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**Estimates of Crash Avoidance: Discrepancies
Between Drivers' Judgments
and Actual Performance**

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ESTIMATES OF CRASH AVOIDANCE: DISCREPANCIES BETWEEN DRIVERS' JUDGMENTS AND ACTUAL PERFORMANCE

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In three experiments, we examine whether drivers can accurately judge whether or not they could avoid a potential collision. Using a driving simulator, we compare drivers' actual avoidance performance with their judgments about whether they could have maneuvered successfully to avoid the collision. At a slow speed (48 kph), drivers underestimated their ability to avoid collisions, judging that more space was required than was actually necessary (they were conservative). At higher speeds (97 kph), however, they tended to overestimate their ability to avoid collisions, judging themselves to require less space than was available; drivers frequently thought they could maneuver to avoid a collision when they actually could not. After drivers experienced simulated collisions, their judgments became more conservative at slower speeds but remained unsafe at higher speeds. We discuss the implications of these results for safety and potential training interventions.

Keywords: overconfidence, margin of safety, driver judgments, collision avoidance

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1. Introduction

A primary goal of driving is to avoid collisions, and doing so requires awareness of what Gibson and Crooks (1938) described as the *field of safe travel*. The field of safe travel represents all the paths that a vehicle may take that will avoid collisions with objects in the traffic environment. The field is dynamic, changing as the driver and other vehicles move. For example, the field becomes restricted when there are more vehicles and other objects around a driver's vehicle. To the extent that drivers preserve greater distances between themselves and other objects, there is greater likelihood that a safe path will remain in an emergency situation. The minimum distance (or separation) that permits safe travel we term the *safety threshold*.

Knowledge or awareness of the safety threshold is important for driver safety, as failures to correctly judge these thresholds might result in drivers putting themselves at risk of an unavoidable collision (i.e., the separation is smaller than the safety threshold). For example, if a driver follows a lead vehicle too closely, they would not be able to avoid a collision if the lead vehicle stopped abruptly. We refer to the difference between the judged and actual safety threshold as the driver's *margin of safety*. A positive margin of safety indicates a conservative judgment, which affords drivers sufficient space to avoid collisions and, if large enough, could accommodate real life distractions and suboptimal conditions. In contrast, a negative or null (zero) margin of safety indicates a risky judgment—one that places the driver in danger of an unavoidable collision (i.e., does not afford drivers sufficient space to maneuver successfully).

Overconfidence in one's driving abilities could lead to miscalibration between the perceived and actual safety thresholds (i.e., an inappropriate margin of safety). In general, people do tend to be overconfident in their abilities (Greenwald, 1980), with most drivers judging themselves to be better than average on many aspects of vehicle control and safety (Deery, 1999; Finn & Bragg, 1986; Groeger & Brown, 1989; Horswill, Waylen, & Topfield, 2004). Such overconfidence could contribute to inadequate margins of safety, with drivers mistakenly believing that they could avoid a collision which they actually could not. Discrepancies between drivers' judged and actual safety thresholds provide the framework for the current study.

Estimates of collision avoidance or the perception of one's ability to avoid a collision with an obstacle involve, among other factors, perception of time-to-contact (TTC; Lee, 1976). Time to contact refers to the amount of time before a perceived object would reach the observer, and it is often used in studying the perception of potential collisions in driving research. Interestingly, people often underestimate the actual time-to-contact, expecting objects to reach them sooner than they actually would (e.g., Caird & Hancock, 1994; DeLucia & Mork, 2006; Hancock & Manser, 1997; Hesketh & Godley, 2002; Hoffman & Mortimer, 1994; Kiefer, Flannagan, & Jerome, 2006; McLeod & Ross, 1983; Sidaway, Fairweather, Sekiya, & McNitt-Gray, 1996). Such underestimates are conservative (or safe) because they afford more time for action and a larger margin of safety (Schiff and Oldak, 1990; Scialfa, Kline, Lyman, & Kosnik, 1987). However, factors other than the actual time to contact affect the ability to avoid collisions. In addition to the time to contact, actual safety thresholds must also incorporate the ability to detect the potential collision object, the ability to determine an appropriate avoidance response, and the ability to actually control the vehicle to avoid the collision. Thus, safety thresholds, as we define them, need to be longer than the time-to-contact because the time needed to avoid collisions includes both the physical

time until contact as well as the time needed to detect and respond to that impending collision. More importantly, even if observers can judge the time-to-contact appropriately or conservatively, they might not be as conservative in judging whether or not collisions are avoidable.

In this paper, we examine whether judgments of collision avoidability are conservative. We report three experiments comparing direct judgments about the ability to avoid a collision with a lead vehicle (judged safety threshold) with the ability to avoid impending collisions (actual safety threshold). If drivers are conservative in their perception of collision avoidability, they will believe they need more space to avoid a collision than they actually do (i.e., have a positive margin of safety). In contrast, if drivers are risky or overconfident, they will give themselves less space than is needed to successfully avoid a collision (i.e., a negative or null margin of safety). In one of the few studies to examine collision avoidance directly, Gray and Regan (2005) had drivers judge whether they would have sufficient time to successfully execute a passing maneuver. Their drivers often indicated that they would initiate a passing maneuver when there was insufficient time to complete it safely (see also Gordon & Mast, 1970; Jones & Heimstra, 1964).

Here we adopt a similar approach, comparing judgments of avoidability to actual collision avoidance. We contrast this approach from more traditional collision judgment tasks in which drivers judge whether or not a collision with an object would occur given different deceleration profiles (e.g., Andersen, Cisneros, Atchley, & Saidpour, 1999). These latter tasks enhance our understanding of the factors that contribute to accurate collision detection, but do not directly compare judgments by each individual to their *own* ability to avoid such collisions. That is, the studies do not examine each observer's margin of safety – whether their judgments are calibrated to their own ability to avoid collisions. Rather, drivers are passive observers of the event. By comparing judgments about collisions to actual avoidance behavior, we can directly examine biases in beliefs about collision avoidance and overconfidence in judgments about driving.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Fourteen drivers from the University of Illinois participated in a single 50-minute session in exchange for payment or course credit (7 men, 7 women; age range 18-20 years, $M = 19$). All had a valid driver's license and they reported driving 10,686 kilometers per year on average. All participants reported normal or corrected-to-normal visual acuity.

2.1.2. Materials

The experiment used the Beckman Institute Driving Simulator at the University of Illinois, a fixed-base simulator consisting of a 1998 Saturn SL with a 135° wrap-around forward field of view and 135° rear field. Driving scenarios were created and controlled using DriveSafety's HyperDrive and Vection simulator software (version 1.6.1). All of the roads used in the study were straight divided freeways with 3 lanes in either direction. No other traffic was present, apart from the incursion vehicles (described below). In order to maintain a constant approach velocity, a cruise control mechanism kept the vehicle's speed at either 48 or 97 kph (30 or 60 mph), depending on the condition. When the brake was depressed, the cruise control disengaged, and when the brake was released the cruise control reengaged after a few seconds, bringing the vehicle back to speed (i.e., after the trial ended).

2.1.3. Procedure

After completing an informed consent form and answering written questions about past driving experience, participants completed a practice session to familiarize themselves with the steering and braking characteristics of the simulator. During this session, drivers were encouraged to explore the limits of the vehicle handling. For all experimental trials, participants were instructed to keep their vehicle in the center lane unless they were actively avoiding a collision.

Drivers performed 2 types of trial blocks (Judgment, Action), each at 2 different speeds (48, 97 kph). They also completed a short block that measured simple reaction time (RT) to the appearance of a target vehicle. The two Judgment blocks were always presented consecutively and earlier in the experiment than the two Action blocks (also presented consecutively), so that judgments would not be biased by feedback from the action blocks. That is, we wanted to obtain judgments before drivers actually experienced collisions (We examine the effect of experiencing collisions on judgments in Experiment 2.) For both Judgment and Action blocks the driving speed was counterbalanced across subjects (some subjects completed the 48 kph block first and others completed the 97 kph block first, and the order of the speeds could vary between the Judgment and Action blocks). Finally, the simple RT block was presented either before both the Judgment and Action blocks, after both, or between the two types of blocks, with the position of the RT block counterbalanced across subjects. Each block lasted approximately 5 minutes (with the exception of the RT block, which lasted approximately 1 minute), and participants were offered a short break after each block.

In Judgment blocks, a stationary Toyota Celica (the target vehicle) periodically appeared on the road in front of the driver's car (at a distance of 20 m, this vehicle subtended $6^\circ \times 4.3^\circ$ of visual angle). Drivers used two buttons mounted on the steering wheel to report, as quickly as possible, whether or not they could have avoided a collision with the target vehicle (by steering and/or braking). As soon as drivers responded, the target vehicle disappeared—in these blocks, they did not actually maneuver to avoid the collision. The headway of the target vehicle was varied across trials using a staircase procedure such that the distance to a given target depended on the response given to the previous one. Following a “no collision” response, the next target vehicle appeared 10% closer (Next distance = $0.9D$, where D was the distance on the previous trial). Following a “collision” response, the next target vehicle appeared 20% farther away (Next distance = $1.2D$). We used a larger distance change after a “collision” response (20% versus 10%) to reduce the likelihood that drivers would encounter two consecutive collision trials. The initial distance for the target vehicle was 25 m and the distance typically stabilized after several events, giving an estimate of the safety threshold (i.e., the distance reflecting the boundary between judgments of collision and no collision). This threshold served as our estimate of the perceived safety threshold. Over the course of each block, drivers made 20 collision judgments, with target vehicles appearing every 4 to 6 seconds (determined randomly).

Action blocks were structured just like the Judgment blocks, except that drivers tried to avoid colliding with the stationary target vehicle by steering and/or braking. They did not judge whether the collision was avoidable—they just tried to avoid it. These blocks allowed an estimate of the actual safety threshold—the distance reflecting the boundary between avoidable and unavoidable obstacles – using the same staircase technique as in the Judgment condition. Unlike the Judgment blocks, the target vehicle remained visible until the driver passed it, stopped before colliding, or collided with it. If subjects failed to avoid the target vehicle, the word “COLLISION” appeared briefly on the display. Drivers experienced 20 target vehicle events in the Action block, with approximately 7 to 14 seconds between events (determined randomly). The extra time between targets in this block allowed drivers sufficient time to return to cruising speed or to the appropriate lane. Once stabilized, the inter-target time approximated that in the judgment blocks. By subtracting the actual safety threshold from the perceived safety threshold, we could calculate that driver's margin of safety.

In the simple reaction time block, the simulator vehicle was stationary (i.e., there was no driving component). As soon as the target vehicle appeared, drivers simply pressed the brake or turned the steering wheel. This condition provided an estimate of target detection speed without requiring a judgment or avoidance maneuver. Following all of the target vehicle tasks, drivers completed additional driver behavior questionnaires and were debriefed.

2.2. Results & Discussion

2.2.1. Analysis notes.

Data from one participant who withdrew after experiencing symptoms of motion sickness were not included in the analyses. In the Action blocks, drivers could elect to brake and/or steer to avoid the target vehicle, but predominantly used steering responses. Assuming drivers considered both types of avoidance maneuver when making their judgments (as per the task instructions), the mode of response is not critical for our analyses or conclusions.

We considered the average of the final 5 target vehicle distances in each block to constitute the judged (Judgment blocks) or actual (Action blocks) safety threshold. For the analyses, we transformed these distance thresholds into times (i.e., the perceived or actual time needed to avoid a collision given the driving speed).

2.2.2. Performance Data.

If the threshold in the Judgment condition was longer than in the Action condition, then drivers had a positive margin of safety — they believed they would need more time than they actually did to avoid a collision (they were conservative). If the threshold in the Judgment condition was shorter than in the Action condition, then drivers had a negative margin of safety — they believed they would need less time to avoid collisions than was necessary (they were overconfident and risky). Ideally, drivers should be conservative at all speeds, but conservative judgments are essential at higher speeds due to the more dire consequences of high-speed collisions in the real world.

A repeated measures ANOVA for Task (Judge, Action) and Speed (48kph, 97kph) revealed a significant main effect for Speed ($F(1,12) = 19.2$, $p < .01$; Cohen's $d = 1.1$), but not for Task ($F(1,12) = 0.03$, $p = .87$). The Speed main effect is best interpreted in the context of the significant two-way interaction ($F(1,12) = 18.4$, $p < .01$; $d = 0.8$). Drivers had a positive safety margin at slower speeds ($t(12) = 2.4$, $p < .05$, $d = 0.8$), with drivers judging that they needed more time to avoid collisions than they actually did. However, judgments were risky at higher speeds ($t(12) = 5.1$, $p < .01$, $d = 0.9$), with drivers maintaining a negative safety margin — they judged that they needed less time than necessary to avoid a collision (see Table 1). Thus, judgments and actions were poorly calibrated, with particularly risky judgments at the higher speed (Gordon & Mast, 1970). Critically, the results at each speed reflected differences in judgments rather than in the time needed to avoid a collision—the actual safety threshold (in time) needed to avoid a collision was unaffected by speed ($t(12) = 0.61$, $p = .56$). The constancy of the actual safety threshold across speeds also validates our use of time rather than distance as the critical determinant of the safety thresholds (e.g., Taieb-Maimon & Shinar, 2001).

Table 1. Mean judged and actual time required in avoiding a collision at both speeds in Experiment 1.

Speed (kph)	Judge (s)	Action (s)	Margin of safety (s)*	Distance** (m)
48	1.69 (0.29)	1.49 (0.14)	+0.20 (0.30)	+2.7
97	1.25 (0.25)	1.47 (0.18)	-0.22 (0.15)	-5.9

Note. Standard deviations are shown in parentheses. Margin of safety = difference between judged time and actual avoidance time (Judge – Action). *Positive values indicate conservative judgments; Negative values indicate risky judgments. **Distance (in m) for the mean margin of safety (time) value and vehicle speed.

3. Experiment 2

In Experiment 1, we purposely had drivers make their judgments before actually completing the maneuvers, so that their judgments would be based on familiarity with the handling of the driving simulator, and not on experiencing repeated collisions. Most drivers have had little real-world experience with emergency avoidance maneuvers and even less experience with actual collisions. This lack of experience might contribute to overconfidence in judgments and consequently riskier driving behavior. To determine whether experience in actual avoidance maneuvers in the simulator would lead to larger margins of safety and better calibration of judgments with actual avoidance, we replicated Experiment 1 but had drivers make judgments before and after the Action blocks.

3.1. Methods

Fourteen drivers from the University of Illinois participated in a single session in exchange for course credit (7 men, 7 women; age range 18-22 years, $M = 19.4$). All had valid driver's licenses and they reported driving 7065 kilometers per year on average. All participants reported normal or corrected-to-normal visual acuity. None of these drivers had participated in Experiment 1. The materials and procedure of Experiment 2 were identical to those of Experiment 1 except that drivers completed two sets of Judgment blocks: one before and one after the Action blocks. Thus, the experiment employed a 3 Task (Pre-Judgment, Action, Post-Judgment) x 2 Speed (48, 97 kph) within-subjects design.

3.2. Results & Discussion

As in Experiment 1, we transformed the average distances from the last 5 target vehicles per block into time values and used these in our analyses. The results of a repeated measures ANOVA revealed significant main effects for Condition ($F(2,26) = 10.2, p < .01; d = 1.1$) and Speed ($F(1,13) = 41.2, p < .01; d = 1.6$) as well as a significant two-way interaction ($F(2,26) = 27.1, p < .01; d = 0.9$). The first set of Judgment blocks (Pre-) were comparable to those of Experiment 1 (Table 2), and judgments at the slower speed were again conservative relative to the actual time required ($t(13) = 4.31, p < .01, d = 1.5$). At the higher speed, though, judgments were not significantly different from the actual time needed to avoid a collision ($t(13) = 0.14, p = .89$). In other words, drivers demonstrated a null margin of safety. As such, only when avoidance behavior is optimal (as in this simulation) would they actually be able to avoid the collisions that they judged to be avoidable. Ideally, judgments should be conservative relative to actual avoidance behavior (i.e., a positive margin of safety).

Table 2. Mean judged and actual time required in avoiding a collision at both speeds in Experiment 2.

Speed (kph)	Condition	Judge (s)	Action (s)	Margin of safety (s)*	Distance** (m)
48	Pre	1.86 (0.39)	1.41 (0.17)	+0.45 (0.39)	+6.0
	Post	2.11 (0.47)		+0.70 (0.46)	+9.4
97	Pre	1.37 (0.24)	1.38 (0.16)	-0.01 (0.34)	-0.3
	Post	1.46 (0.28)		+0.08 (0.36)	+2.1

Note. Standard deviations are shown in parentheses. Margin of safety = difference between judged time and actual avoidance time (Judge – Action). *Positive values indicate conservative judgments; Negative values indicate risky judgments. **Distance (in m) for the mean margin of safety (time) and vehicle speed. Pre = Judgment block that occurred before the Action block. Post = Judgment block that occurred after the Action block.

In the second set of Judgment blocks (Post-), judgments were generally more conservative compared to the original judgments, but the difference was reliable only at the slow speed (slow speed: $t(13) = 2.44$, $p < .05$, $d = 0.6$; high speed: $t(13) = 1.78$, $p = .10$). This result suggests that participants can learn from their experiences with collisions, but this experience might only affect safety margins at slower speeds. Perhaps more targeted training could increase safety margins in high-speed driving behavior, but experience with collisions alone in this case was inadequate to sufficiently increase safety margins at high speeds.

For the slower speed, the results of Experiment 2 are consistent with those of Experiment 1—drivers had a positive safety margin, meaning that their judged safety thresholds were longer than actual ones. Following completion of the Action blocks, safety margins were even greater, with judgments becoming more conservative relative to actual avoidance thresholds; feedback about collisions induced a shift in response criterion toward a larger margin of safety. Unlike Experiment 1, drivers had a null safety margin rather than a negative safety margin at high speeds, with roughly equal perceived and actual safety thresholds. Experience with collisions failed to significantly increase the safety margin at high speeds as judgments remained risky before and after the actual avoidance blocks.

One explanation for the null safety margins at high speeds in Experiment 2 as opposed to the negative safety margins in Experiment 1 is that subjects were faster in their actions, offsetting what would otherwise be a negative safety margin; the average reaction time in Experiment 2 ($M = 440$ ms) was faster than in Experiment 1 ($M = 530$ ms; $t(25) = 2.16$, $p = .02$, $d = 0.9$). If subjects were well-calibrated, we should expect their judgment thresholds to covary with their action thresholds, but judgments and actions were only weakly related at the higher speed ($r = .14$, $p = .48$). Furthermore, at high speeds, those individuals who were able to avoid collisions in less time (lower Action thresholds) had a larger margin of safety and those with slower Action thresholds tended to be riskier: action thresholds were negatively correlated with the margin of safety at higher speeds ($r = -.48$, $p < .05$). Thus, the null rather than negative safety margins in Experiment 2 resulted at least in part from an overall shift in the speed of actual collision avoidance rather than from improved calibration in judgments.

Our data suggest that participants become more conservative rather than better calibrated in their judgments following the Action blocks. One explanation for this pattern is that the Action blocks gave

subjects an experience (we hope) they rarely experience in normal driving—they collided with other vehicles that they could not avoid. This adverse experience might contribute to larger safety margins by making judgments of avoidability more conservative. Consistent with this hypothesis, an exploratory analysis revealed that the number of real-world crashes subjects reported having had was *positively* correlated with the margin of safety ($r = .60$, $p < .05$). In other words, prior exposure to real crashes led people to judge their safety threshold more conservatively in our simulator task. Future research could examine this intriguing possibility more systematically.

4. Experiment 3

In both Experiment 1 and 2, the method used to determine the initial position of each vehicle meant that the target was more avoidable at the slow speed than the high speed. This difference might have anchored driver judgments (Tversky & Kahneman, 1974), leading to larger safety margins at slow speeds than at high speeds. Experiment 3 addressed this possibility by varying the starting distance across individuals.

4.1. Methods

Seventeen drivers from the University of Illinois participated in a single 50-minute session in exchange for payment or course credit (12 men, 5 women; age range 18-25 years, $M = 19.4$). The average annual mileage was 8230 kilometers. None of these drivers had participated in the previous experiments. Except as noted, the simulator and protocol were the same as in Experiment 1. For nine of the subjects, the initial target vehicle position was near (2 standard deviations below the average action threshold in previous experiments: 14.4 m at 48 kph and 28.7 m at 97 kph) and for the other eight subjects, it was far (2 standard deviations above the average action threshold in previous experiments: 23.4 m at 48 kph and 46.8 m at 97 kph). As in Experiments 1 and 2, the position of the target vehicle on subsequent trials was adjusted based on whether or not subjects could avoid the vehicle (or thought they could in the judgment condition). However, in Experiment 3, the adjustment increments in the staircase procedure were proportional to the vehicle speed ($\text{Speed} \times 0.1$), resulting in steps of 1.3 and 2.7 m for slow and fast speeds, respectively. Unlike Experiments 1 and 2, the adjustment was the same size regardless of whether the shift was closer or farther. Finally, because of time constraints, Experiment 3 did not include a reaction time block. The experiment used a mixed design with Starting Distance (Near, Far) as a between-subjects variable and Speed (48, 97 kph) and Task (Judge, Action) as within-subject variables.

4.2. Results & Discussion

For this experiment, we calculated time thresholds based on the average of the final 5 distances. Because the primary focus of the experiment was on the effect of starting distance on judgment thresholds, we used the margin of safety (difference between the judged and action thresholds) as the primary dependent measure. As noted previously, positive margins of safety reflect conservative judgments and negative margins of safety reflect risky judgments. A repeated-measures ANOVA on the difference scores revealed a significant main effect for Start Distance ($F(1,15) = 9.2$, $p < .01$; $d = 1.5$), but not for Speed ($F(1,15) = 3.9$, $p = .07$). Overall, judgments showed anchoring effects (see Table 3), with riskier judgments when the target object first appeared nearby (margin of safety, $M = -0.34$ s) than when it appeared far away (margin of safety, $M = -0.01$ s).

Table 3. Mean judged and actual time required in avoiding a collision at both speeds in Experiment 3.

Speed (kph)	Condition	Judge (s)	Action (s)	Margin of safety (s)*	Distance** (m)
48	Near	1.06 (0.21)	1.42 (0.11)	-0.36 (0.26)	-4.8
	Far	1.54 (0.20)	1.42 (0.18)	+0.12 (0.24)	+1.6
97	Near	1.01 (0.25)	1.35 (0.12)	-0.33 (0.31)	-8.8
	Far	1.18 (0.11)	1.32 (0.15)	-0.14 (0.22)	-3.7

Note. Standard deviations are shown in parentheses. Margin of safety = difference between judged time and actual avoidance time (Judge – Action). *Positive values indicate conservative judgments; Negative values indicate risky judgments. **Distance (in m) for the mean margin of safety (time) and vehicle speed.

Critically, a significant anchoring effect occurred only at the slow speed ($t(15) = 3.9, p < .01, d = 1.9$) and not the high speed ($t(15) = 1.5, p = .16$), as reflected in the significant two-way interaction ($F(1,15) = 5.8, p < .05; d = 1.1$). At high speeds, drivers had negative safety margins both when the initial target was near and when it was far (see Table 3). Thus, anchoring did not account for risky judgments at higher speeds—even when the initial distance was safe, drivers’ final judgments of the safety threshold were overly risky.

5. General Discussion

The purpose of the current experiments was to compare direct judgments about the avoidability of a collision with the actual ability to avoid the collision. Overconfidence in judgments can have important implications for safety. Overconfident drivers might put themselves in risky situations because they mistakenly judge themselves to be safe. In three experiments, drivers sometimes underestimated the time needed to avoid colliding with a car in front of them (i.e., they had a negative or null margin of safety). Experiments 1 and 2 found that drivers made relatively safe judgments when traveling at low speeds, but their judgments were unsafe at high speeds. Experiment 3 took anchoring effects into account and found that judgments were still consistently risky at high speeds. Further, at low speeds, safety margins were greater when judgments followed an Action block. At high speeds, judged safety thresholds were slightly more conservative and safety margins were somewhat larger following training, but not significantly so.

In our experiments, avoidability judgments were conservative only at slower speeds, and risky at higher speeds. In other words, our drivers consistently had positive margins of safety at lower speeds, which would allow them to successfully avoid collisions. However, at higher speeds, these positive margins of safety disappeared and often became negative, which puts drivers at serious risks of life-threatening collisions. These findings suggest that erroneous judgments of the margin of safety might contribute to high speed driving accidents (e.g., Gordon & Mast, 1970).

The finding also contrasts with evidence that drivers conservatively underestimate the actual time-to-contact (e.g., Caird & Hancock, 1994; Hesketh & Godley, 2002; Sideaway et al., 1996; Scialfa et al., 1987), suggesting that factors other than time to contact contribute to avoidability judgments (e.g., the time needed to perceive and react to the impending collision). Given that the avoidability judgment requires decision-making that could be sensitive to payoffs and costs, experience with collisions might have a greater impact on driver biases (leading them to make safer judgments) than on their ability to

accurately estimate avoidability (i.e., they did not become better calibrated at the task). In sum, these results highlight the importance of studying non-perceptual factors when investigating accident avoidability.

Why might drivers become overconfident in their judgments at high speeds? If drivers judged the safety threshold by relying on the distance between themselves and an obstacle rather than the time between the two (Lee, 1976), they might not adequately compensate for the effects of speed on the distance required to respond. That is, they might believe that the distance needed to avoid a collision is more similar across speeds than it actually is. This mistaken belief might explain why highway drivers sometimes fail to adjust their headway with increasing speed. Furthermore, after prolonged exposure to forward visual motion (e.g., after driving for several minutes), drivers' perception of speed becomes distorted, such that they tend to underestimate their actual speed (Denton, 1976). Such distortions might contribute to riskier judgments at higher speeds in our experiments (see Gray & Regan, 2000; 2005, for a detailed discussion of motion adaptation).

As shown in Experiment 2, judgments became more conservative rather than more accurate after exposure to collisions in the avoidance (action) blocks. These results raise the possibility that driver education methods could employ emergency avoidance maneuvers as a training technique to shift drivers toward greater safety margins. However, shifts in the current study only reached significance at the slower speed, suggesting that drivers might need more exposure to collision avoidance at high speeds than they received here. Alternatively, other types of training or feedback might be more effective for higher speeds. We do caution that training interventions should not focus solely on the development of collision avoidance skills. Such approaches can increase overconfidence in collision avoidance, offsetting any benefits to beliefs and judgments that result from training (e.g., Gregersen, 1996; Katila, Keskinen, & Hatakka, 1996).

Although our experiments reveal risky judgments of safety thresholds, the actual danger from these erroneous judgments might be even greater than that estimated in our studies. In fact, a null margin of safety in our tasks would certainly constitute risky behavior under more natural driving conditions. Our task minimized the contribution of distraction, inattention, and uncertainty—drivers were actively looking for and responding to an expected target event. In the real world, drivers cannot readily anticipate when an avoidance maneuver will be needed or even what avoidance maneuver would be effective. Even in our simplified case, drivers in Experiment 3 had safety margins nearly 6 meters too short (the equivalent of almost 2 car lengths) when traveling at 97 kph. In real driving, actual safety thresholds must also include the time necessary to switch attention to the critical vehicle as well as time needed to decide how to react (e.g., Olson, 2002). If drivers do not adjust their margin of safety to account for such factors, then even a null safety margin under ideal detection conditions would be highly risky. Given that people believe, incorrectly, that unexpected events will automatically draw attention (e.g., Levin, Momen, Drivdahl, & Simons, 2000), they likely do not adjust their margin of safety to accommodate the effects of inattention blindness (e.g., Simons & Chabris, 1999; Most, Simons, Scholl, Jimenez, Clifford, & Chabris, 2001) and other failures of awareness. Thus, the riskiness of their judgments in our simplified task would likely be amplified under more naturalistic driving conditions. And, at higher speeds, any period of inattention dramatically increases the severity of accidents because the driver continues to travel at full speed while inattentive (see www.safespeed.org.uk for a detailed analysis).

Taken together, our findings show that drivers in a simulator often think they can avoid a collision when they actually can not. This mistaken belief could contribute to dangerous behaviors, including tailgating at high speeds, thereby making collisions more likely in the event of an unanticipated obstacle. These data further suggest that the extra time often afforded by conservative time-to-contact estimates might not be sufficient for effective maneuvering. Margins of safety do increase, at least at slow speeds, as a result of substantial practice avoiding actual collisions. This improvement might support driver education methods

in which drivers practice emergency avoidance maneuvers. Along these lines, future research can examine suggestive evidence that actual accident experience leads to larger margins of safety. Future research should also examine the relationship between avoidability judgments and actual avoidability under more naturalistic driving conditions and across a wider age-range. Such studies could help determine whether and when beliefs about headway are well calibrated to the realities of driving.

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