trials were deemed “correct” if the observer reported a change and correctly identified the change target, but were deemed “incorrect” if they reported no change or reported the wrong target object. Trials with RTs ≤ 1s (0.95% of the dataset) were designated as motor errors (i.e., the participant pressed the response key too soon, in error), and were removed from the dataset as participants would not have had sufficient duration to view both images in the sequence.

Accuracy was analyzed using an extension of the general linear model, binary logistic Generalized Estimating Equations (GEE; Liang and Zeger, 1986), which can assess whether the probability of a binary outcome (i.e., change detection) varies with within- and between-subject variables. (Standard logistic regression cannot account for within-subjects repeated measurements.) The within-subject factors were change target (sign, car, pedestrian, bicycle) and change type (moved, removed) and the between-subjects factor was road user group (driver, cyclist-driver).

RTs for correct trials were analyzed using linear GEE, which functions similarly to repeated-measures analysis of variance (RM-ANOVA) and can be used to assess whether a scale variable such as RT differs according to within- and between-subject variables. The crucial difference between GEE and RM-ANOVA is that RM-ANOVA is based on the average RT for each condition, whereas GEE is based on individual trials. This is relevant for change detection paradigms as the number of correct trials in each condition (i.e., the number of measurements contributing to the average RT) may vary. In extreme cases, if observers fail to detect all changes in a given condition, they will have no RT for that condition and consequently their entire dataset will be omitted from a standard RM-ANOVA analysis (e.g., in the current study, 3 observers failed to detect all sign changes). GEE is therefore useful as it can accommodate missing data ranging from single trials to entire conditions, and provides greater statistical power compared with RM-ANOVA (Ma et al., 2012). For RT analyses the within-subject factors were change target and change type, and the between-subjects factor was road user group.

3. Results

3.1. Participant Characteristics

The groups were not significantly different in gender distribution, average age, years of licensure, or hours driven per week (see Table 1); however, cyclist-drivers reported driving fewer kilometers and less frequently than drivers. One explanation for the discrepancy in hours vs. kilometers driven is that cyclist-drivers drive slower than drivers (i.e., cyclists reported driving 179 km in 6.0 hours/week, which suggest an average travel speed of approximately 30 km/h, whereas drivers reported driving 302 km in 7.8 hours/week, or an average speed of around 39 km/h). For instance, cyclist-drivers may live in inner-city areas, where local amenities are closer but traffic density is higher, so their trip distances are shorter but travel speeds are slower. Alternatively, cyclist-drivers may over-estimate hours driven per week, or drivers may under-estimate hours driven. Unsurprisingly, cyclist-drivers rode bicycles more frequently than drivers: Only one driver reported riding a bicycle, with less than monthly frequency. Only one participant (a cyclist-driver) reported having a motorcycle licence, and few participants reported having a close family member (e.g., spouse, romantic partner, or immediate family member) who rides a two-wheeler.

Table 1

Means (and Standard Deviations) for Participant Age, Driving Experience and Transport Mode Use

Variable	Cyclist-drivers ($n = 22$)	Drivers ($n = 20$)	Group Comparison
Gender distribution	68% male	50% male	$\chi^2(1) = 1.437, p = .231$
Age in years	40.0 (6.1)	39.6 (4.3)	$t(40) = 0.27, p = .786, d = .08$
Years of licensure	23.1 (6.1)	22.1 (5.0)	$t(40) = 0.53, p = .597, d = .16$
Car use			
– frequency	41% daily 41% 2-5 times/week 18% weekly	95% daily 5% 2-5 times/week	$U = 99.0, z = -3.669, p < .001^{***}$
– hours per week	6.0 (5.9)	7.8 (4.1)	$t(40) = -1.09, p = .282, d = .34$
– kilometers per week	179 (129)	302 (160)	$t(40) = -2.75, p = .009, d = .85^{**}$
Bicycle use			
– frequency	50% daily 36% 2-5 times/week 14% weekly	95% never 5% less than monthly	$U = 0.0, z = -5.897, p < .001^{***}$
– hours per week	9.5 (4.5)	--	
– kilometers per week	212 (108)	--	
Motorcycle use	96% never 4% weekly	100% never	$U = 210.0, z = -0.953, p = .340$
Close family member rides road bicycle	18%	15%	$\chi^2(1) = 0.076, p = .782$
Close family member rides motorcycle	5%	5%	$\chi^2(1) = 0.005, p = .945$

Notes. $^{**} p < .01$, $^{***} p < .001$

3.2. *Accuracy*

After excluding motor errors ($n = 24$) there were 2496 trials across 42 observers. Accuracy was at ceiling for the change-absent trials (99.8% correct), so statistical analyses included change-present trials only.

Before conducting the main analyses, data were examined to identify outlier participants or image pairs (i.e., as indicated by extreme scores for accuracy and/or RT). Data for one participant were excluded because their performance on change-present trials was not significantly better than chance, suggesting insufficient task engagement. After excluding this observer, average accuracy was 72% for sign changes, 86% for car changes, 95% for pedestrian changes and 97% for bicycle changes. Two car-removed images had overall change detection accuracy at or below chance, which was significantly worse than other car-change images. In both cases, the change occurred in the distant background, whereas in other trials the change occurred to foreground road users; as such, the semantic relevance of the change varied between low- and high-accuracy trials, whereas for other change targets (i.e., signs, pedestrians, and bicycles) there was greater consistency between trials in both error rates and semantic relevance. After excluding data for these trials average accuracy for car changes was 95%. Excluding these trials did not alter the pattern of results, but improved the statistical reliability of the analyses.

Binary logistic GEE was used to examine whether accuracy varied according to participant group, change object and/or change type. The initial model was a full-factorial including main effects for group, object and change type, with all possible interactions. None of the interactions reached statistical significance (all *p*s > .1) so for the sake of parsimony a second model was run including only main effects. There was no main effect of group (cyclist-drivers vs. drivers), Wald $\chi^2(1) = 1.08$, $p = .306$, $B = -0.36$, $SE = 0.35$, OR 0.70, 95% CI [0.35, 1.39]. There was also no main effect of change type (moved vs. removed), Wald $\chi^2(1) = 0.58$, $p = .445$, $B = -0.13$, $SE = 0.17$, OR 0.88, 95% CI [0.64, 1.22]. There was a significant main effect of change target, Wald $\chi^2(3) = 67.62$, $p < .001$. As shown in Table 2, change detection for road signs was significantly lower than all other change targets. When signs were excluded from the analyses, there was no longer any effect of change target, Wald $\chi^2(2) = 2.53$, $p = .282$, and the other main effects remained non-significant (group: Wald $\chi^2(1) = 0.24$, $p = .624$; change type: Wald $\chi^2(1) = 0.37$, $p = .545$).

Table 2

Effects of change target on accuracy

Change Target	Mean Accuracy [95% CI]	B	SE	Wald χ^2	OR	95% CI OR
Bicycle	97% [95%, 98%]	2.56	0.39	42.14***	12.98	[5.99, 28.13]
Pedestrian	95% [92%, 97%]	2.03	0.32	41.37***	7.60	[4.10, 14.09]
Car	95% [91%, 97%]	1.95	0.32	36.87***	7.05	[3.75, 13.23]
Road Sign	72% [63%, 80%]	0	-	-	1	-

Notes. Signs were used as the reference group; odds ratios above 1 indicate increased probability of detecting changes for a given change target, compared with signs. OR = Odds Ratio. 95% CI = 95% Confidence Interval. *** $p < .001$

3.3. *Response Time*

RT for correct, change-present trials was analyzed using linear GEE specifying a normal distribution with a log link function because RTs were positively skewed. The initial model was a full-factorial including main effects for group, object and change type, with all possible interactions. As with the accuracy data, the model was reduced by removing non-significant terms (specifically, change type and its interaction with the other variables). The final model included a significant main effect of target, Wald $\chi^2(3) = 290.16$, $p < .001$, a significant main effect of group, Wald $\chi^2(1) = 7.16$, $p = .007$, and a significant group × target interaction, Wald $\chi^2(3) = 8.08$, $p = .044$. As shown in Figure 3, cyclist-drivers detected changes on average 615ms faster than drivers (cyclist-drivers: $M = 3116$, $SE = 152$;

drivers: $M = 3731$, $SE = 172$), but this advantage was greatest when the change target was a bicycle or a road sign. All observers were fastest at detecting changes to bicycles ($M = 2782$, $SE = 110$) and slowest at detecting changes to signs ($M = 4667$, $SE = 201$), with changes to pedestrians ($M = 3218$, $SE = 120$) and cars ($M = 3234$, $SE = 122$) being only slightly slower than bicycles.

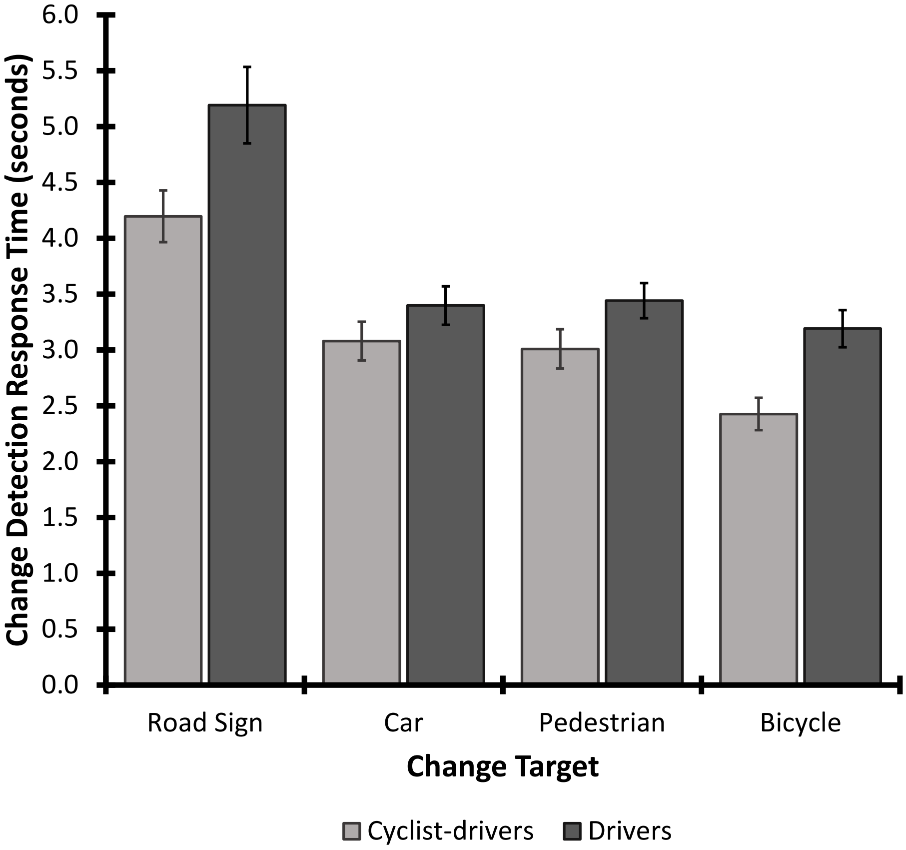

Figure 3. Estimated marginal means for change detection response time, by road user and change target. Analyses include only correct responses. Error bars represent ±1 standard error of the mean.

3.4. *Effects of Object Size and Location*

The accuracy and RT analyses both indicated strong effects of change target. Because our stimuli were photographs taken from a driver's perspective, object type could be confounded with features such as size and location. To investigate this possibility, we compared target size and distance from image center between change targets (road signs, cars, pedestrians, bicycles) using one-way ANOVA. Object size was calculated as the total surface area of the target in pixels, and was not significantly different across change targets, $F(3,36) = 2.33$, $p = .091$, $\eta_p^2 = .16$, and there was no correlation between object size and RT, $r = .01$, $p = .595$. Distance from image center was initially measured as distance in pixels from the central pixel of the image to the central pixel of the target, but was converted to degrees of visual angle for ease of interpretation. Distance from image center differed significantly between change targets, *F*(3,39) = 2.96, $p = .045$, $\eta_p^2 = .20$. Post-hoc tests revealed that pedestrians (*M* = 9.4°, *SD* = 3.5°) were significantly farther from the image center than cars (*M* = 5.8°, *SD* = 1.8°), and were non-significantly farther away than bicycles (*M* = 7.7°, *SD* = 1.9°) and road signs (*M* = 7.8°, *SD* = 3.1°). However, there was no correlation between distance from image center and RT, $r = .01$, $p = .785$.

4. Discussion

The current study compared the abilities of cyclist-drivers and drivers to detect changes to driving-related targets in road scenes. There are two key effects that emerged in the current study: the effect of change target on both accuracy and RT, and the effect of road user experience on RT.

4.1. Effects of cycling experience

Our primary research aim was to compare change detection ability between drivers with and without cycling experience. Change detection accuracy did not differ significantly between groups; however, accuracy was at ceiling for all target types except signs, which suggests that for this specific task, RT is a more sensitive measure of change detection ability than accuracy. This is not uncommon in flicker tasks, where participants have several opportunities to view each image within a trial and make comparisons (e.g., Rensink et al., 1997); accuracy tends to be lower in change detection tasks that present each image once only, reducing the opportunity of comparison (e.g., Zhao et al., 2014).

RT analyses revealed that cyclist-drivers detected changes significantly faster than drivers. This advantage occurred across all types of change targets, although the difference was largest when the change target was a bicycle or a road sign (compared to cars and pedestrians). Thus it appears that cyclist-drivers have an attentional bias towards other cyclists on the road, which is consistent with previous research regarding changes with personal relevance (Jones et al., 2003; Humphreys et al., 2005; Marchetti et al., 2006), but also that cyclist-drivers are more efficient overall than drivers at detecting changing visual information in road scenes. This is consistent with research showing that users of distinct transport modes differ in their situation awareness (Salmon et al., 2013, 2014; Walker et al., 2011), and suggests that users of multiple transport modes have improved situation awareness as a result of their more diverse experiences. The average between-group RT difference of 615ms equates to an extra 10.25m (34 ft) in which to stop or avoid a hazard at a travel speed of 60 km/h, or 17.08m (56 ft) when travelling at 100 km/h. Even when this is not enough time to completely avoid a collision, it will be enough to substantially reduce speed and lessen conflict severity (see Tingvall and Haworth, 1999).

4.2. Effects of change target and type

The largest effects found in the current study were variations in accuracy and RT by change target. Accuracy was close to ceiling for trials in which the change target was another road user (i.e., cars, pedestrians, bicyclist), but was significantly lower for road signs. RT to correctly identify changes followed a similar pattern, with faster responses to non-sign change targets. Many previous studies examining the effect of change target compared relevant versus irrelevant targets (e.g., Galpin et al., 2009; Mueller and Trick, 2013; Zhao et al., 2014), whereas in the current study we found marked differences in change blindness towards different types of driving-related targets. All observers were more likely to experience change blindness when the target that was moved or removed was a road sign, and were slower to notice the changes that they did identify. In contrast, accuracy was close to ceiling when the target was another road user, such as a car, pedestrian or bicyclist. Previous research has demonstrated that many drivers experience change blindness when sign content is changed (Beanland et al., 2017), especially for signs that provide supplementary information (Metz and Krueger, 2014) or are on a highly familiar route (Charlton and Starkey, 2011, 2013; Harms and Brookhuis, 2016; Martens, 2011; Martens and Fox, 2007). The current study adds to this by further demonstrating change blindness for the position and even complete absence of road signs.

One interpretation of these findings is that drivers do not adequately attend to road signs; anecdotally, some of our participants admitted this is the case. However, there is also a fundamental difference between signs and the other change targets we used: signs are static objects that cannot interact with drivers and would not be expected to change. This is relevant because signs do not pose a "hazard" in the same way that other road users do (although they may convey the presence of a hazard, and can therefore still have high safety relevance) and because observers are biased to detect ecologically plausible changes, rather than implausible changes (Beck et al., 2007). However, recent research has demonstrated that it is also common for drivers to experience change blindness for changes to variable message signs, which drivers should expect to change (Harms and Brookhuis, 2016). Future research should also explore whether altering the design or placement of road signs can ameliorate road users' change blindness for signs.

One unusual result is our finding that changes to bicycles were detected faster than changes to cars or pedestrians. This seemingly contradicts previous research, which has found that observers are more efficient at detecting larger versus smaller road users (e.g., Cavallo and Pinto, 2012). There are several factors that explain this discrepancy. First, half our participants were cyclist-drivers, who were disproportionately faster at detecting bicycle changes. Second, as object size was equivalent between change targets, bicycles and pedestrians were effectively positioned closer to the observer's perspective than cars.[2] Similarly, because the stimulus photographs were taken naturalistically while driving around the ACT, bicycles tended to appear in settings with less visual clutter than cars or

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[2] As with all research using naturalistic photographs, there is a trade-off between matching targets on size and matching targets on relative distance from the observer's perspective, when targets are real-world objects that naturally differ in physical size.

especially pedestrians. Previous research has demonstrated that visual clutter can impair change detection in road scenes (Edquist et al., 2011). Finally, the ACT has a higher proportion of cyclists than most other parts of Australia, and is perceived as the safest area in which to cycle (Australian Bicycle Council, 2015), so it may be that local drivers are generally more attentive to and aware of cyclists, even if they themselves do not cycle.

Interestingly we did not find a significant effect of change "type" when comparing objects that were moved to objects that were removed, in contrast to previous studies that found additions or deletions were detected more efficiently than moves (Mondy and Coltheart, 2000; Pearson and Schaefer, 2005). This is likely an artefact of methodological differences between studies, as studies in which additions/deletions were detected more efficiently than moves either used a one-shot task (i.e., each stimulus image was viewed once only, whereas in the flicker method observers can view the images repeatedly) or the change involved one *attribute* of the object being changed or moved within the object, rather than the object itself being removed from or moved within the scene.

4.3. Limitations and future directions

Although it is theoretically plausible that our observed between-groups difference in RT arises from cycling experience, a fundamental limitation of research comparing pre-existing groups is that it is challenging to conclusively determine the source of underlying differences. There may be underlying group differences that contribute to differences in change detection performance. We pre-screened participants to ensure that groups were not significantly different on key characteristics such as age, sex, and driving experience, but other differences may remain between groups. For instance, cyclist-drivers reported driving less frequently than drivers (presumably because they use cycling as a primary transportation mode), although this cannot explain their faster change detection performance as one would expect that less time driving would be associated with less efficient performance. However, cyclists are also likely to be more physically active than non-cyclists, which has been shown to benefit executive functions, especially working memory (Guiney & Machado, 2013). Alternatively, attentional differences may predate cycling uptake: as cycling in traffic can be hazardous and attentionally demanding task, it may be that individuals are more likely to persist with road cycling if they have superior situation awareness and attentional abilities. Finally, although participants were unaware of our hypotheses, cyclist-drivers may have been exerting greater effort than drivers in an attempt to portray cyclists as "better" than other road users. The latter issue is unfortunately common in research focusing on specialized groups; given that cyclists comprise less than 20% of the population (Australian Bicycle Council, 2015), it is extremely challenging to recruit an appropriately large sample without specifically seeking cyclists.

A strength of the current study is that it bridged the gap between previous lab and field studies, by comparing cyclist-drivers and drivers on an identical task, which obviates previous concerns that between-groups differences in situation awareness were due primarily to the varying task demands of cycling versus driving a car. However, although we explicitly instructed participants to view the road scenes as though they were driving, it is possible that they nevertheless adopted a "cyclist" mindset when viewing the images. One option for future research would be to replicate the current study in a driving simulator, which would help address the "mindset" issue by ensuring all participants were engaged in the experimental task as drivers. Another option would be to conduct field tests where virtual reality images (e.g., of vulnerable road users) are superimposed on the windshield, which would allow researchers to experimentally manipulate some aspects of a real environment. (It should be noted, however, that both simulation and virtual reality research are extremely resource-intensive methods that require access to specialist equipment, which most researchers do not have access to.)

5. Conclusions

Overall the current findings are consistent with theoretical predictions and suggest some potentially important practical applications, particularly given the importance of hazard perception to road safety. The high degree of change blindness to road signs is concerning, given that these signs often convey crucial information such as speed limits or hazard warnings. This highlights the need to critically evaluate how signs function within the broader road environment, to ensure that road users attend appropriately to safety-critical messages. Conversely, the finding that cycling experience is associated with more efficient attentional processing is encouraging, as it suggests that it may be possible to improve drivers' hazard perception through additional, non-traditional avenues such as promoting greater engagement in cycling and other forms of active transport.

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