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Testing the effect of the directionality of verbal predictions on decision-making with experience and feedback

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ABSTRACT

Verbal probabilities are either positive, and attract attention towards the outcome occurrence (e.g., "a small likelihood") or negative, and attract attention towards the outcome non-occurrence (e.g., "unlikely"). The effect of directionality on decisions has mostly been evidenced in "context poor" studies, where participants had no other information than a verbal forecast, possibly magnifying the role of directionality. In three experiments, we varied how much information participants receive in a series of decisions in a computer game (shoot/don't shoot) based on positive and negative predictions about the suspect's dangerousness. In Experiment 1, participants received visual information and feedback; in Experiment 2, participants either received normal or ambiguous (blurry) visual information; and in Experiment 3, participants received ambiguous information only and no feedback. The results showed that directionality influenced decision-making (shoot/don't shoot and response time) across experiments, even when relevant information and feedback were provided. However, the effect was larger when decision relevant information was ambiguous. Our results demonstrate that limiting knowledge might have magnified effects observed in past research but also that the effect of directionality is robust in experiential methodologies.

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KEYWORDS Verbal probability; directionality; framing; prediction; decision

One of the axioms of rationality is that the same information should lead to the same preference or decision (Morgenstern & von Neumann, 1943). Yet, in a well-known violation of this rationality axiom, the same information framed differently leads to different decisions (Tversky & Kahneman,

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1981). In a typical verbal framing paradigm, participants' decisions are swayed by the directionality of verbal probabilities in minimalistic scenarios (a treatment has "a small chance of helping" vs. is "unlikely to help") (Collins et al., 2024; Honda et al., 2025; Honda & Yamagishi, 2006; Juanchich et al., 2025; Teigen & Brun, 1999). A criticism of such single-vignette studies is that more experience-based paradigms might elicit smaller, or even opposite effects (e.g., Hertwig et al., 2004; Hertwig & Erev, 2009). The present paper investigates if the framing effect of directionality on decision would be smaller or even disappear in a richer (and more realistic) decision-making context, where participants have relevant information and feedback.

The directionality of verbal probability

Framing effects come in many shapes and forms. Here we focus on framing of information that is expected to be logically equivalent and for which observed differences are often described as biases (e.g., attribute framing, risky framing; Levin et al., 1998). Such framing can be elicited based on complementary numerical frequencies/probabilities focusing on alternative outcomes (a 20% chance of winning vs. an 80% chance of losing) – or positive and negative verbal probabilities focusing on the same outcome ("a chance" of winning vs. "unlikely" to win). In this project, we study verbal probability, but we draw from – and inform – the global literature on framing, both numerical and verbal.

Verbal probabilities are phrases that are used to quantify one's level of certainty; for example, "it is possible" or "it is likely". Lay people and experts alike typically prefer to use verbal probabilities more often than numerical probabilities (Erev & Cohen, 1990; Juanchich & Sirota, 2020; Xu et al., 2009). Importantly, verbal probabilities can elicit a positive or negative framing due to their directionality (Budescu et al., 2003; Budescu & Wallsten, 1995; Juanchich et al., 2010, 2020, 2025; Teigen & Brun, 1995). For probabilities that are very low to very high, the directionality of verbal probabilities can either be positive, because it attracts attention towards the target outcome (e.g., "a small chance", "likely"), or negative, because it attracts attention towards the non-occurrence of the target outcome. The effect of this attention focus can be found in how people combine those judgments too. For example, when an outcome is described positively by two independent forecasters as being "likely", recipients might feel it is actually "very likely", whereas an outcome described negatively by two forecasters as being "unlikely" is more often revised downward as "very unlikely" (Mislavsky & Gaertig, 2022; Strueder & Windschitl, 2024; Teigen et al., 2023).

The effect of directionality on decision-making

Verbal probability directionality impacts decisions (Collins et al., 2024; Honda & Yamagishi, 2006, 2009, 2017; Juanchich et al., 2020; Teigen & Brun, 1999). In the seminal study of the effect, Teigen and Brun (1999)

asked participants to advise Marianne, a woman who suffered from headaches and who was offered a new, costly treatment that had either "some possibility" of being effective or was "quite uncertain" to be effective (manipulated between-subjects). The results showed a clear and strong effect of directionality. Most participants recommended the treatment that had "some possibility" of being effective and advised against the treatment when its chances of success were described as "quite uncertain". The effect was consistently replicated – but almost only in short vignettes, where participants had limited knowledge and did not receive feedback (Collins et al., 2024; Honda & Yamagishi, 2006, 2009, 2017; Juanchich et al., 2020; Teigen & Brun, 1999).

To our knowledge, only a single study demonstrated the effect of directionality in a study where participants could learn whether directionality was useful. In this study, participants made eight decisions based on three positive and three negative predictions and received feedback after each decision (Juanchich et al., 2020). The study showed a robust effect of the prediction directionality on decision. This is a stronger test of the effect of directionality, but participants had nothing else than the prediction to make their decision: they had no expertise in the decision task and no decision relevant information beside the prediction.

Overall, in past studies on the effect of verbal probability directionality, participants had no other relevant information than the (positive or negative) prediction. In a sense, they were completely blindfolded and "had to" rely on the verbal prediction given to them. This kind of experimental set-up is optimal to demonstrate that information framing matters, but it might provide an inflated perception of its magnitude. Would directionality still affect decision when participants have some knowledge to guide their decision and could experience decision quality *via* feedback? According to the description-experience gap body of research, they might not.

Experienced-informed decisions

While it is not uncommon to make decisions with limited knowledge, it is rarely the case that decisions are made in complete ignorance and without experiencing their consequences. Most of the time, people have some (limited) knowledge about situations and have to live with the consequences of their decisions, which shape subsequent decisions in a learning process.

The implications of using a more "natural" type of decision-making context – where people can experience the decision information and outcome – in contrast with decisions based on short descriptions have recently been discussed in decision psychology. When participants can actually experience the outcome (e.g., drawing a series of balls from an urn) and know whether they made a good decision or not (e.g., whether they won their bet), people make different decisions to those that are based on descriptions (Hertwig et al., 2004). In fact, some major theoretical

assumptions have been shown to work in decisions made from descriptions, but not, or in the opposite way, in decisions made from experience. For example, in line with the Prospect theory (Kahneman and Tversky, 1979), people over-weight low probabilities and under-weight high probabilities in decisions that are described to them, yet the opposite occurs in experience-based decisions (Hertwig et al., 2004; Hertwig & Erev, 2009) (see also Fox & Hadar, 2006, for a different perspective). In our work, we respond to the call to replicate existing findings from descriptive paradigms in more realistic decision contexts (Hertwig et al., 2004; Lejarraga & Hertwig, 2021) to further test the theoretical assumptions underpinning the effect of verbal probability directionality. Our methodology uses a sequential, trial-by-trial learning framework, similar to the multi-armed bandit paradigm (Hertwig et al., 2004; Robbins, 1952) in which participants receive decision-relevant information and feedback.

How might decision relevant information affect the effect of directionality?

Would directionality still impact decisions if people could *experience* other pieces of information to decide? Recent evidence suggests that the effect of directionality might be sensitive to people's knowledge and experience. For example, the effect of the directionality used to describe vaccines' risks of adverse side effects mattered more for a fictitious vaccine that people did not know at all, than for the COVID vaccine; and the effect size of directionality seemed to be inversely related to people's growing experience of the COVID vaccine (Juanchich et al., 2023). Research on numerical attribute framing shows more directly the moderating role of knowledge and expertise on the effect of framing on decision. For example, while the framing effect was consistently observed, experts - who knew more about an attribute's distribution - showed a weaker framing effect (Leong et al. 2017; Shan et al., 2020).

How might receiving feedback over trials change the effect of directionality?

People making a decision based on a prediction (e.g., the suspect is likely to have a gun) need feedback to know whether using the prediction helped them make a better decision. Hence, feedback might re-enforce the effect of directionality of the prediction on decision over time, if that information is useful. But what if directionality was not informative at all (if it is randomly selected). Would it still have an effect?

In one shot studies, directionality is presumed to affect decision making because it carries a piece of information that is not explicit but can be inferred by the recipient. It was for instance suggested that recipients infer what the speaker believe recipients *should* do (Hilton, 2008; Teigen,

2023; Teigen & Brun, 1995, 1999), the severity of the event (Juanchich et al., submitted), the past level of certainty of the speaker (Honda & Yamagishi, 2017; Juanchich et al., 2010), the probability of alternative events (Windschitl et al., 2017), or even the probability distribution of the outcome itself (Budescu et al., 2003). According to those inference hypotheses, the effect of directionality could be expected to be reduced over time if it becomes apparent that directionality is randomly selected: it is *not* adding relevant information and not helping improve decisions.

Although it is usually believed that people's focus on the outcome occurrence vs. non-occurrence is connected to the inferences recipients might draw, an inference might not be a necessary condition to directionality affecting decision-making. Instead, directionality might impact decision-making merely automatically – since it is causing a shift in attention towards the outcome occurrence or non-occurrence (Teigen & Brun, 1995). If an effect of directionality remains, despite it having no informative value, then the effect of directionality could be considered as a bias – a departure from formal logic (Keren & Teigen, 2004).

Extending the experimental paradigm beyond simple "one shot" scenarios to a series of experiential decisions with feedback indirectly informs the processes that underpin the effect of directionality and its boundary conditions. In a context where directionality is randomly selected, the provision of feedback (or its withdrawal) offers the possibility to test the minimal conditions required for the effect to occur, which indirectly informs *how* directionality affects decision. The attention hypothesis does not require directionality to be related to specific contextual factors, or to it improving decision, whereas participants might stop inferring information from it, if they noticed it was not providing such information.

The present project

We propose to test whether verbal probability directionality will affect decisions when participants have some information to guide their decisions and experience the outcome of their decisions. We tested the effect of directionality in three pre-registered experiments in which participants made a series of shoot/don't shoot decisions. In the three experiments, participants had to decide to shoot the suspects holding a gun, and not to shoot the suspects holding an inoffensive item. Across experiments, the decision trials followed the same procedure. The participants read a gun prediction, which was a sentence that quantified the probability of a suspect having a gun (e.g., "There is a chance that the suspect has a gun"). The prediction conveyed one of four levels of probability and was either positive or negative (randomly selected). Then, the participants were shown the suspect (with a gun or an inoffensive item – probabilistically set and attuned to the prediction) and had a second or less to decide whether or not to shoot. Each decision trial finished with decision feedback.

Based on past research, we expected that the participants would be more likely to decide to shoot and would make quicker shooting decisions based on a positive verbal probability compared to negative ones. We expected that this effect would occur over and above the fact that high probability predictions would also lead to more and faster decisions to shoot.

Across experiments, we reduced the information given to the participants to see if it would increase their reliance on directionality. In Experiment 1, we tested the effect of directionality on decision with some knowledge and feedback. Experiment 2 tested whether providing less decision-making information would increase the use of directionality (the item in the hand of the suspect was blurred vs. normal), and Experiment 3 evaluated the effect of directionality with limited information (blurred item) and without feedback. We summarised the effect of directionality on decision across experiments in a mini-meta-analysis.

Open science statement

We report all measures in all the studies and all manipulations, along with any data exclusion. All the experiments were preregistered, including hypotheses, sample size, materials and analytical plans. The pre-registration, materials and data from all the experiments are available on the Open Science Framework https://osf.io/bvd6u/overview. In our pre-registrations, we planned to focus on decision (shoot/don't shoot), decision outcome (e.g., correct non-shooting, incorrect non-shooting etc.) and decision response time. In this manuscript, we report the results on decision and response time and the results for decision outcome – similar to those on decisions – are reported in Supplementary Materials. All the studies were approved by the ethical committee of the University of Essex.

Pre-test and material selection

A long-standing debate on verbal probabilities is whether the probability they convey can be dissociated from their directionality (i.e., the framing of attention they elicit; Budescu & Wallsten, 1995, Juanchich et al., 2013). In this work, we do not provide a definitive answer to this question but use a method that gives the possibility of sidestepping it. We used four negative verbal probabilities and four positive ones that altogether conveyed a similar probability based on a pre-test. In the pre-test, 106 student participants completed a probability and directionality task for four pairs of verbal probabilities expected to convey probabilities from very low to very high and to vary in directionality as shown in Table 1.

Participants rated each verbal probability on a numerical 0–100% scale and rated the directionality of the terms (presented individually and in a randomised order to each participant). To assess directionality, participants rated the appropriateness of a probability statement about the guilt of a

suspect, completed once with a reason favourable to their guilt, and once with a reason against their guilt (e.g., "It is likely that the suspect is guilty …" "because the neighbour of the victim recognised him" vs. "because he has an alibi"). The difference of the 1–5 appropriateness scores gave a directionality score, where positive scores indicated a better match with pro-reasonsthan con-reasons and negative scores indicated more appropriateness perception for con-reasons than pro-reasons. The directionality scores could range from −4, when the sentence fitted very well with a reason against the outcome occurrence and not well at all with reason in favour, to +4, when the sentence fitted very well with reasons in favour and not at all with reason against.

After excluding cases where participants failed to answer an attention check question correctly, we retained data from 79 participants. We conducted a univariate analysis testing the effect of expected directionality and probability on directionality and probability perception. The results showed that both the probability and directionality manipulation had an impact on directionality perception, $F(3, 234) = 111.07$, $p < .001$, $\eta_p^2 = .59$ and $F(1, 78) = 99.71$, $p < .001$, $\eta_p^2 = .56$. As shown in Table 2, the directionality manipulation had the expected effect on directionality perception within each pair of verbal probabilities, from very low to very high probability conveyed (using Bonferroni adjusted pairwise comparisons, respectively, $Mdiff_{\text{very low}} = 1.05$, $p < .001$, $Mdiff_{\text{low}} = 1.92$, $p < .001$, $Mdiff_{\text{high}} = 2.73$, $p < .001$, $Mdiff_{\text{very high}} = 0.51$, $p = .001$).

Table 1. Verbal probability pairs tested in the pre-test study and used in Experiment 1–3.

Expected directionality		
Expected Probability	Negative	Positive
Very low	Very unlikely	A very small likelihood
Low	Unlikely	A small likelihood
High	Not completely certain	Likely
Very high	Almost completely certain	Very likely

Table 2. Mean probability and directionality perception for positive and negative verbal probability pairs used in experiment 1–3 (pre-test study, $N = 79$).

Forecast	*M* (*SD*) Probability perception		*M* (*SD*) Directionality scores	
Probability	Negative	Positive	Negative	Positive
Very low	30.00 (29.20)	27.61 (26.16)	−1.90 (1.48)	−0.85 (1.78)
Low	34.15 (23.09)	33.77 (20.15)	−1.97 (1.53)	−0.05 (1.77)
High	54.73 (20.15)	65.87 (18.60)	−0.94 (1.70)	1.80 (1.54)
Very high	83.87 (22.27)	76.53 (19.75)	1.38 (1.68)	1.89 (1.48)
Grand Mean [95%CI]	50.69 [48.30, 53.08]	50.95 [48.30, 53.59]	−0.86 [−1.05, −0.67]	0.70 [0.48, 0.92]

Note: Directionality scores were computed as the difference in 1–5 appropriateness ratings between a verbal probability statement including a pro reason (reason in favour of the event occurrence) and a statement including a con reason (reason against the event occurrence). Higher scores indicate a better match with reasons in favour of the event occurrence than with reason against.

As expected, the probability manipulation had an impact on probability perception $F(3, 234) = 99.78$, $p < .001$, $\eta_p^2 = .56$, and the directionality manipulation did not, $F(1, 78) = 0.04$, $p = .845$, $\eta_p^2 < .01$. As shown in Table 2, there were some variations in probability perception within pairs of positive-negative directionality verbal probabilities. One of the positive phrases conveyed a higher probability than the negative one for one pair (e.g., for the high verbal probability pair, diff: 11.13%) while the other three pairs showed the opposite pattern, the negative one conveying a higher probability (e.g., for the very high verbal probability pair, diff: 7.34%). However, overall, across pairs, the probability perception was the same for negative and positive phrases: 50.69% vs., 50.95%.

To best disentangle directionality from probability perception on decision in our experiments, we opted for using the four pairs of positive-negative verbal probabilities, ranging from very low to high probabilities and for which, altogether, the positive phrases and the negative phrases conveyed the same probability. The overall effect of directionality across pair hence better controls for probability variations and the effect for each positive-negative pair of terms should be considered within the context of probability conveyed by each term.

Experiment 1

Method

Participants

The study was conducted *via* Prolific, took up to 20 min and was paid £2. The conditions to take part were to be fluent in English and over 18 years of age. Overall, 91 participants started the study (adding to 5824 decision trials). Following our pre-registration, we excluded four cases (256 cases) based on two criteria: (i) participants who did not complete the decision task fully and (ii) participants who failed to make a decision in 25% or more of the trials. In our pre-registration, we also considered the possibility of using a series of eight or more identical decisions as indicating a lack of engagement with the task. This was uncommon and seemed to happen randomly (19 instances of a series of 8 shooting decisions in a row and four instances of a series of 8 non-shooting decisions in a row out of a total of 5,568 trials). After careful consideration, this last criteria was deemed unfit given that it was statistically possible that the suspect had a gun in eight trials in a row – hence making it possible for participants to shoot 8 times in a row while paying attention to the task.

After applying the two exclusion criteria (task incomplete and ≥ 25% no decision), the sample included 87 participants whose characteristics are presented in Table 3. Using a conservative sensitivity analysis that does not consider within-subject trials, the sample size gave sufficient

power to detect a small to medium effect of directionality on decision when comparing the number of shooting decision for negative and positive directionality, α = .05, power = .90, d_z = 0.32.

Design

We tested our hypotheses in a 4 (probability magnitude: very low, low, high, very high) x 2 (directionality: negative vs. positive) x 8 (trial) within-subjects design. Thus, each participant made a total of 64 decisions: eight decisions for each of the eight verbal probabilities that conveyed very low to very high probabilities and could either be positive or negative (as shown in Table 1). To break down the length of the task, the 64 trials were organised into 8 blocks of 8 trials, one for each of the 8 prediction conditions presented in a randomised order (2 directionality x 4 probability). In each block, participants therefore made a decision for each of the 8 verbal prediction conditions, which limited the chances of the same condition being presented sequentially. The effect of the trial factor represents changes in decision over time, from experience making decisions and receiving feedback in previous trials.

Table 3. Sociodemographic characteristics of participants in experiments 1–3.

	Experiment 1	Experiment 2	Experiment 3
N	87	110	50
Sample source	Prolific	Prolific	Campus based
% women	71%	64%	47%
Age			
Range	19–51	18–72	18–31
M (*SD*)	24.83 (4.83)	33.23 (11.65)	20.92 (2.26)
Ethnicity			
White British	80%	66%	15%
White Other	14%	16%	26%
Asian (British/Other)	3%	9%	46%
Black (British/Other)	1%	4%	4%
Other	2%	6%	6%
Education			
No formal qualification	1%	1%	0%
GCSE	18%	11%	4%
A level	35%	26%	58%
Undergraduate degree	39%	40%	29%
Postgraduate	7%	23%	10%
Employment status			
Employed in set sectors	45%	46.3%	6%
Unemployed	12%	13%	4%
Students	8%	21%	87%
Retired	5%	5%	0%
Other	30%	16%	2%
English proficiency			
Native	96	91%	60%
Non-native advanced	2%	8%	32%
Non-native Intermediate	2%	0%	6%
Non-native beginner	0%	1%	0%

Materials and procedure

Participants could only complete the study from a computer (it was not possible to take part using a tablet or a phone) since the study required a web plugin to be installed. The procedure and materials were adapted from the Police Officer Dilemma Task (Correll et al., 2002). Participants were given the role of a police officer patrolling a city being sent to apprehend a suspect. The participants were instructed that their task was to shoot suspects holding guns but to withdraw fire towards suspects not holding guns, with a clear set of points allocated to each of four possible decision outcomes based on the Police Officer Dilemma task: correct shooting, +10 points; correct non-shooting, +5 points, incorrect shooting, −20 points; and incorrect non-shooting, −40 points. To minimise non-responses, the game carried a timeout penalty of 10 points if participants failed to make a decision within 1,000 ms.

The participants were told that they were working in tandem with the Central Police Station and that someone there would inform them about the chances of the suspect carrying a gun. The prediction given by the Central Police Station to inform the participants used one of the eight verbal probabilities selected in the pre-test and shown in Table 1. Participants had 3,000 ms to read a gun prediction, then they were shown a fixation cross (500ms) followed by an image of the suspect for 1,000 ms when they had to decide whether to shoot or not to shoot in that time (see Figure 1). The time given to read the prediction is sufficient based on average reading time (about 3.97– 4.33 words/sec; Brysbaert, 2019) and was deemed sufficient in informal piloting. For each decision trial, two images of a suspect from the same ethnic group, within the same background, could be probabilistically chosen. One was holding a gun, and one was holding an inoffensive item (i.e., a can, a wallet or a phone), as in the example in Figure 1 showing a White man in a park holding either a gun or a phone.

In the programme, the probability of selecting the image with the gun was attuned to the experimental probability condition (very low: 28%, low: 34%, high: 60% and very high: 80%). For example, the verbal predictions "it is unlikely the suspect has a gun" and "there is a small likelihood the suspect has a gun" – that were taken to mean a 33–34% probability in the pre-test (Table 2) – were associated with a suspect with a gun 34% of the time and 66% of the time with a suspect with an inoffensive item.

We used 10 pairs of suspects; half were White and half were Black. The participants used the Z and M of their keyboard to record their decision – Z: Shoot and M: Do Not shoot (counterbalanced across participants). The participants were advised to set a finger from each hand on the response keys before the task started, to ensure that they could provide a response only within the one second they saw the suspect. The time participants took to respond was measured.

The participants went through six training trials before completing the experimental trials to get used to the task and experience the informativeness of the predictions. The predictions were presented in a constant order with a set selection of suspects as follows: "The suspect has a gun" (followed by

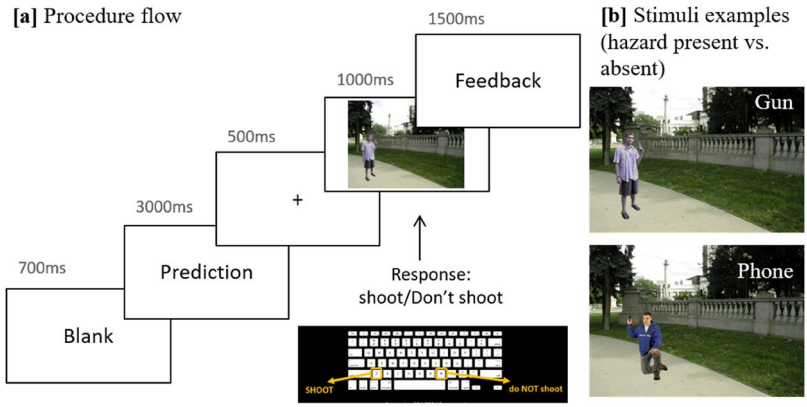


Figure 1. Decision trial flow used in experiment 1 [a], and examples of image showing either a suspect holding a gun or a suspect holding an inoffensive item [b].

a suspect with a gun), "The suspect does not have a gun" (followed by a suspect with a can), "The suspect may have a gun" (followed by a suspect with a gun), "The suspect may have a gun" (followed by a suspect with a can), "The suspect may not have a gun" (followed by a suspect with a gun), and "The suspect may not have a gun" (followed by a suspect with a can).

In the experimental phase, the participants made 64 decisions organised in eight blocks of eight decisions; in each series, the participants saw each of the eight predictions (4 probability x 2 directionality) in a randomised order. The participants were given feedback after each trial and were told whether or not they had made a correct decision and the points they earned/lost in that trial.

The participants followed the instructions and made more correct than incorrect decision (87% correct, 17% incorrect). The rate of incorrect decisions was higher than in the original paper using the Police Officer Dilemma Task (Correll et al., 2002), where participants made an incorrect decision only 4% of the time (and had 850 ms to make a decision-Study 1).

After completing the shooting task, the participants provided socio-demographic details (age, gender, ethnicity), along with their handedness. The participants also reported to what extent they could see the item held by the suspect in the image on a 7-point scale ranging from 0: *Never* to 6: *Always* (0: Never, 1: *Rarely*, 2: *Sometimes*, 3: *About half the time*, 4: *Often*, 5: *Very often, 6: Always*). Using this scale, 62% of the participants reported seeing the item Often, Very often or Always, 14% selected Sometimes, 19% about Half the time, 6% Rarely or Never ($M = 3.78$, $SD = 1.38$).

Variable preparation

We report the frequency of shooting, non-shooting and no decision, but we do not include the "no decision" in the inferential analyses because of their low rate of occurrence and to facilitate interpretation.

Analyses

We tested the effect of our within-subjects manipulation of probability, directionality and trials on decision (shoot vs. do not shoot) and reaction time using a Generalised Estimating Equation (GEE) for binomial distribution for decision, and for continuous outcome for response time. The GEEs included the probability, directionality and trial, along with their interactions, as independent variables, and the hazard (whether the suspect had a gun or not) as a covariate. Hazard was the key decision relevant information (hazard = shoot, no hazard = don't shoot) and therefore it was important to include its role in the analyses and measure its effect. Because the probability of the hazard being shown was matched to the probability conveyed by the prediction, the two were positively correlated (r = .42, p < .001), but not to the extent it would cause a collinearity issue in the analyses, with a Variance Inflation Factor (VIF) of 1.21. The GEE for reaction time also included decision as a factor, based on the expectation that higher probabilities and positive directionality would encourage, and therefore speed up, shooting decisions, but discourage, and therefore slow down, non-shooting decisions. As our main focus is the effect of the prediction, and in particular the effect of the directionality of the prediction, we have focused in the text on the main effect of probability, directionality and trial (akin to experience), and on all of the significant interactions with directionality. The tests of the interactions with directionality are exploratory, except for the interaction with the ambiguity manipulation in Experiment 2, which was a pre-registered hypothesis.

Results

Shooting decision

As shown in Figure 2, participants were more likely to shoot when the directionality of the prediction was positive (57% vs. 54%), despite directionality not being related to any relevant decision cue. In addition, participants were more likely to shoot when they read higher probability predictions. The results of the GEE (Table 4) show a main effect of directionality, prediction probability, and hazard on decision.[1] The analysis also showed that the pattern of decision was stable across probabilities and over time, with no statistically significant interaction effect with probability and decision trial.

[1]The main effects remain the same when hazard was not included as a covariate (i.e., results that are p < .05 or p > .05 remained in the same category).

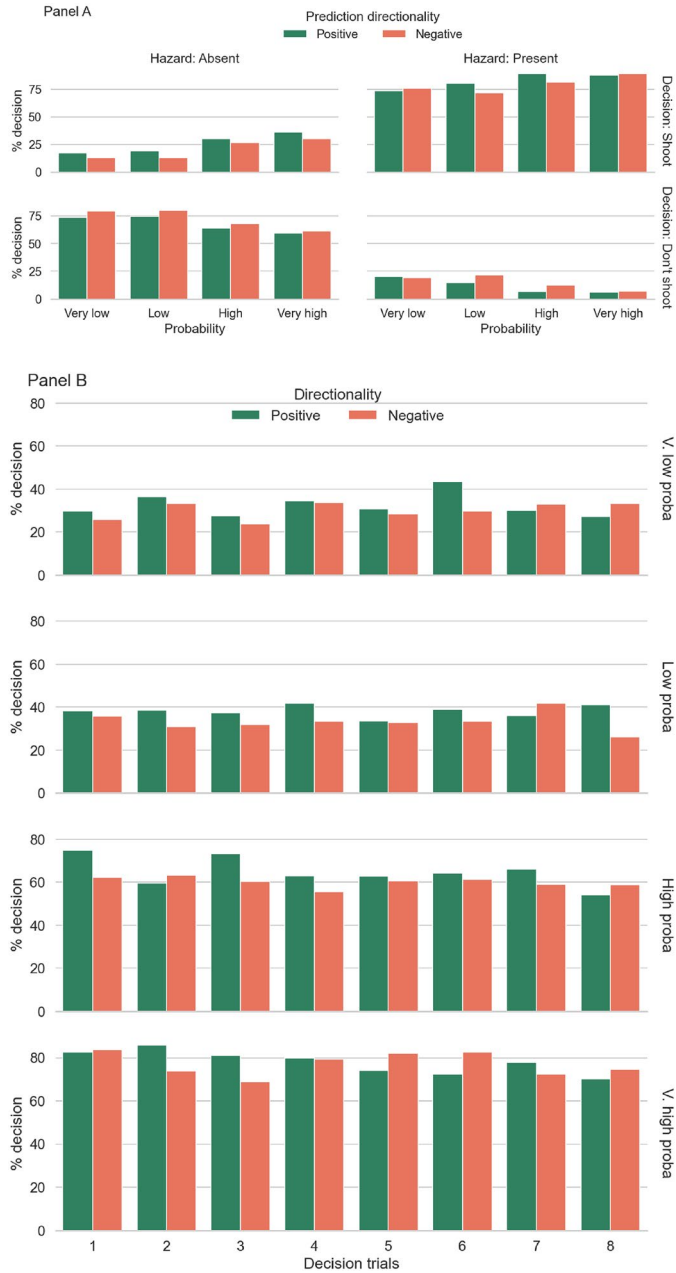


Figure 2. Decision (shoot/don't shoot) as a function of the hazard, prediction probability and directionality used in the prediction of the suspect being armed in experiment 1 ($N = 87$). Panel A shows decisions as a function of the presence/absence of the hazard in the trial (Absent vs. Present) and panel B as a function of decision trials (1–8).
Note: In each trial, shoot and don't shoot decisions do not add to 100% since some participants failed to respond within the time limit and those responses were recorded as "no decision". Trials show participants' decisions for the same experimental condition over trial that were set across blocks, hence reflecting changes over the whole course of the study.

Table 4. Main and interaction effect of directionality, probability and decision trial (with hazard as a covariate) on decision and response time in a GEE (Experiment 1, $N = 87$).

		Decision		Response time	
	df	Wald χ^2	*p*	Wald χ^2	*p*
Intercept	1	528.89	<.001	2123.50	<.001
Main effect					
Probability (very low, low, high, very high)	3	156.48	<.001	1.82	.610
Directionality (pos vs. neg)	**1**	**18.19**	**<.001**	**1.50**	**.221**
Trial per condition (1–8)	7	14.29	.046	15.78	.027
Hazard (covariate)	1	1445.99	<.001	.22	.641
Decision (shoot vs. don't shoot)	1	--	--	99.52	<.001
2-way interactions					
Probability x Directionality	3	3.14	.371	5.33	.149
Probability x Trial	21	24.23	.282	40.72	.006
Directionality x Trial	7	7.75	.355	6.72	.459
Probability x Decision	3	--	--	31.99	<.001
Directionality x Decision	**1**	--	--	**1.95**	**.162**
3-way interactions					
Probability x Directionality x Trial	21	12.95	.910	26.84	.176
Probability x Directionality x Decision	3	--	--	11.14	.011
Probability x Decision x Trial	21	--	--	41.25	.005
Directionality x Decision x Trial	7	--	--	16.44	.021
4-way interaction					
Probability x Direct. x Decision x Trial	21	--	--	42.40	.004

Note: Trial refers to the repetition of the same prediction over the course of the experiment. Each participants received the same prediction in 8 trials organised in 8 blocks (64 decisions), hence here trial represents changes in decisions over time, while testing the effect of the prediction, that was characterised by its probability (very low, low, high, very high) and its directionality (positive vs. negative). Values shown in bold correspond to hypothesised effects of directionality.

Reaction time

In line with our expectation, and as shown in panel A of Figure 3, participants who read a positive directionality gun prediction (shown in green) were generally faster to shoot (upper panel) than when they read a negative prediction (shown in orange). Conversely, when the participants read a negative directionality prediction, they were faster to decide not to shoot (lower panel) than when they read a positive prediction. This trend was true for very low, low and high probability but not for very high probability predictions, for which the opposite pattern was found – and the pattern evolved over time. The interaction pattern is supported by two three-way interactions (Directionality x Probability x Decision and Directionality x Decision x Trial) and a four-way interaction where directionality interacted with Probability, Decision and Trial to predict response time shown in Table 4. The GEE also showed a main effect of decision (participants were faster to shoot than not to shoot) and trial (response

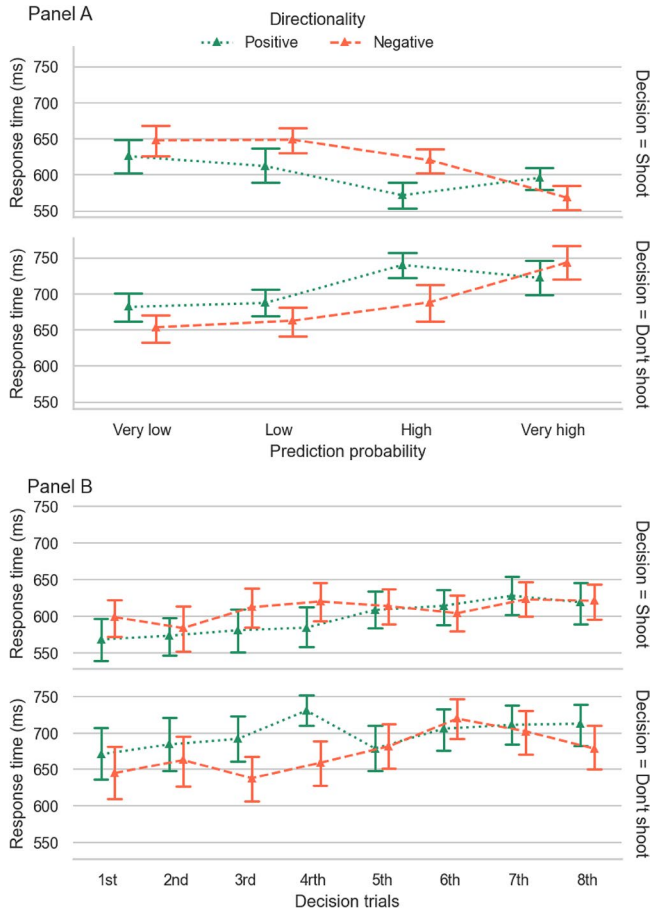


Figure 3. Effect of a hazard prediction directionality and probability on mean decision reaction time (shown as triangles) per decision (shooting vs. not shooting) - as a function of probability in panel A and trials in panel B (error bars show 95% CI).
Note: Trials show participants' response time for the same experimental condition over trial that were set across blocks, hence reflecting changes over the whole course of the study.

time decreased with experience), and no main effect of prediction probability and directionality.[2]

Experiment 2

Experiment 2 aimed to replicate and extend Experiment 1 by testing whether participants would rely on directionality more when we limited their access to relevant decision information regarding the hazard – whether they could see if the person held a gun or an innocuous item.

[2]Running the GEE without the covariate hazard did not change the status of the effects.

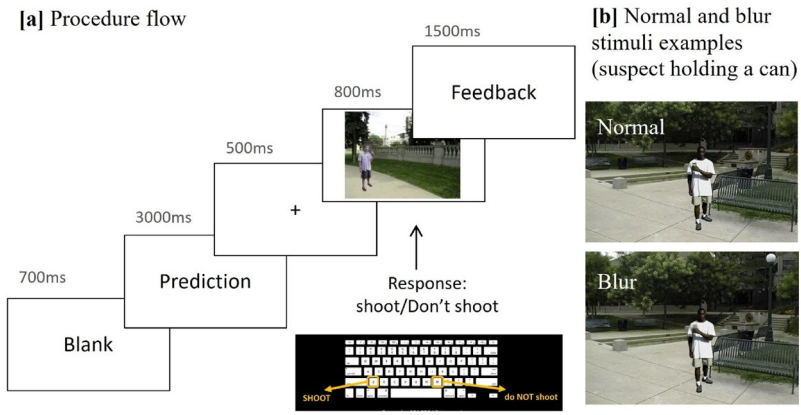


Figure 4. Procedure flow of experiment 2 in panel [a] and examples of stimuli in the normal and ambiguous information condition in panel [b].

We expected that providing more ambiguous visual information would increase reliance on the prediction (and its directionality). We reduce the decision time from 1000 ms to 800 ms and to manipulate information ambiguity, we blurred the item held by the suspect for half of the participants (see Figure 4, right panel, bottom picture).

The design was based on a pilot study which showed that the blurriness manipulation did reduce participants' ability to detect what the suspect held. The Pilot Study of Experiment also included probability perception for the eight verbal probabilities, showing a small but statistically significant difference between positive (51.14%) and negative (48.09%) verbal probabilities; however, including these estimates as a covariate when analysing the effect of manipulations did not change the results, nor predicted decision. The pilot study was conducted on a smaller sample ($N = 69$) and with a large proportion of non-native speakers (49%) and is reported in full in Supplementary Materials.[3]

Participants

Participants from the Prolific platform were paid £2 to complete the 20-minute study. Overall, 115 participants started the study, and we excluded data from five participants based on pre-registered criteria. The characteristics of the remaining sample of 110 participants are presented

[3]The pilot study included all the same manipulations and measures as Experiment 2. The results showed that participants relied mostly on the images rather than the text, likely because of limited English skills. Findings showed only effect of the probability of the suspect having a gun and of the presence of the hazard on decision, while response time showed in addition an interaction Probability x Directionality. The findings from that study are included in the meta-analysis presented at the end of the empirical section.

in Table 3. Using a conservative sensitivity analysis that does not consider within-subject trials, the sample size gave sufficient power to detect a small to medium effect of directionality on decision when comparing the number of shooting decision for negative and positive directionality, α = .05, power = .90, dz = 0.28.

Design, materials and procedure

Design

We tested our hypotheses in a 2 (prediction directionality) x 4 (prediction probability magnitude) x 8 (trials) x 2 (information ambiguity) mixed design, with all of the manipulations in within-subjects except ambiguity (blur: $n = 55$, normal, $n = 55$). An example of the normal and blurred versions of the image is shown in Figure 4, right panel. In the blurred version of the suspect image, one could still see whether or not there was a gun, but it was more difficult. Because the probability of the hazard being shown was matched to the probability conveyed by the prediction the prediction probability was positively correlated with the occurrence of the threat in the trial (r = .42), but not to the extent it would cause collinearity issues (VIF = 1.28).

Materials and procedure

The materials and procedure were the same as in Experiment 1, except that participants were either presented with the normal pictures of the suspects or the blurred ones. The participants' response times were recorded.[4]

After completing the shooting task, the participants reported how often they could see the item held by the suspect in the images as a manipulation check for ambiguity. Participants rated on a 7-point scale whether they were able to see the item held by the suspect in the images (0: *Never*, 1: *Rarely*, 2: *Sometimes*, 3: *About half the time*, 4: *Often*, 5: *Very often*, 6: *Always*). On average, the manipulation of information ambiguity was successful, with 80% of the participants reporting that they could see the item held by the suspect in the normal condition at least "often" (often/very often/always), whereas only 41% did so in the blur condition. On average, participants spotted the item the suspect held on fewer occasions in the ambiguous condition, than in the normal condition, $M = 3.76$, $SD = 1.44$, $M = 2.22$, $SD = 1.07$, $t(91.23) = 6.32$, $p < .001$, *Cohen's d* = 1.21. At the end of the study, participants provided their sociodemographic characteristics.

[4]In a few instances, participants clicked to make a decision before the suspect was shown (during the prediction or the cross). A 800 ms response time was recorded. These values were discarded from the response time analyses.

Results

Effect of prediction on decision

As shown in Figure 5, the participants were more likely to make a shooting decision based on positive directionality predictions than based on negative ones (62% vs. 53%, +9 percentage points). The main effect of directionality on decision was not statistically significant, but directionality was involved in two interaction effects, with information ambiguity and probability magnitude (see Table 5). The interaction effect between directionality and ambiguity reflects that the effect of directionality was larger in the ambiguous condition, with a larger increase in shooting decision based on positive directionality (+5% in the normal condition and +12% in the ambiguous one). The interaction between directionality and probability magnitude reflects that participants were more likely to shoot based on the positive directionality than the negative one, for the very low, low and high probability magnitude, but not for the very high probability prediction. This could be explained by the fact that the probability conveyed by the negative prediction was higher than the probability conveyed by the positive prediction in the very high probability pair (shown in Table 2), possibly countering the effect of directionality. As shown in Panel B of Figure 5, which shows trial-level data, both interaction patterns with directionality changed over time. This is supported by two triple interaction effects Probability x Directionality x Trial and Probability x Directionality x Ambiguity shown in Table 5. Figure 5, panel B shows how the effect of directionality evolved across the blocks and how this pattern was different based on ambiguity and probability magnitude. These effects are exploratory and were not predicted. For very low probabilities, the effect of directionality became sharper over time, especially in the ambiguous condition where the increase is more linear. In contrast, in the low probability condition, while participants shoot more based on the positive directionality than based on the negative one across all trials, in the ambiguous condition the effect reverses over time, with more participants shooting based on the negative condition than on the positive one in the last two trials. For high probabilities, the effect of directionality is clearer in the ambiguous condition across trials than in the normal condition. And finally, the effect of directionality for very high probabilities is null or reversed in most of the trials, especially in the first few trials of the ambiguous condition.

Effect of directionality on response time

As shown in Figure 6, the participants took longer to decide not to shoot based on positive predictions than based on negative ones (see main effect of directionality and the interaction effect Directionality x Decision in Table 5). The pattern also varied over the blocks of trials, depending on probability

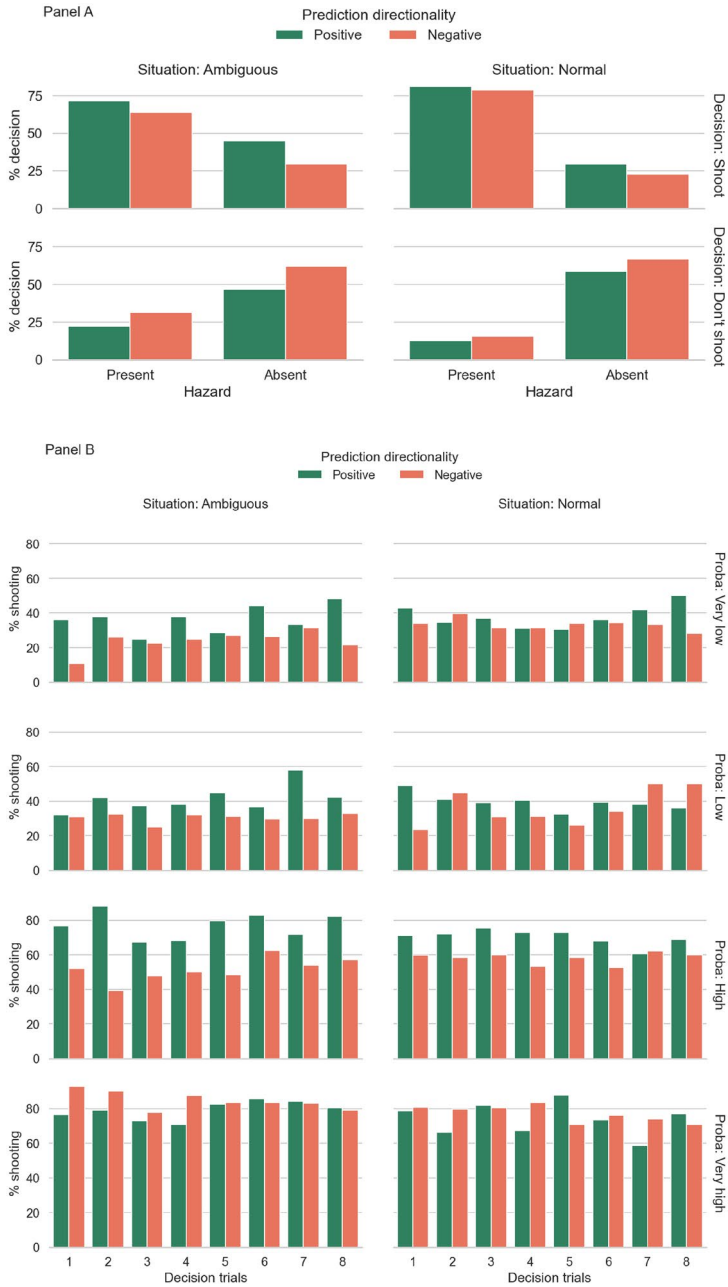


Figure 5. Effect of hazard prediction directionality on decision to shoot as a function of the ambiguity of the situation on decision (Experiment 2, $N = 110$). Panel a shows the effect of directionality on shoot-don't shoot as a function of the presence (vs. Absence) of hazard and panel B shows shoot decisions as a function of probability and trials.
Note: In each trial, shoot and don't shoot decision do not add to 100% since some participants failed to respond within the time limit and those responses were recorded as "no decision". Trials show participants' decisions for the same experimental condition over trials that were set across blocks, hence reflecting changes over the whole course of the study.

Table 5. Main and interaction effect of directionality, probability, ambiguity and decision trial (with hazard as a covariate) on decision and response time in a GEE (Experiment 2, $N = 110$)[a].

		Decision		Response time	
	df	Wald χ^2	*p*	Wald χ^2	*p*
Intercept	1	17.10	<.001		
Main effects				3264.76	<.001
Probability (very low, low, high, very high)	3	205.29	<.001	19.94	<.001
Directionality[a] (positive vs. negative)	**1**	**51.18**	**.101**	**4.59**	**.032**
Ambiguity (ambiguous vs. normal)	1	.00	.993	8.92	.003
Trial (1–8)	7	7.03	.425	25.81	.001
Decision	--	--	--	24.04	<.001
Hazard (covariate)	1	113.89	<.001	0.08	.772
2-way interactions					
Probability x Directionality	3	53.91	<.001	4.75	.191
Probability x Ambiguity	3	10.38	.016	3.84	.278
Probability x Trial	21	53.90	<.001	40.08	.007
Directionality x Trial	7	11.45	.120	56.44	<.001
Directionality x Ambiguity	**1**	**5.72**	**.017**	**0.10**	**.754**
Ambiguity x Trial	7	7.03	.426	9.72	.205
Probability x Decision	3	--	--	56.44	<.001
Directionality x Decision	**1**	**--**	**--**	**13.85**	**<.001**
Trial x Decision	7	--	--	12.47	.086
3-way interactions					
Probability x Directionality x Trial	21	42.97	.003	28.20	.135
Probability x Directionality x Ambiguity	3	12.68	.005	0.59	.900
Probability x Ambiguity x Trial	21	27.46	.156	33.98	.036
Directionality x Ambiguity x Trial	7	3.74	.810	6.85	.444
Probability x Directionality x Decision	3	**--**	**--**	18.49	<.001
Probability x Decision x Trial	21	--	--	29.75	.097
Directionality x Decision x Trial	7	--	--	13.00	.072
Probability x Ambiguity x Decision	1	--	--	16.71	.001
Directionality x Ambiguity x Decision	1	--	--	0.94	.333
Ambiguity x Trial x Decision	7	--	--	13.53	.060
4-way interactions					
Probability x Directionality x Ambiguity x Trial	21	29.66	.099	21.06	.456
Probability x Directionality x Ambiguity x Decision	3	--	--	16.62	.001
Probability x Directionality x Trial x Decision	21	--	--	47.14	.001
Probability x Ambiguity x Trial x Decision	21	--	--	27.40	.158
Directionality x Trial x Ambiguity x Decision	7	--	--	7.09	.419
5-way interaction		--	--		
Probability x Directionality x Ambiguity x Trial x Decision	21	--	--	28.89	.117

[a]When we ran the models without the covariate for the decision, the main effect of directionality became <.05 (Wald $\chi^2 = 36.09$, $p < .001$), Directionality x Ambiguity became ns (Wald $\chi^2 = 3.08$, $p = .079$), Probability x Ambiguity * Decision trial became statistically significant (Wald $\chi^2 = 35.43$, $p = .013$).

Note: Trial refers to the repetition of the same prediction over the course of the experiment. Each participants received the same prediction condition in 8 trials organised in 8 blocks (64 decisions), hence here trial represents changes in decisions over time, while testing the effect of the prediction that was characterised by its probability (very low, low, high, very high) and its directionality (positive vs. negative). Values shown in bold correspond to hypothesised effects of directionality.

and trial ambiguity (4-way interaction in Table 5). As shown in Panel B of Figure 6, the effect of directionality on response time is more consistent with non-shooting decision (right hand side plots), where negative prediction led to slower decision across all decision trials (except in the last one); whereas, with shooting decision the effect was more variable over the rounds, with positive prediction leading to faster decisions in only about half of the trials (left hand side plots). The tendency of a stronger effect of directionality for non-shooting decisions was especially strong in the ambiguous condition (top right plot) compared to the normal condition (bottom right plot).

Experiment 2 partly replicated the effects observed in Experiment 1. For very low, low and high probability predictions – but not for very high probability ones – participants shot the suspect more often and faster based on positive directionality predictions than based on negative directionality ones. Furthermore, the data showed the expected interaction effect between ambiguity and directionality: participants were more sensitive to the effect of directionality when we limited their access to decision-relevant information than when they had more access to it.

Experiment 3

In Experiment 3, all the participants received ambiguous information, and, in addition, we removed the decision outcome feedback. The participants were not told whether they had made a correct or incorrect decision. This was done to impede learning and to assess whether directionality would matter more when the participants did not know that directionality was unconnected with any relevant task cue.

Methods

Participants

Sixty-two participants were recruited on campus at Kingston University.[5] The participants were given a £5 Amazon voucher to participate. As in Experiments 1 and 2, we used two exclusion rules: (i) we excluded data from participants who did not complete the decision task fully (i.e., the program was exited before all trials were completed); (ii) we excluded data from participants who did not make decisions in 25% of the trials or more. Twelve participants were excluded: eight participants exited the task before the end, and four participants made no decision in at least 25% of the trials.

[5] As data collection for Experiment 3 was conducted in small groups, the final sample – after further recruitment to replace participants who withdrew from the study before the end – was slightly over the planned sample of 50.

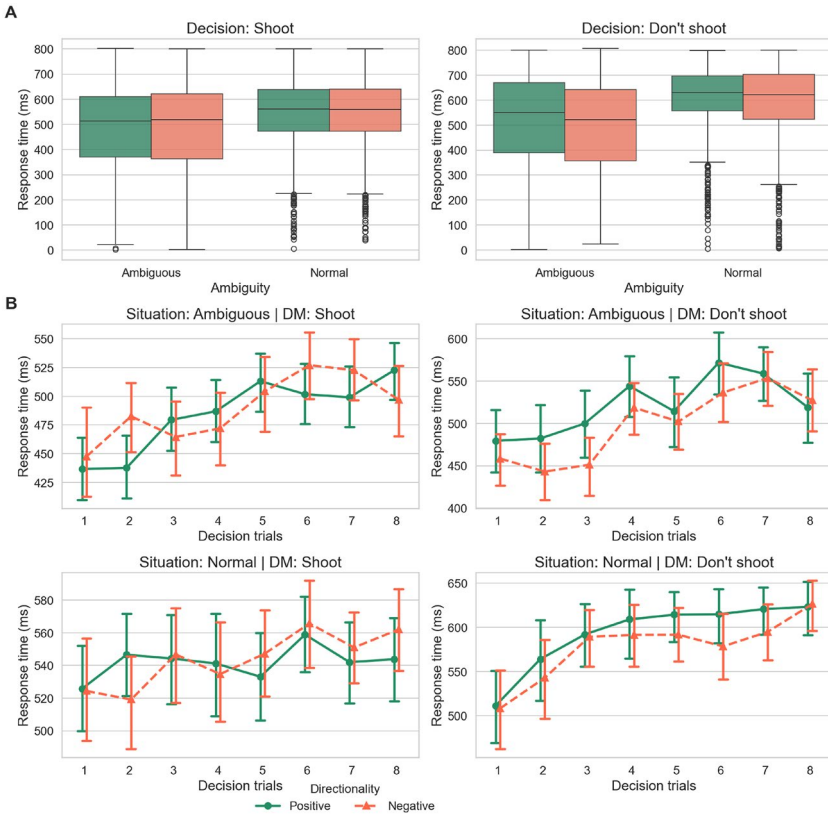


Figure 6. Effect of hazard prediction directionality and situation ambiguity on decision reaction time per decision (panel A) and across trials (panel B; Experiment 2, $N = 110$). *Note*: In panel A the box represents the interquartile range, the line the median, the error bars show the minimal and maximal values without outliers and the outliers are shown as diamonds. Panel B shows the means and 95% CI. Trials show participants' response time for the same experimental condition that was repeated 8 times, each time in a separate block, hence the trend over trials reflect changes over the whole course of the study.

The characteristics of the remaining sample of 50 participants are presented in Table 3. Notably, this sample included more students and was more ethnically diverse relative to the samples of Experiment 1 and 2. Using a conservative sensitivity analysis that does not consider within-subject trials, the sample size gave sufficient power to detect a small to medium effect of directionality on decision when considering the number of shooting decision for negative and positive directionality, $\alpha = .05$, power = .90, $dz = 0.37$.

Design, materials and procedure

The study was conducted in laboratory conditions and used the same design as Experiment 1 (2 directionality x 4 probability magnitudes x 8

trials). The probability of the suspect having a gun was attuned to the probability in the prediction and hence the two were correlated (r = .41), but not to the extent to cause collinearity issues (*VIF* = 1.20).

The study was conducted in laboratory conditions and used the same materials and procedure as Experiment 1, except for two changes. First, we changed the feedback provided at the end of each trial. Participants only received a confirmation of the decision they had made ("You shot the suspect"/"You did not shoot the suspect"/"You were too slow"), and no feedback on whether the decision was correct or incorrect. After 24 and 48 trials, and at the end of the study, the participants were given summary performance feedback based on the point system described in Experiment 1. Second, all images were blurred to render the decision situation ambiguous. The items in the pictures were blurred using Photoshop's Motion Blur effect at 25 pixels and at a 30-degree angle. See example in the lowest panel of Figure SM1.

The shooting task was immediately followed by a questionnaire asking the visibility of the suspect and to "translate" the verbal probabilities into percentage probabilities. Visibility was rated on a 7-point scale whether they were able to see the item held by the suspect in the images (0: *Never*, 1: *Rarely*, 2: *Sometimes*, 3: *About half the time*, 4: *Often*, 5: *Very often*, 6: *Always*). The ambiguity manipulation was effective as only 15% of participants reported that they could see the item held by the suspect often or very often (and 65% "never" or "rarely"). Participants translated the verbal probabilities used in the shooting study ranging from 0% to 100% by increments of 1. Finally, participants answered demographic questions such as age and gender.

Results

As shown in Table 6, the probability perception given in the post-test phase showed differences consistent with the pre-test study with some pairs where the positive verbal probabilities convey a higher probability (high probability) and some pairs where the opposite occurred (very high probability). Overall, participants' perceptions of the probability conveyed by positive and negative verbal probabilities were close to 50%, but there was $a + 3\%$ higher probability perception for the positive verbal probabilities. To control for this difference, we conducted robustness check using participants' probability perception in our analyses.

Decision

As shown in Figure 7, the participants were more likely to shoot based on positive directionality predictions than on negative ones (58% vs. 46%, +12 percentage points). The GEE showed that both the prediction probability and directionality had an effect on the shooting decision (see

Table 6. Mean (*SD*) probability interpretation of predictions of a suspect being a threat as a function of manipulated probability and directionality (post-test of experiment 3, $N = 49$).

Probability of threat		*M* (*SD*) Subjective probability	
		Experiment 3	
Verbal Probability	Hazard	Negative Directionality	Positive Directionality
Very low	28%	29.51% (27.85)	26.92% (18.21)
Low	34%	29.54% (19.85)	36.41% (21.32)
High	60%	50.02% (21.29)	65.67% (16.51)
Very high	80%	78.94% (23.79)	72.90% (20.64)
Overall	51%	47.00%	50.48%

Table 7). Directionality also interacted with probability, because the effect was stronger for very low, low and high probability predictions than for the very high ones (see Figure 7). Trials did not have a main effect on people's decisions, but it interacted with probability. With experience over blocks of trials, participants changed their reliance on probability (visible in Panel B of Figure 7). There were no other interaction effects: experience did not change participants' use of directionality over decision trials, or their combined use of directionality and probability.[6]

To test the robustness of the effect of directionality on decision, we replicated the analysis using participants' probability perception as an additional covariate – this was especially important given that the positive directionality terms overall led to $a + 3\%$ probability perception. The findings were replicated: directionality had a main effect and an interaction effect with probability perception (details reported in SM G). The experimental probability manipulation also had a main effect, as well as an interaction effect with trials. Finally, as before, hazard had an effect on decision, while the subjective translation of the verbal probability also had a statistical effect on shooting decision. The analysis confirmed the effect of directionality was robust to the participants' probability perception variations observed.

Response time

The mean response time across the decision trials and shooting decisions can be seen in Figure 8. Only the prediction probability had a main effect (Table 7), with decisions being faster for higher probabilities. Directionality did not have a main effect on response time, but as predicted, it had an

[6]The same analysis without the Hazard covariate yielded similar results. Probability and directionality had a main effect, Wald $\chi^2 = 88.27$, $p < .001$ and Wald $\chi^2 = 19.17$, $p < .001$. The Probability x Directionality and the Probability x Trial interaction effects were also statistically significant, Wald $\chi^2 = 25.76$, $p < .001$, Wald $\chi^2 = 81.51$, $p < .001$. The only difference was that the triple interaction Probability x Directionality x Trial became statistically significant, Wald $\chi^2 = 33.80$, $p = .038$.

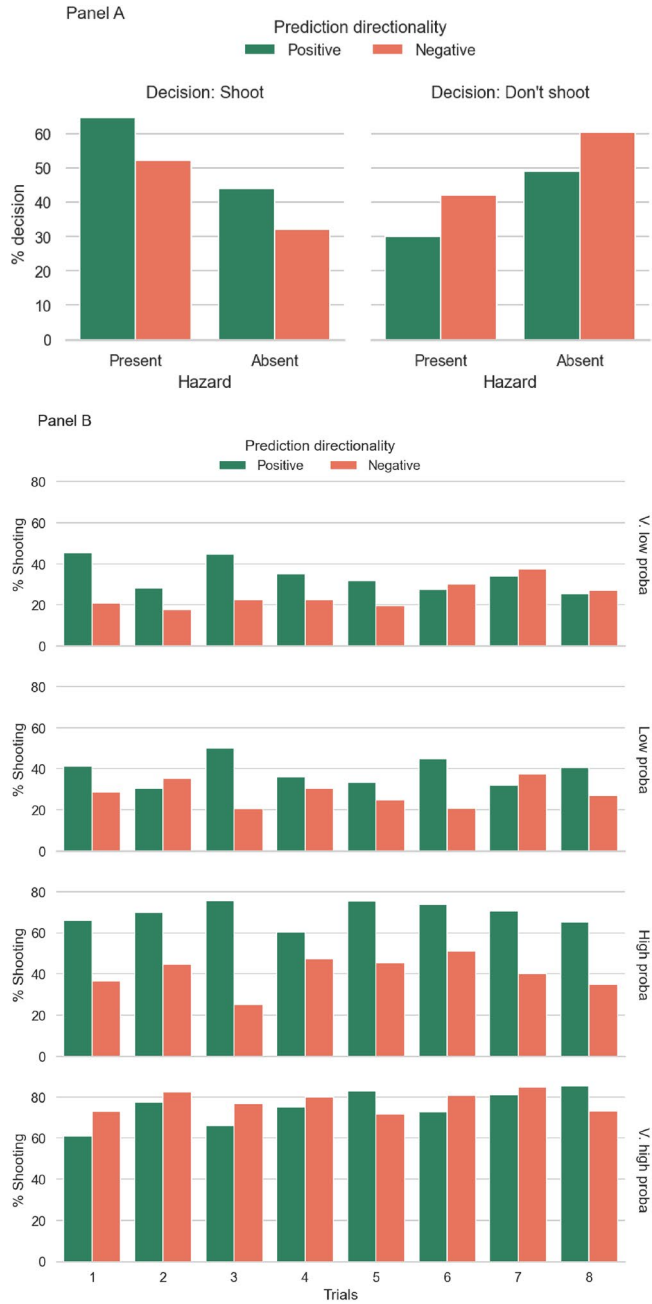


Figure 7. Effect of prediction directionality on shooting decisions in experiment 3, using ambiguous materials and no feedback ($N = 49$). Panel a shows shoot-don't shoot decisions as a function of the presence of the hazard, and panel B shows shooting decisions as a function of probability and trials.

Figure Note: In each trial, shoot and don't shoot decision do not add to 100% since some participants failed to respond within the time limit and those responses were recorded as "no decision". Trials show participants' decisions for the same experimental condition over trial that were set across blocks, hence reflecting changes over the whole course of the study.

Table 7. Main and interaction effect of directionality, probability and decision trial in an ambiguous situation (with hazard as a covariate) on decision and response time in a GEE (Experiment 3, $N = 50$).

		Decision		Response time	
	df	Wald χ^2	*p*	Wald χ^2	*p*
Intercept	1	.003	.960	[1]	[1]
Main effects					
Probability (very low, low, high, very high)	3	81.74	<.001	16.56	<.001
Directionality (positive vs. negative)	**1**	**19.70**	**<.001**	**0.85**	**.355**
Trial (1–8)	7	13.20	.067	14.89	.037
Hazard (covariate)	1	6.39	.011	1.24	.266
Decision	1	--	--	18.94	<.001
2-way interactions					
Probability x Directionality	3	25.65	<.001	3.10	.376
Probability x Trial	21	77.80	<.001	20.34	.499
Directionality x Trial	7	13.79	.055	14.29	.046
Directionality x Decision	**1**	--	--	**12.03**	**<.001**
Probability x Decision	3	--	--	44.75	<.001
3-way interactions					
Probability x Directionality x Trial	21	31.48	.066	67.63	<.001
Probability x Directionality x Decision	3	--	--	11.93	.008
Probability x Decision x Trial	21	--	--	23.86	.300
Directionality x Decision x Trial	7	--	--	12.79	.077
4-way interaction					
Probability x Directionality x Decision x Trial	21	--	--	28.04	.139

Note: Trial refers to the repetition of the same prediction over the course of the experiment. Each participants received the same prediction in 8 trials organised in 8 blocks (64 decisions), hence here trial represents changes in decisions over time, while controlling for the prediction that was characterised by its probability (very low, low, high, very high) and its directionality (positive vs. negative). Values shown in bold correspond to hypothesised effect of directionality.

effect in interaction with decision. The participants were faster to shoot and slower to decide not to shoot based on positive probability predictions. Directionality also interacted with probability and decision in a first three-way interaction. This was possibly because the effect of directionality on response time for shooting decision was smaller for very high probability than for lower probabilities – and this was not the case for the Don't shoot decision (bottom right plot vs. bottom left plot of Figure 8, Panel B). There was also a second three-way interaction between directionality, probability and trial. As the participants gained experience, the difference between positive and negative directionality reduced over the trials for some probability levels but increased for other probability levels (see Figure 8, panel B).

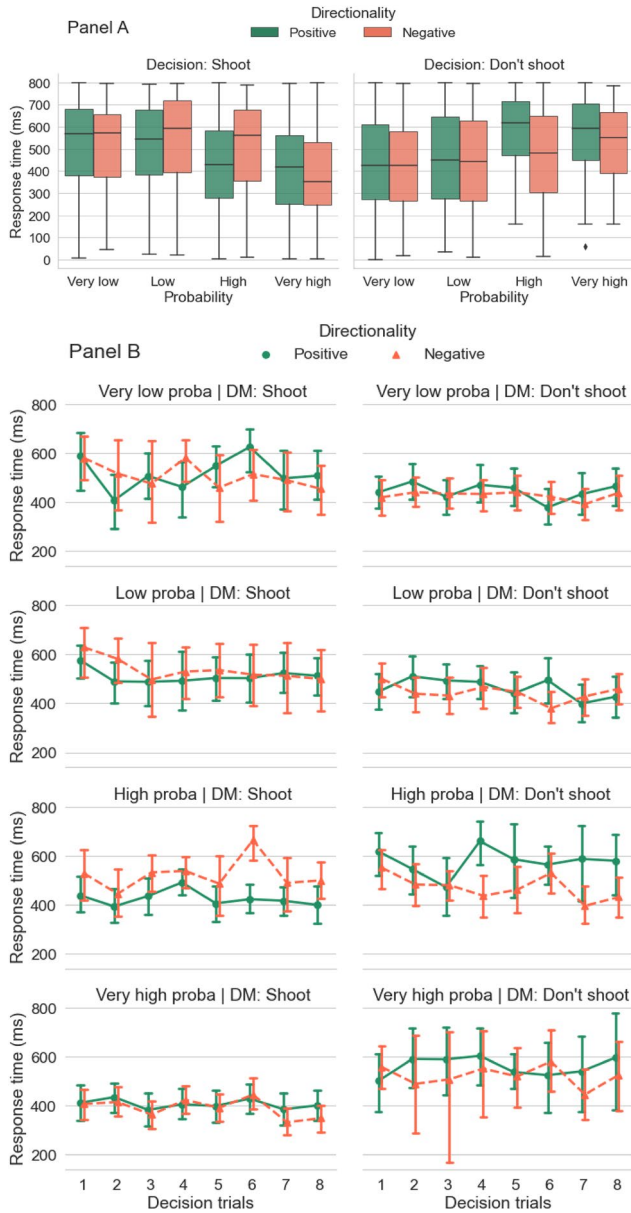


Figure 8. Effect of hazard prediction directionality and probability on decision reaction time per decision (panel A) and across trials (panel B; Experiment 3, $N = 50$).
Note: In panel A the box represents the interquartile range, the line the median, the error bars show the minimal and maximal values without outliers and the outliers are shown as diamonds. Panel B shows the means and 95% CI. Trials show participants' response time for the same experimental condition over trial that were set across blocks, hence reflecting changes over the whole course of the study.

Meta-analysis

Table 8 summarises the study design and the effect on directionality on decision (main and 2-way interaction effects) in Experiment 1–3 and in the pilot study of Experiment 2 when analysed in the GEE with other independent variables and hazard as a covariate. As shown in Table 8, the main effect of directionality was inconsistent and statistically significant in two of four studies. To appraise the overall effect of directionality, we conducted a meta-analysis of the effect across the four studies.

To meta-analyse the overall effect of directionality across the four experiments, we used a paired sampled contingency test on the overall data ($N = 316$) which added up to 20,364 decision trials and 18,970 decisions made (1,394 no decision were excluded). We tested the effect of directionality on decision by focusing on the proportion of shooting decisions in the negative and positive conditions using the program JAMOVI, version 2.6.44 (esci package)

The meta-analysis showed a main effect of directionality on shooting decision as depicted in Figure 9, $\ln(OR) = 0.28$, $p < .001$. Overall, positive directionality predictions led to 59% shooting decisions, whereas the negative ones led to 52% of shooting decisions. The analysis showed a statistically significant effect of directionality in each study and overall, with the largest effect size in Experiment 3, where all the participants received ambiguous information and did not get feedback on their decision. More details about the analysis and results are available in SM section J.

Discussion

In past research, the effect of directionality on decision-making was tested in a design that may have maximised its effect. Participants made a single decision based on a prediction, without having much knowledge about the decision situation and without receiving feedback on the quality of their decision (Collins et al., 2024; Honda & Yamagishi, 2006; Juanchich et al., 2020; Teigen & Brun, 1999). In those studies, the lack of decision-relevant information may have inflated the effect of directionality since the verbal prediction stood out as the only relevant information available. Furthermore, without receiving feedback on decisions made, participants were not able to learn whether it was useful to use directionality and might have relied on it more. Our main research question was therefore whether directionality would still matter in a situation where recipients have some relevant information about the decision at hand, and get feedback on decision quality, while directionality was randomly allocated. A critical perspective on findings in single vignette studies relative to more experiential paradigms suggests that more realistic methods might elicit smaller, or even opposite effects (Hertwig & Erev, 2009; Lejarraga & Hertwig, 2021).

Table 8. Summary of study characteristics across experiments and nature of the effects identified (* shows $p < .05$ and ns $p > .05$) according to the GEE previously reported, including all the experimental factors and hazard as a covariate.

		Experiments			
	Description	1	2's Pilot	2	3
Study characteristics	*N*	87	69	110	50
	Trials	5708	4416	7040	3200
	Visual information	Normal	Normal vs. Ambiguous	Normal vs. Ambiguous	Ambiguous
	Feedback	Yes	Yes	Yes	No
Effects on decision (in GEE)					
Factors	Directionality	*	ns	ns	*
	Probability	*	*	*	*
	Trials	*	*	ns	ns
	Ambiguity	--	ns	ns	--
	Directionality x Probability	ns	ns	*	*
	Directionality x Trials	ns	ns	ns	ns
	Directionality x Ambiguity	--	ns	*	--

Note: Directionality (positive vs. negative), Probability (Very low, low, high, very high). Trials (8 trials spread over8 blocks).

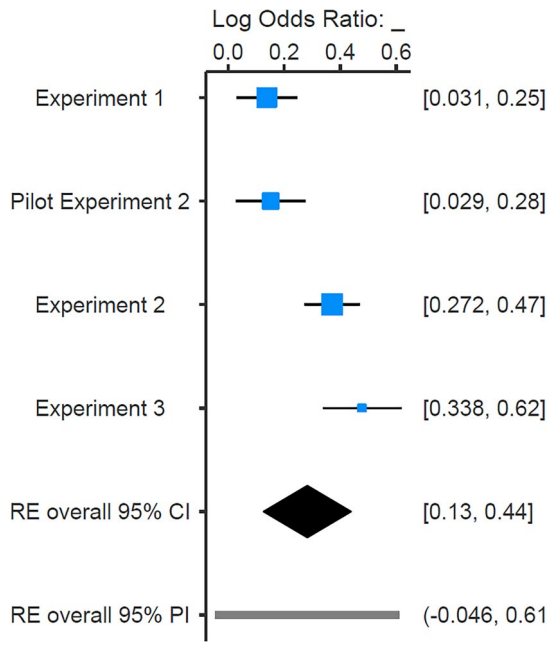


Figure 9. Meta-analytical effect of directionality with overall shooting and non-shooting decisions for positive and negative predictions across studies.

Here we addressed this possibility by testing whether directionality still impacted decision when participants (i) had some information about the decision situation and (ii) could experience the outcome of their decision in a series of trials, while (iii) directionality was manipulated independently from other contextual factors. We tested the effect of directionality in predictions ranging from very low to very high probabilities in a game-like shooting experiment, where participants had to shoot suspects holding guns and not shoot suspects holding inoffensive items (e.g., a can or wallet).

Our studies extend past work on the effect of directionality on decision in three ways. First, we found that the effect of directionality on decision-making is robust. We found that the effect is sustained over time in a paradigm where participants had some *knowledge* of the decision situation. Second, we found that knowledge might moderate the effect of directionality. Finally, the robustness of the effect and the moderation of information inform the processes underpinning the effect.

The effect of directionality is robust

We put the effect of directionality to a more stringent test than in the past by assessing its effect in a situation where participants had some knowledge, and while that seemed to reduce the effect (when comparing Experiment 1 to Experiment 3 where information was ambiguous) the effect of directionality remained statistically significant. This complements findings from past studies showing an effect of directionality on decisions where participants could not experience the probability of the event and were not informed about the quality of their decision. (Did they win the gamble? Was Marianne actually cured?; Collins et al., 2024; Honda & Yamagishi, 2006; Juanchich et al., 2020; Teigen & Brun, 1999).

In two of the three studies, the effect of directionality was qualified by an interaction with probability magnitude showing that the effect of directionality varied across the verbal probability pairs we used. The very low to high probability pairs showed the expected effect but the pair conveying a very high probability did not consistently show a decrease rate of shooting decision based on negative vs. positive directionality. This could be because the negative directionality was not sufficient to offset the very high probability that the suspect would have a gun, in a situation where the worst penalty was for a false negative (failing to shoot). A further – possibly more likely – possibility is that the effect of directionality did not replicate for the very high probability condition because the average probability conveyed by the negative directionality term was higher than that of the positive one – which might have increase shooting decision in that condition, countering the effect of the negative directionality. The difficulty to find a negative term conveying a high probability supports the existence of a link between directionality and probability conveyed (Budescu et al., 2003; Juanchich et al., 2013). However, this link

does not mean that positive verbal probabilities reflect greater probabilities in general, or that the probability conveyed explained the effect of directionality. Both positive and negative ones can be found across the probability spectrum for very low to moderately high probabilities (Harris et al., 2024; Juanchich et al., 2010, 2019). Importantly, data from the Pilot study of Experiment 2 and from Experiment 3 also showed that the effects of directionality (main and interaction) were robust to participants' interpretation of the verbal probabilities. Hence, the effect of directionality observed occurred beyond the probability conveyed.

Testing the moderating role of information provision

Moderation by knowledge

Our results evidence that the knowledge of the decision-maker about a decision situation impacts their decisions and hence may restrict the influence of directionality on their decisions. When the decision relevant information provided was more ambiguous, participants relied more on directionality. This is consistent with findings showing that when people believe an option might not be suitable – such as when offered a vaccine that may have some dangerous side effects – the positive directionality causes a backlash and reduces vaccination intention (Juanchich et al., 2023). Our results are also consistent with results from the attribute framing literature (e.g., a glass is 20% full vs. 80% empty) showing that people who were more knowledgeable were less sensitive to variation in information presentation (Leong et al., 2017; Shan et al., 2020).

Moderation by trials

The moderating effect of the participants' decision knowledge on directionality could have become stronger through the trials (8 trials per condition set in 8 blocks, hence reflecting learning over the course of the study). The participants could have been better able to spot whether the suspect held an inoffensive item or not, and that could have reduced the effect of directionality over the decision trials, but that was not the case (the Directionality x Trial interaction was not statistically significant in the three experiments). Instead, it seemed that predictions were similar to credence goods – goods whose benefits are difficult to evaluate (Darby & Karni, 1973). Recipients did not seem able to evaluate the benefits/drawbacks of their reliance on the directionality of a prediction – and hence the effect of directionality did not fade over time, despite it was merely randomly chosen and was not informative at all. However, note that trials were involved in more complex interaction effects with directionality and probability (e.g., Experiment 2). The pattern was complex and not consistent across experiments (it was not found in Experiment 1 and Experiment 3). Further research – powered to detect three-way interactions – could evaluate the conditions in which the effect of directionality might change over time.

Withdrawing feedback did not seem to change participants' use of directionality either. Participants' decisions in experiments 2 (with feedback) and 3 (without feedback) were very similar (+12% shooting decision for positive vs. negative predictions in both when we consider the ambiguous trials). Withdrawing feedback could have increased the effect of directionality as participants were not able to assess its informativeness – they could have assumed it was useful. This suggests that the participants' experience of their decision quality, *via* the provision of feedback, did not change the effect of directionality. However, because those conditions (with vs. without feedback) were conducted across experiments – with different samples and procedures (online procedure with a general sample vs. lab study with a student sample), we cannot draw a strong conclusion about the comparison. Future research could confirm the role of feedback on the effect of directionality on decision-making.

Theoretical implications

From a theoretical perspective, our results speak indirectly to the factors that might explain the effect of directionality. Our results indicate that the effect might occur even when pragmatic inferences are not supported by participants' experience. According to different inference accounts, directionality has an effect because it implicitly communicates information that the recipient infers. This inference can be about what recipients *should* do (Hilton, 2008; Teigen & Brun, 1995, 1999), how negative the event is going to be (Juanchich et al., in revision), the past level of certainty of the speaker (Honda & Yamagishi, 2017; Juanchich et al., 2010), the probability of alternative threats (Windschitl et al., 2017), or even the skewness of the probability distribution of the outcome (Budescu et al., 2003). However, the effect of directionality did not merely fade over time, when participants could have noticed that directionality was not providing relevant advice, nor informing them about the value of different options (shoot/don't shoot), about the severity of the outcome or the probability of the event.

The results are more consistent with an attention driven account of the effect of directionality that would assume that the effect of directionality on attention might be sufficient to explain the effect (without requiring inferences). Hence, the effect of directionality could be labelled as an attention bias leading to a departure from formal logic (Keren & Teigen, 2004). The fact that specific inferences might not be needed for the effect to occur is consistent with results from the numerical attribute framing literature. Recent findings showed that such framing effects occurred even when the choice of framing was not chosen by the speaker, and hence was not conditional on reflecting a personal preference (Harris et al., 2021). The effect also occurred when the speaker was perceived as not trustworthy (e.g., competitive motives) but it was smaller and less consistent

(Ghasemi et al., 2025). Together with the literature on attribute framing, our work shows that a specific inference might not be needed for the effect of directionality to occur but also that inferences have an additive effect. Our results do not support the possibility that inferences drive the effect of directionality, but they do not rule it out either, since in our study design and materials, the directionality was "un-naturally" random and not chosen by a speaker to reflect their preference and beliefs. Past research showed that speakers given a choice of directionality, did not merely choose randomly – and were for instance influenced by a reference point (Honda & Yamagishi, 2017; Juanchich et al., 2010).

The time constraints set in our study design provide important context for interpreting the findings. In our studies we limited the time people had to read the gun prediction (3 sec) and to make their decision (≤ 1 sec). This design feature might have limited people's ability to learn about the (lack of) informational value of directionality. The time limit might have limited people's analytical abilities to process information (De Neys & Pennycook, 2019; Horstmann et al., 2010) – and hence to learn through the trials. The time limit may have also limited participants' ability to draw inferences from directionality. Drawing inference form quantifiers require some cognitive effort (Bott & Noveck, 2004; Sperber & Wilson, 1995), which require time, whereas the emotion associated with the focus on the outcome occurrence vs., non-occurrence is considered more automatic (Gosling & Moutier, Gosling and Moutier 2019; Holford et al., 2022). Overall, our results suggest that inferences might not be necessary for the effect to occur, hence supporting a faster pace effect, but they do not rule out the possibility that inferences would play a role, given the time.

Further research should identify which components of the decision-making process are shaped by the directionality and probability of the prediction. Drift diffusion modelling is well-suited to distinguish between several possibilities because it jointly models choices and response times as evidence of unfolding evidence-accumulation process (Pleskac et al., 2018). One possibility is that predictions create a pre-stimulus response bias, shifting the starting point of evidence accumulation closer to either the shoot or the do-not-shoot boundary before the visual stimulus is processed. A second possibility is that predictions affect the drift rate, changing how quickly visual evidence accumulates towards one response once the suspect appears. A third possibility is that predictions alter threshold separation, changing how much evidence participants require before committing to a shooting or non-shooting decision. This approach has been applied to the classic first-person shooter task - similar to our task, but without verbal predictions (Pleskac et al., 2018). Race effects in shooting decisions were better explained by differences in evidence accumulation than by a consistent initial bias to shoot: evidence accumulated more rapidly towards the shoot response for Black suspects than White ones (Pleskac et al., 2018).

Limitations

While we draw from the literature that compares decisions from experience (vs. description), our methodology departs from classic methodology used in decisions from experience. In our studies, we implemented information provision using an image, and participants received feedback, so that they could experience the consequences of their decisions. Based on the description-experience gap literature we expected results in a more experiential setting to differ from text description, but we did not test that directly. In our studies, we did not compare a text condition to an experience condition. Instead, we used experience as a more stringent test of the role of directionality. Future research could follow more closely the classical description vs. experience methodology (Hertwig & Erev, 2009) to test the role of experience vs. description.

In our studies, the method was similar to a bandit task (Robbins, 1952; Shimomura & Morita, 2025), since we gamified decision-making, with points earned or lost depending on the consequence of their decision. Participants' decision (shoot/don't shoot) could be seen as the selection of a gamble with uncertain consequence as in a bandit task. The influence of the task incentive structure is therefore important to consider as well. The points structure meant that it was more consequential to forget to shoot a suspect holding a gun, than to shoot a non-armed suspect (−40 vs. −20) and participants earned more points by correctly shooting an armed suspect (+10) than by not shooting a non-armed suspect (+5). This might have facilitated shooting decision and hindered non-shooting decision – hence possibly further limiting the effect of directionality. A more equal level of reward and rewards for correct and incorrect decisions might facilitate the effect of directionality on decision.

Applied implications

From an applied perspective, our results highlight the powerful effect verbal framing can have in situations where people have little information and little feedback. One example of such a situation of uncertainty, where framing risk might have been instrumental, was the onset of the COVID-19 pandemic in 2020. Consistently, recent results show that the directionality used to describe vaccines' risk of adverse side effects mattered in vaccination intention (together with trust; Juanchich et al., 2023). The evidence, however, suggested that the effect changed over time, with framing effects reducing in magnitude when people learned about the vaccine and had more experience with it. Our results may also inform risk and uncertainty communication guidelines, where the present format of communication could be considered suboptimal. For example, in climate change communication (IPCC, 2021), the present guidelines are to use negative verbal probabilities to inform people about low likelihood – but

potentially high stake – climate events (e.g., "It is unlikely that the flood will be higher than the flood gate"). Given the situation where inaction can be costly, these guidelines are therefore conducive to risk-taking, whereas the use of a positive alternative may foster more cautious decisions and more trust in the long term (e.g., "There is a chance that the flood will be higher than the flood gate"; Juanchich et al., 2020). Further research should evaluate the impact of verbal directionality on real-life decisions and, in particular, the interplay between directionality, prior belief and trust in high-stakes contexts with high uncertainty such as in policing and climate change.

Conclusion

We find corroborating evidence of the effect of verbal probability directionality on decision-making. We refined our understanding of the effect by showing that it occurred even when participants had some knowledge about the situation and that directionality was completely independent of the probability of the event, an awareness increased by the provision of feedback on decision quality. The effect was robust, but smaller when participants had more knowledge about the situation (which is more akin to real life), than when the situation was ambiguous. Altogether, our findings suggest that the effect might be smaller in real life than one could expect based on vignette research, where participants are uninformed and do not get feedback.

Author contributions

CRediT: **Marie Juanchich**: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing; **Amélie Gourdon-Kanhukamwe**: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – review & editing; **Anine Riege**: Data curation, Methodology, Writing – review & editing; **Elena Broggin**: Resources, Software, Writing – review & editing; **Miroslav Sirota**: Conceptualization, Methodology, Writing – review & editing.

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