Management Science

Publication details, including instructions for authors and subscription information:
http://pubsonline.informs.org

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MANAGEMENT SCIENCE
Vol. 61, No. 4, April 2015, pp. 851–863
ISSN 0025-1909 (print) | ISSN 1526-5501 (online)

http://dx.doi.org/10.1287/mnsc.2014.1912

Bias in Spatial Risk Assessment

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In instances of decision making under uncertainty with a visual component, we propose that individuals show a bias and estimate a higher probability of a threat affecting them if the threat is located in their left visual field compared to their right visual field. Across four studies we demonstrate the bias in naturalistic settings such as pedestrians assessing the risk of crossing the street, individuals estimating the risk posed from an unsavory person, and people assessing the contamination risk of an object. Moreover, we discuss four potential mechanisms that could cause the proposed effect. Finally, we discuss theoretical, managerial, and policy implications.

Keywords: spatial risk; risk assessment; bias; intuitive processing
History: Received May 24, 2012; accepted November 13, 2013, by Yuval Rottenstreich, judgment and decision making. Published online in *Articles in Advance* June 6, 2014.

1. Introduction

Past research has extensively documented decision making under uncertainty such as investing in a stock, choosing a medical procedure, going to court, or predicting which team will win a game. The findings suggest that when the chances of success or failure are uncertain, people are more likely to apply intuitive or lay beliefs to assess likelihood of occurrence (Koehler and James 2009, Tversky and Kahneman 1974, Windschitl 2002). However, many risk assessments in everyday life differ from conventional scenarios examined in some of the past research because they bear a strong visual component; people have to visually scan the environment around them to assess risk. Past research on decision making under uncertainty would not be able to shed much light on the factors that can influence such visual risk assessment since is generally documents instances where risk can be assessed without needing to actually see the scenario (e.g., reading or hearing about a situation suffices).

Some instances of assessing visual risk in the environment commonly faced by individuals are crossing the street after deciding that they will not be hit by an oncoming car, looking at a map shown on the news and deciding whether to stay or evacuate when an earthquake hits a nearby city, determining whether an object in one's environment poses a contamination risk, or even soldiers evaluating the threat level in urban warfare while patrolling hostile neighborhoods. Although these are instances of decisions made under uncertainty (when the odds of an event are not always precisely known), they exemplify a specific category of risk assessment—spatial risk. Despite the prevalence of spatial or visual risk in the environment, we have very few insights into how objective people are in assessing these risks.

In this research we propose a bias that occurs in such spatial risk assessments. Consider the following situation: Jane wants to cross a one-way street. She sees a car approaching from the north and moving south. If Jane is facing east, the car would be moving from her left visual field to her right visual field. If she is facing the opposite direction (west), the same car would be moving from her right visual field to her left. In which of these two situations would Jane be more concerned that the car might hit her? The answer should be that in both cases she should be equally cautious since the rate of change in the car's location with respect to her location is the same. However, we posit that Jane would perceive greater threat when the car approaches from her left compared to when it approaches from her right. Specifically, we propose that individuals assign higher risk to a threat if the location of the threat is in their left visual field compared to when the threat is located in their right visual field. They feel that a threat approaching from their left has a higher likelihood of affecting them than a threat approaching from their right. Therefore, we propose that an individual will cross the street faster when traffic is approaching from the left than from the right, will sit nearer to an unsavory or potentially harmful person if he is located to their right than to their left, will move farther away from a contaminating object on the left than on the right, and will be more likely to evacuate when shown on a map that an earthquake has struck a location to the left of their city than when the same calamity has occurred in a city located to the right.

For ease of reference, in the remainder of this work we will refer to the proposed bias as the location bias.

1.1. Research Overview

We first present four studies that help test the location bias. Studies 1a and 1b are controlled lab studies that demonstrate the location bias for two different types of disaster. However, past research has recommended that biases observed in the controlled lab setting have policy implications only if they are observed to influence people's everyday lives: when people are making real decisions with incentives in their natural environment, especially in situations that they encounter every day (Simonsohn 2007). Moreover, utilizing data from lab versus field studies, which have produced divergent findings even with the use of the same procedures, researchers have argued the need to replicate results in the real world (Voors et al. 2011). Therefore, Studies 2, 3, and 4 are field studies that test the robustness of the location bias and its applicability to real-world situations. In the first field study, we demonstrate the location bias as people cross a one-way street where they must assess the threat of traffic approaching from either their left or their right visual field. In the second field study, we measure the distance people move away from a disgusting object on the sidewalk, located either to their left or to their right. In the third field study, we measure how far to their left or right people prefer to keep a person who affords a social threat. We consider threats that might appear stationary (e.g., unsavory individual) versus those that are described as moving toward the target (e.g., moving traffic). In all instances, the individual is assessing the risk of the threat affecting them by moving from the source to them, the target.

After we present the four studies, we discuss four theoretical mechanisms that have the potential to explain the findings of the studies. We hope future research can disentangle which theoretical mechanism is at work or whether more than one mechanism is possible. The accounts we discuss are based on reading directionality (our habit of visually scanning from left to right while reading), hemispheric specialization (based on handedness), pseudoneglect (based on the tendency to overestimate features to the left rather than the right), and fluency (ease of processing a stimulus).

2. Location Bias for Natural and Human-Made Disasters

The aim of Studies 1a and 1b is to demonstrate how individuals underestimate the severity of a disaster (earthquake or radioactive spill) spreading from a location to their right versus to their left.

2.1. Study 1a

One hundred and sixty-six participants from a North American university took part in this study in return for partial course credit. Each of them was seated at a separate computer terminal with a 22-inch screen having a resolution of $1{,}680 \times 1{,}050$. Each participant was shown a map with two small squares, one on the left side and the other on the right side of the screen. The square on the left was marked to represent city A, and the square on the right represented city B. The distance between cities A and B was marked as 200 miles in all conditions.

Participants were randomly assigned to either the left-city or the right-city condition (the condition names indicate the location of the threat). In the right-city condition, participants were informed through a cover story that they lived in city A (located on the left) and had just heard that a massive earthquake had struck city B (located on the right) with a possibility of aftershocks affecting surrounding areas. In the left-city condition, participants saw the same information, except they were told that they lived in city B (located on the right), and city A (located on the left) had been struck by an earthquake. Participants were then asked to indicate the likelihood, on a 1 (very unlikely) to 7 (very likely) scale, of the earthquake affecting the city in which they lived.

Results and Discussion. A one-way analysis of variance (ANOVA) revealed that participants in the right-city condition indicated a lower likelihood of the earthquake affecting them ($M_{\text{right}} = 4.72$) compared to the participants in the left-city condition ($M_{\text{left}} = 5.21$, $F(1, 164) = 5.19$, $p = 0.024$, partial $\eta^2 = 0.03$).[1] The participants in this study perceived the earthquake occurring in a city to their left to have higher likelihood of affecting them than an earthquake in a city to their right.

Before we move to Study 1b, it is worth mentioning that we ran another study with a tornado as the natural disaster. The procedure used was the same as in Study 1a, with 93 participants randomly assigned to the left-city or right-city condition. However, for this specific disaster there was no statistically significant difference between the left and right conditions ($F(1, 91) < 0.7$, $p > 0.4$). We can only conjecture that this could be because tornadoes, unlike earthquakes, are not very common to the region where the participants lived, and hence their risk estimation was influenced.

Finally, a concern for the earthquake is that the bias emerged because of the way people perceive weather patterns in the United States, which generally follow a west-to-east (left to right on a flat map)

[1] The 95% confidence intervals of the difference between left and right conditions' standardized dependent variables across all studies are reported in the meta-analysis provided at the conclusion of the studies.

pattern because of the polar and subtropical jet streams (National Oceanic and Atmospheric Administration 2012). Therefore, it would appear that left (from west) disasters are likely to spread more than right (from east) disasters. We try to address this concern in our field studies where the disasters are not weather related.

2.2. Study 1b

Building on the results of Study 1a, one aim of this study was to provide a conservative test for the location bias. If people perceived a natural flow from left to right, we expected to find that even when the distance to a threat located on the right was shorter compared to that of a threat located on the left, people would still consider the former less threatening. In other words, even if a right-located threat were nearer, people would find it less threatening than a farther away left-located threat.

Eighty-nine participants took part in the study in return for partial course credit and were randomly assigned to either the left-city or the right-city condition. Participants were informed that a city to their right (right-city condition) or to their left (left-city condition) was experiencing problems in its radioactive waste facility, which might prove hazardous to nearby areas. Since a radioactive facility was located near the region, this was a relevant threat to the participants. To provide a conservative test, participants in the left-city condition were informed that the left-city was located 200 miles from their home city, whereas participants in the right-city condition were informed that the right city was located 180 miles from their home city. Subsequently, participants indicated the probability of being affected on a 0% to 100% scale. We expected that if they used distance information in their estimates, right-city condition participants would indicate greater (or at least equal) probability of the threat affecting them than left-city condition participants. However, this pattern should reverse if participants felt that a threat on their left was more likely to affect them than a threat on their right.

Results and Discussion. A one-way ANOVA with probability estimate as the dependent variable and location of threat as the independent variable showed that participants in the right-city condition indicated a lower probability of being affected by the radioactive threat even when it was 20 miles closer to them than to the participants in the left-city condition ($M_{\text{left(200 miles away)}} = 65.6\%$ versus $M_{\text{right(180 miles away)}} = 52.72\%$, $F(1, 87) = 4.23$, $p = 0.042$, partial $\eta^2 = 0.046$). The results of this study demonstrate that even when the right-located threat was a physically nearer, human-made calamity participants still underestimated its threat compared to a farther away left-located threat.

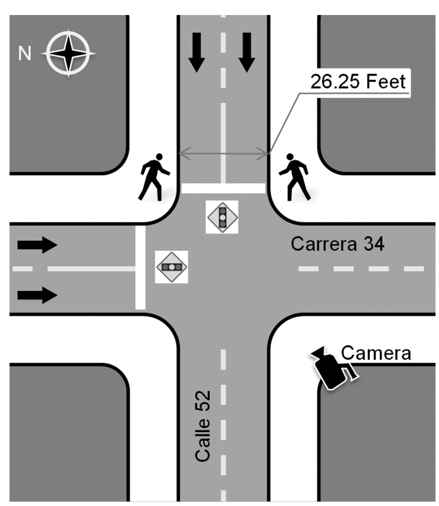
However, one could still argue that radioactive waste might be carried along with dust particles to nearby locations because of wind flow. Since wind flow, again, generally follows a left-to-right (LTR) trajectory, people might perceive that an affected left location might be more harmful than a right location. Also, some research has shown that, contrary to intuition, it is possible that people could perceive 180 miles to be greater than 200 miles (Birnbaum 1999). To address these concerns of Studies 1a and 1b, the next three studies are field studies that examine the location bias in naturalistic settings.

3. Study 2: Field Study Demonstrating the Location Bias for Street Crossing

The main aim of this field study was to test the location bias in a naturalistic setting. In many developing countries, accidents at railway crossings or traffic intersections are a leading cause of death. Many of these crossing do not have barriers or walk signals, and hence it is the decision of the individual to assess the risk from the oncoming vehicle and then decide whether to cross or not. Specific to the location bias and similar to the scenario discussed in the beginning of this manuscript, we wanted to test whether individuals were likely to perceive a vehicle approaching from their left as more threatening than one approaching from their right.

We filmed pedestrians in a commercial area of Bucaramanga, Colombia (South America; population, 524 thousand) who were crossing a one-way street with no walk signals. It was the intersection of two one-way streets: Calle 52 and Carrera 34 (refer to Figure 1). We were given a permit to film for two hours. Permission from local authorities was obtained ahead of the two-hour filming of the pedestrians. A video camera mounted on a tripod was placed on the second floor of an adjacent building to film the pedestrians as they crossed the street. The camera captured the movement

Figure 1 Reproduction of the Street Crossing



of pedestrians as they crossed Calle 52. There was a traffic light in the intersection, but there was no signal for the pedestrians indicating whether the light was red or green. The distance that pedestrians had to cover to cross the street was 8 meters (26.25 feet). It is safe to assume that in the absence of a walk signal, it was in the pedestrians' best interest to cross the street as quickly as possible: even more so when considering that pedestrian–vehicle crashes are one of the major causes of traffic fatalities in Colombia. For instance, in the month before the video was filmed, 9 pedestrians were killed and almost 200 were injured in Bucaramanga (Vanguardia.com 2011b).

Although the traffic moved in only one direction on the one-way street, the pedestrians could cross the street from either side. This allowed us, despite it being a field study, to keep most things constant (noise, time of the day, speed of traffic, risk inherent in crossing a street with no walk signal, types of vehicles, etc.) and to study how direction of traffic (coming from a pedestrian's right or left) influenced the speed at which they crossed the street.

The pedestrians were filmed for the two continuous hours allocated to us. The dependent variable was the time pedestrians took to cross the street when they had oncoming traffic from their left or from their right. Faster crossings (shorter time) would suggest that they perceived greater risk from the oncoming traffic. To minimize estimation errors, Kinovea (an open-source video analysis software, version 0.8.15) was utilized to measure the time a pedestrian took to cross the street. Kinovea is primarily used to explore and analyze the performance of athletes. We used this software because of its perspective grid tool, a feature that overlays a three-dimensional grid over a plane in the video. Using Kinovea, we created a virtual grid on the video and designated lines in the grid that represented the borders of the street. Crossing time was estimated from the time the pedestrian stepped off the sidewalk until one of their feet touched the sidewalk on the opposite side of the street. An independent coder, blind to the research hypothesis, recorded the time it took pedestrians to cross the street. Only people who crossed from one sidewalk to the other were considered in the study. Therefore, pedestrians who crossed diagonally or tried to cover both street crossings were not used in the analysis. The coder also recorded whether traffic was approaching from the right or left of the pedestrian, if vehicles had a green signal to move or red signal to stop, and if people were crossing in a group or alone.

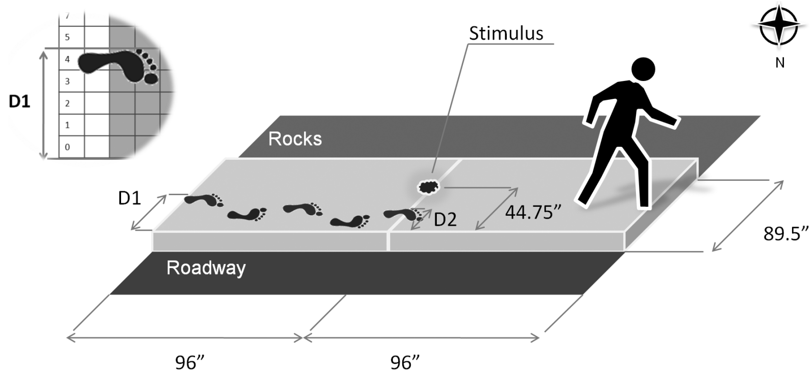
Results and Discussion. Out of the 390 pedestrians who crossed the street from one sidewalk to the other, 45.38% crossed alone, and 46.15% crossed when traffic lights were green (i.e., when vehicles were moving), and these distributions were statistically identical across people crossing with traffic approaching from their left or their right. Not surprisingly, people took less time to cross the street alone ($M = 5.89$ s) than in a group ($M = 6.44$ s, $F(1, 388) = 18.42$, $p < 0.0001$). Similarly, people who crossed the street when vehicles were moving (i.e., when the traffic light was green) took less time ($M = 5.86$ s) than those who crossed when vehicles were not moving (i.e., red light; $M = 6.48$ s, $F(1, 388) = 24.37$, $p < 0.0001$). Pertinent to our prediction, we then tested whether the direction of traffic (left or right) changed the time to cross the street while controlling for the traffic light (red versus green) and group (crossing alone versus in a group). As predicted, we found that people crossing the street took less time when traffic was on their left ($M = 6.05$ s) than on their right ($M = 6.32$ s, $F(1, 386) = 3.81$, $p = 0.051$). Similar results emerged when no covariates (red or green traffic light or crossing alone versus in a group) were included in the analysis ($F(1, 388) = 4.3$, $p = 0.038$, partial $\eta^2 = 0.01$). The results indicate that even in such a commonly occurring situation as crossing the street, people perceive a threat approaching from their left to be greater than a threat approaching from their right. It is worth noting that the likelihood of being hit does not depend on whether the vehicle is oncoming from the left or the right. In the next field study we utilize another naturalistic setting to test the robustness of the location bias.

4. Study 3: Location Bias in Assessing Contamination Risk

Research has demonstrated that contamination risk is another form of risk that people are exposed to frequently in their everyday environments. Many infectious diseases have their roots in such spread of contamination from a contaminating object or an infectious person. One unmistakably infectious object is feces; it is looked upon with disgust, and people keep away from it as much as possible. The feelings of disgust have their roots in evolutionary theory related to beliefs about the spread of contamination (Frazer 1959, Tylor 1974). Although in the case of feces the source is stationary (compared to the automobiles or natural disasters), the infectious essence from the contaminant would be construed as moving toward the target. As a result, individuals would perceive the essence from a source located on the left as more likely to reach the target than that from a source located on the right.

With this in mind, in the second field study we kept a contaminating stimulus on the sidewalk and measured how much distance to the right or left people moved away from it. The contaminating stimulus chosen was dog feces, which was modeled out of chocolate syrup and peanut butter. The sidewalk chosen for the study was near a parking lot in a North American university, which was used by faculty, staff, and students.

Figure 2 Reproduction of the Sidewalk with Depictions of Stimulus, Pedestrian, D1, and D2



A roadway on one side and a rocky surface on the other bordered the sidewalk. The sidewalk was made of concrete and casted in slabs that were 96 inches long with joints between the slabs. The stimulus was kept in the middle of the path on top of a concrete joint (see Figure 2).

Pedestrians moved in both directions on the sidewalk, toward the campus (west) and toward the parking lot (east). Hence, in this field study the location of the spatial risk was kept the same, in the middle of the sidewalk, but based on the relative location of the pedestrians it could appear to their left or their right. A video camera, kept in one of the rooms of a nearby building, filmed people as they moved by the stimulus. People were unaware that they were participating in the study. We observed the distance that people moved away, on encountering the stimulus, to their left versus to their right. Finally, we also considered whether people might have an inherent tendency to veer left versus right while walking, which could introduce a confound in our study design. However, research in biology has found that no such systematic preference exists, and it can be quite random whether people veer left versus right (Souman et al. 2009).

4.1. Dependent Variable

Again, a coder blind to the research hypothesis coded the data. The coder for Study 3 was different from the coder for Study 2 to ensure that no learning (or guessing of the research hypothesis) could occur across the two studies. Similar to the previous field study, we used Kinovea (version 0.8.15) to measure the distance pedestrians moved away from the stimulus. For this study, the perspective grid was overlaid on the concrete sidewalk and aligned with the edges of the slabs to ensure that the grid was parallel to the walking surface. The grid was used as a ruler having 20 lines (maximum number of divisions allowed by software) that were parallel to the length of the sidewalk. The first line of the grid (on the edge of the sidewalk closest to the street) was given a value of zero, and each line increased by a value of one, stopping at 20 (the other edge of the sidewalk). The width of the sidewalk was 89.5 inches, and the difference between each line was $89.5/19 = 4.71$ inches.

On the grid, the position of the stimulus was in the middle of lines 10 and 11 (i.e., 44.75 inches away from each edge of the sidewalk). Using the grid ruler, the location of the pedestrian was measured at two locations along their path: (1) 96 inches before the stimuli was encountered (i.e., at the concrete joint prior to the stimulus; D1) and (2) at the stimuli (i.e., the concrete joint on which the stimulus was kept; D2; see Figure 2). Note that 96 inches corresponds to the length of each concrete slab. The location D1 or D2 of the pedestrian was based on the foot closest to the stimuli. Thus, for a pedestrian that had the stimuli on her left (right), her location would have been based on the location of her left (right) foot.

For a pedestrian moving west, if D1 was less than 10 (greater than 11), then the stimulus was coded as left (right). We took the difference score $(D1 - D2)$ to measure the distance moved away from or toward the stimulus. If the stimulus was to the left and the difference score was positive (negative), the pedestrian moved away from (toward) the stimulus. On the other hand, if the stimulus was to the right and the difference score was negative (positive), the pedestrian traveled away from (toward) the stimulus.

A similar difference score was constructed for pedestrians moving to the east. To keep interpretation consistent in both east and west directions for this set of pedestrians, the difference score was $(D2 - D1)$. In this case, if D1 was less than 10 (greater than 11), then the stimulus was to the pedestrians' right (left). The interpretation of the difference score for pedestrians moving east was the same as that for those moving west.[2]

[2] One simple dependent variable could have been the distance between the stimulus and the closest step to the stimulus of the pedestrian on the sidewalk. Using this distance, if we found that when the stimulus was to the left the distance of the closest step was

Results and Discussion. Of the 227 people we filmed, 40.9% were female, and 48.9% were moving east. We analyzed the influence of the location of the stimulus, left versus right, on the relative distance moved (difference score) while controlling for gender. Although gender had a statistically significant influence on the relative distance moved (female $= 1.68$ inches versus male $= -0.1$ inches, $F(1, 224) = 3.69$, $p = 0.056$), it did not interact with the location of the stimulus (left versus right; $F < 0.5$, $p > 0.5$). More pertinent to our prediction, the results show the relative distance that people moved away from the stimulus was higher when they saw it on their left ($M = 1.7$ inches) compared to their right ($M = -0.13$ inches, $F(1, 224) = 3.93$, $p = 0.048$). Similar results emerged when gender was not used as a covariate ($F(1, 225) = 4.18$, $p = 0.042$, partial $\eta^2 = 0.018$).

5. Study 4: Field Study Demonstrating Location Bias in Social Risk Assessment

Unlike the previous two field studies where we were observing people's behavior when a threat appeared to their left versus their right, in this field study we were able to manipulate the location of the threat, giving us more control over the study design.

Our study context was a developing country, since many reports of social threat in the form of mugging are common in these regions. Hence, we obtained permission from local authorities to arrange a setup to collect data in an upmarket shopping district of Bucaramanga, Colombia. In Colombia, muggings that take place on the street are a real threat (Vanguardia.com 2011a); thus people are quite vigilant and strongly avoid suspicious individuals. We set up a mock survey during the day, on a block with high pedestrian traffic. We were given permission to set up in an open area in front of a night club, which was closed during the day. Eight chairs were arranged in a row. We recruited a homeless person for monetary compensation to sit in either the leftmost or the rightmost chair (Figure 3 depicts the scene). The homeless person appeared quite threatening in appearance. A research assistant was recruited locally (who could speak the language)

Figure 3 **Picture of the Study Setup**

to administer the mock survey. He was blind to the research hypothesis and was paid on an hourly basis. People passing by on the sidewalk were solicited by the research assistant to fill out a short survey on their Internet usage experiences. Monetary compensation equivalent to \$2.70 was offered for filling out the survey. To make it easier for them to fill out the survey, they were offered a clipboard and the option to sit in one of the chairs.

The dependent variable was how far from the threatening person people sat depending on whether the individual was to their left or the right. On both days none of the respondents knew the homeless person nor interacted with him. Some instances occurred of two people coming to fill out the survey at the same time. Since the second person always sat in the same location as their friend, we did not record data when such instances occurred.

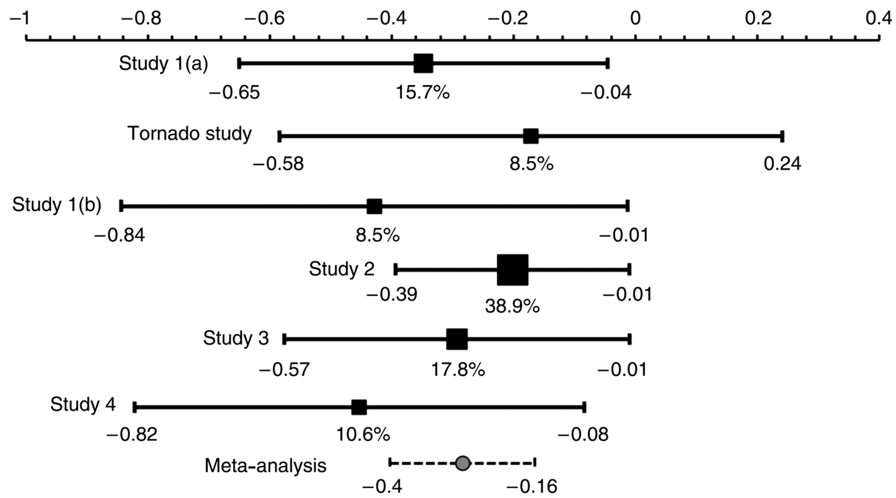
Results and Discussion. The sitting locations of 105 people (46.67% were female) were recorded. Since gender could potentially play a role in people's choice of chair because the homeless person was male, we used gender as a covariate in our analysis. The results show that the location of the homeless person (on the leftmost chair versus the rightmost chair) significantly influenced the distance people sat away from him. People kept more distance when the homeless person sat in the leftmost chair ($M = 5.06$ chairs) than the rightmost chair ($M = 4.32$ chairs, $F(1, 102) = 5.92$, $p = 0.016$). It is interesting to note that gender did not have a statistically significant influence on the distance ($F < 0.05$, $p = 0.892$) and did not interact with the threat location. Similar results emerged when gender was not used as a covariate ($F(1, 103) = 5.96$, $p = 0.016$, partial $\eta^2 = 0.054$).

An interesting issue regarding vantage point exists for Study 4: When a respondent approaches the seats, the unsavory man is to their right (left), but becomes positioned on their left (right) when they actually sit down.[3] Hence, it is important to know the exact

further away from the stimulus compared to when the stimulus was on the right, it would indicate that people moved away more when the stimulus was to their left versus to their right. We could offer this as evidence for the location bias; however, an argument based on traffic rules could be used against this evidence. One could argue that this habitual movement of keeping to the right would result in their moving further right when the stimulus was to their left. Hence, it would be erroneously interpreted that the stimulus on the left resulted in greater movement away when it was merely driven by habitual walking patterns and not by the threat. To address such concerns as this, the dependent variable was created as a difference.

[3] We thank a reviewer for suggesting this account.

Figure 4 **Forest Plot**



point in time when the seat is chosen. Do respondents choose a seat as they are walking toward the chairs, or do they choose a seat when they are actually at the point of sitting down? Or is it a combination in which they have a general idea where they will sit as they walk toward the seats, but make a final decision (or adjustments) only when they have turned to sit down? We do not have empirical evidence to provide a conclusive answer, and hence conjecture that the final seat chosen reflects how near or far away they want to put the threat when they are actually seated to fill out the survey. Thus, the critical decision point could be when they have turned and are in the act of sitting down. At this point they realize that it will take them at least a few minutes to fill out the survey and they have to decide at what distance they would like to keep the unsavory individual.

6. Robustness Tests

Across studies we found that people perceive a threat approaching from their left to pose a higher risk than a threat approaching from their right, which is captured through various dependent variables ranging from probability assessment to actual behavior. To test the robustness of the effect, we conducted two tests: a meta-analysis and a replication of one of the field studies.

In Figure 4, we present a forest plot that depicts the point estimates and 95% confidence intervals of the differences between left and right conditions' standardized dependent variables across all the studies. Along with the error bars showing 95% confidence intervals, the percentages indicate the weight assigned to each study.[4]

With the exception of Study 2, the difference scores represent the right condition minus the left condition. Across the studies (be it probability estimates or distance moved), the dependent variable in the left condition had a higher value than that in the right condition. This is the reason the point estimates have a negative sign. For Study 2, since the dependent variable was the time to cross the street, lower values from the left condition and higher values from the right condition were consistent with the location bias. To make the comparison consistent across all studies, the estimates for Study 2 represent the left condition minus the right condition. Finally, adding the tornado study in the meta-analysis did not substantially alter the outcome of the meta-analysis.

To further test the robustness of the location bias, we conducted a replication of one of the studies (Study 2, the traffic field study). We chose this study since it had fewer alternate accounts associated with it and because it provided greater implications for policy. We conducted a replication in the same intersection as before. However, prior to conducting the study we did a power analysis to determine sample size. Based on the power analysis it was determined that we would need approximately 550 to 600 participants for the

[4] It is evident from the forest plot displaying overlapping confidence intervals across studies that there was very little heterogeneity across studies. In other words, statistically these studies seem to indicate that a common mean has been estimated by each of the studies (stated differently, a true effect size is shared by all studies and variations across studies are the result of sampling errors). Considering this, we could have used a fixed effects model for the meta-analysis, which assumes study samples to be from the same population with a fixed mean. However, we used a random effects model for the following reasons: First, a random effects model does not assume that studies are coming from the same population. Thus, it provides a much wider overall confidence interval of meta-analysis, i.e., it is more conservative. Second, a random effects model converges to a fixed effects model if the studies are indeed homogeneous, making it applicable to both homogeneous and heterogeneous sets of studies (see Cumming 2012).

study to be considered high powered (around 0.9). Accordingly, we again obtained permission to film at the intersection and were able to film from the same vantage point as before. Otherwise, the filming procedure, coding, dependent variable measurements, covariates recorded, software used for coding, etc., were the same as in Study 2.

The results of the high-powered replication study also indicated that the location bias emerges when people cross the street with traffic coming from the right versus the left. Out of the 581 pedestrians who crossed the street from one sidewalk to the other, 29.43% crossed alone, and 23.41% crossed when the traffic lights were green (i.e., when vehicles were moving), and these distributions were statistically similar across people crossing with traffic approaching from their left or their right. People took less time to cross the street alone ($M = 5.86$ s) than in a group ($M = 7.06$ s, $F(1, 579) = 81.22$, $p < 0.0001$). Similarly, people who crossed the street when vehicles were moving (i.e., when the traffic light was green) took less time ($M = 6.27$ s) than those who crossed when vehicles were not moving (i.e., red light; $M = 6.84$ s), $F(1, 579) = 13.87$, $p < 0.0001$). Pertinent to our prediction, we then tested whether the direction of traffic (left or right) changed the amount of time to cross the street while controlling for the traffic light (red versus green) and group (crossing alone versus in a group). As predicted, we found that people crossing the street took less time when traffic was on their left ($M = 6.56$ s) than on their right ($M = 6.85$ s, $F(1, 577) = 8.22$, $p = 0.004$). Similar results emerged when no covariates were included in the analysis ($F(1, 579) = 5.19$, $p = 0.023$, partial $\eta^2 = 0.01$).

In sum, we demonstrate that spatial risk estimation is biased by the location of the threat. A threat presented in the left visual field is considered to have a greater likelihood of affecting an individual compared to the same threat presented in the right visual field. We refer to such differential spatial risk estimation as the location bias. Across lab studies and field studies, we tested the robustness and applicability of the location bias in situations relating to assessing risk with the presence of an earthquake, with the spread of radioactive waste, while crossing the street, with presence of a contaminating object, and with presence of a social threat. Across all these commonly occurring and potentially threatening situations, we see that individuals perceive a greater risk from a threat on their left than on their right.

Along with demonstrating the bias, we next put forth four theoretical accounts (reading directionality, hemispheric specialization, pseudoneglect, and various versions of fluency) that could explain why the bias might emerge. We hope that future research will not only test for the bias in other areas, but will also examine which of these accounts cause it to occur.

7. Potential Theoretical Accounts

The location bias, like many other biases, could be influenced by lay beliefs. Just like scientific rules, lay rules (also known as lay theories, lay beliefs, or heuristics) help people make sense of their environment. Decision theorists have generally categorized these lay rules as System 1 automatic processes (Kahneman and Frederick 2002, Stanovich and West 2008) or gist-based intuitions (Brainerd and Reyna 1990). Some lay rules can be innate (e.g., affective flight tendencies upon seeing a snake), whereas others are learned (mere exposure or conditioning). We next discuss theoretical accounts, which could potentially explain the location bias, that consider lay rules that are either learned (reading directionality) or innate (laterality, pseudoneglect), or a combination of both (fluency). We further note that it is possible that some of the studies may differ in their underlying processes.

7.1. Reading Directionality

Most people read an immense amount every day and scan printed material from left to right. This trajectory is followed because most languages have an LTR script that results in individuals beginning to read from the left visual field to the right.[5] Over time, this scanning habit could acquire the form of a lay rule about how things should flow—it becomes a heuristic that people unknowingly apply to unrelated domains.

Evidence for language-scanning habits influencing subsequent preferences and decisions can be found in past work across different domains. Tversky et al. (1991) found that language-scanning habits dictated people's perceptions of numerical directionality from a very young age. If the dominant language of children required reading from left to right, children assumed that numerical increases also followed that direction. Similar findings based on reading direction have been reported in areas such as time perception and the formation of mental number lines. For instance, research has found that people who had the habit of scanning from left to right responded faster when phrases in past tense (e.g., "he spoke") appeared to the left of a silhouette on the screen than when phrases written in future tense (e.g., "he will speak") appeared on the left. Conversely, people were faster at responding when future tense (as opposed to past tense) phrases appeared to the right of the silhouette on the screen (Torralbo et al. 2006, Ulrich and Maienborn 2010). Italian speakers (LTR language script) positioned agentic groups (men and young people) to the left of less agentic groups

[5] It is worth noting that a majority of individuals are attuned to perceive motion with a left-to-right trajectory. Of the world's 50 most spoken languages, 88% have an LTR script (Lewis 2009, W3 Consortium 2011), making the left-to-right reading trajectory the most common across the world.

(females and old people), but a reversal was observed in Arabic (right-to-left (RTL) language script) speakers, who tended to position the more agentic groups to the right (Maass et al. 2009). Italian speakers, having an LTR language script, perceived a soccer goal with an LTR trajectory to be stronger and faster than the same goal with the opposite trajectory (RTL), yet Arabic speakers having an RTL language script perceived the RTL goal as being faster and stronger. Similarly, movie scenes depicting aggression with an LTR (RTL) trajectory were perceived as more violent by those with an LTR (RTL) language script (Maass and Russo 2003, Maass et al. 2007).

In sum, these findings can be used to suggest that individuals perceive motion, mirroring the direction of eye movements, to have a default left-to-right trajectory (for those with an LTR dominant language script). Hence, a left-to-right movement seems to be in line with the habitual flow, whereas a right-to-left movement seems to go against the flow. When the lay rule about LTR directionality is applied to scanning the environment for visual threats, a threat approaching from the left appears in line with the flow since it is easier to perceive that it will flow from the left (source) to the right (target); threats appear to move more freely (appear less encumbered) from left to right than from right to left. Hence, individuals assign a greater probability of being affected by a threat located on their left. Conversely, a threat approaching from the right appears opposite to the habitual flow and they are hindered in perceiving the flow of the threat to themselves (i.e., from right to left); hence, they assign a lower probability of being affected by the threat located on their right. Conversely, individuals with a dominant RTL language script (e.g., Arabic, Persian) habitually move their eyes from the right to the left and, hence, are more likely to consider a threat approaching from their right to have a greater likelihood of affecting them than a threat approaching from their left. In ongoing preliminary tests, we have some evidence that language directionality could be one of the theoretical accounts explaining the location bias. For instance, we find that the direction of language script of participants (LTR versus RTL) has the ability to moderate perceived risk from a threatening object appearing to their left versus their right. We see this happening both for participants' inherent language directionality as well as when they practice reading left to right versus right to left. However, this cannot be considered conclusive evidence of reading directionality because other mechanisms could also be at work.

7.2. Hemispheric Specialization

This line of research argues that the events we observe in everyday life are encoded both propositionally (e.g., boy kisses girl) and also spatially, where we form a spatial representation of that event in our mind (Chatterjee 2001). Research has proposed that there is an underlying primitive structure, which spatially represents events with a left-to-right trajectory (Kinsbourne 1987). A sentence stating that a boy kisses a girl gets represented in the mind with the boy on the left and the girl on the right. This relative positioning happens because the left cerebral hemisphere deploys action from a left to right vector—the action flows from the boy, the doer of the action, on the left to the girl on the right. Evidence for this occurrence comes from several studies, suggesting that people have an innate preference to see motion from the left to the right (Chatterjee 2001, Kinsbourne 1987). This innate preference has been attributed to the left and right cerebral hemispheres processing different types of information, also known as hemispheric specialization.

In one study, right-handed participants (a commonly used proxy for hemispheric specialization since it is more likely that language for right-handed individuals would be processed in the left hemisphere) listened to verbally presented sentences while viewing pictorial depictions that described events such as X pushed Y. The pictures sometimes had X on the right and sometimes on the left. Participants were asked to indicate as fast as possible, by pressing buttons, whether the picture matched the sentence or not. The results revealed that when X was shown on the left, participants' responses were faster than when X was shown on the right. In another study, right-handed participants heard verbally communicated information and had to spatially represent it in the form of stick figures (Chatterjee et al. 1995). For instance, they were asked to spatially represent "the circle hits the square." The researchers found that participants drew the circle (agent) on the left of the square (patient). These findings indicate that the left hemisphere tends to direct attention with a left-to-right vector (Kinsbourne 1987).

The innate origin of the lay rule suggests a left-to-right trajectory for motion based on hemispheric specialization, which can have the ability to influence spatial perception. Therefore, this account would argue that the location bias is caused because of hemispheric specialization, in such a way that right-handed participants would perceive a left threat to have a greater likelihood of affecting them compared to a right threat, and this pattern would reverse for left-handed individuals. Empirical process tests of the location bias that control for reading directionality and manipulate handedness can test for this account.

It is worth noting that many empirical tests have utilized the same stimulus and found evidence for either hemispheric specialization or language directionality. For instance, Chatterjee et al. (1995) used sentences to show that the agent is perceived on the left because of hemispheric specialization. In their studies, they utilize people from different cultures to show that the effect emerges despite language directionality. On the other hand, Maass and Russo (2003) have used the same sentence task as Chatterjee et al. (1995) and by using only right-handed participants have shown differential influence among participants with LTR versus RTL dominant languages.

7.3. Pseudoneglect

A mechanism related to the two accounts discussed above, pseudoneglect, could also be argued to be at work in causing the location bias. Pseudoneglect refers to how when normal participants bisect space during line bisection tasks (a commonly used procedure is to ask participants to mark the midpoint of a line in space), they are more likely to err to the left of the veridical (true) center of the line (Bowers and Heilman 1980, Jewell and McCourt 2000), thus bisecting the visual field into a smaller left side and a larger right side. This is said to be caused by neglect of the right hemispace, because of which the features/properties to the left of the stimulus are overestimated. Pseudoneglect has been considered an outcome of either hemispheric specialization or scanning direction. One set of studies suggests that it is caused by hemispheric specialization, with greater right hemisphere specialization being used for spatial attention (Fierro et al. 2000, Göbel et al. 2006, Nicholls et al. 2007). However, another set of findings implicates the role of scanning directionality, with the direction of the bisection changing for LTR versus RTL scanning (Chokron et al. 1998). By observing French (LTR script) and Tunisian children (RTL script), Fagard and Dahmen (2003) discovered that before reading age (five years old), both groups display a similar leftward tendency in the line bisection task, but after reading age (nine years old), the French children continued to display the leftward bias, whereas the Tunisian children showed no bias. These results matched the hypothesis of pseudoneglect having an innate component due to a neural bias and a learned component due to writing directionality. Furthermore, confirming this hypothesis, a meta-analysis compiling the varied findings on pseudoneglect as well as its proposed underlying causes (Jewell and McCourt 2000) found that both right- and left-handed individuals err to the left of the veridical center in the line bisection task, but scanning direction results in the participants erring in the direction from which scanning is initiated (subjects scanning left to right err to the left, whereas those scanning right to left err to the right of the veridical center). Researchers now report that pseudoneglect is not restricted to humans, but is shared by birds, suggesting pseudoneglect may reflect evolutionary adaptations that allow animals to devote attention to multiple aspects of their environment (Wilzeck and Kelly 2013). Hence, if future studies consider the role of pseudoneglect in causing the bias, it would be of importance to consider the mechanism through which pseudoneglect is occurring.

Applied to the location bias, this account would argue that people visually place themselves nearer to the left threat (or overestimate its properties) because of pseudoneglect and hence perceive it to be more likely to affect them than a threat that is located to their right. However, one needs to keep in mind that across studies the threat was to the left (or right) and the person was not in the center. Despite this, the interesting aspect of pseudoneglect is that it could be an outcome of either scanning direction or hemispheric specialization, so it would help to discover, by testing in an in-depth manner, the process through which location bias might be caused.

7.4. Fluency

Research on many types of fluency suggests that the ease or difficulty with which a stimulus is processed can have many downstream influences. For instance, a more easily processed stimulus is liked more than a less easily processed stimulus (Whittlesea 1993). Applied to the location bias, fluency would suggest that the location bias occurs because the direction of motion is more fluent from left to right than from right to left, and hence it is easier for an individual to perceive a higher likelihood of the threat affecting them from the left than from the right. This perception of fluency could emanate from different sources. One source of learned fluency is reading directionality, which would suggest that the left-to-right trajectory appears more familiar and hence more fluent for people with an LTR dominant language script. This would reverse for those with an RTL language script. Another source could be cultural or language based when people consider right with good things but left with bad things. For instance, in Latin, *dexter*, meaning "right" or "located on the right," has positive associations of being auspicious or favorable, whereas *sinister*, meaning "left" or "located on the left," has negative associations of being evil or unlucky. Many religions consider the right hand to be the more auspicious hand and forbid use of the left hand in religious rituals (e.g., Hindu religion). Hence, this would predict that people expect bad things from the left rather than from the right. Moreover, recent research on motor fluency considers the role of the dominant side of the body in influencing perceptions of good or bad (Casasanto 2009). This research suggests "the dominant side may be good in people's minds because dominant-side actions tend to be more fluent than nondominant-side actions" (Casasanto and Chrysikou 2011, p. 420). Hence, this account would argue that right-handed people find a left threat more threatening because it is on their nondominant side; this pattern would be reversed for left-handed people. It is worth noting that although the predictions of this motor fluency account appear similar to the hemispheric specialization account, their theoretical underpinnings are different.

In sum, we considered four potential explanations for the cause of location bias. It is possible that only one of these may be responsible for the bias or that a combination of these causes it. We next summarize our empirical findings and its implications.

8. Implications of This Research

The location bias has both theoretical and practical implications, as we describe in the following paragraphs.

8.1. Theoretical Implications

First, our findings contribute to the literature on decision making under uncertainty. Although extant research has looked at the judgment biases that are nonspatial in nature, very little work has explored how spatial factors lead to biases in risk estimation. We show that when people are assessing spatial risk, the relative location of the threat can bias risk estimates. It also shows that spatial risk estimation has many unique nuances, such as the location of the threat, that differentiate it from nonspatial risk estimation (e.g., odds of winning a gamble).

Second, findings of this work add to prior research, suggesting that individuals allow factors (at times, nondiagnostic) to distort their risk and probability estimates of events (Koehler and James 2009, Labella and Koehler 2004, Tversky and Kahneman 1974, Windschitl 2002). Third, one of the assumptions of normative decision rules is the principle of invariance—changes in the representation of a problem should not alter people's preferences. Past work has documented instances where this assumption is violated (Tversky and Kahneman 1974). Our research adds to this line of work by showing that, while keeping the information constant, changing the relative location of a threat significantly changes people's risk perceptions and behavior.

Fourth, this work also contributes to research that examines cultural bases of risk estimation. Past research has demonstrated that people from eastern cultures tend to be more risk seeking in financial decisions than those from western cultures (Weber and Hsee 1999). Location bias adds further nuances of whether language directionality (which has cultural roots) or handedness influence risk estimation to understand its boundary conditions.

Finally, the location bias influences magical thinking or beliefs about the spread of contamination (Frazer 1959, Tylor 1974). In Study 3 (and to some extent in Study 4) we show that contaminants, such as the essence from an unsavory object or person, are perceived to spread more strongly from the left than from the right. This has implications when testing for such contagion beliefs.

8.2. Managerial and Policy Implications

In developing countries where public safety and health are largely the responsibility of the individual with little government assistance, awareness of biases in spatial risk assessment can result in saving lives. For instance, countries like India and Vietnam have thousands of unmanned, open railway crossings and busy streets with no pedestrian signals. Individuals must decide whether to cross the street or railway tracks or to wait. Location bias would suggest that in such situations individuals underestimate the risk of an oncoming vehicle (train, bus, or car) if it is approaching from their right side compared to their left. Such risk underestimation can result in pedestrians crossing railway tracks or streets and causing major accidents. Capturing pedestrians crossing a one-way street without the assistance of a walk signal as in Study 2 corroborates this notion. Two additional types of major threats in many countries are the possibility of being mugged and the spread of infectious diseases from contaminating object to person due to population density. Given the teeming populations and lack of basic amenities, developing countries are facing thousands of fatalities each day because of infectious diseases that, according to a United Nations report, range from tuberculosis and bacterial pneumonia to SARS, bird flu, and swine flu. In Studies 3 and 4, we show that people are more willing to be near a person who may appear unsavory or harmful if he is located to their right, and put less distance between themselves and contaminating objects on the ground when they are located to their right. Awareness of such biased risk estimation can be critical in saving lives, and public awareness campaigns can help significantly since individuals can then correct for these errors.

Furthermore, considerable evidence suggests that many people who should purchase insurance do not do so, whereas those who do not really need insurance purchase many types of coverage. This observation is one example that reflects individuals' inability to assess which factors in their environment are really threatening and which are not (Kunreuther and Pauly 2005). For instance, data show that in an earthquake-prone state like California, fewer than 12% of homeowners actually purchase home insurance, indicating that there may to be an underestimation of risk (Matheny 2011). Our research would suggest that if a location prone to earthquakes (or any natural disaster) appears to the left of an individual's city on a map, there is a greater likelihood that she will purchase insurance than if the same threat is associated with an equidistant city located to the right on the map, which has implications not just for consumers, but also for insurance companies.

Finally, research has shown the influence of culture on risk assessment (Weber and Hsee 1999). In this research we show that, just like cultural differences affect risk perception, lay beliefs based on learned (reading either left to right or right to left) habits also have the ability to affect spatial risk perception.

It would be worth exploring other implications that this proposed effect might have for organizational interactions. Would people who are aware that an object (or person) to the left appears more threatening try and keep the threatening object to their right? For instance, in interactions, would they try to stay on the left of their superior (so that he appears to their right)? Similarly, would consumers put sales people to their right, to reduce the influence or pressure felt? Future research could examine whether such benign influences exist or whether location bias is specific only to actual threats in the environment.

It is not uncommon to show a threat on a screen or a map to communicate its risk. The location bias suggests that in these situations a left-located threat could be considered more perilous than a right-located threat. For example, news reports of natural disasters such as earthquakes, hurricanes, or volcanic eruptions show maps of the affected location. If people see that the affected location is to the right of their location on the map, they may underestimate the threat and not evacuate—a decision that may lead to adverse outcomes. In war zones, defense personnel might instinctively display the location bias and consider a threat approaching from their left to be more dangerous than a threat approaching from the right. Hence, making people aware of the location bias can help them make better decisions and avoid potentially disastrous outcomes by correcting for their instinctive perception of a left-to-right flow being applicable everywhere.

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