The effect of context on decisions: Decision by sampling based on probabilistic beliefs

Hidehito Honda (hitohonda.02@gmail.com)
Faculty of Psychology, Otemon Gakuin University
2-1-15, Nishiai, Ibaraki-shi, Osaka, 567-8502, Japan

Toshihiko Matsuka (matsuka@chiba-u.jp)
Department of Cognitive and Information Science, Chiba University
1-33, Yayoi-cho, Inage-ku, Chiba-shi, Chiba, 263-8522, Japan

Kazuhiro Ueda (ueda@gregorio.c.u-tokyo.ac.jp)
Graduate School of Arts and Sciences, The University of Tokyo
3-8-1, Komaba, Meguro-ku, Tokyo, 153-8902, Japan

Abstract

Previous studies have shown that people's decisions are affected by context in various ways, even when they are provided with the same or analogous information. In the present study, we analyzed decisions based on verbally expressed probabilistic phrases (verbal probabilities) and examined how contextual factors affected such decisions. In particular, we focused on the difference in contexts that produced different probabilistic beliefs with regards to uncertain events. We hypothesized that such contextual effects could be explained in terms of a Decision by Sampling (DbS) account (Stewart et al., 2006). In order to examine our hypothesis, we proposed a modified version of DbS, *Decision by Belief Sampling* (DbBS), and conducted behavioral experiment about decision making. In this experiment, we set different contexts that we expected to produce different probabilistic beliefs regarding uncertain events for decision-makers and examined how such differences affected decision making. Results showed that decisions were significantly affected by the variation in contexts, and DbBS well explained such effects.

Keywords: verbal probabilities; Decision by Sampling (DbS); directionality of verbal probabilities; contextual effects in decision making

Introduction

In research on decision making, many researchers have shown that people are affected by various contextual effects. For example, people tend to exhibit different risk attitudes depending on the gain or loss domains of the situation in which they make their decision (Kahneman & Tversky, 1979), or make different decisions with regards to logically equivalent but differently described problems (Tversky & Kahneman, 1982). In the present study, we shall discuss the effect of context on decisions based on probabilistic information. In particular, we shall focus on decisions based on verbally conveyed probabilistic information.

Probabilistic information can be conveyed in two main ways: the numerical way or the verbal way. Probabilities are usually represented by numbers such as "50%." However, in daily life, people often use verbal expressions such as "it is likely" or "it is uncertain." We call these kinds of expressions *verbal probabilities*. Verbal probabilities are known to be categorized into positive or negative expressions in terms of *directionality* (Teigen & Brun, 1999). The directionality refers to a communicative function that focuses listeners' attention toward the occurrence or non-occurrence of an uncertain event. For example, when conveying a low probability, a person may say, "There is a small hope," or, "It is unlikely." Although these two expressions convey a similar degree of probability (i.e. a low probability), their nuances are quite different. The former positive expression causes listeners to focus on event occurrence. In contrast, the latter negative expression causes listeners to focus on event non-occurrence. Previous studies showed that this directionality affects decisions. Teigen and Brun (1999) and Honda, Matsuka, and Ueda (2017) showed that even when positive expressions (e.g., there is some possibility) and negative expressions (e.g., it is quite uncertain) were interpreted as conveying similar probabilistic information about the effectiveness of a treatment (e.g., the two expressions were interpreted as conveying around "30%"), participants were still more likely to recommend the treatment to a friend if they had been presented with a positive expression than if they had been presented with a negative expression. Thus, the directionality generated a "framing" effect (Teigen & Brun, 2003).

How does the framing effect caused by the directionality occur? Previous findings (e.g., Honda et al., 2017; Honda & Yamagishi, 2017) indicated that listeners' inferences about speaker's probabilistic belief were related to the effect of directionality. When presented with a positive expression such as "There is some possibility," listeners tended to infer that the speaker had a low probabilistic belief for the effectiveness of a treatment. For example, listeners tended to infer that the speaker believed that the probability of effectiveness of the treatment was low (e.g., around 10%). In contrast, when presented with a negative expression such as, "It is quite uncertain," people tended to infer that the speaker had a high probabilistic belief such as "90%." This listeners' inference can become the reference region, and the reference region affects decision making. For example, when the two expressions, "There is some possibility," and, "It is quite uncertain," are interpreted as conveying a similar probability (30%), the meaning of the 30% may differ depending on the reference region: In referring to the low reference regions

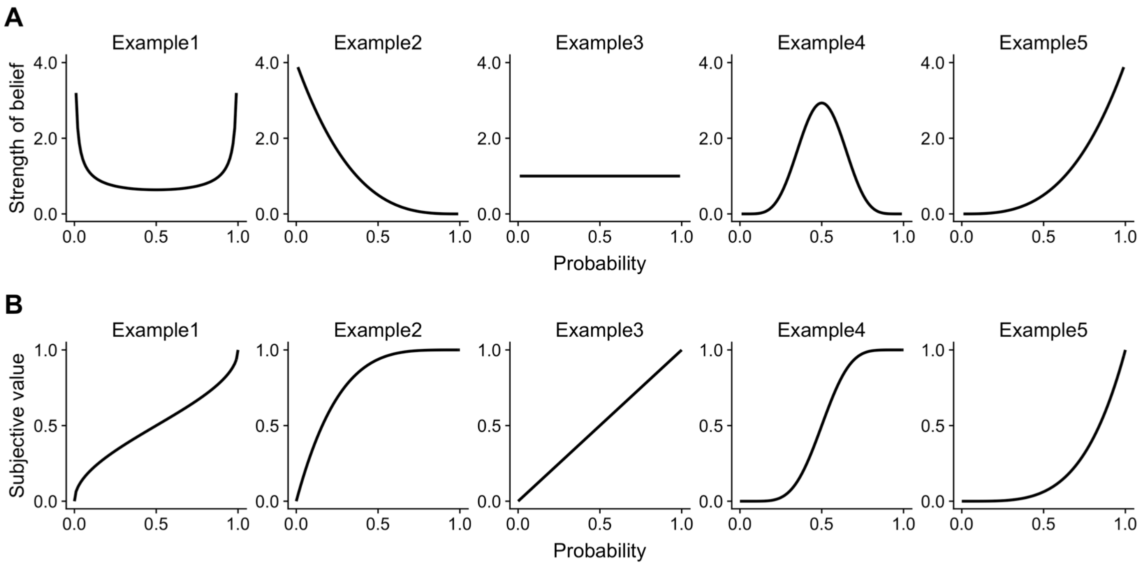

Figure 1. Summaries of the DbBS. (A) Probabilistic belief regarding an uncertain event (probability density function of beta distribution). (B) Subjective target value (cumulative distribution function of beta distribution).

around 10%, people may regard 30% as a "good" probability since 30% is better than the reference region. In contrast, in referring to the high reference region around 90%, 30% may be regarded as a "bad" probability since 30% is worse than the reference region. That is, directionality implicitly indicates a speaker's probabilistic belief and a listener will refer to that belief in making decisions. This argument was based on the *information leakage* account of the framing effect (McKenzie & Nelson, 2003; Sher & McKenzie, 2006, 2008): Logically equivalent, but different frames "leak" information that is relevant to decision making, and people refer to such information in making decisions.

Honda et al. (2017) proposed the *Decision by Belief Sampling* model (hereafter, *DbBS*) in order to model this decision process. This model was essentially based on the *Decision by Sampling* model (Stewart, 2009; Stewart, Chater, & Brown, 2006, hereafter, *DbS*). In DbS, subjective attribute values are constructed by a series of binary, ordinal comparisons to a sample of attribute values that reflect the immediate decision context and real-world distribution. The subjective value for a target is calculated as follows:

$$r = \frac{R - 1}{N - 1} \quad (1)$$

where r ($0 \leq r \leq 1$) denotes the subjective value for a target, and R denotes the rank of the target within the decision sample of N items. In this model, if the decision sample differs, r varies in the relationship between R and the decision sample. Imagine the subjective value for \$40. When decision samples are \$10, \$20, \$30, \$30, and \$50, the subjective value is r = (5-1) / (6-1) = 0.8. In contrast, in decision samples of \$20, \$30, \$70, \$80, and \$90, the subjective value is r = (3-1) / (6-1) = 0.4. That is, even when the target has the same attribute value, the subjective value varies depending on the decision samples. Previous studies indicated that by controlling decision samples, people's decision tendencies were changed (e.g., Alempaki et al., 2019; Noguchi & Stewart, 2018; Walasek & Stewart, 2015, 2019)

DbBS is the model for the decision making context wherein a person has to make a decision based on probabilistic information (e.g., whether a person recommends the treatment to her/his friend based on probabilistic information, "There is some possibility that the treatment is effective"). Figure 1 summarizes DbBS. There are two basic assumptions in DbBS. First, the decision-maker (DM) refers to her/his probabilistic belief of an event occurrence and the decision sample is then constructed according to that belief. Figure 1 (A) shows five examples of probabilistic beliefs. Example 1 represents the belief that an event will occur or not with high uncertainty and without skewness. Similarly, in Examples 2 and 5, the DM has the belief that the event will occur with low or high probability with relatively low uncertainty and positive or negative skewness. Example 4 represents the belief that an event has approximately a 50% chance of occurrence with low uncertainty and without skewness. Example 3 represents the belief in which the DM has no idea about the probability of an event. In DbBS, these beliefs are represented by probability density function (PDF) of beta distribution. Second, we assume that a subjective value for a target probability is constructed from the comparison between the target probability and the probabilistic belief. The subjective value of a target has a direct connection to the cumulative distribution function (CDF) of the beta distribution. This is because the subjective value of a target is determined by its relative rank (cumulative frequency) within the sampled events (Stewart et al., 2006). Figure 1 (B) shows the subjective values. As is apparent, the subjective values depend on the probabilistic beliefs, and so the subjective values can differ even for the same target probability.

Honda et al. (2017) showed that DbBS can well explain decisions based on verbal probabilities. Specifically, they showed that participants tended to have low (or high) probabilistic beliefs when presented with positive (negative) expressions and that this difference could well explain the different decisions depending on the presented directionality.

The contextual effect: How does the shift of probabilistic beliefs affect decisions?

DbBS hypothesizes that when a DM has a different probabilistic belief about an event (i.e., a different decision sample is constructed), that DM will exhibit different decisions even for the same probabilistic information. Thus, by controlling DMs' probabilistic beliefs, decisions based on probabilistic information can vary.

In their study, Honda et al. (2017) only used the cover story of decision about whether people would recommend treatment of migraine to a friend. This context may have been rather vague in terms of probability of success of the treatment, and probabilistic belief about the cover story was not controlled. In the present study, we controlled DM's probabilistic beliefs by decision context and examined its effect on decision making. Consider the probability of success with regards to the operation for appendicitis or a serious disease. People may believe that the probability of success is high (or low) for appendicitis (or a serious disease). DbBS predicts that the evaluation for a "50% success rate," differs: Since the DM may refer to a decision sample of low probability, the evaluation of the "50% success rate for the operation for a serious disease," may be higher than that for appendicitis (see Examples 2 and 4 in Figure 4). Thus, even in response to the same probabilistic information, a DM may recommend an operation for a serious disease more than they would for appendicitis.

This hypothesis may be true for decisions based on verbal probabilities. DbBS predicts that people recommend operation for serious diseases more than they do for appendicitis, even when presented with the same expression such as, "There is some possibility," or, "It is unlikely."

In the following sections, we shall report the behavioral experiment and analyses based on DbBS.

Behavioral experiment

Method

Participants One hundred and twenty Japanese people (n_{female} = 59, n_{male} = 61; M_{age} = 45.33, SD_{age} = 8.26) participated in this experiment. They were randomly allocated into either the Appendicitis group or the Serious Disease group.

Tasks, materials, and procedure We conducted three tasks: a decision task, a numerical translation task for verbal probabilities, and a manipulation check for the probabilistic belief of operation. The decision task was based on Study 1 conducted by Teigen and Brun (1999) and the behavioral experiment carried out by Honda et al. (2017) with just a minor revision. The cover story in the Appendicitis group was as follows: "Your friend X is going to undergo an operation for appendicitis in hospital A. You relay this to another friend Y, who is knowledgeable about hospital A. Then, your friend Y tells you the probability of success in hospital A." Participants were presented with a verbal probability and asked to rate, using a 20 point scale, how much they would recommend their friend X to undergo the operation in hospital A (1; "I do not want to recommend it at all"- 20: "I want to recommend it very much." The cover story in the serious disease group was basically the same as the story in the Appendicitis group, but "appendicitis," was replaced with "the serious disease of CDJ."

In the numerical translation task, participants answered what percentage they thought the expressions presented in the decision task represented. In the manipulation check for probabilistic belief in the success of the operation, participants answered the following question by number: "Generally speaking, in percentage terms, what is the success rate of the operation for appendicitis (or a serious disease)."

We used 8 positive and 8 negative verbal probabilities (see Table 1). These expressions were based on Honda et al. (2017). We conducted the three tasks on the Internet. Participants responded to the three tasks in the following order: the decision task, the numerical translation, and then the manipulation check. In the decision task and the numerical translation task, each expression was presented individually. The

Table 1. Verbal probabilities used in the experiment.

	Verbal probabilities		
	Positive phrases		**Negative phrases**
P1	It is almost certain that *	N1	There are minor concerns that *
P2	There is a good chance that *	N2	It is quite doubtful that *
P3	It is possible that *	N3	It is not certain that *
P4	It is likely that *	N4	It is uncertain whether *
P5	There is a small possibility that *	N5	It is quite unlikely that *
P6	There is some possibility that *	N6	There is little hope that *
P7	There is a slight hope that *	N7	It is unlikely that *
P8	There is a tiny hope that *	N8	It is almost impossible that *

*(the operation will be a success.)

presentation order of the 16 verbal probabilities was randomized for each participant and task.

Results and discussion

Twelve participants both in the Appendicitis group and the Serious disease group answered exactly the same numbers for the 16 verbal probabilities in the numerical translation task. We removed these participants in the following analyses (i.e., in total, we analyzed the data for 96 participants).

In the following analyses, we rescaled the 20-point scale of decision rating (or 0-100 number of numerical translation and explicit probabilistic belief) to a 0-1 scale.

Manipulation check First, we analyzed the data concerning the manipulation check. We found that the probability of success for an appendicitis operation was believed to be significantly higher than that for a serious disease ($M_{Appendicitis}$ = 0.889, $M_{Serious\ disease}$ = 0.363, $t[94] = 14.38$, $p < .0001$, d = 2.94). Thus, as we expected, the probability of success for an appendicitis operation was perceived to be higher than that for a serious disease.

Analyses with an aggregated level Next, we analyzed the data with an aggregated level in order to examine the general trends. Figure 2 shows the relationship between mean numerical translations and decision ratings for the 8 positive and 8 negative expressions in each group. As is apparent, the decision ratings in the Serious disease group tended to be higher than those in the Appendicitis group.

For the statistical examination of our hypothesis (i.e., even for the same probabilistic information, the participants in the Serious disease group would recommend the operation more than those in the Appendicitis group would), we conducted the following analysis. We calculated mean values (i.e., decision rating and numerical translation) for 8 positive and 8 negative expressions for each participant. That is, 4 values (i.e., mean decision ratings and numerical translations for positive and negative phrases) were calculated for each participant. We regarded these values as decision ratings and numerical translations by each participant for positive and negative expressions. By comparing these values across the 2 groups, we examined the present hypothesis.

We found that decision ratings were significantly higher in the Serious disease group than they were in the Appendicitis group for both positive and negative verbal probabilities (Positive phrases, $M_{Appendicitis}$ = 30.91, $M_{Serious\ disease}$ = 46.24, $t[94] = 3.87$, $p = .0002$, $d = 0.790$: Negative phrases, $M_{Appendicitis}$ = 15.83, $M_{Serious\ disease}$ = 29.17, $t[94] = 3.22$, p = .002, $d = 0.657$), supporting our hypothesis.

Some researchers may point out that decision ratings could have differed between the two groups because the numerical translations for verbal probabilities differed. It is well known that numerical translations for verbal probabilities depend on context (e.g., Budescu & Wallsten, 1993; Weber & Hilton, 1990). From this perspective, the above results may be explained such that decision ratings in the Serious disease group were higher than those in the Appendicitis group because the numerical translations in the Serious disease group were higher than those in the Appendicitis group. However, this was not true. The numerical translations were very similar between the 2 groups (Positive phrases, $M_{Appendicitis}$ = 0.407, $M_{Serious\ disease}$ = 0.382, $t[94]$ = 1,02, p = .312, d = 0.21: Negative phrases, $M_{Appendicitis}$ = 0.256, $M_{Serious\ disease}$ = 0.247, $t[94]$ = 0.399, p = .691, d = 0.08).

Model-based analyses Next, we analyzed the individual data using DbBS. In using DbBS, we assumed that the subjective value of probability conveyed by a phrase corresponded to the CDF in the beta distribution. Therefore, we estimated two parameters (α and β) of the beta distribution whose CDF best explained the decision ratings. The two parameters were estimated using a grid search in the range of 0.1 and 10, with increments of 0.1. That is, we estimated the parameter using 10000 sets. We calculated root mean square deviations (RMSD) between the observed ratings and the model predictions, and regarded the parameter set showing the lowest RMSD as the best model. We searched for the best parameter sets for positive and negative phrases, respectively, for each participant.

Figure 3 shows the models that were the best fit for each participant. The left (or right) panel shows the strength of the belief (or the subjective value). Figure 4 shows the mean of the estimated belief and the subjective value (i.e., PDF and CDF of beta distribution). As is shown, the estimated belief and the subjective value differed depending on the disease type and the presented directionality of verbal probabilities. Our specific prediction was that these results would derive from the difference in decision sample: 1) people would refer to a higher decision sample of probability for appendicitis than for a serious disease, and 2) people would refer to a higher decision sample of probability when presented with negative phrases than when presented with positive ones. For this hypothesis, we examined the mean of distribution of the estimated beliefs. Figure 5 shows the distributions of the mean of the estimated probabilistic beliefs (i.e., the mean of the PDF of beta distribution). We conducted 2 (the type of disease) by 2 (the directionality of verbal probabilities) ANOVA on the mean of the estimated probabilistic beliefs. The significant main effects of type of disease (F[1,

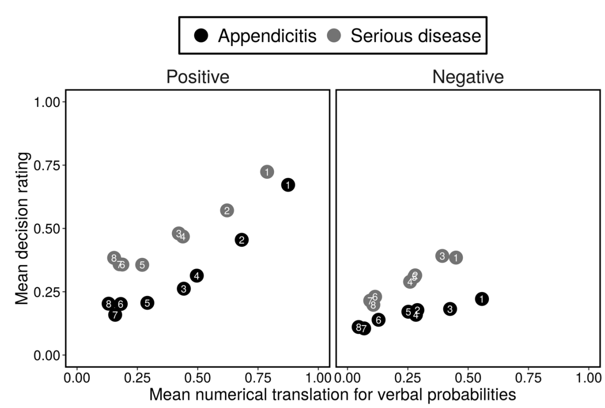

Figure 2. The relationship between numerical translations and decision ratings. Each number corresponds to that in Table 1.

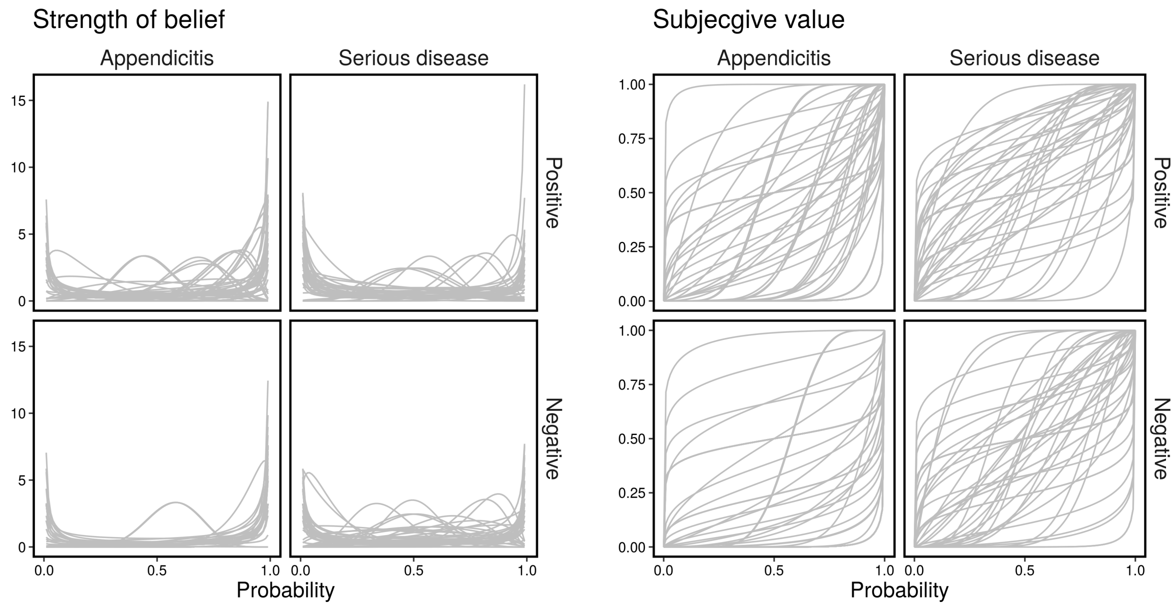

Figure 3. The best models for individual data.

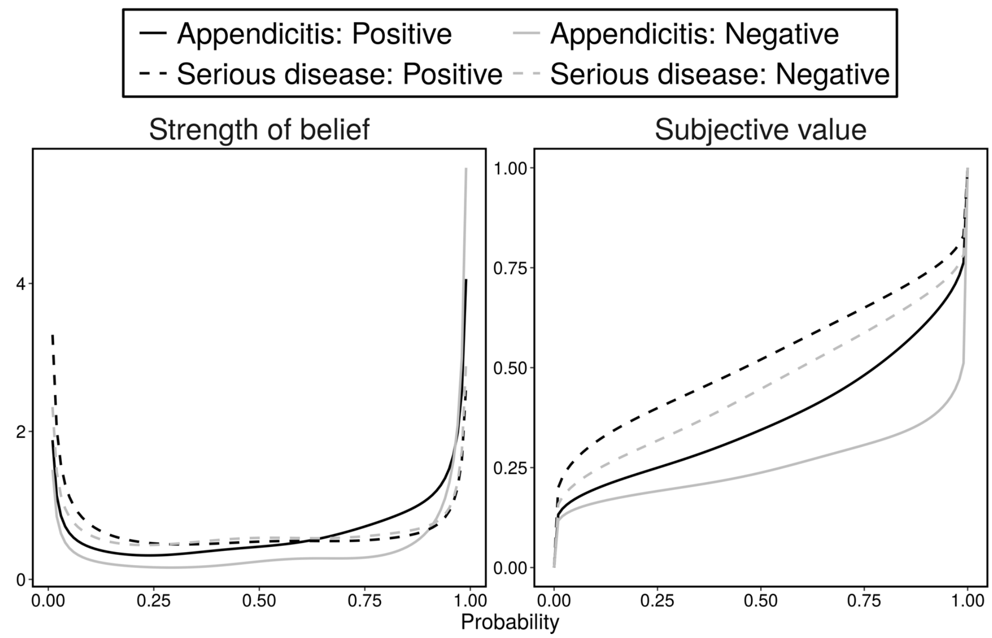

Figure 4. Mean of estimated decision sample and subjective value (i.e., PDF and CDF of beta distribution).

94] = 27.17, $p < .00001$, partial $\eta^2 = 0.514$, $M_{Appendicitis} = 0.718$, $M_{Serious\ disease} = 0.520$) and the directionality ($F[1, 94] = 31.08$, $p < .00001$, partial $\eta^2 = 0.248$, $M_{Positive} = 0.564$, $M_{Negative} = 0.675$) were observed, but their interaction was not significant ($F[1, 94] = 1.97$, $p = .16$, partial $\eta^2 = 0.020$). These results corroborated our specific prediction.

Taken together, our model-based analyses generally supported our hypotheses. Decisions varied depending on the context in which they were made. In particular, people's probabilistic beliefs about the success of an operation were highly related to decisions, and our model-based analyses indicated that participants referred to different decision samples and such difference was well explained in terms of participants' probabilistic beliefs.

General discussion

In the present study, we examined contextual effects on decisions based on verbal probabilities. In particular, we examined how probabilistic beliefs about uncertain events affected people's decisions. The DbBS model hypothesized that DMs would refer to a different decision sample depending on

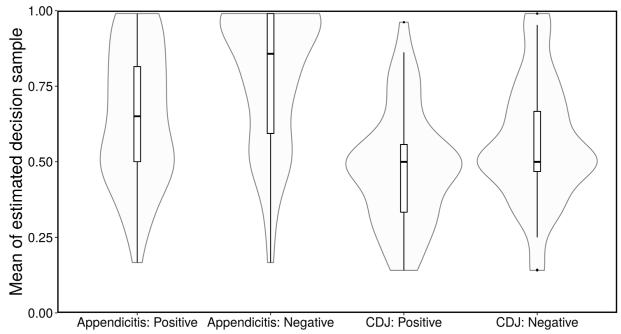

Figure 5. Distributions of mean of estimated decision samples (i.e., mean of PDF of beta distribution).

her/his probabilistic belief and such difference critically alters decision outcomes. The results of our experimental study and model-based analyses corroborated our hypotheses.

We believe that the present findings made the following two contributions to the research about decision making. First, we identified contextual factors that had effects on decisions based on verbal probabilities. Previous studies have shown that numerical translations of verbal probabilities vary depending on contexts (e.g., Budescu & Wallsten, 1993; Weber & Hilton, 1991). However, relatively few studies have examined contextual factors that affect decisions. In particular, few studies have examined how contextual factors change decisions based on even the same verbal probabilities. We showed that decisions based on the same verbal probabilities significantly shifted depending on the difference in context that produced the difference in probabilistic beliefs (e.g., see Figure 2), and that the DbBS model clearly predicted such shifts. Second, and more importantly, the present findings provided evidence that decision processes based on verbal probabilities are explained in terms of the DbS processes. We proposed a modified version of the DbS, which we called the DbBS, and showed that the effects of directionality and context could be explained by the DbBS. Previous studies have shown that a wide range of decision phenomena can be explained by the DbS processes (Alempaki et al., 2019; Noguchi & Stewart, 2018; Stewart et al., 2006; Walasek & Stewart, 2015, 2019). Thus, we provided further evidence of decision-making processes that are consistent with the account of the DbS.

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