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Abstract

Investigating decision-making with two-alternative forced choice (2AFC) tasks may artificially constrain decisions, especially in the moral domain where we may want to express nuance. We aimed at examining whether paradigm constraints—i.e., binary (as in 2AFC tasks) versus continuous response mode—constrained early decision-making dynamics, as traceable in mouse movements. In the moral domain, long sentences are often used, and we therefore developed a new mouse-tracking design adapted to long-to-process stimuli, while also introducing mouse-tracking compatible continuous response scales. Two preregistered studies, with adapted (Study 1) and newly designed (Study 2) mouse-tracking paradigms tested how trajectories differed between response modes from an early stage onwards. Overall, findings provide evidence consistent with hypothesis, ruling out alternative explanations in terms of motor planning, hence questioning the prevalence of 2AFC tasks in decision-making research. Discussion further focuses on paradigmatic challenges addressed by the present research and basic contributions regarding the bidirectional influences between ongoing actions and decisions.

Keywords: decision-making, two-alternative forced choice, mouse-tracking, morality, situated social cognition

Introduction

Decision-making studies often rely on two-alternative forced choice (2AFC) tasks, a paradigm in which participants must choose between only two response options (Bogacz et al., 2006; Ratcliff & McKoon 2008; Smeding et al., 2016). A binary response mode may seem more appropriate to get a high correspondence between the operationalized binary construct and its (re)presentation in the task (Levine, 2001), considering the tendency of thinking in a dichotomous way (e.g., using words). Dichotomous thinking has indeed been proven to be useful in human cognition for categorizing information and reducing world complexity (Berlin, 1990). However, despite the apparent benefits of dichotomization, relying on binary rather than continuous representations could distort reality, therefore impacting judgments and decisions (Gonzalez et al., 2010; Kvam 2019; Master et al., 2012). For example, studies on emotion perception showed that categorical judgment modifies perception and mental representations, for them to become consistent with the proposed categories (Satpute et al., 2016). In addition to such perceptual constraints, the world is not always black and white, and we may prefer compromise when facing a difficult social choice (Evans et al., 2015; Cheng & González-Vallejo, 2018), given that in addition, we tend to avoid extreme options (so-called ‘compromise effect’; Neumann, 2016; Leong & Hensher, 2012). This should be particularly relevant in the realm of morality where, rather than a two-alternative forced choice, people may prefer a more nuanced position, for instance by responding on a continuum. Philosophers sometimes consider morality and moral judgments as being continuous, depending on which normative moral theory is used (Segev, 2021). Also, moral values were shown to be counterintuitively malleable and context-specific (Iliev et al., 2009). Decisions in general, and moral decisions, may thus be substantially influenced by the response mode context.

Context, paradigm constraints, and decision-making dynamics

The importance of context to understand cognitive processes has been widely studied and is a view endorsed by the situated (social) cognition approach (Smith & Semin, 2004), according to which cognition is action-oriented, embodied, and emerging from a dynamic process of interaction. For example, context effects such as framing of the decision (e.g., framing in terms of loss or gain) can substantially impact the final decision (Tversky & Kahneman, 1985). Also, the impact of response mode on decisions has been highlighted by Slovic (1995), as preference seems dependent on context and how it is presented, and how such preference can be expressed with the available response mode. Precisely, enhancing the compatibility between a response mode and a stimulus attribute can increase the weight of this attribute in the decision. In the case of moral decisions, Kahane (2015) emphasizes the importance of context with what he calls common-sense morality, an adaptive moral normative theory where the situation plays an important role. Similarly, Bartels and colleagues highlight the key role of situation features in determining and influencing moral choices and judgments (Bartels et al., 2015). Indeed, situational pressure is known to constrain and influence moral decision-making, as highlighted with the concept of Personal Ethical Threshold (Comer & Vega, 2008). For instance, individuals have been shown to be more vulnerable to situational pressure for issues of low moral intensity (i.e., those with few consequences for others) and will less likely abide by their moral standards. This is consistent with the flexibility of moral judgments in the case of everyday morality where considerations for outcomes gain weight relatively to universal and rigid moral principles (Leavitt et al., 2012), and the idea that moral decisions do not rely on a clear set of moral rules which is consistent across situations, leading them to be very sensitive to the context (Kahane & Shackel, 2010; Broeders et al., 2011). Among the many factors influencing moral decisions, the adopted empirical paradigm therefore represents a salient context that should be factored in when analyzing decision-making dynamics.

Consistent with the Embodied Choice framework (Lepora & Pezzulo, 2015), when decisions are expressed by actions, bidirectional influences between ongoing actions and decisions should be fully considered, as they may lead to nonlinearities and bifurcations in decisions (e.g., while moving the computer mouse to click on a response; see Figure 1). More particularly, some descriptive models of moral decision-making have specific assumptions on decision dynamics. The default-interventionist model (Evans, 2008) postulates that moral decisions result from an initial emotional response which is then overridden by a rational and deliberative thinking. For example, when assessing if violence can sometimes be justified, the first emotional reaction could be the reluctance against violence, then rationalized by a deliberation about the perhaps utility of violence in some cases. In this context, the mouse-tracking study of Koop (2013), which tested this model without confirming the associated predictions, highlighted how a mouse-tracking paradigm could reveal important information about decision dynamics.

Adopting a dynamical systems approach to decision-making, Figure 2 illustrates decisions (or mouse trajectories) unfolding through time as rolling over attractor landscapes (e.g., Spivey & Dale, 2006). Reaching a decision is equivalent to reaching the attractor at the bottom of a valley, yet the landscape itself depends on the task constraints, stimuli, and ongoing interactions with the paradigm. For instance, if a participant moves her hand toward a given response location on screen, she already engages in such response, thus digging the associated valley deeper and deeper, making it harder to come back and choose another distant response (Lepora & Pezzulo, 2015; Quinton & Smeding, 2015; Quinton et al., 2014). In presence of a continuous response mode, stimulus information progressively processed by the participant may dig and contribute to the emergence of attractors anywhere on the response continuum, leaving room for late bifurcations and nuanced responses. On the contrary, a binary response mode imposes a single ridge between two valleys of varying depth, weakening the impact of factors at later stages of the decision process, making it harder to switch to the other response once a bifurcation starts. Even when considering perceptions as decisions based on sensory signals, there might be a tight interplay between sensory and motor processes (e.g., in active vision; Quétard et al., 2016). Empirically, an example of the way a subtle motor bias could impact final moral decisions is given by Falandays et al.'s (2021) research. Decision-making process thus emerges from a strong interplay between perceptual, motor and cognitive constraints (represented by response mode for instance).

To understand how variations in empirical paradigms can lead to qualitative changes in decision, we will mainly focus on the underlying decision-making dynamics: Does the 2AFC paradigm constrains decision trajectories toward the final decision from an early stage onwards? The 2AFC paradigm forces respondents to endorse categorical representations, while underlying decision mechanisms may rather fit more gradual representations of responses options (e.g., ordinal or interval scales) or lean towards compromise when meaningful. When stimuli defined on a perceptual continuum lie at the boundary between two forced categorical representations, the interpretation of stimuli is most strongly influenced by top-down knowledge, which may produce qualitative changes in decisions from negligible differences in bottom-up signals (e.g., visual information). This consequence of the symbol grounding problem (Harnad, 1990) has also been consistently found in mouse-tracking experiments derived from the dynamic interactive theory of person construal (Freeman & Ambady, 2011). In the associated 2AFC paradigms, the two alternatives are not only presented as semantically opposed in the context of the task (e.g., *strongly disagree* versus *strongly agree*), but also spatially (being usually presented on opposite sides of the computer screen) and motorically (being associated to different keys or click locations). Despite these expected consequences on decision dynamics, the 2AFC paradigm is largely adopted thanks to its many advantages: it may facilitate data and statistical processing (e.g., focusing on a single alternative response frequency); theoretical predictions are easier to cast and operationalize; also, it is sometimes required to force participants to choose one option or the other, making otherwise subtle effects apparent (i.e., magnifying effect sizes).

The fact that subtle differences (e.g., in context) can lead to qualitative changes in decision is supported by prominent neurophysiological models of action selection, where alternative choices compete for action while evidence is accumulated continuously (for a review, see Cisek & Kalaska, 2010). Such models provide a mechanistic (and not only conceptual) account of the final decision, simply triggered when the accumulated evidence in favor of one option reaches a threshold, but also of the underlying process of reaching that decision with binary (Ratcliff & McKoon, 2008; Wojnowicz et al., 2009) or graded response modes (Ratcliff, 2018). Subsequently, the nature of the response depends on the paradigm, but does not allow to infer the discrete or continuous nature of the underlying decision processes. Reversely, we can assume that paradigms imposing a binary response mode, as in 2AFC tasks, (i) constrain decision-making dynamics from an early stage; (ii) and that the nature and impact of the constraint is reflected in decision-making dynamics and sometimes final decisions.

Stakes related to the possibility that paradigm features constrain (moral) decision-making are not mainly methodological. A major theoretical challenge is addressed, which is to determine whether individuals merely contrast the two response alternatives to provide a final answer after a graded decision has been adopted, or whether the presentation of dichotomized responses facilitates the discretization at the basic cognitive level (concepts, linguistic units, etc.). In the latter case, this would signal that paradigm constraints do not only influence responses through motor constraints, but also decision-making processes occurring at earlier stages. We will therefore examine the influence of response modes (binary versus continuous) on moral decision-making, with a focus on the early stages of this process, as traceable in decision dynamics obtained with computer mouse data.

Present Research

In the present research, considering the influence of situational factors on morality, we aim at examining whether paradigm constraints influence the dynamics and outcomes of decision-making processes. Specifically, changing the response mode for the same statements acts as a constraint which reduces response possibilities (i.e., 2AFC versus continuous). The present research will focus on the moral domain, relying on moral statements where extreme moral standards and particular outcomes or circumstances must be weighed. For example, if someone has to position themselves about if they can trust strangers to do good, the universal principle of having to trust people can be activated, but being moderated by examples they have in mind where they should not be trustful. This is a stringent experimental setup to test whether the influence of situational factors may be reflected through nuanced decisions, and whether decision dynamics may be influenced while leading to the same final decision. We relied on quantitative measures of decisions (e.g., continuous response scale) as other forms of measures (e.g., free text) do not allow studying the dynamics of online decision-making.

We conducted two studies to examine the influence of response mode on early decision-making processes in commonsense morality. Participants had to judge moral statements adapted from Pärnamets et al. (2015), answering with the computer mouse, and we recorded trajectories generated during the entire decision process. This mouse-tracking paradigm builds on the previously mentioned theoretical models, translating the competition between alternative responses at the cognitive level into movements of the hand to control the mouse on the screen (Freeman et al., 2011; Spivey et al., 2005). This allows tracing the decision-making process in real time from early stages onwards, revealing information about all the steps, hesitations, and biases that contribute to the final decision and response time (Hehman et al., 2015). In mouse-tracking paradigms, the main theoretical assumption (validated through many studies) is that participants initiate their decision process as soon as the stimulus appears.

Indeed, some cues are processed in the first hundreds of milliseconds in the perceptual stream and revealed in early mouse movements (Hehman et al., 2015.; see also in psycholinguistics Barca & Pezzulo, 2015). Recent studies have also shown that process measures could be used to trace decision dynamics with graded responses (using finger tracking in Dotan et al., 2019), to measure ambivalence in moral decisions (e.g., mouse-tracking in Buttlar & Walther, 2018; Koop, 2013), and to manipulate moral decisions (using eye-tracking in Pärnamets et al., 2015).

To investigate the influence of response mode on early dynamics of moral decision-making, we introduced two conditions: a binary mode, matching 2AFC paradigms, where the two response options were located on opposite sides of the computer screen (i.e., *strongly disagree* versus *strongly agree*); and a continuous mode, where the whole range of graded responses was available in between these two extremes, as with continuous response scales. While the continuous mode allows responses on opposite sides of the screen, the binary mode prohibits responses in the middle of the screen, which should mechanically lead to more extreme average end coordinates. Therefore, we rather focused on differences in the recorded mouse trajectories, with increased deviations expected in the binary compared to the continuous response mode condition. The stakes lie in early stages of the dynamics, when even the mere direction of the final decision has not yet been decided, and when comparing trajectories which end at the same location on the answer space (i.e., screen). In a complementary way, we were additionally interested in direction changes in final decisions, as it could reveal an impact of the response mode not only on decision process but also on resulting decisions.

To test our hypothesis, we relied on two mouse-tracking paradigms, corresponding to the two studies, each study comprising both response modes. In Study 1, the design was adapted from the standard mouse-tracking (MT) paradigm (Freeman et al., 2011), allowing to check consistency with previous research, the feasibility of a continuous response mode, but also testing limitations related to the present moral stimuli—complex sentences instead of images or single words (as in most MT research)—and getting meaningful effect sizes for Study 2. In Study 2, the paradigm from Study 1 was further modified to address several limitations. For both studies, we analyzed data using mixed effect models with participant and moral stimuli random factors, to allow generalization at the two levels despite the large expected variability across both factors (Judd et al., 2017).

Contributions therefore combine the introduction of a new mouse-tracking paradigm adapted to long-to-process stimuli (here written moral assertions), with the adaptation and comparison of mouse-tracking paradigms on different response scales (binary vs. continuous) using mixed model analysis with generalization at both participants and stimuli populations. Together, these contributions are thus at the psychometrical and theoretical level, by contributing to the study of spatiotemporally continuous decision-making processes. Indeed, we study decisions which are both extended in time compared to classical stimuli used in mouse-tracking designs (i.e., we use sentences instead of fast-to-process stimuli like images), and which are continuous in space (i.e., through mouse trajectories and final response scales).

Study 1

Methods

Participants.

Due to the novelty of the continuous response mode in mouse-tracking designs, and the focus on differences between conditions, effect sizes could not be reliably estimated from earlier studies. Considering a larger body of mouse-tracking studies, a priori statistical power analysis using a smallest effect size of interest (SESOI) of Cohen's $d = 0.2$ aiming at 80% power led to an expected sample size of 150 participants. This estimate did not incorporate information on variance partitioning, required for more adequate estimates with mixed models and exceeded resources that could be allocated to this study. Consequently, as preregistered, we aimed at recruiting 100 participants. Participants provided written informed consent before participation and the project was approved by the local ethics committee. The study and data collection were conducted in accordance with the ethical principles of the American Psychological Association and the Declaration of Helsinki. All measures, manipulations, and exclusions are disclosed. All data were collected prior to analysis. One hundred and four social sciences undergraduates (94 female, $M_{age} = 20.1$, $SD_{age} = 0.9$) took individually part in the study in exchange for course credits. All participants were included in analyses, except for one who did not finish the study, leaving a final sample of 103 participants.

Stimuli and apparatus.

Sixty-three moral statements were translated in French and adapted from Pärnamets et al. (2015). As the original statements sometimes included a negation, and sometimes not, hence possibly introducing a confound in terms of processing time (Margolin & Abrams, 2009), we controlled this confound by generating both positively and negatively framed versions of each statement. Minor adjustments were subsequently made to improve the symmetry of the formulations at the semantic level. Besides alleviating a limitation of the original set of statements, this adaptation doubled the number of trials per participant and further increased heterogeneity. Item heterogeneity was sought after, with some statements expected to be very divisive and others more consensual, adding to the generalizability of results.

Concerning the setup in the binary condition, it closely paralleled that of the standard MT paradigm: the two available response options were presented in the top-left and top-right corners of the computer screen, resulting in two clickable response boxes. Mouse trajectories were recorded on each trial from the click on the "START" button (at the bottom-middle of the screen), triggering the onset of the stimulus, until the click on the chosen response. For the continuous condition, the width of the clickable response area was extended to have a continuous single full-width bar on the top of the screen (in grey on Figure 3). As the boxes or bar were displayed on the screen before the start of the trial, condition was expected to have an influence from the very beginning of the trial, at a stage where a decision has not yet stabilized.

Procedure.

The design was a 2 (response mode: binary, continuous) × 2 (linguistic framing: positive, negative) fully crossed within-participants design. Apart from 3 training statements, the 60 other statements were presented within two blocks, each block associated to a single response mode. Order of presentation of blocks was counterbalanced across participants. Each block was composed of 120 trials, as the initial set of 60 statements was presented with the two different framings. The 60 statements were randomly split in two halves (subsets), framed in their positive and negative versions, randomly ordered, then interleaved within each response mode block, with framing alternating between trials (for a total of 8 subsets and 240 trials). This ensured that at least 30 trials (i.e., one subset) would separate the presentation of the same statement and ensuring that each was presented in the four conditions.

After reading instruction screens, participants completed a first training phase composed of 6 statements with alternated response modes and linguistic framings. Participants then completed the two test blocks, each preceded by an instruction screen and 3 additional training statements to remind the participant of the response mode to be used in the current block. Breaks were introduced every 30 trials, although participants had control over trial initiation. Indeed for each trial, a single statement was displayed in the middle of the screen when the participant clicked on the "START" button and remained visible until an answer via a mouse click within a grey response area at the top of the screen was provided. If the participant did not move the mouse for more than 500ms (standard cutoff in mouse-tracking studies; see Hehman et al., 2015), a "Faster" message appeared in red. Constraining response time is indeed necessary in mouse-tracking to prevent participants from making a decision before initiating a movement. Preregistration, materials, data and analysis scripts can be retrieved on OSF (https://osf.io/hqgfd/?view_only=2a31f147fbd9493db22e9492a1f65771), while software will be made available upon acceptance (on https://osf.io/xj2w3/).

Results

Analytic procedure.

Compared to prior MT research, the time required for sentence reading and processing was significantly increased, with a mean response time of 4.6 seconds. Due to the dilemma-like nature of stimuli, many trajectories also displayed sudden changes of direction, as illustrated in Figure 3. Consequently, spatial indices based on x-y coordinates (e.g., maximum deviation, area under the curve; see Hehman et al., 2015) could not appropriately be used. We therefore retained mouse coordinates on the x-axis of the screen (X) as a function of time (as a proxy for hesitations between response alternatives) as our dependent variable of interest. In the following paragraphs, deviation thus refers to the distance away from the origin of the trajectory on the X-axis, and not away from the ideal straight trajectory towards the final response. This specific feature will yield great importance in the development of the new paradigm in Study 2. Coordinates were bounded between -1 (left of the screen) and 1 (right), with the "START" button being centered on 0 (neutral position). To make them easily comparable, trajectories (X as a function of time) were time-normalized between 0% (click on START) and 100% (click on response), then linearly interpolated to generate 100 points per trajectory. Therefore, in all conditions, the last X-coordinates correspond to final responses of the participants and the associated inferential results to those which would be obtained without tracing mouse coordinates. Finally, coordinates were made positive since the focus was on comparing attraction toward extreme answers across conditions.

We used mixed-effects models for the main analyses, using lme4 package in R language (Bates et al., 2015). Since approximate degrees of freedom were large enough for all effects of interest, resulting in negligible differences compared to asymptotic results, the latter are reported for simplicity. Given our fully-crossed design, the maximal random structure includes intercept, main and interaction random effects between response mode (R) and linguistic framing (F) for both participant (P) and statement (S) random factors, as well as intercept and main random effects for each statement judged by each participant (P: S) (Judd et al., 2017). Using the R equation formalism, this led to a maximal model specified by: $X \sim R * F + (R * F|P) + (R * F|S) + (R + F|P: S)$. Random structure reduction following Bates, Kliegl, Vasishth, and Baayen (2015) led to little change in structure, reflecting the large variability in effects across participants and statements (also see Matuschek et al., 2017). Despite differences in moral judgments across participants for any given statement, the statement-by-participant interaction random factor was dropped to keep estimations tractable and comparable for the whole trajectories, as changes in fixed effects and variance components were negligible.

Contrast coding was used for both response mode (−0.5 for continuous; +0.5 for binary) and linguistic framing (−0.5 for negative; +0.5 for positive). To control type I error rate in presence of multiple testing with temporal dependencies (with 100 tests performed along the trajectories), 8 successive p-values below .05 were needed to conclude for significance (demonstrated as conservative in appendix of Dale et al., 2007). Effect sizes are reported as Cohen's d, adapted to linear mixed model designs (Judd et al., 2017). In accordance with preregistration, we first performed an unconditional analysis, keeping all trajectories. We subsequently ran a conditional analysis, keeping all trajectories for binary response mode and only those ending at extreme coordinates for continuous response mode, hence allowing a test of response mode for comparable trajectories (i.e., all ending at extreme coordinates).

Unconditional analysis.

We found a significant main effect of response mode starting at 61% of trajectory time ($b = 0.016$, $SE = 0.008$, $z = 2.05$, $p = .041$, 95% CI [0.0006,0.031], $d = 0.07$), increasing until the end of the trajectory ($b = 0.167$, $SE = 0.017$, $z = 9.69$, $p < .001$, 95% CI [0.133,0.201], $d = 0.87$). This effect was slightly yet significantly moderated by linguistic framing between 59% and 77%, with a peak at 67% in terms of raw effect size ($b > -0.017$, $SE < 0.007$, $z > -3.29$, $d > -0.04$), reflecting a stronger effect of framing in binary mode. We also observed a significant negative main effect of framing between 6% and 76%, with a peak at 66% ($b > -0.032$, $SE < 0.006$, $z > -8.69$, $d > -0.14$). This effect was reversed and became significantly positive between 82% and 97%, with a peak at 90% ($b < 0.034$, $SE < 0.006$, $z < 9.06$, $d < 0.14$), reflecting more extreme judgments when presented with positively framed statements. Besides, there was no final difference ($|b| < 0.0001$), signaling a correct interpretation of linguistic framing. Regarding the effect of response mode, it may simply reflect where participants were allowed to click (two boxes in binary mode, but a screen-wide box in continuous mode). This issue will be partially alleviated with the conditional analysis but so far, results confirm its impact on a meaningful portion of participants' response behavior (trajectories), including its sensorimotor component, growing from null at the beginning to very large for end coordinates. Finally, we looked at the distribution of final responses for continuous response mode, with 44% of final answers out of the corresponding response areas in binary response mode (see distributions on Figure 4C). It is possible that some participants did not understand the possibility to answer in a nuanced way in the continuous response mode (according to post-experimental feedback), limiting the amount of nuanced responses. Results are displayed in Figure 4.

We also looked for dichotomized final responses, i.e., responses to the left (resp., right) of the middle of the scale considered as "Disagree" (resp., 'Agree'). We observed a significant difference of 15% ($p < .001$) of change between the continuous and binary response mode.

Finally, we performed analyses while controlling and checking for interaction with response mode presentation orders (whether participants responded with the continuous or binary response mode first; using LMM with both participant and assertion random factors, to better account for randomization and counter-balancing within/between participants). We observed a significant main effect of presentation order with more extreme answers when binary response mode is presented first (b = -0.09, SE = 0.03, $\chi^2(1)$ = 7.88, p = .005, 95% CI [-0.15, -0.03], d = -0.23). Of importance, our target main effect of response mode remained significant and unchanged (b = 0.16, SE = 0.02, $\chi^2(1)$ = 97.90, p < .001, 95% CI [0.13, 0.20], d = 0.88).

Conditional analysis.

As preregistered, we proceeded to a conditional analysis of trajectories, only keeping those ending at extremes coordinates ($|X| > 0.7$ corresponding to response boxes for the binary mode), thus keeping all binary mode trajectories, but only a subset from continuous mode. Although mean trajectories were more similar, a small non-significant positive effect remained observable from the start until 80% of trajectory time ($b < 0.013$, $SE < 0.010, z < 1.57$, $p >$ .11). However, this effect was then reversed and became significant from 85% ($b = -0.020$, $SE < 0.009$, $z = -2.07$, $p = .039$, $95\% CI[-0.038, -0.001]$, $d = -0.07$) until the end ($b = -0.022$, $SE = 0.004$, $z = -5.50$, $p < .001$, 95% CI $[-0.029, -0.014]$, $d = -0.32$). The interaction with linguistic framing was not significant (once controlling for multiple sequential testing) yet remained negative ($b > -0.017, SE < 0.008, z > -2.09, d > -0.03$). As previously, we also observed a significant negative main effect of framing between 7% and 70%, with a peak at 67% ($b > -0.033$, $SE < 0.006$, $z > -7.40$, $d > -0.14$), and its significant reversal between 82% and 99%, with a peak at 90% ($b < 0.040$, $SE < 0.007$, $z < 9.96$, $d < 0.18$). While we focused on the effect of response mode at the beginning of the trial (yet non-significant), the inverse significant effect found at the end of trajectories could again be explained by distributions of end coordinates. Indeed, for the binary mode, the same decision and behavioral meaning is associated with any click location within the response boxes. Consequently, there were fewer clicks near the borders of the screen compared to the continuous mode, for which such clicks really expressed extreme judgments. Results are displayed in Figure 5. We again calculated the number of dichotomized final response change between the two response modes, revealing 11% ($p < .001$) of change, even when considering only extreme final responses.

Discussion

Results of the unconditional analysis provide initial support for the impact of response mode on trajectories, which is consistent with the possibility that paradigm features constrain decision-making. However, a first limitation is that this effect was robustly observed only later in the trajectories. A second, and possibly related limitation, is an interpretation of this result as relating to the sensorimotor part: because screen composition constrained where participants were allowed to click (two boxes in binary mode, but a screen-wide box in continuous mode), a late effect can be explained by differences in hand dynamics to accommodate clicks at different places. Results of the conditional analysis further question interpretation of effects, with the effect of response mode being non-significant at the beginning of trajectories but showing an unexpected significant reversal at the end. The latter may be explained by distributions of end coordinates, hence hinting again at the impact on sensorimotor behavior. Indeed, the mode of absolute end coordinate distributions is close to the minimal value of 0.7 in the binary mode (corresponding to the border of the response boxes), since a click anywhere on the response area conveys the same meaning and participants usually aim at the point closest to their current mouse position if they want to answer quickly. Nevertheless, we still observe an impact of the response mode on final decisions because it led to changes in direction of final responses relatively to the middle of the scale for a significant amount of trials. This phenomenon also significantly occurred when considering only extreme final decisions, where participants change from one extreme to the other between response modes. This occurred despite good reliability across assertions, participants and conditions (see descriptive statistics reported in supplemental files). Finally, the analysis of the order of response mode possibly shows how participants manage to adapt to the change of response mode when manipulated across blocks of trials. Particularly, it seems that when facing a binary response mode first, participants tend to answer more extremely, as it could encourage to think in a dichotomous way. In addition, a visual inspection of the data revealed that several participants presented trajectories with the same peculiar aspect: an initial departure to the left, a straight line to cross the screen to the right, then the rest of the trajectory to choose the answer. A likely interpretation would be that people moved the mouse cursor over the statement displayed in the middle of the screen while reading it. We conservatively kept these data for analyses, knowing that the main consequence would be an underestimation of our effects of interest. A final limitation pertains to the visual presentation of the two response modes (two rectangles on the two sides of the screen for the binary response mode, and a single rectangle for the continuous response mode). As a result, the two rectangles of the binary response mode may have been more visually salient than the rectangle in the continuous response mode, therefore exerting greater attraction both visually and motorically.

To summarize, results pertaining to the unconditional and conditional analyses signal the importance of paradigm features on mouse trajectories and decision dynamics. However, limitations of this adapted version of the MT paradigm for moral statements did also emerge, including the possible use of the mouse cursor while reading statements and differences in visual saliency between response modes. This is not surprising as the standard MT paradigm has been largely and successfully used with images and words, but there was no guarantee of successful transposition to complex sentences. Consequently, in Study 2, the paradigm of Study 1 was modified in several important ways to address these limitations.

Study 2

Methods

Participants.

Since the design has been improved in Study 2 to reduce or eliminate some sources of variance, effect size was expected to be larger compared to Study 1. Using PANGEA (Westfall, 2015), exploiting effect size estimates and variance partitioning coefficients from Study 1, we estimated statistical power for different sample sizes and performed a sequential analysis based on the recommendations of Lakens (2014). We performed our first analysis at 65 participants, and obtained a significant effect for response mode (p-value below the interim threshold at 0.017), so we stopped data collection (details on this procedure provided in supplemental files). Participants were all social sciences undergraduates (57 female, $M_{age} = 20.0$, $SD_{age} = 0.8$) and took part individually in exchange for course credits. Participants provided written informed consent before participation and the project was approved by the local ethics committee. The study and data collection were conducted in accordance with the ethical principles of the American Psychological Association and the Declaration of Helsinki. All measures, manipulations, and exclusions are disclosed. All data were collected prior to analysis.

Stimuli and apparatus.

The same 63 statements as in Study 1 were used. The new design consisted of a slider of varying width that became visible inside a horizontal bar once the trial was initiated by the participant (clicking on a central "START" area), then following the mouse cursor along the x-axis of the screen (see Figure 6). The slider had a linear color gradient to blend with the white background, and the most contrasting color corresponded to where the cursor pointed. The width of the slider varied with time: it decreased when the participant did not move the mouse and increased when they did, with a trial considered failed if the slider fully disappeared (reaching zero width). This behavior was an adaptation of the "Faster" message from Study 1, encouraging quick answers and continuous moves, but without the ‘flashing effect’ induced by the apparition of the message which could distract the participant during her decision. Response mode was signaled by the color of the slider: if it was green, clicking to provide a final response was possible and ended the trial; if grey, it was not taken into account. Hence, when the slider was green whatever its position in the horizontal bar, it signaled the continuous response mode; when it was grey in the middle and green at the two sides of the bar, it signaled the binary response mode. The mouse cursor itself was made invisible, resulting in useful mouse movements limited to the horizontal axis, which was more adapted for long statements and prevented hovering the cursor over these stimuli. In addition, the use of the color scheme to signal continuous versus binary response mode when the cursor was moved (but not beforehand) reduced the imbalance in visual saliency between conditions and made it easier to randomize response mode through trials.

We pretested several versions of the slider design, mostly to test different slider width dynamics (a summary descriptions of the different versions can be found as supplemental files). Because simplicity and ergonomics were paramount, we retained the version with (i) a predefined initial slider size; (ii) a continuous reduction of the slider size with time; (iii) an instantaneous reset to its maximum size when mouse movement are performed; (iiii) and a temporal smoothing filter applied to the slider size to prevent perceptual discontinuity for the user.

Procedure.

The design was a 2 (response mode: binary, continuous) × 2 (linguistic framing: positive, negative) fully crossed within-participants design. As in Study 1, a screen containing global instructions was presented first. To familiarize with the slider design, an additional training was added containing 6 simple food images. Responses options were *I like it* and *I don't like it* for the binary response mode, and a scale between these two extremes for the continuous response mode. Then, as in Study 1, the training with the moral statements was introduced. As in Study 1, breaks were introduced every 30 trials, for a total of 240 trials, but response mode was this time randomized across trials. To avoid having the same statement presented with different response modes a few trials apart, randomization of stimuli was adapted accordingly (details provided in supplemental files). Preregistration, materials, data and analysis scripts can be retrieved on OSF (https://osf.io/hqgfd/?view_only=2a31f147fbd9493db22e9492a1f65771), while software will be made available upon acceptance (on https://osf.io/n4rky/).

Results

Analytic procedure.

We conducted the same (unconditional and conditional) analyses as in Study 1. Data treatment and variable coding were also similar, except for the additional removal of missed trials (i.e., where the participant did not move fast enough and the width of the slider fell to zero before an answer was given). This led to discard 2.5% of the trials.

Unconditional analysis.

After fitting the linear mixed model to the interpolated coordinates, we observed the same phenomenon as in Study 1 (see Figure 7), with an earlier effect of response mode. There was a significant difference between response modes almost at the beginning of the trial, starting at 3% ($b = 0.0012$, $SE = 0.0006$, $z = 2.11$, $p = .03$, 95% CI [0.00009,0.002], $d = 0.04$), with trajectories deviating more in the binary response mode. As expected, this difference increased through time, until the end of the trajectory ($b = 0.21$, $SE = 0.02$, $z = 12.56$, $p < .001$, 95% CI [0.18,0.24], $d = 1.10$). Such an early effect argues for an early constraint of the binary response mode, well before the decision was made. This effect was not significantly moderated by linguistic framing. We also observed a significant negative main effect of framing between 4% and 20%, and between 37% and 74% with a peak at 64% ($b > -0.022$, $SE < 0.006$, $z > -4.39$, $d > -0.9$). This effect was reversed and became significantly positive between 83% and 97%, with a peak at 92% ($b < 0.038$, $SE < 0.006$, $z < 7.81$, $d < 0.15$), reflecting more extreme judgments when presented with positively framed statements. Finally, we looked at the distribution of final responses for continuous response mode, with 52% of final answers out of the corresponding response areas in binary response mode (see distributions on Figure 7C). The design issue of the first study leading some participants to not understand the possibility to answer in a nuanced way in the continuous response mode was here alleviated. Nevertheless, with the one-dimensional design of this second study, participants tended to move the slider away from the START button (i.e., the middle of the scale), thus almost never answering at the very center. Also, the trial-level randomization of continuous and binary response modes may also lead to extremize responses in the continuous response mode, explaining the proportion of extreme decisions we observe.

We then dichotomized the final answers, and calculated the number of final response change between the two response modes. We observed 17% ($p < .001$) of final response changes. Finally, we performed analyses while controlling and checking for interaction with response mode presentation orders (whether participants responded with the continuous or binary response mode first; using LMM with both participant and assertion random factors, to better account for randomization and counter-balancing within/between participants). This time, we did not observe a significant effect of the order of presentation of the response mode (b = -0.03, SE = 0.01, $\chi^2(1)$ = 3.62, p = .06, 95% CI [-0.05, 0.0008], d = -0.07). Nevertheless, the main effect of response mode remained significant and unchanged (b = 0.21, SE = 0.02, $\chi^2(1)$ = 157.94, p < .001, 95% CI [0.18, 0.25], d = 1.10).

Conditional analysis.

We again conducted a conditional analysis of trajectories, only keeping those ending at extremes coordinates ($X \vee 0.7$ corresponding to response boxes for the binary mode, as in Study 1). Again, the results showed a significant difference in deviation early in the trajectories, from 10% to 98%, reaching a maximum at 80% ($b < 0.059$, $SE < 0.02$, $z < 6.32$, $d < 0.19$), and this time demonstrating almost no difference between conditions at the end of trajectories ($b =$ 0.003). Thus, even for the same final decision, we observed a difference in trajectories between response modes. This effect was slightly yet significantly moderated by linguistic framing from 89% until the end of the trajectory, with a peak at 90% in terms of raw effect size ($b > -0.036$, $SE < 0.02$, $z > -3.9$, $d > -0.07$), reflecting a stronger effect of framing in binary mode. We still observed a significant negative main effect of framing between 4% and 13% ($b > -0.008$), and between 34% and 78%, with a peak at 64% ($b > -0.032$, $SE < 0.008$, $z > -4.77$, $d >$ -0.12), and its significant reversal between 84% and 99%, with a peak at 90% ($b < 0.051$, $SE < 0.006$, $z < 7.24$, $d < 0.17$). Results are displayed in Figure 8.

We again checked the number of dichotomized final response changes between the two response modes and observed 12% ($p < .001$) of changes, again giving a significant amount of change between the two response modes.

Discussion

As expected, we obtained an earlier effect of response mode on mouse trajectories with this new slider design, compared to what was observed in Study 1. This effect was observed on almost the entire mean trajectory in both unconditional and conditional analyses, supporting the robustness of the results. Of importance, as these findings were obtained while several alternative interpretations of Study 1's results were alleviated, Study 2 provides evidence consistent with an interpretation in terms of the impact of paradigm constraints on early stages of decisions. Results of the conditional analyses are certainly the most straightforward here, because the early and ongoing effect of response mode was observed while differences at the end of trajectories were negligible. Paradigm constraints---here, a binary versus continuous response mode---may therefore contribute to shape decision-making dynamics, at least as traceable in mouse movements. Consistent with results obtained in the first study, we also observed significant decision reversals between the two response modes, and even in the conditional analysis where only extreme final responses were kept. This again occurred despite good reliability across assertions, participants and conditions (see descriptive statistics reported in supplemental files). Unlike Study 1, we did not observe a significant effect of the presentation order of the response mode. This difference could be explained by the fact that response mode was randomized across trials in this study, compared to Study 1 where it was counterbalanced across blocks and participants - which could thus have increased its influence on the decision process.

In the visual inspection of the trajectories, we observed “random” movements (or oscillations) for some trials made to simply comply with time constraints of the paradigm. However, it was negligible in the whole data set and should have a near zero mean effect with very large variance, thus only contributing to noise in the statistical analysis. Indeed, we are not interested in predicting or even interpreting individual trajectories, but in the mean effects across participants and trials, so that the estimates of response mode and linguistic framing effects should not be biased by such random movements.

General Discussion

The present studies provide evidence consistent with the hypothesis that a paradigm with a binary response mode constrains early decision dynamics, as trajectories deviated more in the binary compared to the continuous response mode. This hypothesis was only partially supported in Study 1, given a rather weak effect with the conditional analyses and alternative interpretations of some of the results. Study 2, however, tested this hypothesis with a new slider paradigm designed to alleviate limitations of Study 1's MT paradigm and discard proposed alternative interpretations. Results are in line with the possibility that the binary response mode, widely used in decision-making research with 2AFC tasks, may constraint decision dynamics from an early stage onwards.

This initial constraint may then be amplified during the decision-making process, resulting in less room for change and less flexible decisions. This is consistent with theoretical and formal models of decision-making based on accumulation of evidence, as the binary mode may induce a stronger integration of weaker evidence towards the extreme response alternatives (see Figure 2). This may be particularly problematic in the morality domain. Somewhat extrapolating from present results, we may expect that people regularly confronted with such binary options would tend to take more extreme positions at the end than they would spontaneously. This could be the case with our experimental designs, as suggested in the first study with the significantly more extreme decisions made when binary response mode was presented first, as well as with most 2AFC tasks, since participants are exposed to series of statements. Adding to the idea that the paradigm could impact the decision process, possibly leading to different outcomes, the observed significant amount of change in the two studies shows that the response mode could lead to swings between extreme responses even for moral decisions. Consequently, one may question the relevance of 2AFC tasks to study moral decisions, unless their advantages are explicitly sought after (e.g., maximizing effect sizes by forcing one or the other response option, facilitating theoretical predictions and operationalizations).

Limitations and perspectives

It is to mention that conditional analyses may not be representative of the whole set of empirical data we obtained, as they required discarding non-extreme decisions. This is thus complementary to unconditional analyses where those decisions were also included. Also, the necessary presence of time constraints in order to be able to track decision dynamics through mouse tracking (explicit feedback to the user in Study 1 or progressive slider disappearance in Study 2) introduces additional noise to measures and may lead to underestimation of effects. Alternatively, this could result in less reflexive and more hasty decisions, which may also accentuate the dichotomous thinking in the binary response mode (compared to no time-constrained decisions) to be able to converge and answer toward one or the other opposite alternative.

To further investigate early decision dynamics and how they could amplify and further constrain decision-making, future research may rely on computational modeling as an interesting tool in this endeavor. To address differences between binary and continuous response modes, models relying on a fixed set of accumulators (e.g., Drift Diffusion Model; Ratcliff et al., 2016) could be contrasted and combined with models operating on continuous scales (e.g., Dynamic Neural Field; Schöner, 2020), or a model already contrasting binary and continuous response mode for a pricing task (Kvam & Busemeyer, 2020) can also be used, implementing computationally the formal model illustrated on Figure 2.

Another avenue for future research pertains to the effects of linguistic framing. Indeed, as this variable was not a focal point of the present research, we did not investigate it further. However, it is worth highlighting that the same consistent pattern was observed in both studies:

for negative framing, participants deviated more than for positive framing at the beginning of the trial, the effect was then reversed, yet with no significant difference in final responses. A possible explanation of this pattern is that the presence of negation in the statement creates a preference toward the answer with a negation (“Do not agree”). Then, by getting the meaning of the statement, the participant needs to rectify her trajectory and amplifies the movement in the opposite direction to correct it. At the end, the correction is made, and no difference is observable in final responses. This explanation is speculative but corresponds to overshooting dynamics often observed in MT designs. Future research may therefore investigate it further, either with human or simulated participant data, as linguistic framing-related parameters can be integrated into computational models.

Finally, moral decisions were investigated in these studies without studying dimensions of morality on an a priori basis. Yet, Moral Foundation Theory for instance postulates moral pluralism with the existence of five different moral foundations (care/harm, fairness/cheating, loyalty/betrayal, authority/subversion, and sanctity/degradation) (Graham et al., 2013). Disentangling these moral dimensions and testing whether some of them are more affected by response mode could be an interesting perspective for future research.

Conclusion

The present research contributes to decision-making and cognition research more broadly, beyond the moral domain. First, the slider design provides a relevant tool to trace dynamics in the case of linguistically complex stimuli, such as complex sentences. This takes the MT paradigm one step further, making it a useful cognitive process tracing method for a wide range of stimuli and response modes. Regarding complex sentences in particular, the fact that the slider design prevented hovering the cursor over the sentences while reading is a desirable feature for many studies, beyond the specific reasons that led to this new development in the present research. But the contribution of the present research is also at the basic level: evidence was found that the 2AFC paradigm could lead to a cognitive constraint, impacting decision-making processes by dichotomizing social objects and changing the way information is considered and integrated, and potentially even change decision outcome. Those aspects should thus be considered when using this paradigm.

Also, in line with the embodied choice perspective (Lepora & Pezzulo, 2015) the alternative interpretations of Study 1's results were primarily related to the central role of sensorimotor behavior. Thus, when decisions are expressed by actions, bidirectional influences between ongoing actions and decisions should be fully considered, as they may lead to nonlinearities and bifurcations in decisions. The importance of feedback loops between cognitive processes and observable behaviors should thus be considered as intrinsically involved in cognitive dynamics. More generally, this raises the question of what should be considered part of decision dynamics. Consistent with a situated cognition perspective, the present research highlights the importance of brain, body, and task as crucial parameters to understand cognitive dynamics.

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Conflict of interest

The authors declare no potential conflict of interests.

Data availability statement

Data that we are allowed to share (as some data cannot be shared in order to insure privacy protection) that support the findings of the studies reported in this paper are openly available on OSF at https://osf.io/hqgfd/?view_only=2a31f147fbd9493db22e9492a1f65771 (to be updated to https://osf.io/hqgfd/ upon acceptance). In particular, preregistration forms are available on files timestamped before running the experiments in order to follow the requirements in terms of open science practices.

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Supporting information

Additional supporting information may be found in the online version of the article at the publisher’s website, and on OSF.

References

Barca, L., & Pezzulo, G. (2015). Tracking second thoughts: Continuous and discrete revision processes during visual lexical decision. *PLoS One*, *10*(2), e0116193.

Bartels, D. M., Bauman, C. W., Cushman, F. A., Pizarro, D. A., & McGraw, A. P. (2015). Moral judgment and decision making. *The Wiley Blackwell handbook of judgment and decision making*, *63*, 478–515.

Bates, D., Kliegl, R., Vasishth, S., & Baayen, H. (2015). Parsimonious mixed models. *arXiv preprint arXiv:1506.04967*.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, *67*(1), 1–48. Doi: 10.18637/jss.v067.i01

Berlin, S. B. (1990). Dichotomous and complex thinking. *Social Service Review*, *64*(1), 46–59.

Bogacz, R., Brown, E., Moehlis, J., Holmes, P., & Cohen, J. D. (2006). The physics of optimal decision making: a formal analysis of models of performance in two-alternative forced-choice tasks. *Psychological review*, *113*(4), 700.

Broeders, R., Van den Bos, K., Müller, P. A., & Ham, J. (2011). Should I save or should I not kill? How people solve moral dilemmas depends on which rule is most accessible. *Journal of Experimental Social Psychology*, *47*(5), 923-934.

Buttlar, B., & Walther, E. (2018). Measuring the meat paradox: How ambivalence towards meat influences moral disengagement. *Appetite*, *128*, 152–158.

Cheng, J., & González-Vallejo, C. (2018). Unpacking decision difficulty: Testing action dynamics in intertemporal, gamble, and consumer choices. *Acta Psychologica*, *190*, 199-216.

Cisek, P., & Kalaska, J. F. (2010). Neural mechanisms for interacting with a world full of action choices. *Annual Review of Neuroscience*, *33*, 269–298.

Comer, D. R., & Vega, G. (2008). Using the pet assessment instrument to help students identify factors that could impede moral behavior. *Journal of Business Ethics*, *77*(2), 129–145.

Dale, R., Kehoe, C., & Spivey, M. J. (2007). Graded motor responses in the time course of categorizing atypical exemplars. *Memory & Cognition*, *35*(1), 15–28.

Dotan, D., Pinheiro-Chagas, P., Al Roumi, F., & Dehaene, S. (2019). Track it to crack it: Dissecting processing stages with finger tracking. *Trends in Cognitive Sciences*, *23*(12), 1058–1070.

Evans, A. M., Dillon, K. D., & Rand, D. G. (2015). Fast but not intuitive, slow but not reflective: Decision conflict drives reaction times in social dilemmas. *Journal of Experimental Psychology: General*, *144*(5), 951.

Falandays, J. B., Spevack, S., Pärnamets, P., & Spivey, M. (2021). Decision-making in the human-machine interface. *Frontiers in Psychology*, 99.

Freeman, J. B., & Ambady, N. (2011). A dynamic interactive theory of person construal. *Psychological Review*, *118*(2), 247.

Freeman, J. B., Dale, R., & Farmer, T. (2011). Hand in motion reveals mind in motion. *Frontiers in Psychology*, *2*, 59.

Gonzalez, C. M., Zosuls, K. M., & Ruble, D. N. (2010). Traits as dimensions or categories? Developmental change in the understanding of trait terms. *Developmental Psychology*, *46*(5), 1078.

Graham, J., Haidt, J., Koleva, S., Motyl, M., Iyer, R., Wojcik, S. P., & Ditto, P. H. (2013). Moral foundations theory: The pragmatic validity of moral pluralism. In *Advances in experimental social psychology* (Vol. 47, pp. 55-130). Academic Press.

Harnad, S. (1990). The symbol grounding problem. *Physica D: Nonlinear Phenomena*, *42*(1-3), 335–346.

Hehman, E., Stolier, R. M., & Freeman, J. B. (2015). Advanced mouse-tracking analytic techniques for enhancing psychological science. *Group Processes & Intergroup Relations*, *18*(3), 384–401.

Iliev, R., Sachdeva, S., Bartels, D. M., Joseph, C., Suzuki, S., & Medin, D. L. (2009). Attending to moral values. *Psychology of Learning and Motivation*, *50*, 169-192.

Judd, C. M., Westfall, J., & Kenny, D. A. (2017). Experiments with more than one random factor: Designs, analytic models, and statistical power. *Annual Review of Psychology*, *68*, 601–625.

Kahane, G., & Shackel, N. (2010). Methodological issues in the neuroscience of moral judgement. *Ming & Language*, *25*(5), 561-582.

Kahane, G. (2015). Sidetracked by trolleys: Why sacrificial moral dilemmas tell us little (or nothing) about utilitarian judgment. *Social Neuroscience*, *10*(5), 551–560.

Koop, G. J. (2013). An assessment of the temporal dynamics of moral decisions. *Judgment and Decision Making*, *8*(5), 527.

Kvam, P. D. (2019). Modeling accuracy, response time, and bias in continuous orientation judgments. *Journal of Experimental Psychology: Human Perception and Performance*, *45*(3), 301.

Kvam, P. D., & Busemeyer, J. R. (2020). A distributional and dynamic theory of pricing and preference. *Psychological review*, *127*(6), 1053.

Lakens, D. (2014). Performing high-powered studies efficiently with sequential analyses. *European Journal of Social Psychology*, *44*(7), 701–710.

Leavitt, K., Reynolds, S. J., Barnes, C. M., Schilpzand, P., & Hannah, S. T. (2012). Different hats, different obligations: Plural occupational identities and situated moral judgments. *Academy of Management Journal*, *55*(6), 1316–1333.

Leong, W., & Hensher, D. A. (2012). Embedding decision heuristics in discrete choice models: A review. *Transport Reviews*, *32*(3), 313-331.

Lepora, N. F., & Pezzulo, G. (2015). Embodied choice: how action influences perceptual decision making. *PloS Computational Biology*, *11*(4), e1004110.

Levine, T. R. (2001). Dichotomous and continuous views of deception: A reexamination of deception ratings in information manipulation theory. *Communication Research Reports*, *18*(3), 230–240.

Margolin, S. J., & Abrams, L. (2009). Not may not be too difficult: The effects of negation on older adults' sentence comprehension. *Educational Gerontology*, *35*(4), 308–322.

Master, A., Markman, E. M., & Dweck, C. S. (2012). Thinking in categories or along a continuum: Consequences for children's social judgments. *Child Development*, *83*(4), 1145–1163.

Matuschek, H., Kliegl, R., Vasishth, S., Baayen, H., & Bates, D. (2017). Balancing Type I error and power in linear mixed models. *Journal of Memory and Language*, *94*, 305–315.

Neumann, N., Böckenholt, U., & Sinha, A. (2016). A meta-analysis of extremeness aversion. *Journal of Consumer Psychology*, *26*(2), 193-212.

Pärnamets, P., Johansson, P., Hall, L., Balkenius, C., Spivey, M. J., & Richardson, D. C. (2015). Biasing moral decisions by exploiting the dynamics of eye gaze. *Proceedings of the National Academy of Sciences*, *112*(13), 4170–4175.

Quétard, B., Quinton, J. C., Mermillod, M., Barca, L., Pezzulo, G., Colomb, M., & Izaute, M. (2016). Differential effects of visual uncertainty and contextual guidance on perceptual decisions: Evidence from eye and mouse tracking in visual search. *Journal of Vision*, *16*(11), 28–28.

Quinton, J. C., & Smeding, A. (2015). Dynamic competition and binding of concepts through time and space. *Cognitive Processing, 16(1)*, 349-353.

Quinton, J. C., Volpi, N. C., Barca, L., & Pezzulo, G. (2013). The cat is on the mat. Or is it a dog? Dynamic competition in perceptual decision making. *IEEE Transactions on Systems, Man, and Cybernetics: Systems, 44(5)*, 539-551.

Ratcliff, R. (2018). Decision making on spatially continuous scales. *Psychological Review*, *125*(6), 888.

Ratcliff, R., & McKoon, G. (2008). The diffusion decision model: theory and data for two-choice decision tasks. *Neural Computation*, *20*(4), 873–922.

Ratcliff, R., Smith, P. L., Brown, S. D., & McKoon, G. (2016). Diffusion decision model: Current issues and history. *Trends in Cognitive Sciences*, *20*(4), 260–281.

Satpute, A. B., Nook, E. C., Narayanan, S., Shu, J., Weber, J., & Ochsner, K. N. (2016). Emotions in “black and white” or shades of gray? How we think about emotion shapes our perception and neural representation of emotion. *Psychological Science*, *27*(11), 1428–1442.

Schöner, G. (2020). The dynamics of neural populations capture the laws of the mind. *Topics in Cognitive Science*, *12(4)*, 1257-1271.

Segev, R. (2021). Continuity in morality and law. *Theoretical Inquiries in Law*, *22*, 45–85.

Slovic, P. (1995). The construction of preference. *American Psychologist*, *50*(5), 364.

Smeding, A., Quinton, J.-C., Lauer, K., Barca, L., & Pezzulo, G. (2016). Tracking and simulating dynamics of implicit stereotypes: A situated social cognition perspective. *Journal of Personality and Social Psychology*, *111*(6), 817.

Smith, E. R., & Semin, G. R. (2004). Socially situated cognition: Cognition in its social context. *Advances in Experimental Social Psychology*, *36*, 57–121.

Spivey, M. J., & Dale, R. (2004). On the continuity of mind: Toward a dynamical account of cognition. *The Psychology of Learning and Motivation: Advances in Research and Theory*, *45*, 87–142.

Spivey, M. J., & Dale, R. (2006). Continuous dynamics in real-time cognition. *Current Directions in Psychological Science*, 15(5), 207-211.

Spivey, M. J., Grosjean, M., & Knoblich, G. (2005). Continuous attraction toward phonological competitors. *Proceedings of the National Academy of Science*s, *102*(29), 10393–10398.

Evans, J. St. B. T. (2008). Dual-processing accounts of reasoning, judgment, and social cognition. *Annual Review of Psychology*, *59*(1), 255–278.

Tversky, A., & Kahneman, D. (1985). The framing of decisions and the psychology of choice. In *Behavioral decision making* (pp. 25–41). Springer.

Westfall, J. (2015). PANGEA: Power analysis for general ANOVA designs. *Unpublished manuscript. Available at http://jakewestfall.org/publications/pangea. pdf.*

Wojnowicz, M. T., Ferguson, M. J., Dale, R., & Spivey, M. J. (2009). The self-organization of explicit attitudes. *Psychological Science*, *20*(11), 1428–1435.

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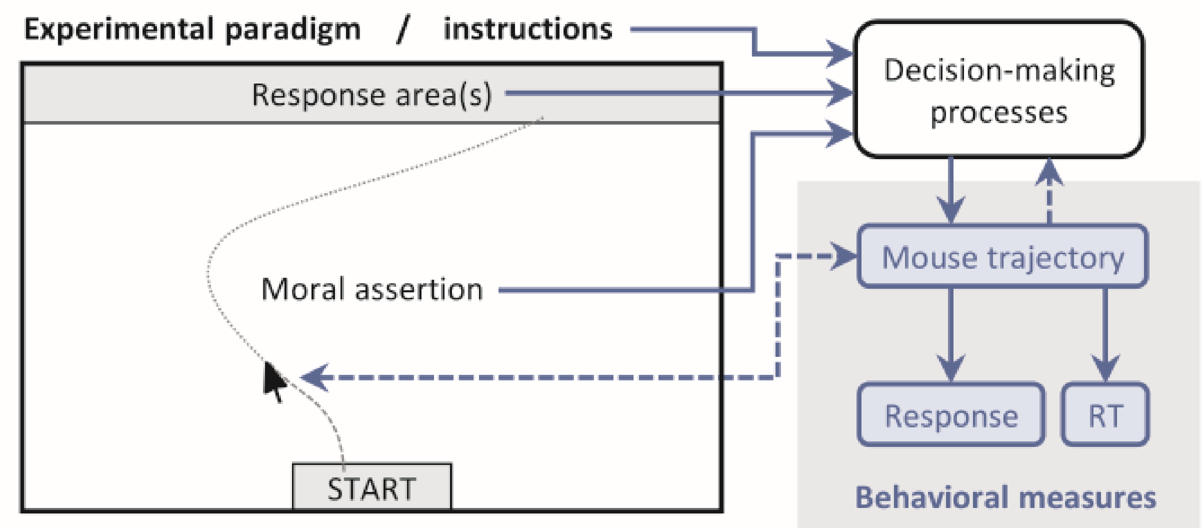

FIGURE 1. Decision-making process as emergent from reciprocal interactions between instructions and visual components of the paradigm (*left*), and motor components that determine final response and response times (*right*). With mouse-tracking, trajectories may at the same time reflect and influence decision dynamics.

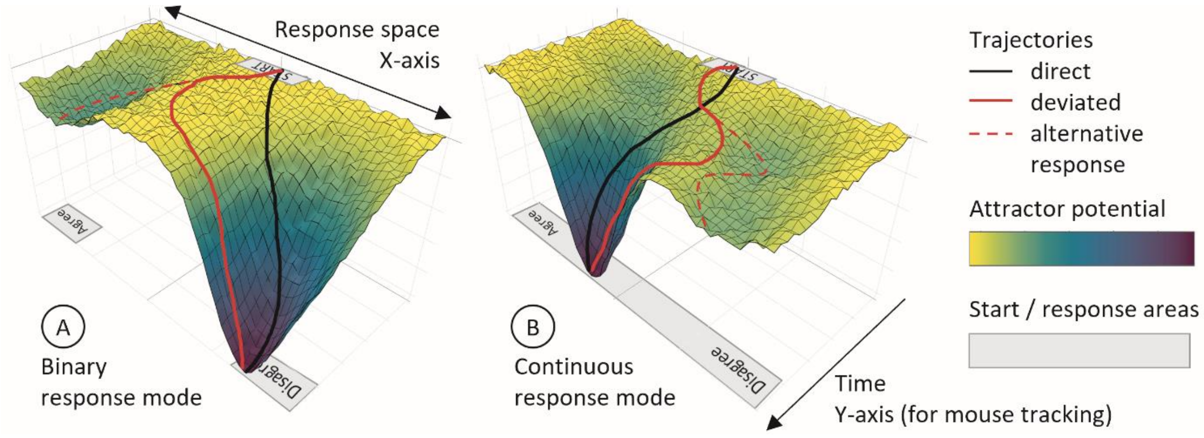

FIGURE 2. Attractor landscape representations of decision-making processes. Although each landscape should correspond to a single decision (mouse) trajectory unfolding through time (and space), several trajectories are represented for communication purposes. Small bumps and deviations may be the consequence of partial stimulus information processing, noise in perception or motor control, while deep valleys generally correspond to basins of attraction and final responses. Response mode (binary or continuous) may impact the entire decision process by constraining the landscape and location of valleys.

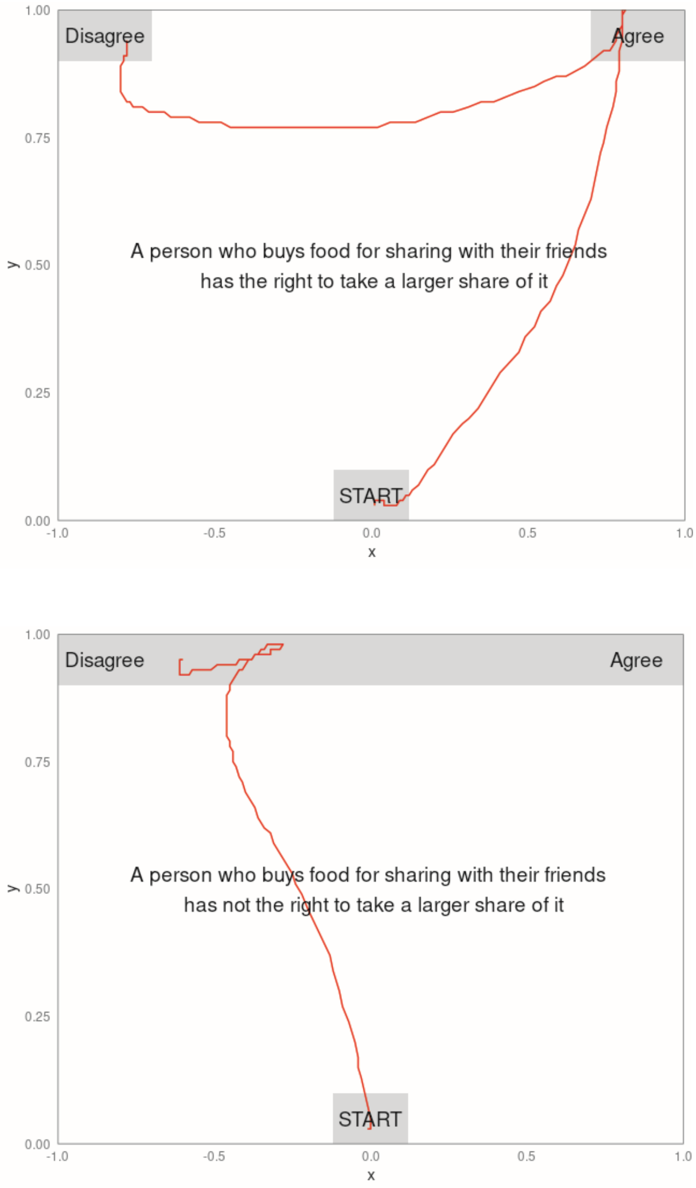

FIGURE 3. Mouse-tracking design from Study 1. Positively framed assertion in binary response mode (*top*) and negatively framed assertion in continuous response mode (*bottom*), with superimposed sample of representative / late-change mouse-trajectories (*in red*).

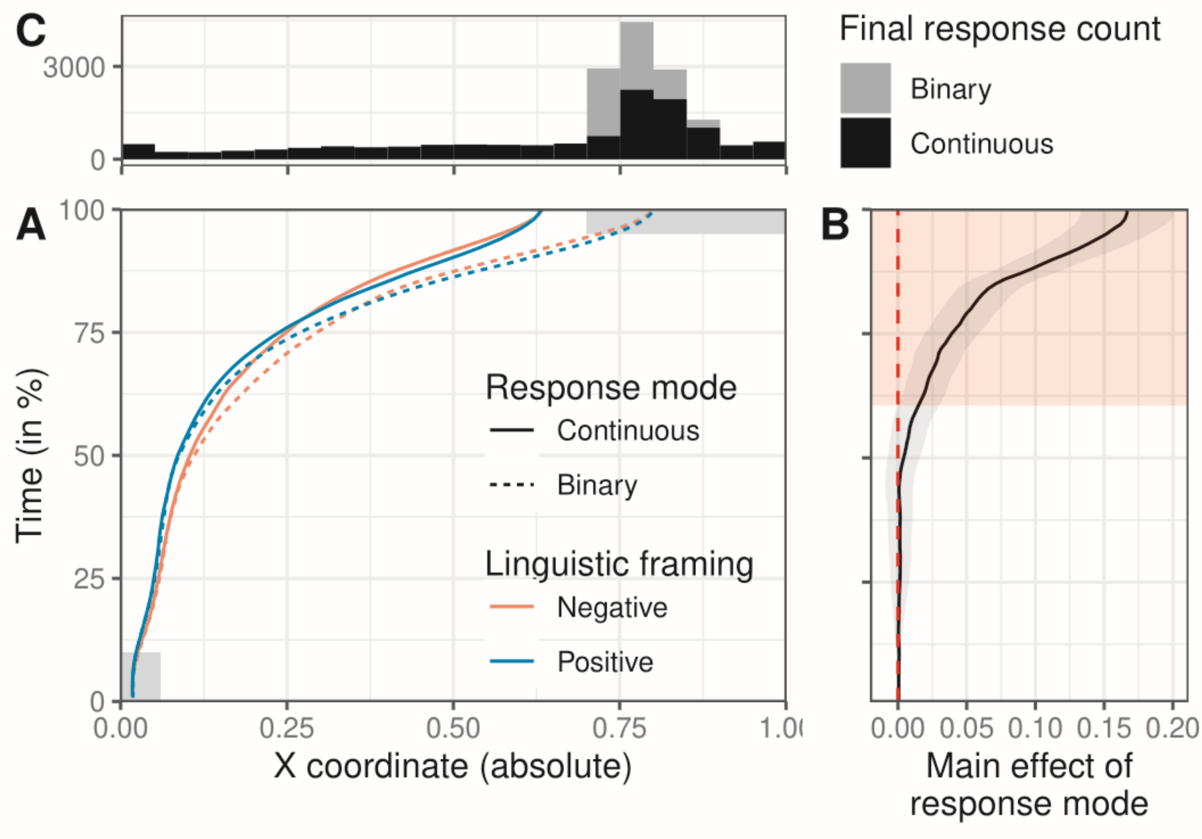

FIGURE 4. Mean trajectory in each condition of Study 1 with the unconditional analysis (*A*), difference between binary and continuous response modes (*B*; with grey 95% CIs, pink background for corrected significance), and the overlayed distributions of final responses for both response modes (*C*) where we had 44% of nuanced answers in the continuous response mode.

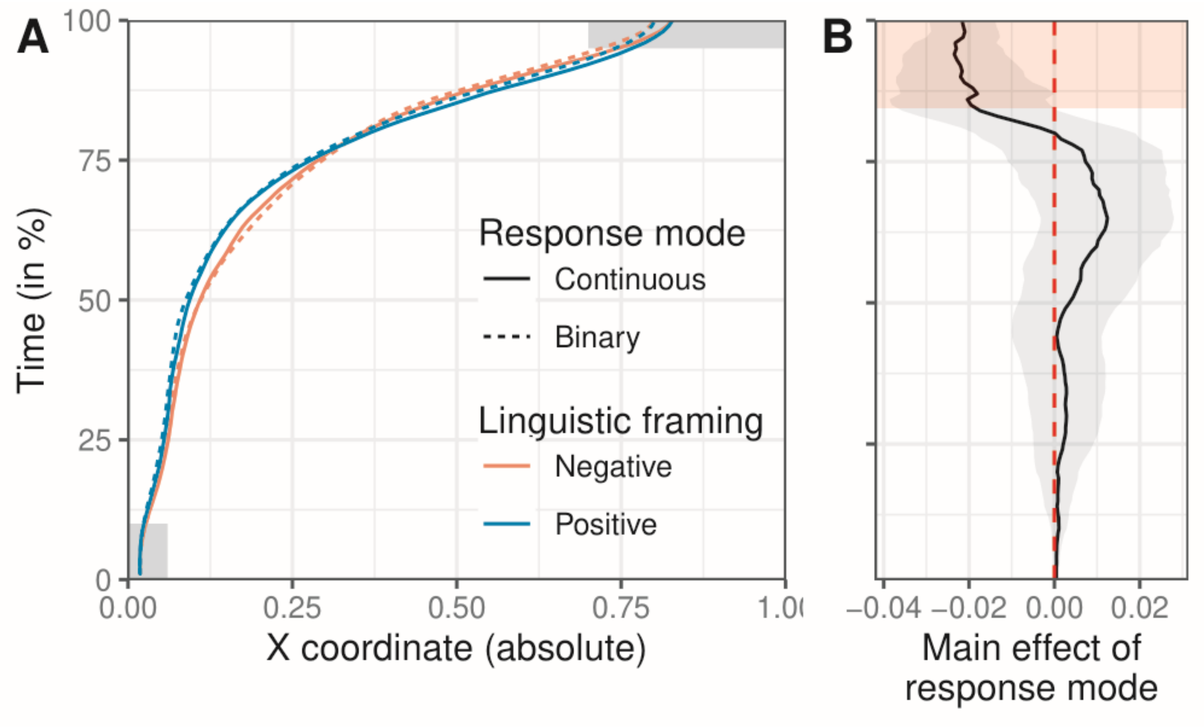

FIGURE 5. Mean trajectory in each condition of Study 1 with the conditional analysis, using all binary mode trajectories but only extreme answer trajectories for the continuous mode (*A*), and difference between binary and continuous response modes (*B*; with grey 95% CIs, pink background for corrected significance).

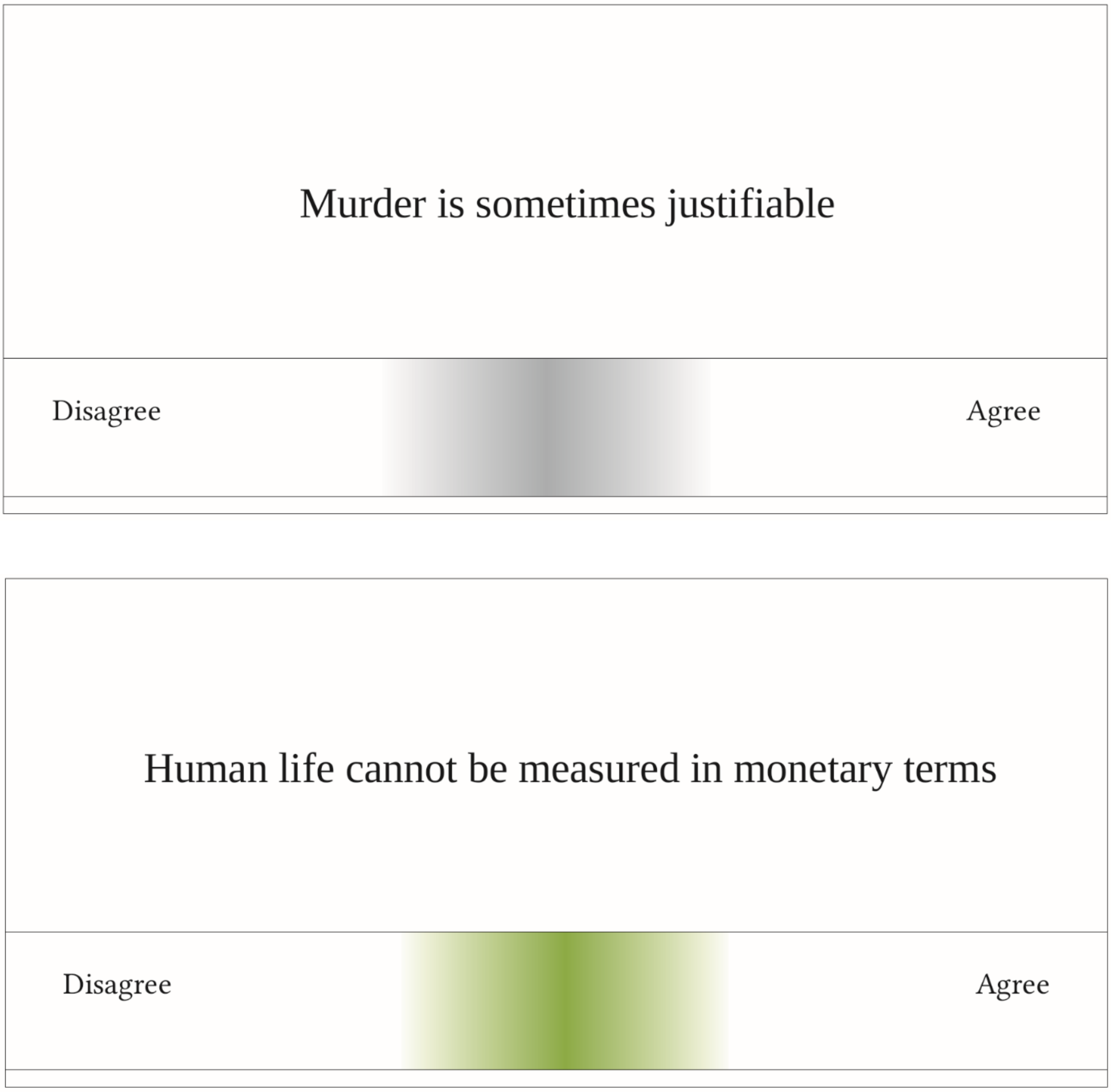

FIGURE 6. Slider design from Study 2. Positively framed assertion in binary response mode (*top*) and negatively framed assertion in continuous response mode (*bottom*). The slider appears in green when clicking at current mouse position is authorized to provide a final response.

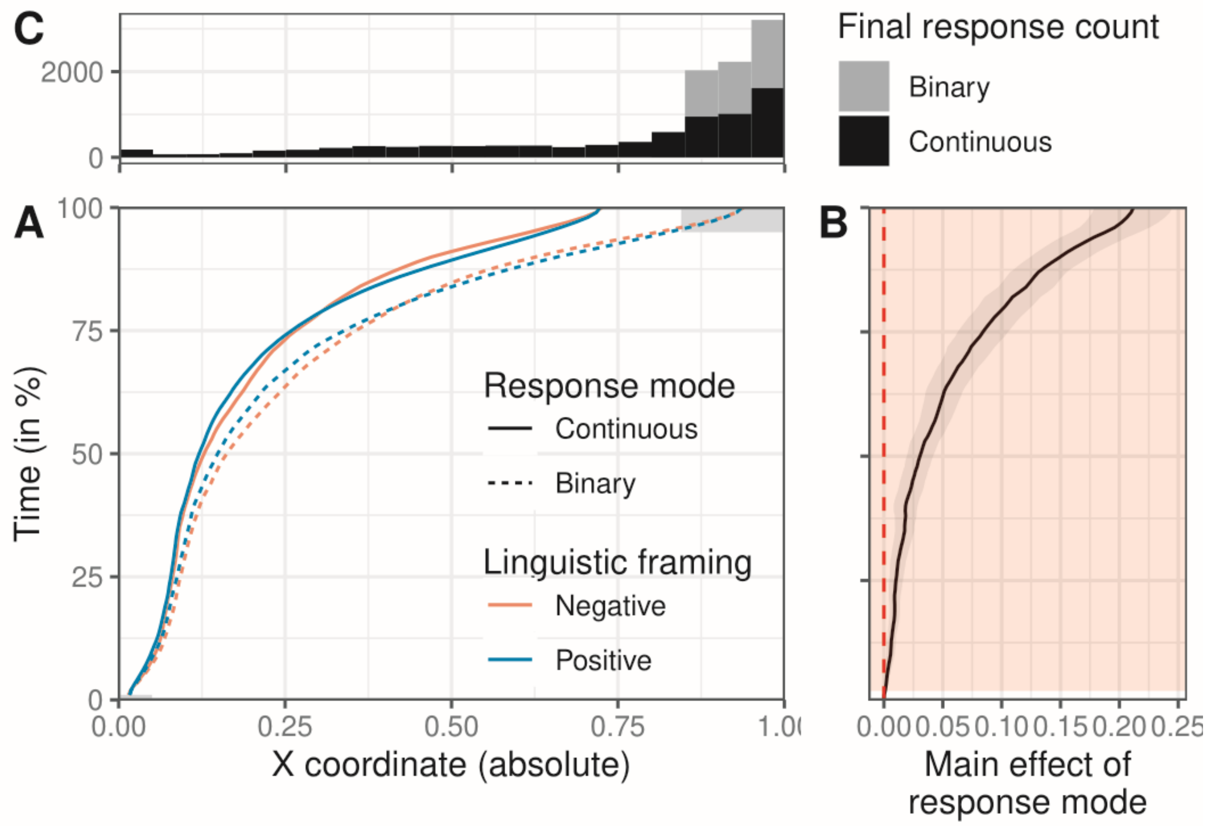

FIGURE 7. Mean trajectory in each condition of Study 2 with the unconditional analysis (*A*), ~~and~~ difference between binary and continuous response modes (*B*; with grey 95% CIs, pink background for corrected significance), and the overlayed distributions of final responses for both response modes (*C*) where we had 52% of nuanced answers in the continuous response mode.

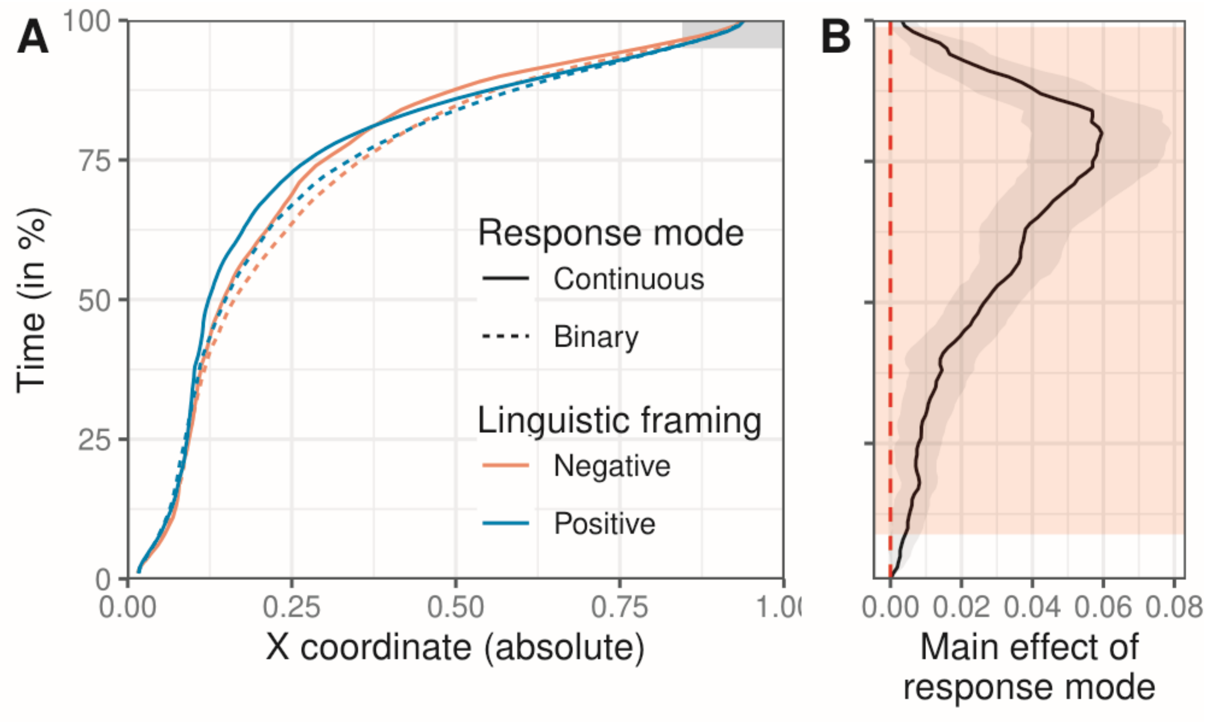

FIGURE 8. Mean trajectory in each condition of Study 2 with the conditional analysis, using all binary mode trajectories but only extreme answer trajectories for the continuous mode (*A*), and difference between binary and continuous response modes (*B*; with grey 95% CIs, pink background for corrected significance).