

# **The role of lane position in right-of-way violation collisions involving motorcycles**

by  
Bertrand Sager

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# Approval

**Name:** **Bertrand Sager**

**Degree:** **Master of Arts**

**Title:** **The role of lane position in right-of-way violation collisions involving motorcycles**

**Examining Committee:** **Chair:** John McDonald  
Professor

**Thomas M. Spalek**  
Senior Supervisor  
Professor

**Richard Wright**  
Supervisor  
Associate Professor

**Lana Trick**  
External Examiner  
Professor  
Department of Psychology  
University of Guelph

**Date Defended:** December 2nd, 2016

## Ethics Statement



The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

- a. human research ethics approval from the Simon Fraser University Office of Research Ethics

or

- b. advance approval of the animal care protocol from the University Animal Care Committee of Simon Fraser University

or has conducted the research

- c. as a co-investigator, collaborator, or research assistant in a research project approved in advance.

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## **Abstract**

Low motorcycle conspicuity is believed by many researchers, drivers, and motorcyclists to be causally involved in motorcycle collisions that involve another driver. Substantial improvements in motorcycle conspicuity have been made over the last four decades, but in spite of this, motorcycle collisions involving other vehicles are on the rise, specifically the type of collision where another driver violates the motorcyclist's right-of-way because they "did not see them". Because the hypothesis that motorcycles lack conspicuity in traffic is so intuitively appealing and so pervasive, it has never been tested. This work provides an argument against the notion that right-of-way-violation collisions are due to poor motorcycle detection resulting from their low conspicuity and proposes an alternate hypothesis: These collisions seem related to failures in motion-perception which are partially caused by the motorcycle's approach path in a left-of-lane position which, ironically, is partly intended to increase the motorcycle's conspicuity.

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# Introduction

## Why is the problem important?

The city of Vancouver faces a transportation challenge. High real estate prices mean that much of the population commutes from suburbs, and with limited roads into the city this leads to traffic congestion. Vancouver is indeed reputed to be Canada's most congested city (Canadian Press, 2015). Congestion inevitably leads to more greenhouse gas emissions (vehicles are inefficient when idling in traffic) and longer commute times, which are associated with a decrease in the population's quality of life (Hilbrecht, Smale, & Mock, 2014). However, because of its climate and layout, Vancouver is particularly well suited to an alternative form of personal transportation: Powered two wheelers (PTW), which include motorcycles and motor scooters. These PTWs are very fuel-efficient, with typical fuel consumption between 25% and 50% that of a small car. Blessed with a small environmental footprint, PTWs are also easy and cheap to operate, and require very little space to park. Predictably, because of their suitability as commuter vehicles, British Columbia has seen a steady increase in the number of PTWs registered over the years. The number of motorcycles registered in British Columbia increased from 96,000 to 107,000 between 2010 and 2014, an 11.46% growth; by comparison, the passenger car population only grew by 6.25% during those same years (Insurance Corporation of British Columbia [ICBC], 2015). We can expect this trend to continue because motorcycle sales (and fatalities too, unfortunately) correlate positively with increasing gasoline prices (Zhu, Wilson, Stimpson, & Hilsenrath, 2015). With an increase in the number of PTWs on our roads, we can expect a proportional increase in the number of collisions in which they are involved. In the 2010-2014 period, motorcycle collisions averaged 2,125 per year in BC, with 1,425 injuries

and 33 fatalities (Insurance Corporation of British Columbia [ICBC], 2016). It is therefore necessary to develop a good understanding of the causes and factors involved in PTW collisions and to develop strategies aimed at reducing their frequency and severity.

## **What do we know about the problem?**

Most of the information currently available about motorcycle collisions today comes from a 1981 report produced by Hurt, Ouellet, and Thom for the National Highway Traffic Safety Administration (Hurt, Ouellet, & Thom, 1981). During 1976 and 1977, an interdisciplinary team of investigators who were also trained as motorcyclists studied and reconstructed over 900 motorcycle collisions in the greater Los Angeles area. They identified the most common causes for the collisions and provided recommendations as to which countermeasures might be effective. The major finding of this study is reported in the technical summary before the report's table of contents: *"The most common motorcycle accident involves another vehicle causing the collision by violating the right-of-way of the motorcycle at an intersection, usually by turning left in front of the oncoming motorcycle because the car driver did not see the motorcycle"* (Technical Summary, para. 5).

This sentence explains the large emphasis that motorcycle training and safety campaigns put on motorcycle conspicuity. Hurt et al. recommend some countermeasures aimed at reducing injuries due to motorcycle collisions: Mandatory rider training, daytime use of the headlight, and the use of a qualified safety helmet.

A more recent study examining the factors in motorcycle collisions was conducted in 2009 by the Association of European Motorcycle Manufacturers (Association de Constructeurs Européens de Motocyclettes [ACEM], 2009) in France, Germany, Netherlands, Spain and Italy. There, investigators studied 921 motorcycle

collisions in detail, which involved a full reconstruction, vehicle inspections, and witness interviews. Among the many findings of this study, the most relevant to the study of motorcycle conspicuity are as follows:

*“In 50% of the cases, the primary accident contributing factor was a human error on the part of the [other vehicle] driver” (Item 7, Page 132).*

*“[Motorcycles] are more involved in collisions where the [motorcycle] and the [other vehicle] are travelling in opposite directions, with the [other vehicle] turning in front of the motorcycle (10.5%)” (Item 11b, Page 134).*

*“Among the primary contributing factors, over 70% of the [other vehicle] driver errors were due to the failure to perceive the PTW” (Item 13, page 134).*

An even more recent Australian study of 102 motorcycle collisions reports 36 failure-to-see crashes. In 68% of these, the driver of a car turned into the path of an approaching motorcycle even though their line of sight was unobstructed (Brown et al., 2015). The fact that driver's the line of sight was unobstructed suggests that there may be something about motorcycles which makes it difficult to see them or to judge their speed.

Currently another study by the American Federal Highway Administration is investigating at least 350 motorcycle collisions; at the time of writing data had been collected on 355 collisions (Federal Highway Administration [FHWA], 2015). While the results of this study are expected later in 2016, there is little reason to suspect that the findings will differ significantly from the Hurt et al. (1981), ACEM (2009), and Brown et al. (2015) studies.

All of the aforementioned reports suggest that motorcycles suffer from a lack of conspicuity, and many researchers agree. Indeed, the claim that motorcycles suffer from low conspicuity has a lot of face validity; drivers invariably claim not to have seen the

PTW at all, or not until it was too late to avoid the collision (Pai, 2011). The fact that motorcycles are relatively smaller than other traffic objects, and presumably harder to detect because of their small size, lends credence to this claim, and traffic safety experts and motorcycle instructors all over the world operate under the assumption of motorcycle inconspicuity. For example, in an email exchange I had with Jim Ouellet, one of the authors of the 1981 NHTSA report, he expressed the belief that “it would be useful to have a sky-facing light sensor that would automatically turn the headlight to high beam during the day” (J. Ouellet, personal communication, September 17, 2011). In his opinion, the brighter high beam would make the motorcycle easier to detect in traffic and this will increase the rider’s safety. Many other researchers also conclude that motorcycles must be difficult to see in traffic and recommend that motorcyclists use of some version of daytime running lights as a means of increasing their safety (Olson, Halstead-Nussloch, & Sivak, 1981; Thomson, 1980; Smither & Torrez, 2010; Lenné & Mitsopoulos-Rubens, 2011).

## **What have we done about the problem?**

Because of the assumption that motorcycles suffer from a lack of conspicuity, efforts in decreasing PTW collision risks have focused almost exclusively on making the vehicle or rider more conspicuous. Always-on motorcycle headlights have become mandatory in Canada and many other countries, where motorcycles built since 1981 are manufactured without a switch to turn the headlight off. A growing proportion of riders are also adopting high-visibility motorcycle clothing (See Figure 1).



**Figure 1: A high-visibility motorcycle jacket in fluorescent yellow with reflectors**

Photo: Hein Gericke Cruise GORE-TEX Jacket by GORE-TEX Products, CC 2.0

France went as far as making it mandatory for all motorcyclists riding a machine of more than 125cc to wear a reflective fluorescent vest, but the law was repealed in January 2013, following protests by motorcyclists opposed to the mandatory use of such a garment. The French government instead lowered the tax on protective gear such as helmets and armoured clothing, as this was deemed to be a more effective measure toward the reduction of PTW related injuries. However, a new law took effect in January 2016, which requires all motorcyclists to wear a fluorescent vest while stopped at the side of the road in case of an emergency such as an accident or a flat tire (Legifrance, n.d.).



## **How have researchers approached the problem?**

Typically, researchers have approached the problem of motorcycle conspicuity from two angles: Sensory conspicuity, a bottom-up process which depends on stimulus factors such as size, contrast, and brightness, and cognitive conspicuity, which depends on higher-order factors such as task demands and expectations. Before looking at some of the research, it will be useful to define the terms conspicuity and salience as they pertain to motorcycles.

### **Conspicuity**

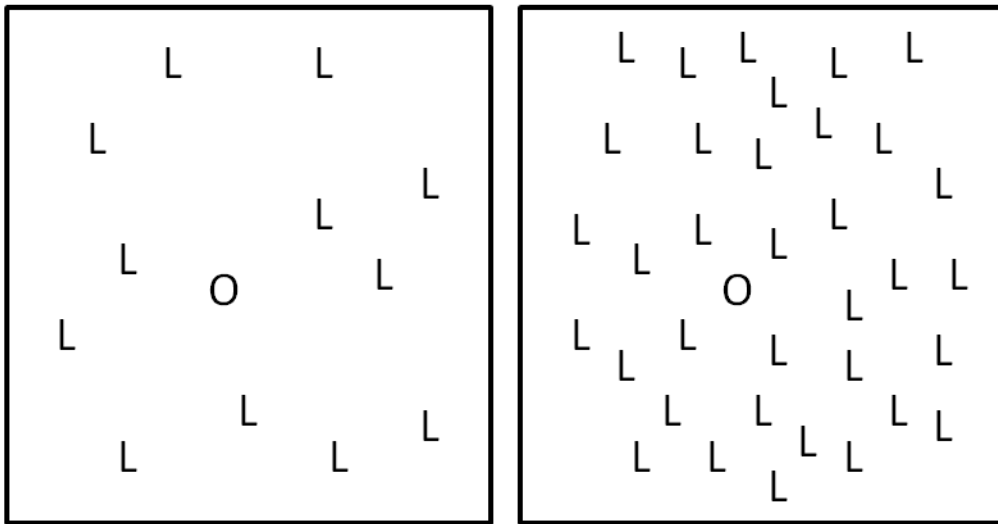
Conspicuity is generally defined as the quality of an object that attracts an observer's attention and causes it to be noticed, but this definition is imperfect at best; it implies that conspicuity lies with the object and this not true. Whether an object captures an observer's attention does not depend solely on the object properties; the observer is an active participant, and their state of mind contributes greatly to whether and how their attentional mechanisms will process the object and whether they will become aware of that object. Certain tasks, for example, place specific demands on an observer; perhaps they must search a display for a target that suddenly appears, or for a target of a certain colour. In such a scenario, distractors that share properties with the target have been shown to slow reaction times to the target, but only when the shared properties matched the demands of the task (Folk, Remington, & Johnson, 1992). Herein, I shall refer to the object's contribution to conspicuity as salience, or sensory conspicuity.

## **Salience**

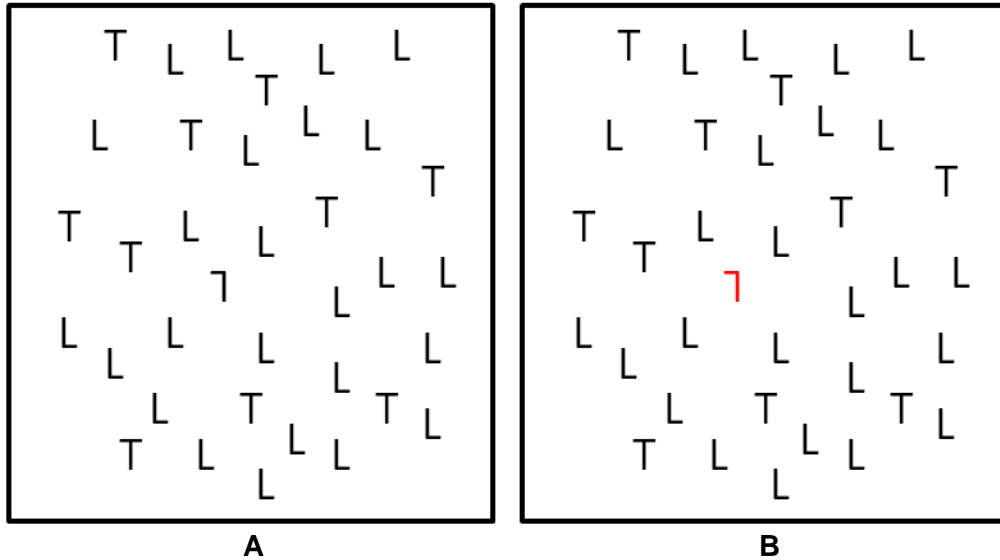
Salience is “the tendency of a stimulus to attract attention without regard to the observer’s desires” (Evans et al., 2011, p.505). Salience depends on the object and is driven by sensory information; it is a strictly bottom-up process. The guidance of attention based on salience is thought to be a parallel process and highly efficient (Nakayama & Silverman, 1986). A target’s salience is relative; it depends on how different that target is from the distractors, the other objects in the visual field (Duncan & Humphreys, 1989). The differences that cause an object to stand out can be on a number of dimensions, such as its shape, colour, brightness, or orientation. Previous research (Treisman & Gelade, 1980) has shown that the facility (measured with accuracy in brief displays, or reaction time in longer displays) with which an observer detects a target made salient by means of a unique feature is constant, regardless of the number of distractors. In simpler terms: The time required to detect the target is independent of the amount of visual clutter (See Figure 2). But as the target’s distinctiveness from the distractors decreases, and as the distractors become more heterogeneous, it becomes increasingly more difficult to detect; it no longer pops out (Duncan & Humphreys, 1989). This is illustrated in Figure 3A: The upside-down “L” is harder to detect because it shares more features with the distractors, and the distractors are more heterogeneous (there are Ls and Ts). However, the target can be made distinctive again by making it unique in a different dimension, such as colouring it red. This is illustrated in Figure 3B, where the red upside-down “L” pops out again. If the distractors were multi-coloured, however, the target would, of course, no longer be salient and search efficiency would be worse.

The effect illustrated in Figure 3 is similar to the effect of the daytime running light (DRL) on motorcycle conspicuity: When motorcycle DRLs were introduced in the early

80's, motorcycles stood out among the rest of the traffic (by virtue of their unique feature), but now that every vehicle is equipped with them (they are mandatory in Canada and many other jurisdictions), this benefit has been lost. Perhaps motorcycles could be made salient again by employing yellow daytime running lights; this unique feature would immediately identify them as a motorcycle, in the same way that their yellow headlights identified French cars as such on European roads from 1937 to 1993. Every motorcycle in North America could be easily rendered distinctive for the cost of a light bulb. If motorcycle identification were thusly facilitated, oncoming drivers intending to turn left may take some extra time to assess the speed of the motorcycle before turning.



**Figure 2: The letter “O” stands out, regardless of the number of distractors.**



**Figure 3:** **A:** The upside-down L shares features with the distractors and does not pop out. **B:** The red upside-down L pops out again, because it was made distinctive by a new unique feature.

While researchers concerned with motorcycle safety acknowledge the observer's role in perception and generally describe two types of conspicuity, sensory and cognitive, the majority of their efforts seem directed at enhancing sensory conspicuity via the motorcycle's features. This is problematic because, rather than the property of an object, conspicuity is the result of an interaction between an object's physical salience (due to size, motion, and brightness) and the state of an observer's attentional mechanisms. Furthermore, conspicuity cannot be directly measured, not in the way that size or brightness can; the only evidence of an object's conspicuity is found in an observer's performance on detection tasks. When we talk of low or high conspicuity for a given object, we are simply talking about low and high performance on detection tasks involving that object.

Conspicuity then is not strictly a property of the motorcycle, but a highly context-specific effect of the interaction between the motorcycle's salience and the observer's state of mind, the result of which determines whether the motorcycle enters the

observer's conscious awareness. Most research however focuses strictly on the physical properties of the motorcycle affecting its salience (often referred to as sensory conspicuity). This is probably because it is easier to manipulate the motorcycle's salience than it is to manipulate the observer's state of mind.

## **Research involving sensory conspicuity**

An early example of motorcycle conspicuity research takes the form of a gap acceptance study involving normal traffic where the test subject was not aware of the experiment (Olson et al., 1981). Researchers riding specially instrumented motorcycles followed a lead vehicle (the driver of which was also unaware of the experiment) as it approached an intersection. The riders left a gap of three, four, or five seconds between the lead vehicle and themselves and recorded whether other drivers manoeuvred between the lead car and the motorcycle. The authors examined scenarios where the subject vehicle approaches from a cross street on the right of the motorcycle (and crosses the motorcycle's path or merges in front of it) or where the subject vehicle is part of the oncoming traffic and makes a left turn across the path of the motorcycle. In each case, the authors collected hundreds of trials in daytime and night-time for each conspicuity treatment (treatments involved orange or green fairings and helmets, as well as low-beam and modulating headlight; an automobile and untreated motorcycle were also included). High-visibility materials were found to be effective, but more so when worn by the rider than when fitted to the motorcycle, which surprised the authors. One explanation they offered is that the high-visibility garment must have drawn attention to the rider and increased the accuracy of distance judgements based on apparent size because drivers are more familiar with the size of people than they are with the size of motorcycles. This observation and its accompanying explanation are interesting,

because they suggest that the problem involves distance judgement rather than detection, but the authors did not pursue that notion. Instead, they report that the use of headlight in day time is the simplest treatment effective at reducing other drivers' tendency to accept too short a gap in front of a motorcycle.

Nowadays, most review boards do not allow researchers to ride motorcycles in possibly dangerous situations, and few are tolerant of the study of unsuspecting subjects that did not volunteer for the experiment. Instead of naturalistic settings, it has become much easier for researchers to employ driving simulators, and while the benefits to motorcyclists of daytime headlight use have been documented and discussed at great length since the 1970's, a more recent study tested their effectiveness in a driving simulator. Here, the authors (Lenné & Mitsopoulos-Rubens, 2011) examined the case where an oncoming driver turns onto a side-street across the path of a motorcyclist by varying the salience of the motorcycle (headlight on or off) and the size of the gap ahead of it (five, seven, or nine seconds). Headlight use was found to reduce the tendency of oncoming drivers to turn in front of the motorcycle, but only at short gaps, which is unsurprising because the seven or nine second gaps used in that study provide ample time for a driver to turn across a single lane of traffic. Where daytime running lights are concerned, it is important to note that another thing has changed since the 1980's: Motorcycles are no longer the only vehicles equipped with them, and whatever advantages they confer may disappear in an environment where all vehicles are equipped with daytime running lights, a factor which was overlooked in this study.

The effect of car daytime running lights (DRL) on motorcycle conspicuity has been examined and found to be detrimental (Cavallo & Pinto, 2012). Participants were briefly presented (250 ms) with images of oncoming traffic stopped or stopping at an intersection and tasked with detecting and identifying vulnerable road users

(pedestrians, cyclists, and motorcyclists). The detection and identification rates of all three types of vulnerable road users were lower for the images where car DRLs had been added with Photoshop. Interestingly, detection rates for motorcycles were higher than those for pedestrians and cyclists; the authors attribute this to greater motorcycle conspicuity owing to their larger size compared to pedestrians and bicyclists, but there may be an alternate explanation. Sager et al. (2016) also report higher detection rates for motorcycles than for pedestrians in a change-blindness study involving images of traffic scenes, but there, motorcycle detection was superior to that of the larger cars, suggesting that the motorcycle superiority that Cavallo and Pinto observed may have been due to something other than their size. As discussed later, a motorcycle is a relatively rare object in North-American traffic, and it may stand out due to its novelty.

Research on fluorescent or high-visibility clothing is inconclusive. Contrary to the findings of Olson et al. (1981) discussed above, an earlier study comparing the effects of headlight-off, headlight-on, and a fluorescent jacket on drivers' gap-acceptance behaviour found no difference between the treatments (Kirby & Stroud, 1978, as cited in Olson et al., 1981), but this cannot be taken as evidence of their ineffectiveness, as the study only involved a motorcycle circling a roundabout, which is not representative of the majority of motorcycle collisions. It should be noted, however, that while a high-visibility yellow or orange motorcycle jacket is certainly more noticeable in a store display, where it might be surrounded by black motorcycle clothing, the same may not be true in different traffic environments. Indeed, the effects of high-visibility clothing seem to be context dependent. That is, while they offer a detection benefit in a mostly grey urban environment, they are less effective than dark blue or black clothing when viewed in a visually brighter rural setting where the darker colours facilitate detection due to their higher contrast (Gershon, Ben-Asher, & Shinar, 2012; Hole, Tyrell, & Langham, 1996).

There may also be reason to believe that high-visibility clothing would have little impact on oncoming motorcycle detection rates, as the garment would likely not be visible behind the motorcycle's headlight and fairing (See Figure 4).



**Figure 4:** The large fairings on this Honda Gold Wing (left) and Harley Davidson Electra Glide (right) would render a fluorescent jacket ineffective. When viewed from the front, it is nigh-impossible to tell what a rider is wearing because their body is hidden behind the motorcycle's bodywork. Not all motorcycle fairings are this large, but because they are designed to protect the rider's body from the wind, they also obstruct the view an oncoming driver has of the motorcyclist's body; the only part of the rider that is always visible is the helmet.

Photos: Gold Wing by RL GNZLZ, CC 2.0; Electra Glide by Laureen Stokes; used with permission.



## Research involving cognitive conspicuity

The sensory conspicuity to which most motorcycle safety researchers refer, is really the same thing as salience. The salience of an object is proportional to how different or distinctive it is from its surroundings, whether that difference is due to brightness, colour, or shape. Salience certainly facilitates the initial bottom-up input into the visual attentional system, but whether an object (here, we are interested in motorcycles) undergoes further attentional processing and enters an observer's awareness is affected by factors related to the observer. For example, the brain may be otherwise engaged, as in the case of inattention blindness (Mack & Rock, 1998).

Inattention blindness refers to an observer's tendency to fail to detect an unexpected object or event if they are engaged in a task requiring their attention. Perhaps the most famous example this has become the "invisible gorilla" (Simons & Chabris, 1999): Observers watch a video of players passing two basketballs around and are required to count the number of passes made by the players wearing white; a large proportion of observers fail to notice the actor in a gorilla suit that walks across the screen. Studies like these highlight the importance of attentional set, something that is more generally referred to as "cognitive set". Thus, the guidance of visual attention is not limited to the bottom-up processes described earlier, but it is also greatly influenced by the observer's goals and expectations. In the case of motorcycle conspicuity, this is evidenced by studies that manipulate the observer's expectations and goals and show that those manipulations affect motorcycle detection rates. For example, there is evidence from simulator experiments that shows that when a certain colour was made pertinent to the experimental task (for example, when signs of a particular colour indicate the route to take) drivers were more likely to notice motorcycles of that colour (Most & Astur, 2007).

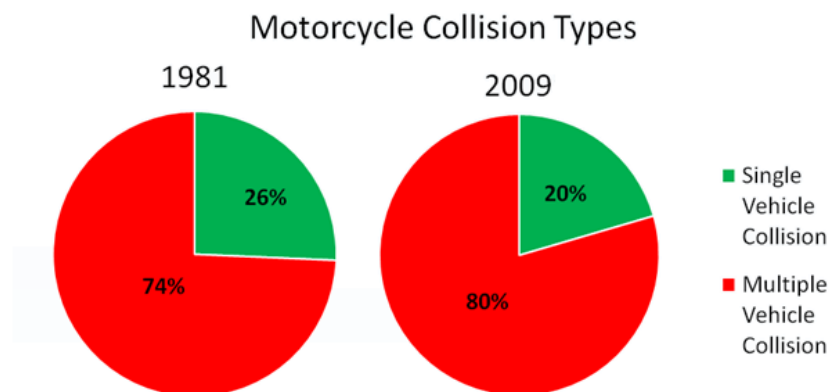
Another factor that may play a role in motorcycle detection is how often they are encountered on the road, or their prevalence. There is strong evidence that low-prevalence targets yield lower detection rates than high-prevalence targets (Wolfe, Horowitz, & Kenner, 2005; Wolfe et al., 2007), and prevalence effects have been studied in the context of motorcycle detection with the aid of a driving simulator (Beanland, Lenné, & Underwood, 2014). In a first phase, drivers were exposed to a high prevalence of either motorcycles or buses while driving normally; while they were told to pay attention to the ambient traffic, they were not explicitly told to watch for or otherwise process any specific vehicle type. In a later detection phase, they drove in an environment where either buses or motorcycles were more prevalent and were asked to report every time they detected a bus or a motorcycle. The authors report a main effect of vehicle type, with buses being detected from further away than motorcycles, which is unsurprising since they are much larger (a faraway motorcycle would be rendered as a couple of pixels, while the bus might be recognisable as such), and a main effect of target prevalence, with high-prevalence targets detected at greater distances during the second phase of the experiment, but they note that previous exposure to an environment with a high-prevalence vehicle type during the first phase only benefitted bus detection rates in the second phase. In spite of this, they conclude that “drivers’ real-world difficulties in perceiving motorcycles can be attributed to the fact that motorcycles constitute a ‘low prevalence’ target [...], as well as the fact that they have low physical salience” (Lenné, Rößger, & Underwood, p. 179).

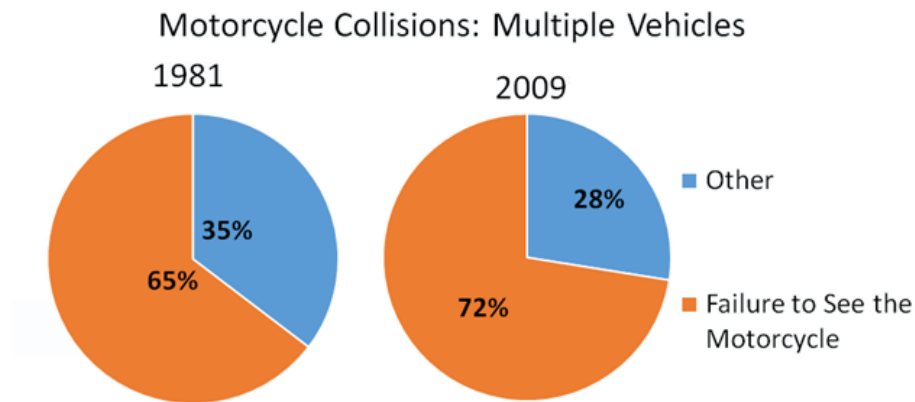
The final evidence that driver experiences affect motorcycle collisions comes from collision data showing that drivers who hold both a motorcycle and a car license are less likely to collide with motorcycles (Magazzù, Comelli, & Marinoni, 2006). Presumably, this is because these dual drivers are better at detecting motorcycles due

to their experience with them, which makes them more aware of the issues surrounding motorcycle conspicuity and motivates them to look more closely for them.

## Why the problem is likely not one of conspicuity at all

Most campaigns and researchers focus on the properties of a motorcycle that makes it salient because the common belief is that “all of the research indicates that simply increasing the sensory conspicuity of motorcycles (for example, by changing headlight configurations or adding high-visibility treatments) may reduce conspicuity-related crashes but will probably not eliminate them” (Lenné, Rößger, & Underwood, p. 40). However, there does not seem to be much, if any real-world evidence that shows a direct causal relationship between motorcycle salience and right-of-way violation collisions. To the contrary, available data suggest that the increases in motorcycle conspicuity made over the years have had no effect on failure-to-see collisions: Failure-to-see collisions seem, in fact, to be on the rise (See Figure 5). What follows is a critical examination of the mostly unchallenged (but see Olson, 1989) hypothesis that motorcycle collisions are due to poor sensory conspicuity, or salience.





**Figure 5: Motorcycles collisions in 1981 (Hurt et al.) and in 2009 (ACEM). The number of motorcycle collisions attributed to failure to see the motorcycle has increased.**

The primary evidence offered in support of the hypothesis that motorcycles lack conspicuity comes from the other driver's claim that they did not see the motorcycle at all, or not until it was too late to avoid the collision (Pai, 2011). There are reasons, however, that this account should be regarded as potentially suspect. Indeed, the driver of the offending vehicle can make no other claim without admitting negligence (or homicidal intention). When recalling the details of a collision with a motorcycle, a driver is going to reconstruct the account based on what information they have available to them, as is the case with all recollections. Most drivers think of themselves as good drivers (Svenson, 1981) and it is likely that in trying to make sense of the traumatizing event they were just involved in, they may think to themselves: "I am a good driver; how could this have happened? I am careful and skilled; I must not have seen the motorcycle". This "good driver" bias, combined with other schema-consistent information may be capable of distorting a driver's memory to the point where they forget ever seeing the motorcycle. The effects of schemas on memory are well documented in the eyewitness testimony literature: Mock jurors in a robbery trial tend to recall testimony

items that were never presented but that are consistent with a robbery scenario (Holst & Pezdek, 1992). The same could be happening in the case of a car-motorcycle crash, where a driver with an unclear memory of the events preceding the collision fills in the missing details with information consistent with scripts they are familiar with, scripts which include the claim that motorcycles are difficult to see.

Further support for the hypothesis that motorcycles lack conspicuity is found in the observation that riders who wear high-visibility clothing and equip their motorcycles with extra lighting are underrepresented in collision statistics (Wells et al., 2004). It is important to note that this correlation should not be confused for a causal relationship. Riders that choose to wear high-visibility motorcycling gear are clearly safety-conscious and probably have overall better risk management strategies than the general population of motorcyclists. Without a controlled experiment, it is impossible to tell whether their low involvement in motorcycle collisions is due to their increased conspicuity or to their safety-conscious attitude leading them to be more careful riders, and it is that rather than the increased conspicuity that results in fewer collisions. Such an experiment, however, would be difficult to conduct (if only for ethical reasons).

Another fact that is often offered as evidence consistent with the idea that motorcycles lack conspicuity, is that large touring motorcycles (the kind that are equipped with fairings and additional lighting) are underrepresented in collisions (again, a correlation). The thinking here being that because large objects are easier to see than small objects, a motorcycle's relatively small size makes it more difficult to detect in traffic. The notion that motorcycles are involved in collisions because they are smaller than other vehicles and, therefore harder to see, while intellectually unstraining, is likely wrong because it presumes that no factors other than motorcycle size affect these collisions. It is more likely that the reduced collision-involvement of larger motorcycles is

due to rider experience, rather than to the motorcycle's size. The large touring motorcycle, some examples of which are the Honda Goldwing and the BMW k1600GTL, is designed to deliver performance and comfort on long-distance trips. Because of this, they are large, expensive, and heavy; both bikes cost upwards of 25,000 USD and weigh in excess of 350 kg. This means that these motorcycles are neither appropriate for, nor appealing to the novice rider. Conversely, the high-risk rider who is typically a male in their 20's tends to prefer smaller, cheaper, lighter, and faster sport bikes which have a higher power-to-weight ratio (See Figure 6). An example of such a motorcycle is the Suzuki GSXR750, which retails for 12,000 USD, has a power-to-weight ratio of 0.65 hp/kg and reaches 100 km/h from a full stop in 2.9 seconds. To get an idea of how powerful these machines are, the Ferrari Enzo, a 670,000 USD limited production supercar offers a good comparison: It has a power to weight ratio of 0.44 hp/kg, and takes an additional quarter of a second to reach 100 km/h from a full stop. Given these performance figures, it becomes frighteningly apparent that these machines are not suited to novice riders, yet too many new motorcyclists gravitate toward them because of their low cost and weight.



**Figure 6:** Size comparison between the BMW k1600 GTL (top), a large touring bike weighing 348 kg, and the Suzuki GSXR-750 (bottom), a sport motorcycle of the same year, weighing a mere 190 kg. Both motorcycles are equally powerful, and neither is suited to novice riders.

Photos: k1600gtl by Sungwon Kim, CC 2.0; GSXR-750 by H-Y-P-E, CC 2.0

Because rider inexperience is associated with much higher collision risk (Liu, Hosking, & Lenné, 2009), it is sensible to believe that the low collision-involvement of large touring motorcycles has more to do with their riders' experience than with the motorcycle's larger physical size. Furthermore, if larger motorcycles are less involved in left-turn collisions because of their increased conspicuity, then one would expect to see the same effect of size when looking at four-wheeled vehicle collision-rates (where the size of the vehicle is not confounded with driver experience, as it is for motorcycles). Comparisons of four-wheeled vehicle collisions are difficult, because details are only available for police-attended collisions that resulted in serious injury or fatality, meaning that the numbers are going to be underestimates of the actual collision numbers. Further complicating analysis is the fact that passengers in larger vehicles such as pickup trucks and SUVs tend to sustain less severe injuries, and that the collisions they are involved in may not be reflected in the available data. Nonetheless, after contacting the Insurance Corporation of British Columbia, I obtained data on police-attended collisions involving a vehicle turning left at an intersection for the years 2010-2014. Complete interpretation of these data is hindered by the fact that population data were not provided, but it is still possible to determine whether a given type of vehicle involved in a left-turn collision is more likely to be the vehicle turning left or the other vehicle by calculating the ratio between the number of left-turning to other collisions involving that vehicle type. In such a calculation, higher ratios would indicate that other drivers were more likely to turn in front of that vehicle type (the data are provided in Table 1).



**Table 1:** In collisions that involve a vehicle turning left, motorcycles are much more likely to be the other vehicle. One could attribute this to their smaller size, but then one would have to explain why tractor-trailers and heavy trucks are also more likely to be in the same position than the more prevalent vehicles on the road.

Table 1				
<i>Collisions involving a vehicle turning left</i>				
<u>Vehicle Type</u>	<u>Manoeuvre</u>		<u>Total</u>	<u>Other/Left</u>
	<u>Left Turn</u>	<u>Other</u>		
Passenger Car Only	1453	1362	2815	0.94
Sport Utility Vehicle	242	195	437	0.81
Single Unit Truck/Light	238	180	418	0.76
Panel Van <= 4500 kg	143	107	250	0.75
Motorcycle	18	128	146	7.11
Comb Unit Tractor/Trailer	11	19	30	1.73
Single Unit Truck/Heavy	11	16	27	1.45

The theory that right-of-way violation motorcycle collisions are due to detection errors owing to the motorcycle's small size seems to be supported by the observation that larger cars (SUVs and pickup trucks) are less likely to have someone turn left in front of them, but it fails to explain the fact that large trucks are also more likely than the average vehicle to have their right-of-way violated by an oncoming driver. Because of this, one must conclude that size, if it is indeed a factor, is not the only variable at play. Another hypothesis that is contradicted by the above large-truck data suggests that oncoming drivers may not perceive the motorcycle to be a threat and therefore fail to exercise proper caution when turning left in front of them. Surely such drivers would perceive a truck weighing in excess of 20 tons to be a threat to their safety. It seems however reasonable to wonder whether these errors involving large trucks and motorcycles are due to difficulty in judging their approach speed due to their relative rarity on the road. In any case, it seems more likely that larger motorcycles are

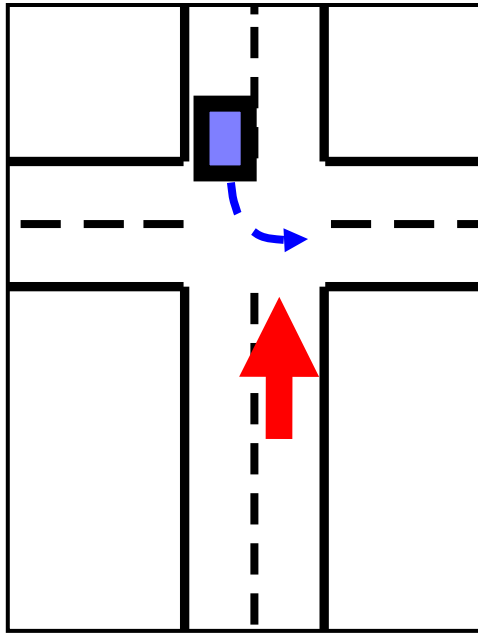
underrepresented in motorcycle collisions because of their rider's greater level of expertise rather than because of facilitated detection to the motorcycle's larger size.

Finally, what are we to make of the observation that drivers who also hold a motorcycle license are less likely to be involved in collisions with motorcycles? Is it because, riding one themselves, they have learnt to look for motorcycles and are therefore better at seeing them (a type of high-level cognitive conspicuity)? I believe that an alternate explanation for the low involvement of dual drivers in motorcycle collisions, one which has nothing to do with conspicuity, is more likely: These dual drivers are familiar with the performance characteristics of motorcycles, and therefore better able to judge how fast an oncoming motorcycle is travelling, when it will enter an intersection, and whether it is safe to turn in front of it.

Based on the above discussion, it seems unlikely that a simple "failure-to-see" is responsible for multi-vehicle motorcycle collisions. Given the increases in motorcycle conspicuity over the past decades and the increase in so-called conspicuity-related motorcycle collisions, it is necessary to examine other factors that may play a causal role in these collisions.

## **Why the problem may be one of motion perception**

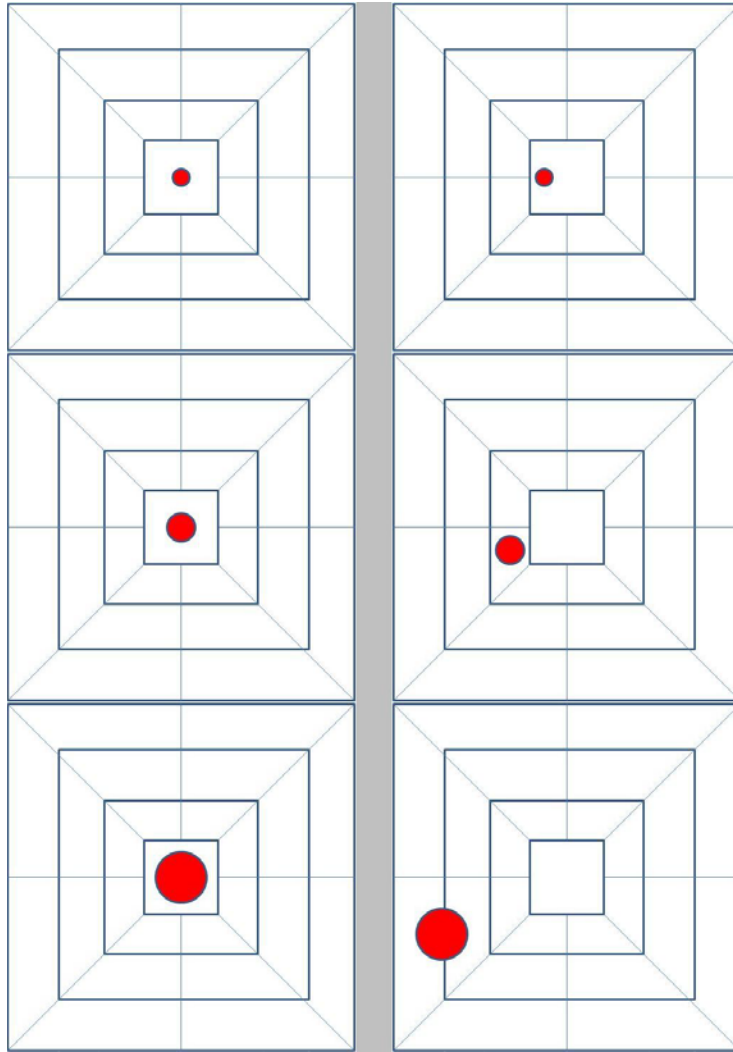
If the cause of motorcycle collisions were a lack of conspicuity, we should see motorcycles overrepresented in all types of collisions, but this is not the case. When comparing car-car and car-motorcycle collisions, we find that motorcycles and cars have the same types of collision at the same frequency, except for one collision type: The case where an oncoming driver turns across the path of the motorcycle (de Craen, Doumen, & van Norden, 2014) (See Figure 7).



**Figure 7: The most common car-motorcycle collision involves a driver turning left in front of an oncoming motorcycle. This is the only collision configuration where motorcycles are overrepresented.**

In this particular collision configuration, the motorcycle is approaching head-on from the perspective of a driver intending to turn left. It can and has been argued that these collisions are due to detection errors due to the motorcycle's small frontal area, but this account is likely wrong; motorcycles, or at least their headlights, are clearly visible in that scenario. The motorcycle's relatively small frontal area may pose a different kind of perceptual problem: It may interfere with a car driver's ability to accurately judge the distance and speed of the motorcycle. Because these speed and distance judgements are critical to determining the amount of time available before a vehicle enters an intersection, drivers turning in front of an oncoming motorcycle may do so as the result of a miscalculation. This is evidenced by studies of Time To Arrival (TTA) judgements, which find that larger vehicles are judged to arrive sooner than smaller vehicles (Caird & Hancock, 1994; Horswill, Helman, Ardiles, & Wann, 2005). One of the mechanisms

offered as an explanation this effect is that drivers may base time-to-arrival estimates on the rate of expansion of an object's image on the retina; because objects that are further away (and smaller) expand at a lower rate than large objects which are close, they are judged to arrive later. There is also evidence that the approach trajectory plays a factor, with research showing that the accuracy for time-to-arrival judgements decreases as approach angles become more obtuse (Schiff & Oldak, 1990; van Loon, Khashawi, & Underwood, 2010). Motorcyclists are generally trained to ride in the left portion of their lane, as this discourages other car drivers from encroaching on the motorcyclist's lane while passing and affords the motorcyclist a better view of the road ahead, as it puts them close to the centre line. This lane position is also intended to make the motorcycle more visible to oncoming traffic, but it puts the motorcycle's approach at a very obtuse angle from the perspective of an oncoming driver that is preparing a left turn (See Figure 8). It might be that this behaviour (which is partly intended to increase the motorcyclist's conspicuity) actually makes it more difficult for an oncoming driver to judge the speed and distance of the motorcycle and to decide whether it is safe to turn (Sager et al., 2014).



**Figure 8:** An object approaching directly along the line of sight (left) offers only one motion cue: Looming. By contrast, an object approaching at a less obtuse angle (right) will offer additional motion cues as it occludes and reveals different parts of the background; this makes it easier for an observer to judge its speed.

## **Goals of the present research**

The present work aims to address the problem of right-of-way violation collisions by building on two lines of previous work, one of which was designed to determine whether motorcycles are in fact inconspicuous in traffic, and the other to test whether the motorcycle's approach path sufficiently explains drivers' propensity to accept unsafe gaps in front of oncoming motorcycles. It should be noted that the case where a driver turns (left, in North-America) in front of an oncoming motorcyclist is the only scenario in which car collisions and motorcycle collisions differ (de Craen, Doumen, Bos, & van Norden, 2011; de Craen, Doumen, & van Norden, 2014). Given the arguments presented against the hypothesis that motorcycles lack conspicuity, and the aforementioned time-to-arrival judgement difficulties posed by an oncoming motorcycle's obtuse approach angle, which cause observers to overestimate a motorcycle's time-to-arrival, it becomes apparent that the problem with right-of-way violation motorcycle collisions may be one of motion-perception due to the motorcycle's trajectory rather than one of detection due to its supposed lack of conspicuity.

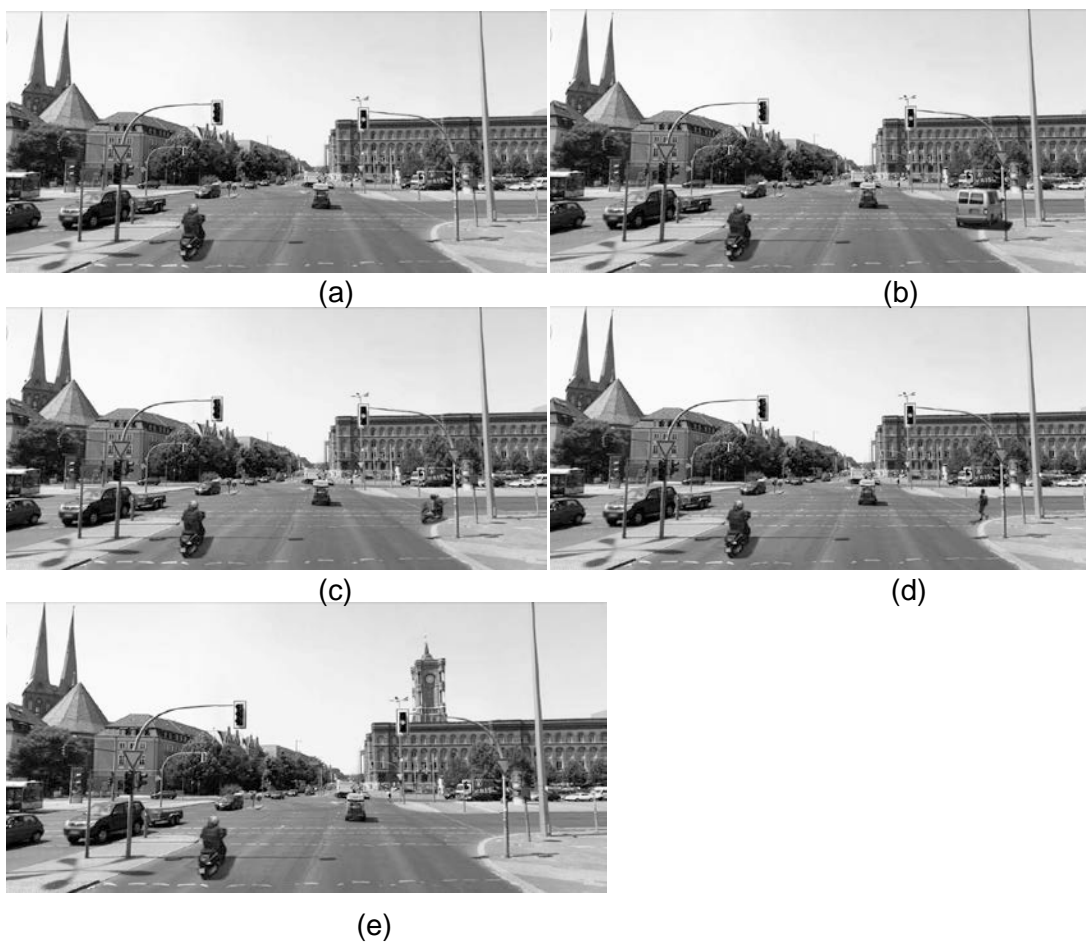
## **Previous work**

### **Change Blindness: A test of conspicuity**

In an unpublished study, my co-authors (Elisabeth Kreykenbohm, Brie Wish, Daniel Bernstein, Farhad Dastur, David Frowd, & Thomas Spalek) and I employed change-blindness to compare the relative conspicuity of cars and motorcycles in static traffic scenes (Sager et al., 2016). Change blindness is an inability to detect changes to an object or a scene, even when those changes are large, repeated, and anticipated (Rensink, 2002). Characteristically, changes involving attended objects are detected

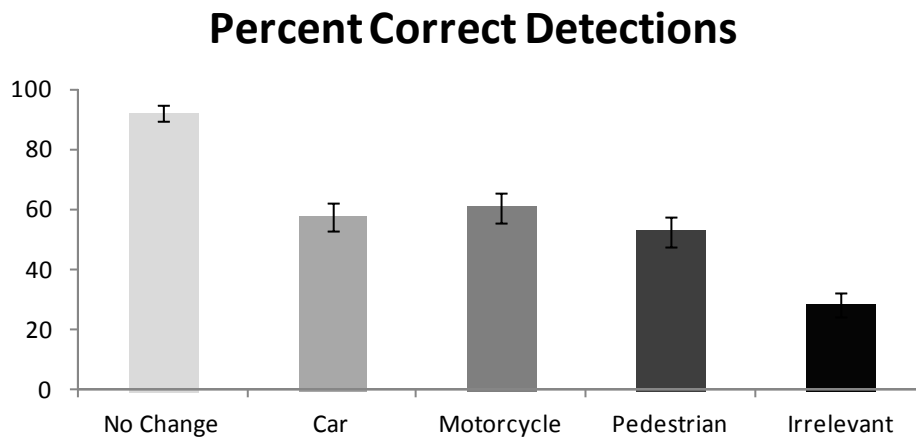
more readily than changes involving unattended objects, making change blindness a useful paradigm for the study of attention. Because conspicuity is context-dependent, as discussed above, it can be defined as an object's ability to capture attention with respect to the object's background (Wertheim, 2010). Therefore, high detection rates for a particular object in a change blindness paradigm should be taken as an indication of that object's conspicuity.

We presented 52 subjects with greyscale images of intersections that flickered between two versions, one of which had an object removed. The target object on each of the 30 experimental trials was a car, a motorcycle, a pedestrian, or a traffic-irrelevant object; one fifth of the trials involved no change (See Figure 8). Targets were equated for salience by careful control of brightness and contrast. Surprisingly, we found higher detection rates for changes involving motorcycles than for changes involving cars (See Figure 9).



**Figure 9:** Sample stimuli: (a) original image, (b) with a car added, (c) with a motorcycle added, (d) with a pedestrian added, and (e) with a driving-irrelevant object added to the right of the image. Note that in this particular image, only 50% of our participants detected the tall building to the right of image (e).





**Figure 10: Percentage of correct change detections by condition for Experiment 1. Error bars represent 95% confidence intervals.**

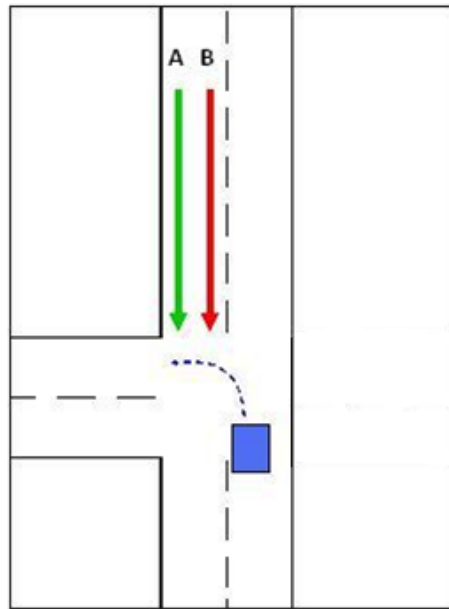
Our participants did not detect changes involving motorcycles less frequently than changes involving cars or pedestrians. Detection rates in our paradigm are reflective of how people attend to objects; presumably, this is because the ability to attend to an object depends on the object's conspicuity. Given this, the high detection rates of motorcycles reported here suggest that motorcycles do not suffer from a lack of conspicuity and that their detection rates are not related to their smaller size, at least in static greyscale traffic scenes.

The static nature of the stimuli we used is a major limitation of this study, and part of the work presented here aims to address this shortcoming.

### **Gap acceptance: A test of motion cues**

Suspecting that a failure in detecting the presence of the motorcycle was not the root cause of these left-turn right-of-way violation collisions, and that the problem might instead be due to difficulty in perceiving the rate of approach of the oncoming motorcycle, I conducted an experiment in a driving simulator (Sager et al., 2014).

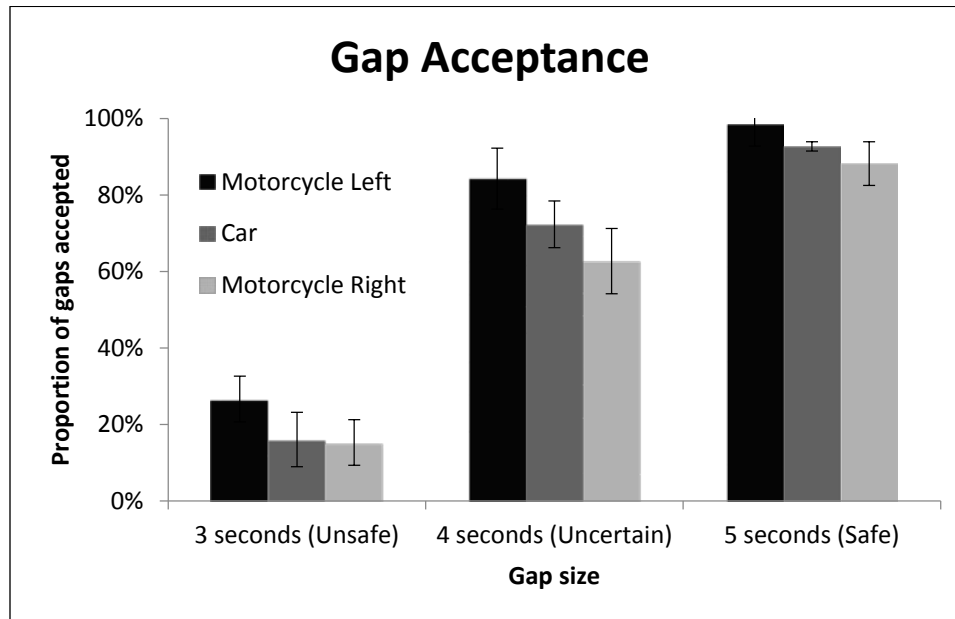
In this experiment, participants sat in the driver's seat of a high-fidelity driving simulator, with the simulated vehicle positioned at a three-way intersection on the main road, ready to make a left turn onto the intersecting roadway (Figure 10).



**Figure 11:** Scenario for the gap-acceptance study. Oncoming motorcycles were either riding in the right-of-lane (A), or in the left-of-lane (B).

Participants viewed a stream of oncoming vehicles (white cars and red motorcycles) traveling at 50 km/h. Within this stream were 135 experimental trials which consisted of a gap (three, four, or five seconds), which was closed by a specific vehicle type (a car, a motorcycle in a right-of-lane position, or a motorcycle in a left-of-lane position). Participants' task was to indicate via a button press which gaps they thought were large enough for them to safely make a left turn. Our results suggest (see Figure 11) that a driver's propensity to turn left in front of an oncoming motorcycle is related to that motorcycle's lane position, with drivers more likely to turn left in front of a motorcyclist riding in the left portion of their lane. Critically, and consistent with the findings of Lenné & Mitsopoulos-Rubens (2011) reported above, this effect is greatest in

the short gaps, which were selected based on pilot data that showed a three-second gap to be unsafe, and a four-second gap to be just-sufficient to make a left turn in our simulator.



**Figure 12:** Drivers were more likely to accept gaps in front of an oncoming motorcycle in the left-of-lane position. This effect was more pronounced for unsafe and uncertain gaps. Error bars represent 95% confidence intervals.

Presumably, we observed this pattern of results because an oncoming motorcyclist riding in the left portion of their lane offers too few motion cues to a driver waiting to turn left at an intersection.

This seems intuitive, because the motorcyclist in a left-of-lane position approaches directly along an oncoming driver's line of sight, which offers only looming as a motion cue. In contrast, the motorcycle in the right-of-lane position offers additional motion cues: The angle of regard changes as it approaches; the motorcycle occludes and reveals elements of the background as it gets closer, and finally, it moves across the retina. The single motion-cue afforded by the motorcycle's left-of-lane position is

insufficient for an oncoming driver to construct an accurate estimate of the motorcycle's time of arrival. But it is unknown whether this paucity of motion cues suffices to explain these left-turn right-of-way-violation collisions. Further experimentation is required in order to examine drivers' behaviour in a dynamic experiment, and to determine whether motorcycle lane-position does indeed affect their judgement of when the motorcycle will enter the intersection.

The other part of the present work then aims to correct two of the shortcomings of this study. Firstly, participants were not driving the simulated vehicle; they merely viewed a stream of oncoming vehicles and indicated the gaps that they thought were safe by pressing a button in the simulator, which, while informative, is not necessarily reflective of their driving behaviour. Secondly, the participants were stopped at the intersection, while in the real world, drivers often make a decision about whether to turn in front of another vehicle while they are approaching an intersection. The present work therefore aims to examine driver's braking, yielding, and gap-acceptance behaviour in a dynamic experiment where they actually drive the simulated vehicle.

## **Current experiments**

From the above discussion and the data obtained from the previous change-blindness experiment, it seems that the problem with right-of-way-violation motorcycle collisions may not be related to conspicuity. However, that change-blindness study lacks ecological validity because the stimuli were static images, and because the flicker paradigm does not correspond to the way we observe traffic in reality. When we drive a car, we don't scan a flickering static scene for a change; instead, we continually observe our surroundings, and build and maintain a mental image of where the relevant objects are and of how they are moving, prioritizing the objects that may pose a threat to us. For that reason, the experiment needs to be repeated in a dynamic driving scenario. This is the first experiment presented here.

When faced with evidence that motorcycles are detected at least as well as cars in traffic, one must reconsider the hypothesis that right-of-way-violation collisions are caused by poor motorcycle conspicuity and search for another cause. The hypothesis that these types of motorcycle collisions are due to difficulty in judging the approach of an oncoming motorcycle seems a promising candidate, but it is in need of testing. The second and third experiments presented here are therefore tests of that hypothesis.

## **Experiment 1: Dynamic change-blindness**

### **Description**

In order to address the shortcomings due to the static nature of the stimuli used in the Sager et al. (2016) change blindness experiments, this experiment employed a high-fidelity driving simulator to produce dynamic scenes through which the participants drove. Critically, this experiment will serve to show that the superior conspicuity

observed for motorcycles in the aforementioned experiment is not due to the static nature of the stimuli or to the flicker paradigm.

At regular intervals, the simulator's screens flickered, and one of the ambient vehicles (either a car or a motorcycle) was removed from the scene. Following the screen flicker, participants indicated whether they detected a change in the scene. The hypothesis under examination is that motorcycles are less conspicuous than cars, and therefore, sensitivity to them should be lower. Data are expected to replicate the results of the aforementioned static change-blindness study, leading to the conclusion that motorcycles are no less conspicuous than cars, even in a dynamic traffic environment.

## **Participants**

Forty-one students (18 male, mean age = 20 years, SD = 2.4 years) with a minimum of two years of unsupervised driving experience were recruited from SFU's psychology research pool and received partial course credit for their participation. None of the participants were motorcyclists.

## **Apparatus**

For this experiment, we used the DS-600 high-fidelity research simulator produced by DriveSafety. The simulator consists of the front half of a Ford Focus mounted on a motion platform that simulates acceleration and braking via pitch. The cockpit includes all the instrumentation and controls found in that car. The displays provide 180 degrees of forward view and refresh at 60 Hz, which is also the rate at which the simulator collects data. The simulation was authored using HyperDrive and rendered using Vection simulation software (DriveSafety version 1.9.35).

## Design

This experiment is a one-flicker change-blindness paradigm with three independent variables, the target type (car or motorcycle), the target action (entering or exiting the intersection), and the target location (left, centre, or right side of the intersection). Compared to the flicker paradigm used previously, in the one-flicker or “one-shot” change blindness paradigm, observers are only exposed to the change once; images do not alternate between a target-present and a target-absent version. Participants compare a post-flicker scene to their memory of a pre-flicker scene; detection of a change indicates that the changed object was stored in memory, which suggests that it was attended. Changes are present on only half of the trials, so as to permit the calculation of signal detection measures. The dependent variable is  $d'$ , which is a measure of each participant's sensitivity to the target. Sensitivity will be computed for each target type and then compared across conditions in order to see if participants are more sensitive to cars or motorcycles. Beta, a measure of the criterion a participant sets for when there is sufficient evidence to make a “yes” response, will also be computed, and will serve to confirm that participants' responses are not due to an overly liberal bias in any given condition.

## Procedure

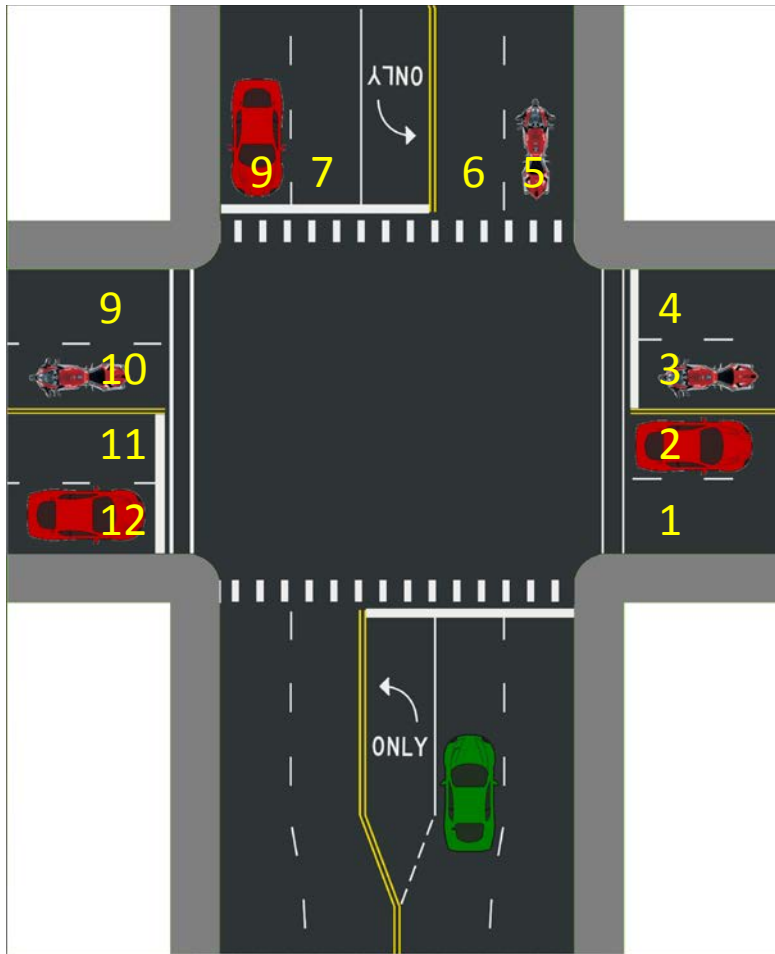
Subjects drove the simulator toward an intersection (See Figure 12). Other vehicles, which were either cars or motorcycles, approached the intersection at the same time as the participant, and manoeuvred so that they would be positioned in one of the 12 positions identified in Figure 12 just before the participant entered the intersection.

For each trial, ambient traffic was composed of a mixture of cars and motorcycles that were programmed to reach one of the other positions at the intersection. Ambient traffic was selected so that each end-position had a 50% chance of receiving a vehicle, and the type of vehicle was randomly determined by the computer (with equal probability of being a car or a motorcycle). Distractor cars and motorcycles were of the same make and colour as the target cars and motorcycles (the only motorcycle available in the simulator is red, so the car was chosen to be of the same colour). Trials were created so that there were 5 trials for each target type in each end-position, and were presented in random order. The intersection was free of any other traffic and landmarks.

Participants were instructed to steer as if proceeding straight through the intersection (for which they had a green light), and to monitor the ambient traffic as they would do during normal driving. The simulation controlled the speed of the participant's car for the purpose of synchronization with the ambient traffic; participants were not required to use the accelerator or brake pedals.

Each trial began with the simulated travelling at 50 km/h toward a four-way intersection from a distance of 100 meters. When the participant was 15 metres from the intersection, the screens turned black for 300 milliseconds, during which time, on half the trials, the target vehicle was removed from the simulation. As the participant entered the intersection, the simulation paused and prompted them to report whether they detected a change in the ambient traffic by pressing one of two buttons located behind the steering wheel. As soon as the participant made a response, the simulation teleported the vehicle back to the starting point and the next trial began.





**Figure 13:** Overhead view of the intersection at which the experimental trials took place, showing the locations at which the ambient traffic was placed at the time of the flicker (red vehicles) and the subject's vehicle (green); each location had a 50% probability of containing a vehicle.

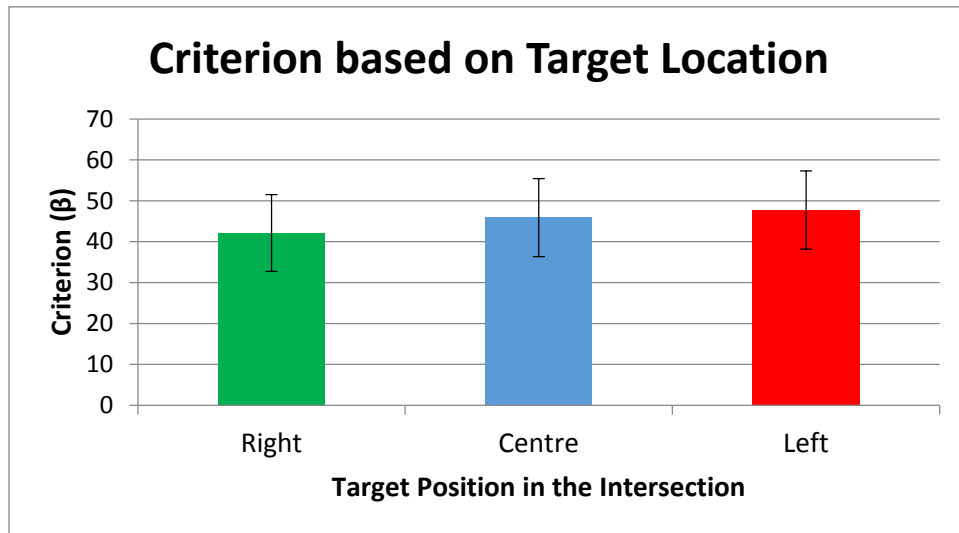
## Results

Data were analyzed using a 3 (target location in the intersection or visual field: Right, centre, or left) by 2 (target action: Entering or exiting the intersection) by 2 (target type: Motorcycle or car) repeated measures ANOVA.

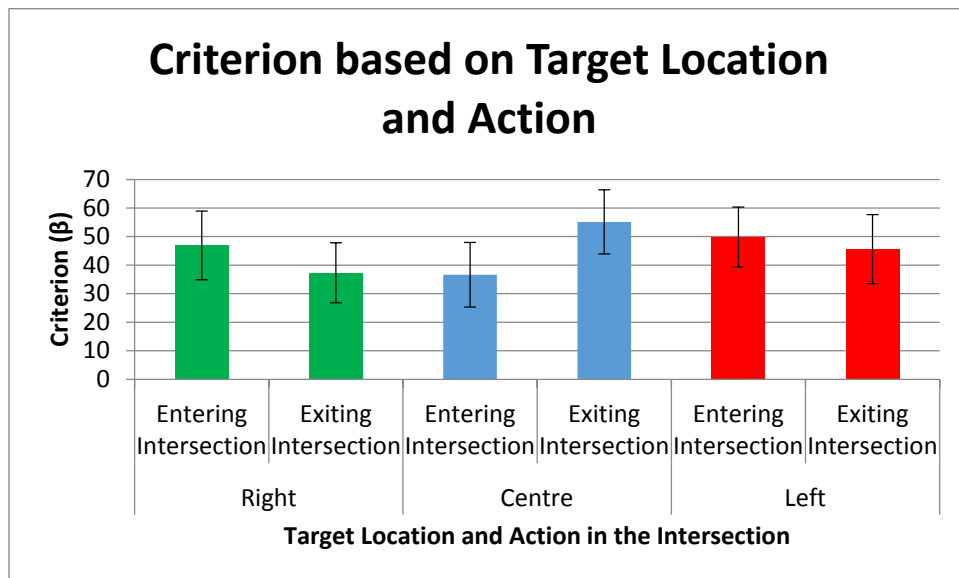
### ***Criterion***

The results of the ANOVA conducted on the bias data ( $\beta$ ) reveal no main effects of target location ( $F(2, 80) = .865, p = .425$ ), of target action ( $F(1, 40) = .186, p = .669$ ),

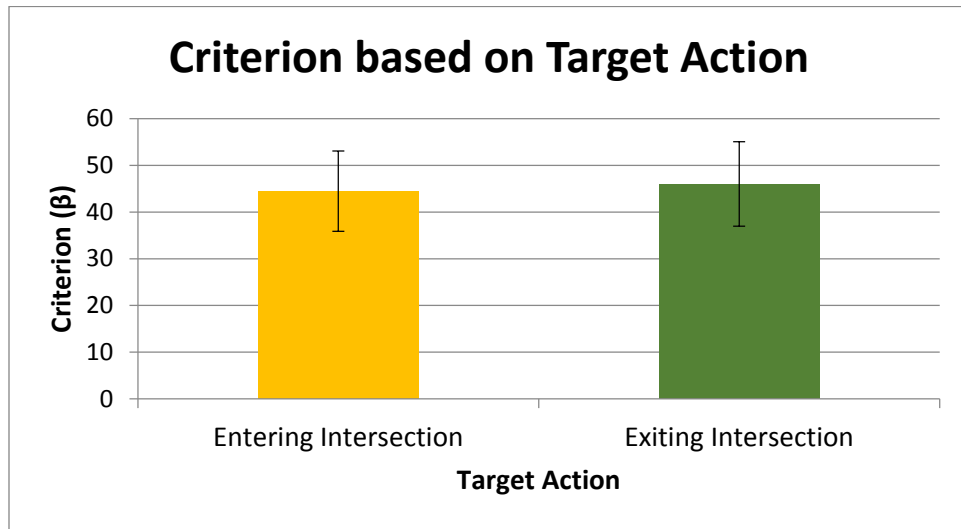
or of target vehicle type ( $F(1, 40) = 4.029, p = .052$ ); only the interaction between target location and target action was significant ( $F(2, 80) = 6.26, p = .003$ ), with a more conservative criterion to vehicles exiting the intersection centrally. The means for criterion are shown in figures 13, 14, 15, and 16.



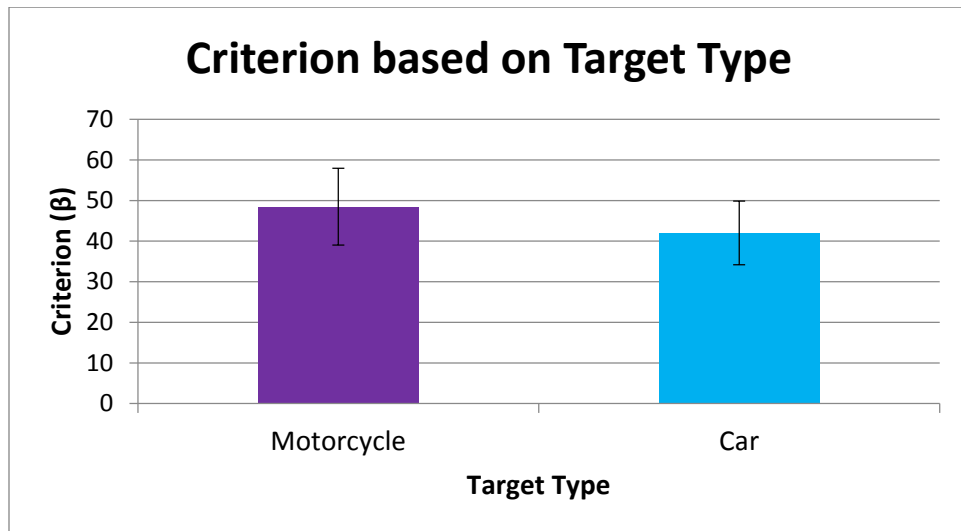
**Figure 14:** Criterion based on target location; no significant effects were found. Error bars represent 95% confidence intervals.



**Figure 15:** Criterion based on target location and action. Error bars represent 95% confidence intervals.



**Figure 16:** Criterion based on target action; no significant differences were found. Error bars represent 95% confidence intervals.

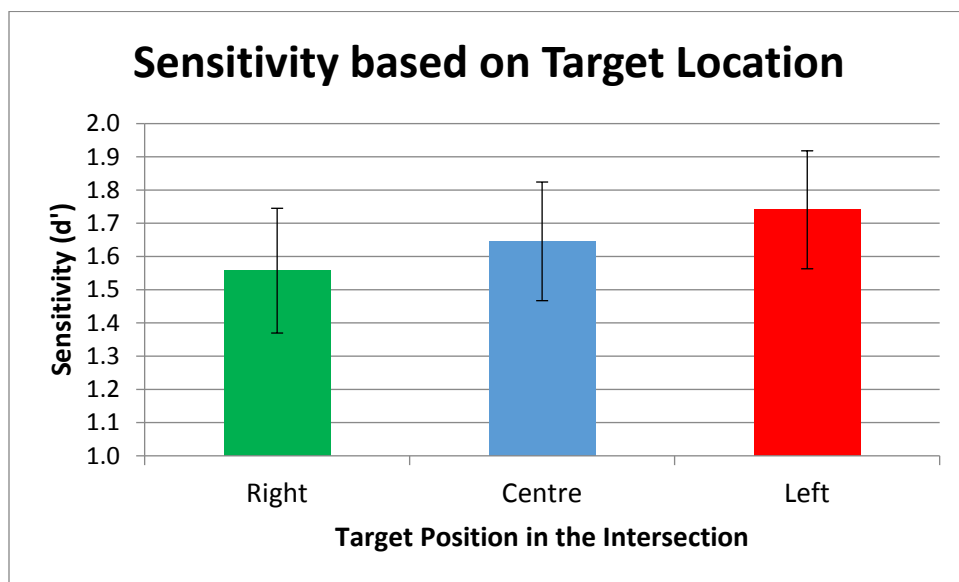


**Figure 17:** Criterion based on target type; no significant differences were found. Error bars represent 95% confidence intervals.

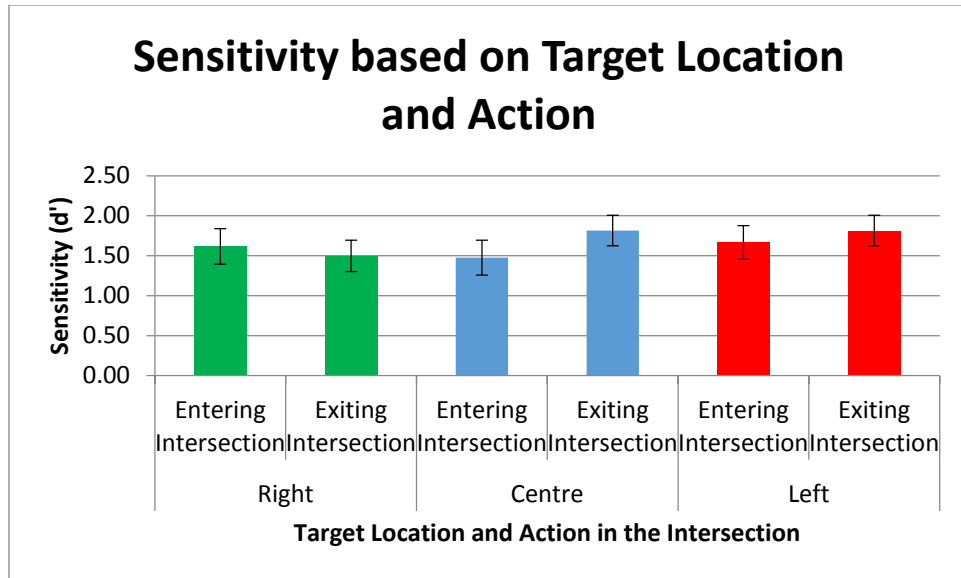
## Sensitivity

The ANOVA conducted on the sensitivity data ( $d'$ ) revealed a main effect of target location ( $F(2, 80) = 4.060, p = .021$ ). This effect is driven by the right-left difference, with higher sensitivity to vehicles on the left. The analysis also revealed a main effect of target vehicle type ( $F(1, 40) = 6.356, p = .016$ , with higher sensitivity to motorcycles. There was no main effect of target action ( $F(1, 40) = 3.974, p = .053$ , but this trend suggests that sensitivity was slightly higher to vehicles exiting the intersection.

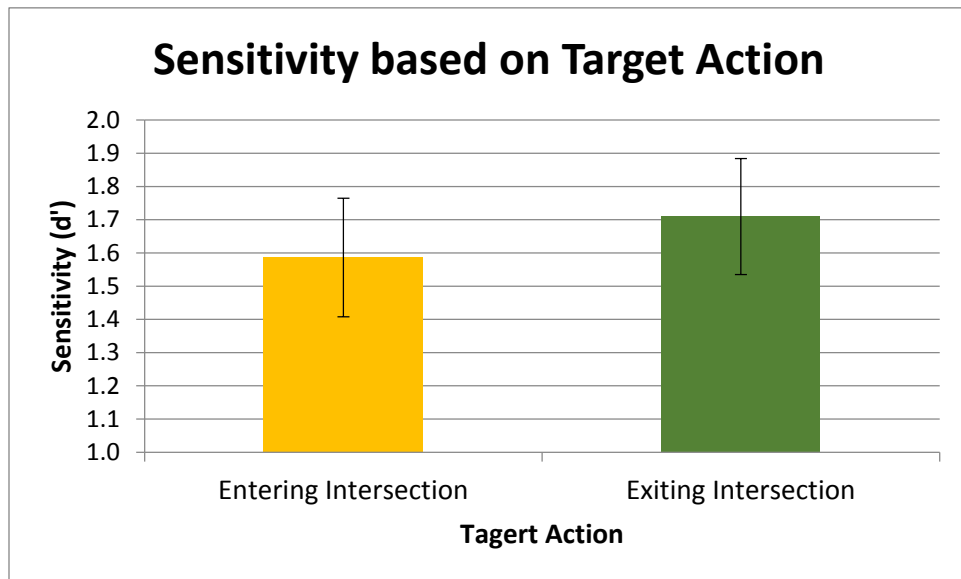
A significant interaction was found between target location and target action ( $F(2, 80) = 6.666, p = .002$ ), with higher sensitivity to vehicles exiting the intersection centrally; none of the other interactions were significant (all  $p > .449$ ). The means for sensitivity are shown in figures 17, 18, 19, and 20.



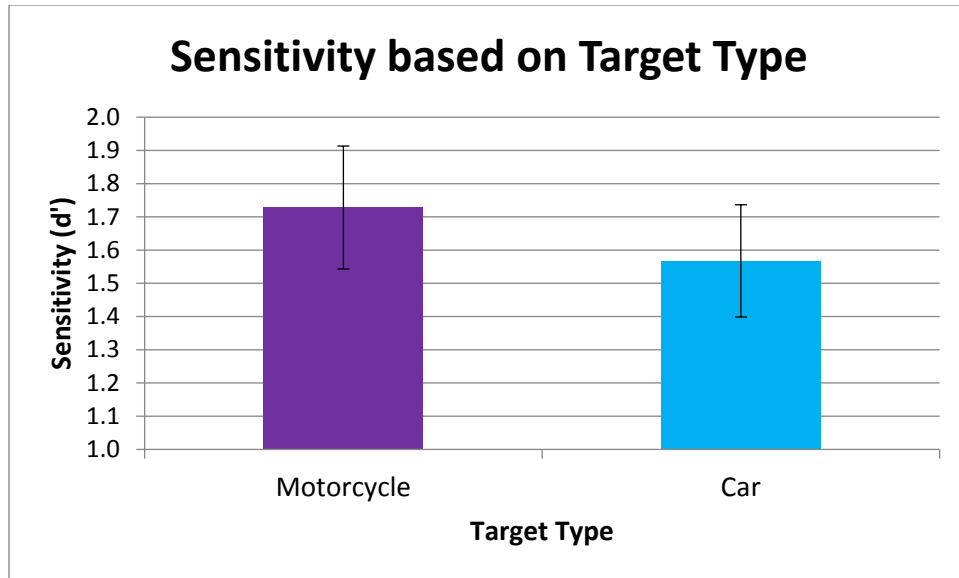
**Figure 18:** Sensitivity based on target location; participants were more sensitive to targets on the left. Error bars represent 95% confidence intervals.



**Figure 19:** Sensitivity based on target location and action. Error bars represent 95% confidence intervals.



**Figure 20:** Sensitivity based on target action; participants were equally sensitive to vehicles entering and exiting the intersection. Error bars represent 95% confidence intervals.



**Figure 21: Sensitivity to motorcycles was higher than sensitivity to cars. Error bars represent 95% confidence intervals.**

## Discussion

This experiment was designed to test whether drivers are less sensitive to motorcycles than to cars when experiencing them in a dynamic simulated context. Results replicated the findings of the static change-blindness experiments discussed previously (Sager et al., 2016) and showed that motorcycles are no less conspicuous than cars. This experiment is a stronger and more ecologically valid test of the hypothesis that motorcycles are inconspicuous in traffic, because the stimuli in this experiment are dynamic and the task involves actual driving in a realistic situation that reproduces a common motorcycle collision scenario. Because participants' sensitivity was higher to motorcycles than to cars, with no difference in bias, we must reject the assumption that motorcycles fail to capture attention in traffic. This may explain why the application of previous research on motorcycle conspicuity, especially involving high-

visibility treatments seem to have had no effect on so called “failure to see” motorcycle collisions. If the cause of multi-vehicle motorcycle collisions is not one of insufficient conspicuity, then it should not be surprising that the pursuit of increased-conspicuity solutions does not yield a decrease in the frequency of these collisions.

One surprising (and slightly alarming) observation that can be made from these data is that participants seemed to be more sensitive to vehicles exiting the intersection rather than to vehicles entering the intersection, especially when they were centrally located. It was my expectation that vehicles about to enter the intersection would be attended preferentially because they pose a potential threat, given the possibility of colliding with them. Instead, it seems that participants paid more attention to what was in the intersection than to what was going to be in the intersection. I believe that this shows poor risk management, because on the road, where things move at 50 km/h, one needs to look at least two seconds (or 30 metres) into the future; any objects already in the intersection should have been attended to earlier. This issue needs to be addressed in driver training programs.

## **Experiment 2: Dynamic yielding behaviour during left turn**

### **Description**

Experiment 1 provided evidence that motorcycles are no less conspicuous than cars in a dynamic traffic environment. This finding challenges the idea that poor motorcycle conspicuity is a major factor in motorcycle right-of-way violation collisions. As a result, it becomes necessary to explore other possible explanations for these collisions. One promising alternative is that the oncoming driver fails to accurately judge the rate of approach of the motorcycle, as suggested by Sager et al. (2014). If this is the

case, then one would expect to see evidence of this difficulty in a driver's braking behaviour, and based on Sager et al., this should be exacerbated for a motorcycle in a left-of-lane position. This is because a motorcycle in a left-of-lane position approaches on a more head-on trajectory and, therefore, offers fewer motion cues to an oncoming driver.

The aim of the current experiment is therefore to test if a driver's reactions differ depending on whether they face a motorcycle in the right-of-lane or in the left-of-lane position as they prepare to turn left turn at an intersection. Participants were placed in a high-fidelity driving simulator where they performed a series of left turns. After some practice driving the simulator and making turns at intersections, participants made four critical turns in which they were faced with an oncoming vehicle to which they needed to yield before turning in order to avoid a collision. This vehicle was either a motorcycle in a right-of-lane position, a motorcycle in a left-of-lane position, a car, or a pickup truck. This experiment is a dynamic version of the Sager et al. (2014) gap-acceptance study described above. In that study, participants remained stationary and responded whenever they judged a presented gap to be safe enough to make a left turn. Here, participants actually drove the vehicle toward an intersection and were faced with an oncoming vehicle that was programmed to arrive at the intersection at the same time as them, causing a conflict, and their braking responses to the oncoming vehicle were measured. Examination of this braking behaviour will allow a test of the hypothesis that the rate of approach of an oncoming motorcycle in a left-of-lane position is more difficult to judge than the rate of approach of a motorcycle in a right-of-lane position. If the hypothesis is correct, then the data are expected to show more erratic braking responses to the motorcycle in the left-of-lane position, as would be expected if the driver is having more difficulty in judging the rate of approach of that motorcycle.



## **Participants**

Two hundred and twenty one SFU psychology students (100 male, mean age = 21 years, SD = 4.4 years) with a minimum of two years of unsupervised driving experience (74% of the participants reported driving daily) were recruited from SFU's research pool and received partial course credit for their participation. None of the participants were motorcyclists.

## **Apparatus**

For this experiment, we again used the DS-600 high-fidelity research simulator produced by DriveSafety. The simulator consists of the front half of a Ford Focus mounted on a motion platform that simulates acceleration and braking via pitch. The cockpit includes all the instrumentation and controls found in that car. The displays provide 180 degrees of forward view and refresh at 60 Hz, which is also the rate at which the simulator collects data. The simulation was authored using HyperDrive and rendered using Vection simulation software (DriveSafety version 1.9.35).

## **Procedure**

After filling out a motion-sickness questionnaire to exclude those prone to motion-sickness, participants drove the simulated vehicle around an urban area that included a series of intersections at which they were instructed to perform left turns by verbal instructions built into the simulation, similar to those that would be provided by a GPS. The experiment began with a 15 minute acclimatization phase, which was designed to let the participants get a feel for how the simulated vehicle accelerated, steered, and braked. The acclimatization phase was immediately followed by four

experimental trials, which lasted three minutes each. The total duration for the experiment was approximately 30 minutes. Participants were told to obey all traffic laws, and an auditory prompt warned them when they were driving too slow or too fast (they were expected to drive at about 50 km/h). The roadway included a lane of traffic in each direction, parked cars, and a sidewalk. Oncoming ambient traffic was randomly generated during the acclimatization phase and between the experimental trials. Each trial began when the subject vehicle was 150 metres away from the centre of the target intersection; from this point, the simulation stopped generating random oncoming ambient traffic, and began recording the subject vehicle's deceleration as a function of the distance until the point where they began their left turn.

On each trial, an oncoming vehicle to which the participant would have to yield began its approach 150 meters away from the intersection and instantly matched speed with the subject vehicle until it was one second away from entering the intersection (at which time the oncoming vehicle's speed was fixed at 50 km/h). The speed of the oncoming vehicle was rigorously controlled to create a situation that would result in a collision if the participant did not brake to yield to it. There was no other traffic following the oncoming vehicle, nor was there any pedestrian traffic at the intersection. On two of the four experimental trials, the oncoming vehicle was a motorcycle, and was placed either in a right lane position or in a left lane position (1.3 metres from the centre of the lane in either case). On the other two experimental trials, the oncoming vehicle was a car, or a pickup truck. Because the only motorcycle available in the DS-600 simulator is red, the car and truck were chosen to be of that same colour. Headlights were turned off to avoid attracting attention to the vehicle when they suddenly turn on at a distance at which the simulator can render them. Trials ended 45 metres after the subject completed the left turn, and trial order was counterbalanced across participants.

## **Results**

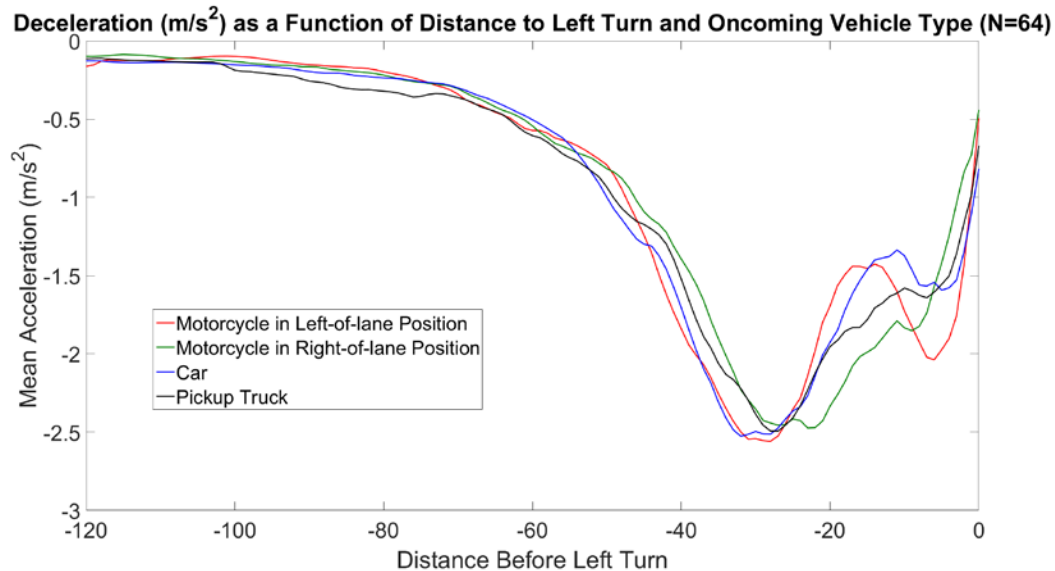
### ***Exclusion criteria***

Twenty-three participants did not complete the experiment due to motion-sickness and were excluded from the analysis. In addition, because each participant's braking data are referenced to the moment when that participant began making their left turn, and because the accuracy and stability of the steering data were critical to identifying that moment, participants who displayed erratic steering during their approach to the intersection or during the execution of the left turn (they turned wide and climbed the sidewalk, or accelerated hard before turning the wheel) were also excluded. One-hundred three participants had to be excluded based on the former criterion, and 31 because of the latter. This left 64 participants in the final analysis; 34 were male, and the mean age was 20.31 years ( $SD = 2.5$  years).

### ***Braking Data***

Deceleration data, a measure of braking behaviour, were calculated as a function of distance from the beginning of each trial's left-turn manoeuvre and averaged across participants; the deceleration plot is presented in Figure 21. Visual comparison of the four conditions indicates that the braking pattern exhibited when participants were faced with a motorcycle in a left-of-lane position seems to differ from the other three conditions, with a much greater reapplication of brake near the end of the approach. The deceleration exhibited when facing an oncoming motorcycle in a left-of-lane position is consistent with an initial overestimation of the motorcycle's time-to-arrival; once the motorcycle is closer, drivers realize their mistake and reapply the brake more firmly in order to yield to the motorcycle. It is plausible that drivers initially decided that they would have time to turn in front of the motorcycle, and changed their mind as they got

closer. By contrast, the deceleration exhibited when facing an oncoming motorcycle in a right-of-lane position shows a more cautious approach; perhaps drivers were better able to monitor the motorcycle's speed and decided early on that they should yield to it.

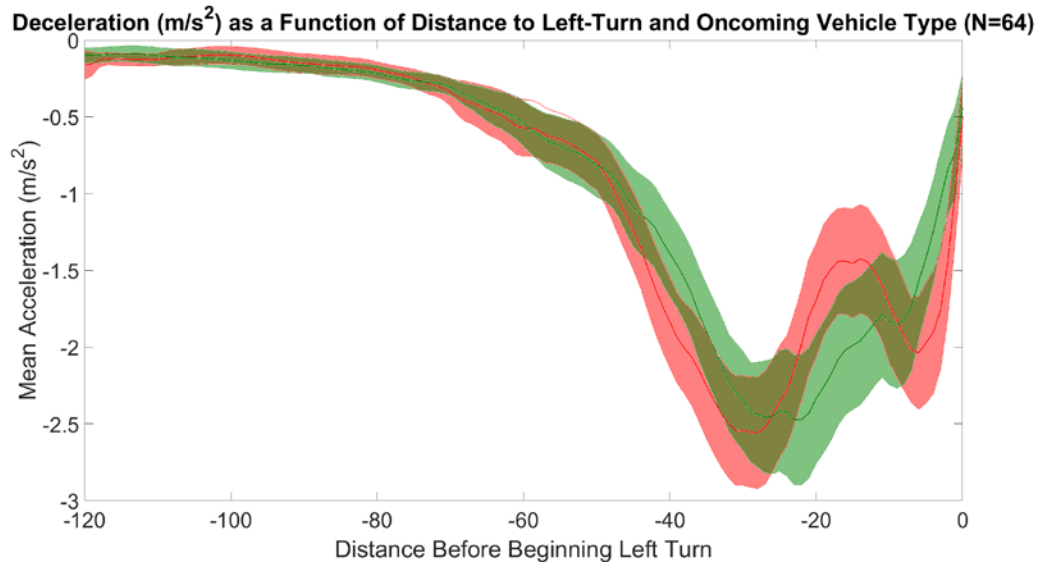


**Figure 22:** Deceleration as a function of distance to the left turn: Participants gradually decrease their amount of deceleration as they prepare to turn left in front of a motorcycle in a right-of-lane position (green), a car (blue), or a pickup truck (black), but in the case of a motorcycle in a left-of-lane position, they reapply the brake as they get closer to their turn, which suggests a correction to what was initially insufficient braking.

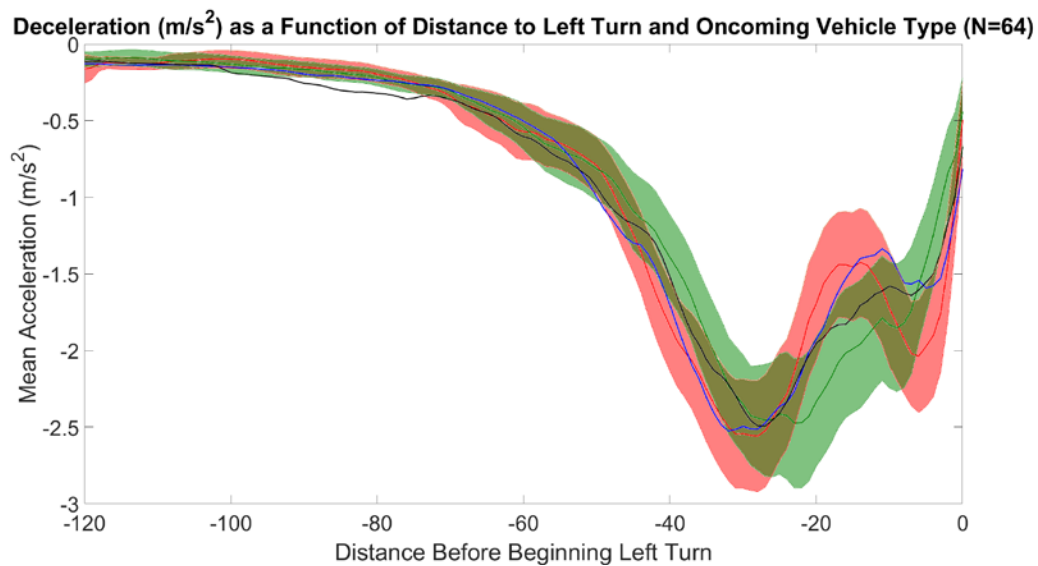
Statistical comparison of these deceleration curves presents complex difficulties. Onset, duration, and peak amplitude, which are common measures when analyzing graphical data like these (for example, in event related potential research) do not provide a complete picture of the phenomenon under study, as they tend to only compare averages at a single point in time. The determination of where a signal begins to peak is also somewhat subjective. A comparison of area under the curve across conditions is equally uninformative: Because participants start braking from the same speed and

ultimately decelerate to approximately the same speed before turning, the areas under each of the four curves presented in Figure 21 are expected to be identical (the total area under the curve represents the total amount of deceleration). For example, the area under the deceleration curve for someone that stops by braking gently for a long distance would be the same as for someone who brakes hard for a shorter distance, given that they both start braking from the same speed. Specific regions of interest could be identified, and the areas under the curves in those regions could be statistically compared, but the choice of those regions is ultimately arbitrary and therefore subject to bias.

Each of the curves plotted in Figure 21 is an average, and the variability across participants is unlikely to be constant over the entire length of each curve. Furthermore, the variability may also vary across experimental conditions: Participants' braking behaviours may be more consistent when yielding to an oncoming car than when yielding to an oncoming motorcycle, for example. To get an accurate picture of what is going on with these data, it is necessary to take that variability into account. To this end, 95% confidence intervals were plotted around the curves of interest (motorcycle in a right-of-lane position and motorcycle in a left-of-lane position), effectively transforming the lines from Figure 21 into ribbons of varying thickness, with the thickness representing variability around the mean. Figure 22 presents the plot of those ribbons and allows for the objective and statistically plausible identification of differences between braking behaviours. Where one curve's mean resides outside of the other curve's 95% confidence intervals, one can be reasonably sure that the two curves are different. Figure 23 shows the mean curves for the car and pickup truck conditions superimposed on Figure 22.



**Figure 23:** Comparison of deceleration curves between the motorcycle in a right-of-lane (green) and in a left-of-lane (red) position. The widths of the red and green bands represent the variability at any given point on the curve (expressed as 95% confidence intervals). The differences or similarities between the two curves are quantified by the amount of overlap between them, and immediately noticeable.



**Figure 24:** The deceleration curves in reaction to oncoming cars (blue) and oncoming trucks (black) are shown superimposed on the previous graph. Oncoming motorcycles in a right-of-lane position produce braking responses similar to those produced by an oncoming pickup truck. Braking responses to oncoming motorcycles in a left-of-lane position produce braking responses more similar to those elicited in response to an oncoming car.

## Discussion

This experiment provides valuable insight into the effect that a motorcycle's lane position has on the braking/yielding behaviour of an oncoming driver intending to turn left. Results show an earlier braking response to an oncoming motorcycle in a left-of-lane position relative to a motorcycle in a right-of-lane position, suggesting that it is detected earlier. This validates the behaviour of motorcyclists who ride in a left-of-lane position in order to make themselves more conspicuous. However, drivers faced with an oncoming motorcycle in a left-of-lane position tend to release brake pressure early, which suggests that they underestimate the oncoming motorcycle's rate of approach when it is in a left-of-lane position. Presumably, this is due to the lack of motion cues offered by a motorcycle approaching at a very obtuse angle, which makes it difficult to judge its time of arrival accurately. As the oncoming motorcycle gets closer and begins to offer more motion cues, drivers readjust their estimates and increase brake pressure a second time, correcting the initial misjudgement. In a real-world scenario, drivers planning a left turn may be looking for pedestrians, cyclists, and other vehicles, all the while monitoring the traffic light to ensure that it does not change to red. In such a situation, they may not allocate sufficient attention to the oncoming motorcycle to correct their braking in response to it, and fail to yield, which would account for the right-of-way-violation collisions under study here.

Close examination of the data presented in Figure 23 indicates that the deceleration responses to an oncoming motorcycle in the left-of-lane position are similar to those elicited by an oncoming car, while those to a motorcycle in a right-of-lane position resemble those to a pickup truck. This pattern is interesting and indicates that there may be an effect of vehicle size, where larger vehicles (in this case, the pickup truck) are judged to arrive at the intersection sooner than smaller vehicles (the car and

the motorcycle). Except for the reaction to the motorcycle in a right-of-lane position, this is consistent with studies of time to arrival judgements that also show this effect (Caird & Hancock, 1994; Horswill et al., 2005). If it is the case that larger vehicles are judged to arrive sooner, why do the deceleration data for the motorcycle in a right-of-lane position show a similar pattern even if it is small? One possible explanation involves how the motorcycle moves across the observer's retina. Because a motorcycle in a right-of-lane position is further removed from the focus of expansion than a motorcycle in a left-of-lane position, it moves faster across the retina, and this may cause its speed to be overestimated. Regardless of the reason, the right-of-lane position confers an advantage to a motorcyclist facing an oncoming driver that might be planning a left turn.

## **Experiment 3: Time of arrival estimates**

### **Description**

A final experiment employed a disappearance paradigm similar to that used by Caird and Hancock (1994) to determine whether the motorcycle's lane position and the resulting approach path affect the accuracy of time-of-arrival judgements and whether differences in the accuracy of those judgements can explain gap-acceptance errors that result in motorcycle collisions.

### **Participants**

Thirty-nine students (13 male, mean age = 20.33 years, SD = 2.7 years) with a minimum of two years of unsupervised driving experience were recruited from SFU's research pool and received partial course credit for their participation. Two participants



(1 male) did not complete the experiment and were excluded from the analysis. None of the participants were motorcyclists.

## **Apparatus**

For this experiment, we again used the DS-600 high-fidelity research simulator produced by DriveSafety. The simulator consists of the front half of a Ford Focus mounted on a motion platform that simulates acceleration and braking via pitch. The cockpit includes all the instrumentation and controls found in that car. The displays provide 180 degrees of forward view and refresh at 60 Hz, which is also the rate at which the simulator collects data. The simulation was authored using HyperDrive and rendered using Vection simulation software (DriveSafety version 1.9.35).

## **Design**

This experiment is a 2 (disappearing distance: Near [50 metres] or far [100 metres]) by 2 (closing speed: Slow [50 km/h] or fast [100 km/h]) by 2 (lane position: Right-of-lane or left-of-lane) repeated-measures design with eight trials per condition.

## **Procedure**

On each of the 64 trials, the participant's vehicle was kept stationary at the entrance to an intersection and faced an oncoming motorcycle in either the right-of-lane or left-of-lane position. Motorcycles began their approach from 300 metres away at a speed of either 50 km/h or 100 km/h and became invisible either 50 or 100 metres before entering the intersection. The participant's task was to keep track of the approaching motorcycle and to press a button located on the steering wheel at the moment they believed the invisible motorcycle would cross the white line marking the

entrance to the intersection (Figure 25 shows a sample stimulus). Trials were presented in random order and time-of-arrival (TOA) judgement errors (in seconds) were collected for each trial. Negative TOA error values indicate that the participant pressed the button before the oncoming motorcycle reached the intersection (an underestimation of TOA) and positive TOA error values indicate that participant pressed the button after the oncoming motorcycle reached the intersection (an overestimation of TOA). It is expected that TOA will be overestimated for motorcycles in the left-of-lane position and underestimated or accurate for motorcycles in the right-of-lane position. Such an overestimation of time of arrival would indicate that drivers underestimate of the speed of an oncoming motorcycle in the left-of-lane position, underestimation which might them to believe that they have more time to complete a left turn than they actually do.



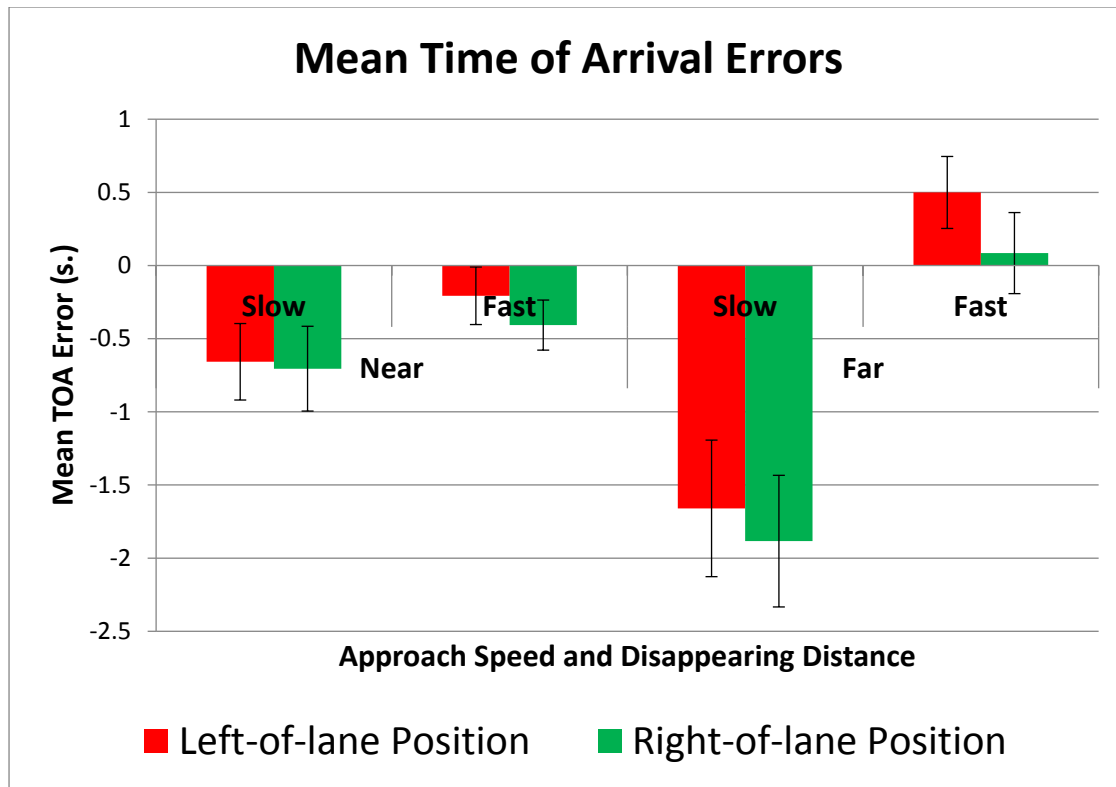
**Figure 25:** Participant's view in Experiment 3. The oncoming vehicle, in this case, a motorcycle, becomes invisible during its approach, and the participant presses a button when they think the invisible crosses the white line marking the entrance to the intersection.

## Results

Data were analyzed using a 2 (disappearing distance: Near [50 metres] or far [100 metres]) by 2 (closing speed: Slow [50 km/h] or fast [100 km/h]) by 2 (lane position: Right-of-lane or left-of-lane) repeated measures ANOVA. Overall, TOA judgements were underestimated ( $M = -.616$ , range: -4.73 to 2.20). The results of the ANOVA conducted

on TOA judgement errors reveal a main effect of distance, with greater TOA underestimates for far motorcycles ( $F(1, 36) = 4.55, p = .016$ ), a main effect of closing speed, with greater TOA underestimates for slow closing speeds ( $F(1, 36) = 163.78, p < .001$ ), and a main effect of lane position, with greater TOA underestimates for motorcycles in a right-of-lane position ( $F(1, 36) = 19.64, p < .001$ ).

Significant interactions were found between disappearing distance and approach speed ( $F(1, 36) = 199.38, p < .001$ ), with a greater effect of speed on TOA estimates at far distances, between disappearing distance and lane position ( $F(1, 36) = 6.93, p = .012$ ), with a greater effect of lane-position on TOA estimates at far distances, and between speed and lane position ( $F(1, 36) = 4.93, p = .033$ ), with a slightly greater effect of lane position on TOA estimates at higher approach speeds. The three-way interaction was not significant ( $F(1, 36) = .03, p = .855$ ). The means are presented in Figure 24.



**Figure 26:** Average time of arrival (TOA) judgement errors. While TOA is generally underestimated, it is overestimated for rapidly approaching motorcycles in a left-of-lane position at long range. By contrast, TOA judgements for rapidly approaching motorcycles in a right-of-lane position at long range were fairly accurate. This effect of motorcycle lane position vanishes at shorter range or at slower speeds. Error bars represent 95% confidence intervals.

## Discussion

The interaction between disappearing distance and lane position provides an explanation for the different braking behaviours exhibited in the previous experiment in response to oncoming motorcycles depending on whether they were in a right-of-lane or a left-of-lane position. When the oncoming motorcycle is in a left-of-lane position, far away (in this case, 100 metres), and closing the distance to the observer at a high rate of speed (in this case, 100 km/h.), participants overestimate how much time they have to complete a left turn before the motorcycle enters the intersection. Conversely, when the

same oncoming motorcycle is in a right-of-lane position, participants' estimates of how much time they have to complete a left turn before the motorcycle reaches the intersection are fairly accurate. This initial overestimation is what causes participants to decrease their rate of deceleration early when yielding to an oncoming motorcycle in a left-of-lane position; as the oncoming motorcycle gets closer its time of arrival is underestimated, which results in a reapplication of brake to avoid the collision which has by then become apparent.

The fact that estimates of time-to-arrival (TOA) are mostly underestimates, which is consistent with the literature (Caird & Hancock, 1994; Horswill et al., 2005), may be indicative of a real effect, but they might also be an artefact of the simulation.

Participants do not have a lot of experience with simulated vehicles, and the simulated scenario only offers monocular cues due to the fact that it is displayed two-dimensionally on a projection screen. For that reason, the speed and distance judgements observed here might be different if the stimuli were actual vehicles on an actual road rather than two-dimensional renderings in a simulator. While this means that the absolute TOA errors observed here are unlikely to map directly to their real-world counterparts, there is no reason to believe that the relative differences observed between the conditions are due to the simulation; if anything, these differences would be expected to increase in a natural environment that affords all the motion cues that drivers are used to. The conditions where the motorcycles are far and approaching fast and where they are close and approaching slowly conceptually reproduce the situation created in the previous yielding experiment: Initially, the oncoming motorcycle is far away and approaching at a high rate of speed (the initial closing speed in Experiment 2 was 100 km/h, which is why this speed was chosen here); as the driver gets closer to starting their turn, the motorcycle is closer and approaching at a lower rate of speed (in Experiment 2, that

speed was 50 km/h, which is why it was chosen here). In any case, a right-of-lane approach consistently yielded greater underestimations of time of arrival, which, from the perspective of the motorcyclist, is a safety benefit; if an oncoming driver believes that they have less time to complete a turn than they actually do, they are less likely to attempt that turn.

The results of this experiment are consistent with the notion that a motorcycle's lane position has an effect on a driver's ability to judge how much time they have to complete a manoeuvre. This might explain right-of-way violation collisions between motorcyclists and oncoming drivers intending to turn left. If a driver believes that they have more time to make a left turn than is actually available to them, then they are more likely to attempt to make that turn.

## General discussion

Taken together, these experiments aim at providing an alternate explanation for right-of-way violation collisions involving motorcycles. These collisions have historically been attributed to poor motorcycle conspicuity, but evidence from collision statistics and from the motorcycle conspicuity literature suggests that the problem is more likely one of motion-perception. More specifically the problem seems to be an inability to accurately judge the speed of approaching motorcycles. Motorcyclists generally ride in the left portion of their lane in an effort to make themselves more visible, and, ironically, it may be that this behaviour makes it more difficult for oncoming drivers to judge their approach speed.

An interesting effect, discovered by Olson, Halstead-Nussloch, and Sivak (1981) is that high-visibility treatments were beneficial only when applied to the rider. The authors hypothesized that the difficulty in judging a motorcyclist's time to arrival might be reduced by drawing attention to the rider. The thinking goes like this: The size of an object's image on an observer's retina can be used to judge that object's distance, assuming that the observer is familiar with the object. Because of the large variability in motorcycle sizes, and because most drivers have no clear idea of how big a given motorcycle is, they cannot use the size of the motorcycle's retinal image as a distance cue. However, everybody has a pretty good mental representation of the average size of people, and it may be that fluorescent garments, by drawing attention to the rider, enabled drivers to use the rider's size and more accurately judge the distance separating them from the motorcycle. At the time of the study (1981), few motorcycles were equipped with large fairings and daytime running lights; today, these features would likely negate the effects of a fluorescent garment, as it might be hidden behind the fairing



or drowned out by the headlight. The above account is somewhat consistent with the observation that dual drivers who have experience with motorcycles are less likely to turn left in front of an oncoming motorcycle (Magazzù, Comelli, & Marinoni, 2006). This may be due to a perceptual advantage resulting from their increased familiarity with motorcycles, which enables them to use the size of the motorcycle's retinal image as a distance cue. Alternatively, the effect documented by Magazzù et al. may be due to increased familiarity with the performance characteristics of motorcycles, which reduces the tendency to underestimate their speed. The idea that familiarity with the size of the motorcycle, or that added rider conspicuity improves distance judgements may be worth exploring. An experiment could be devised that manipulates familiarity with motorcycles as a between-subjects factor and enhanced rider conspicuity as a within-subjects factor; the accuracy of distance-judgements could then be compared across the resulting conditions in order to determine which of these factors, if any, enhance accuracy.

Of the data presented here, the change-blindness results showing a detection advantage for motorcyclists are in need of an explanation, as they contradict the hypothesis that motorcycles suffer from a lack of conspicuity in traffic. It should be noted that this change-blindness experiment (as well as the ones that precede it) compared the detection of cars to the detection of motorcycles. As such, it differs fundamentally from much of the motorcycle conspicuity literature where the comparison is between various treatments applied to motorcycles (Olson, Halstead-Nussloch, & Sivak, 1981; Rößger, Hagen, Krzywinski, & Schlag, 2012; Pinto, Cavallo, & Saint-Pierre, 2014; Cavallo et al., 2015). Thus while certain conspicuity treatments might be more effective than others, and while their study has its place, the aim here was to establish whether motorcycles were in fact less conspicuous than cars, as had been previously assumed. The experiment presented here, combined with previous results obtained in change-

blindness paradigms employing static images, suggests that motorcycles are no less conspicuous than cars, at least not in way that can be measured in a change-blindness paradigm.

Explaining why motorcycles might actually be more conspicuous than cars in a traffic environment requires a return to the previous discussion of conspicuity and salience. In the same way that an object's low-level salience, or sensory conspicuity, depends on how physically distinctive that object is from those surrounding it, that object's high-level (or cognitive) conspicuity also depends on how semantically distinctive that object is from those surrounding it. For example, motorcycles are encountered less frequently on the road, at least in North America where they account for about 3.3% of the traffic (Santos, McGuckin, Nakamoto, Gray, & Liss, 2011), and it may be the case that it is precisely their low prevalence which makes them unique and causes them to attract more attention. Indeed, it is reasonable to expect that North American drivers would be less familiar with motorcycles than they are with cars. It is then precisely because of their relative rarity that motorcycles stand out against a background of more familiar objects, which makes their detection and identification easier. This is consistent with Wang, Cavanagh, and Green's (1994) findings that unfamiliar objects are more easily identified when they are presented against a background of familiar objects.

In the same way that headlights can make motorcycles physically salient if no other vehicles employ daytime running lights, those headlights also make motorcycles cognitively salient by distinctively identifying them as motorcycles. Perhaps this semantic distinctiveness plays a greater role in motorcycle conspicuity than the brightness afforded them by daytime running lights. Indeed, in today's DRL dominated traffic

context, drivers have certain expectations about the traffic they are most likely to encounter.

In addition, cars, trucks and vans all share a common feature: They all have two headlights spaced more or less the same distance apart, and they all have a windshield. These features help drivers identify them as vehicles that need to be assessed as potential threats, as opposed to objects that lack those features, like billboards, buildings, and garbage cans. The fact that the space between the headlights is approximately constant for most cars and trucks also provides a convenient distance cue. That is, because we are familiar with that distance, we can judge how far away a pair of headlights is by how far apart their projections are on our retina. Due to the prevalence of headlights and windshields on all these vehicles, and because of the predictable configuration of these features, it is possible that drivers have come to rely on them. Motorcycles, on the other hand, exhibit much greater variability in their headlight and windshield configurations; not all motorcycles have a windshield, and the number and spacing of headlights varies, rendering them relatively useless as a distance cue.

Given that the problem of right-of-way motorcycle collisions might not be one of conspicuity, and in the absence of the distance and motion cues offered by cars, motorcyclists must rely on a different strategy to indicate their distance and approach velocity to an oncoming driver intending to turn left across their path. Motorcyclists generally ride in a left-of-lane position because it affords them a better line of sight and makes them more visible to oncoming drivers. However, this behaviour may well contribute to right-of-way violation collisions at intersections. As discussed above, a right-of-lane position offers additional motion cues to an oncoming driver: A changing angle of regard during the approach, occlusion of various aspects of the background,

and motion across the retina. Motorcyclists may therefore wish to ride in the right portion of their lane when they approach intersections, assuming that they do not face a greater threat from a driver on the cross-street that is in the process of turning right. The motorcyclist's left-to-right motion as they adjust their lane position may also serve to attract attention to the motorcycle's presence.

The present work provides evidence that motorcycles are detected at least as well as cars in traffic environments, which suggests that the problem of right-of-way violation collisions involving motorcycles is not related to a lack of conspicuity, as is often believed. Instead, the evidence presented here points to a motion-perception problem, specifically, one due to the motorcycle's left-of-lane position. Ironically, motorcyclists ride in the left portion of their lane in order to be more conspicuous. The data presented here have implications for motorcycle safety research; perhaps progress can be made by abandoning the study of conspicuity-enhancing treatments and employing dynamic paradigms to study drivers' motion-perception errors instead. The data presented herein also have implications for motorcyclist training; if riders are taught to employ active collision-avoidance strategies that make use of how other drivers perceive motion, the number of motorcycle collisions may eventually be reduced.

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