**Introduction**

Whether with volitional control or spontaneous intuition, people are frequently engaged in causal reasoning. Evaluating causal candidates and establishing “the cause” allows people to modify their future behaviors to avoid harmful outcomes and achieve optimal ones. How people determine causal relationships, however, remains unclear, given that such reasoning is highly influenced by a variety of factors, such as perceived norms and expectations (e.g., Knobe, 2009; Knobe & Fraser, 2008), the degree to which candidate causes and effects covary (Cheng & Novick, 1991; Wasserman, Chatlosh, & Neunaber, 1983), events that did not happen (e.g., Henne, Niemi, Pinillos, De Brigard, & Knobe, 2019; Clarke, Shepherd, Stigall, Waller & Zarpentine, 2015), and causal structure (e.g., Icard, Kominsky, & Knobe, 2017). Inaccurately establishing causality presents potentially severe legal and/or social ramifications (Hart & Honoré, 1985), so to avoid such consequences, it is critical to understand the process by which people navigate the complexities of causal reasoning.

**Mechanistic accounts of causal reasoning**

*Process theories* of causality argue that, when determining causal relationships, people will focus on the direct interaction between covarying events to assess whether there was an exchange of some conserved quantity, such as energy or momentum, from the candidate cause to the given outcome (Dowe, 2000; Salmon, 1997; Wolff, 2007). Supportive evidence shows a greater propensity for people to attribute causation when there is a continuous mechanism that links an action (e.g., kicking a ball) to the outcome (e.g., the ball landing in the goal; Walsh & Sloman, 2011). Relatedly, events that are identified as candidate causes usually directly precede the outcome, and possible enabling conditions (e.g., effective coaching strategies) are less often judged as candidate causes (e.g., Goldvarg & Johnson-Laird, 2001). Therefore, process theories of causality argue that a single consideration of what *actually happened* between the candidate cause and the outcome will be sufficient, and preferred, for establishing causality.

As one alternative account, *counterfactual theories* of causal reasoning argue that people will engage in counterfactual thinking to determine causal relationships (e.g., Lewis, 1973). That is, they consider alternative scenarios to assess whether the candidate cause made a difference in the actual outcome. Counterfactual thinking, thus, engages cognitive (e.g., Weisberg & Gopnik, 2016) and neural (e.g., Parikh, Ruzic, Stewart, Spreng, & De Brigard, 2018; Kulakova, Aichhorn, Schurz, Kronbichler, & Perner, 2013) processes that support both memory reactivation as well as future simulation (for review, see De Brigard & Parikh, 2019). More nuanced accountsshow that counterfactual thinking frequently occurs when outcomes are negative and/or unexpected (Roese, 1997), but that the counterfactual alternative needs to be relevant (Halpern & Hitchcock, 2014; Icard et al., 2017; Kominsky & Phillips, 2018) and plausible (Petrocelli, Percy, Sherman, & Tormala, 2011) to impact causal judgments. Therefore, the idea underlying counterfactual theories of causality is that people will consider what actually happened relative to what reasonably *might have happened* had the candidate cause been absent or altered in some way.

Gerstenberg, Peterson, Goodman, Lagnado, & Tenenbaum (2017) attempted to adjudicate between process andcounterfactual theories by using eye movements to characterize the internal thoughts engaged during casual reasoning. This approach was empirically grounded in a large body of research showing a tight relationship between eye movements and the real-time visuospatial information-processing priorities of the visual system (e.g., Just & Carpenter, 1976; Kowler, Anderson, Dosher, & Blaser, 1995). That is, eye movements reveal what visuospatial information is overtly attended, encoded, and/or recalled at a given moment in time. With this in mind, Gerstenberg et al., (2017) measured eye movements of participants watching videos of two balls (Balls A and B) moving toward a goal and colliding with each other. Prior to viewing, and as a between-subject design, participants were instructed to engage in one of three possible thoughts while watching the video: 1) assess the extent to which Ball B did or did not score into the goal (outcome assessment), 2) think about what would have happened to Ball B had Ball A not been present (counterfactual thinking) or, 3) judge whether Ball A colliding into Ball B caused or prevented Ball B from scoring in the goal (causal reasoning). The authors then compared eye movements across these three conditions to gauge whether gaze behaviors evoked during causal reasoning were more similar those evoked during counterfactual thinking or outcome assessment.

Findings showed that the participants who engaged in causal reasoning and counterfactual thinking showed the most similar gaze behaviors: before the balls collided, participants showed a greater tendency to look at a location in space were Ball B would have traveled had Ball A not interfered. In comparison, those engaged in outcome assessment tended to just look directly at Ball B. These results were most robust when Ball B did not score (i.e., a negative outcome). The authors therefore suggested that participants engaged in causal reasoning were, to some degree, relying on counterfactual thinking to determine causality. The authors acknowledged, though, that gaze behaviors during causal reasoning might not be counterfactual per se but instead reflect anticipatory or hypothetical simulation. Even so, the authors argued that the information overtly attended during causal reasoning could at least be used for counterfactual contrasts once the visual input was removed. Just looking directly at the actual course of Ball B would not afford such contrasts. This idea, though, could not be tested directly, given that the eye movements were recorded online as the stimuli remained visually available.

**The current work**

The current research will build on the findings from Gerstenberg et al. (2017) to further adjudicate between process andcounterfactual theories of causal reasoning. Specifically, gaze behaviors and percept-related event judgements will be used to predict the extent to which counterfactual thinking, as opposed to just outcome assessment, is used for causal reasoning. Participants will complete a ball-shooting-paradigm where they will try to shoot a ball into a goal and retrospectively reflect on the outcome. To do this, participants will 1) decide to shoot a ball to the left or right of a goal, 2) watch a video of the outcome (whether they successfully scored or whether a computer-controlled goalie blocked their ball), 3) retrospectively think about what just occurred (*outcome assessment*), a possible alternative outcome (*counterfactual thinking*), or the candidate cause of the outcome (*causal reasoning*) while looking at a blank screen (within-subject manipulation), and 4) answer percept-related event questions about the outcome relative to the retrospective thought. Participants will be unaware of the specific retrospective thought and event question until after the outcome video. Eye movements will be recorded both while participants watch the outcome video and engage retrospective thoughts, each measurement providing unique insights (further described below).

**Insights from eye movements.** The eye movements that will be recorded during the outcome video will indicate which components of the event were overtly attended. Because participants will not know a priori which event question they will need to later answer, these eye movements will reflect baseline natural tendencies. As such, we do not predict differences in eye movements across retrospective thoughts at initial encoding.

The eye movements recorded during retrospective thinking will then reveal how visuospatial information is recalled within a mental simulation. This idea is supported by research suggesting that eye movements can facilitate the mental recreation of visuospatial information (see Ferreira et al., 2008 for review). For instance, while visualizing previously encoded images, people tended to spontaneously move their eyes in similar patterns as those enacted at initial encoding, which improved the vividness of the mental image and subsequent memory performance (e.g., Damiano & Walther, 2019; Laeng & Teodorescu, 2002; Wynn, Ryan, & Buchsbaum, 2019). Moreover, when instructed to attend to a specific component of the mental image, people moved their eyes toward to the visuospatial information that they were in-the-moment attending (e.g., Johansson & Johansson, 2014; Noton & Stark, 1971). These collective findings suggest that eye movements, even in the absence of online visual inputs, can facilitate the mental recreation of visuospatial information in a way that can, in real-time, delineate which components of a mental image are being recalled.

To adjudicate between process andcounterfactual theories of causal reasoning, we will use the eye movements evoked during outcome assessment and counterfactual thinking to predict the eye movements evoked during causal reasoning. Such predictions will reveal to degree to which participants relied on counterfactual thinking to determine causality. That is, if eye movements during retrospective causal reasoning resemble those during counterfactual thinking, the evidence would support the idea that participants, to a certain degree, engaged counterfactual thinking to determine causality, supporting counterfactual theories. If, however, they more closely resemble those during outcome assessment, evidence would support process theories. Given their retrospective nature, such eye movements will not reflect any future-oriented hypothetical simulations thus address the possible alternative explanation from Gerstenberg et al. (2017).

**Vividness of mental imagery.** We will consider the degree to which participants create visually vivid mental images when engaged in retrospective thinking. Specifically, the degree to which people can subjectively, voluntarily create vivid mental images ranges considerably (Pearson, 2019), with some people reporting photo-like illusions (hyperphantasia) while others reporting a complete lack of visual mental experience (aphantasia; Zeman, Dewar, & Della Sala, 2015). Consequently, the degree to which mental images are reported as vivid and perception-like corresponds to the similarity of neural activation patterns across initial perception and later imagery (Dijkstra, Bosch, & Gerven, 2017), and people who reported more vivid mental imagery were better at recalling previously viewed images (Damiano & Walther, 2019; Laeng & Teodorescu, 2002; Marks, 1973; Wynn, Ryan, & Buchsbaum, 2019). We will, therefore, ask participants to subjectively rate the vividness of any mental image or simulation evoked while engaged in retrospective thinking, predicting that this report will correspond to how much participants move their eyes (e.g., Damiano & Walther, 2019; Laeng & Teodorescu, 2002; Wynn, Ryan, & Buchsbaum, 2019).

We further predict that the vividness of mental imagery will correspond to more extreme precept-related event judgements (e.g., Swann & Miller, 1982). …

**Personal and impersonal perspective.** The current work will also incorporate a personal vs. impersonal perspective between-subjects manipulation in which participants, while engaged in retrospective thoughts, will focus on personal or impersonal aspects of the imagined event. This manipulation will ensure that observed eye movements reflect deliberate, overt attention and memory processes as opposed to any natural bias to focus on one component of the event over the other. Moreover, personal and impersonal episodic simulation, including counterfactual thinking (De Brigard, Spreng, Mitchell, & Schacter, 2015), engage similar but dissociable neural processes (Addis, Wong, & Schacter, 2007; Addis et al., 2009; Hassabis et al., 2007). Moreover, people tend to attribute successes to personal factors and failures to impersonal one (e.g., Bernstein, Stephan, & Davis, 1979), and these responsibility attributions are often related to causal perceptions (e.g., Phillips & Shaw, 2014). Therefore, with a more exploratory objective, we will also ask participants to report self- and goalie-focused responsibility for the given outcome, and we will compare these judgments across personal/impersonal perspectives as well as retrospective thought type.

**Methods**

**Participants**

Participants will be volunteers recruited from Duke University and the local community. An *a priori* power analysis (*f* = .25, (1 - β) = .80 and α = .05, two-tailed) estimated a target sample size of 86 participants. We will over-recruit by ~10% to account for possible cancellations and technical issues, for an estimated 94 recruited participants. Because there is little consensus on the proper approach for conducting a power analysis with mixed-effect, we will also use Monte Carlo simulations to estimate the minimally detectable effect sizes from our data and will interpret our results in the context of those results.

Informed consent will be obtained from each participant following procedures approved by the University Institutional Review Board, and participants will be compensated $12/hr.

**Stimuli and apparatus**

The stimuli will consist of video clips that will be generated with JBox2D. The videos will be presented centered on a screen with a refresh rate of 50 Hz. All stimuli will be presented on a 24-in LCD monitor with a screen refresh rate of 59 Hz. Viewing distances of 94-cm will be maintained with a desk-mounted chin and forehead rest. Therefore, the videos will subtend 13° x 10° of visual angle.

The videos will contain three objects that move around and interact. These objects (illustrated in **Figure 1A**) will include: 1) a goal, in which the participants are trying to score, 2) a ball, which participants will decide where to shoot in attempt to score, and 3) a goalie, which will move horizontally left or right in attempt to block the ball. The ball will always start centered along the edge of the screen, it will always move in the direction chosen by the participant, and it will always move at the same angle and speed. The goalie will always start in the middle of the goal, it will always move either to the left or the right at the same time as the ball, and it will always move at the same speed each trial. The orientation of the display will vary by 180° on 50% of trials, randomized by block. This manipulation will ensure that findings reflect deliberate eye movements indexing internal thoughts as opposed to any subliminal bias to look in a particular direction.

While participants view these videos, we will track eye movements using the EyeLink 1000 Plus (SR Research, Inc.), sampling at a rate of 1000 Hz. The eye-tracker will be calibrated using a nine-point calibration at the beginning of the study. A one-point calibration will be used before each video to correct for drift in eye tracking validity that may occur naturally over time. Saccades will be operationalized as changes in recorded fixation position that exceeds 0.2° with either a velocity that exceeds 30°/s or an acceleration that exceeds 9,500°/s2. All participant responses will be registered with a standard computer mouse click.

**Design and procedures**

After providing written consent and following the 9-point calibration procedures, participants will watch several instructional videos to learn how the objects can move and interact with each other. These videos will expose participants to the starting position of each object, the speed and angle by which each object moves, and how the ball may score or miss the goal according to whether the goalie blocked the ball.

A screenshot of a cell phone

Description automatically generated

**Figure 1.** A) Example video display with upward orientation. B) Example trial sequence for outcome assessment.

Illustrated in **Figure 1B**, at the start of each trial, participants will arbitrarily decide whether to shoot the ball to the left or right of the goal. They will then watch a video of the outcome, including whether they scored or missed. Unknown to the participant, these outcomes will occur equally often as either a *score* (50% of total trials) or *miss* (50% of total trials) trial. Participants will then see a text-prompt in the center of the screen for 2 seconds: Remember, What If, or Cause. This prompt will indicate what type of thought should be engaged during the subsequent blank display, with, as a between-subject manipulation, a focus on either the ball (*self-focused* *condition*) or the goalie (*other-focused* *condition*). Specifically, as a within-subject manipulation, if participants see the prompt Remember, they should think about/visualize the actual sequence of events that just occurred (*outcome assessment*). If participants see the phrase What If, they should think about/visualize what would have happened had the ball or the goalie moved in a different direction (*counterfactual thinking*). If participants see the word Cause, they should think about/visualize the candidate cause for the ball scoring or not scoring (*causal reasoning*). Last, participants will answer a series of percept-related questions about the given event and their retrospective thoughts, which are listed in **Table 1** and described below in sequential order. The next trial will start once all questions are completed. Participants will complete 4 blocks of 18 trials. All experiment procedures are estimated to take no more than 60 minutes.

*Table 1. Trial-by-trial percept-related questions for each thought type*

|  |  |
| --- | --- |
| **Vividness of mental image** | |
| Outcome assessment | How vividly could you visualize what [your ball/the goalie] just did? |
| Counterfactual thinking | How vividly could you visualize what would have happened if [your  ball/the goalie] went in the other direction? |
| Causal reasoning | How vividly could you visualize whether [your ball/the goalie]  caused the outcome? |
|  |  |
| **Event ratings** | |
| Outcome assessment | To what extent do you think your ball scored? |
| Counterfactual thinking | To what extent do you think the ball would have scored if [your ball/the goalie] had gone in the other direction? |
| Causal reasoning | To what extent did [your ball’s/the goalie’s] moving cause the ball to  [score/not score]? |
| All: Confidence | How confident are you in your response? |
|  |  |
| **Responsibility judgements** | |
| All: Responsibility | How responsible are you for the ball [scoring/not scoring]? |
| How responsible is the goalie for the ball [scoring/not scoring]? |

*Note.* Brackets indicate how each question varies by self- vs. other-focused thinking and/or score vs. miss trials.

**Vividness.** Subject vividness of the mental image created during retrospective thinking will be gauged with a 1-5 Likert scale adapted from the second edition of the Vividness of Visual Imagery Questionnaire (VVIQ2; Marks, 1995), with 1 indicating *No image at all, you only “know” that you are thinking of the objects* and 5 indicating *Perfectly clear and lively as real as seeing*.

**Event ratings.** Participants will next answer a percept-related question about the given event, which will vary by thought type, and asked to rate the confidence in their response using a continuous slider scale, with the leftmost extreme end *Not at all* and the rightmost end indicating *Very much*. These questions are adapted from those used in Gerstenberg et al., (2017).

**Responsibility judgments.** Lastly, participants will use the same continuous slider scale to ascribe self- and goalie-oriented responsibility for the outcome.

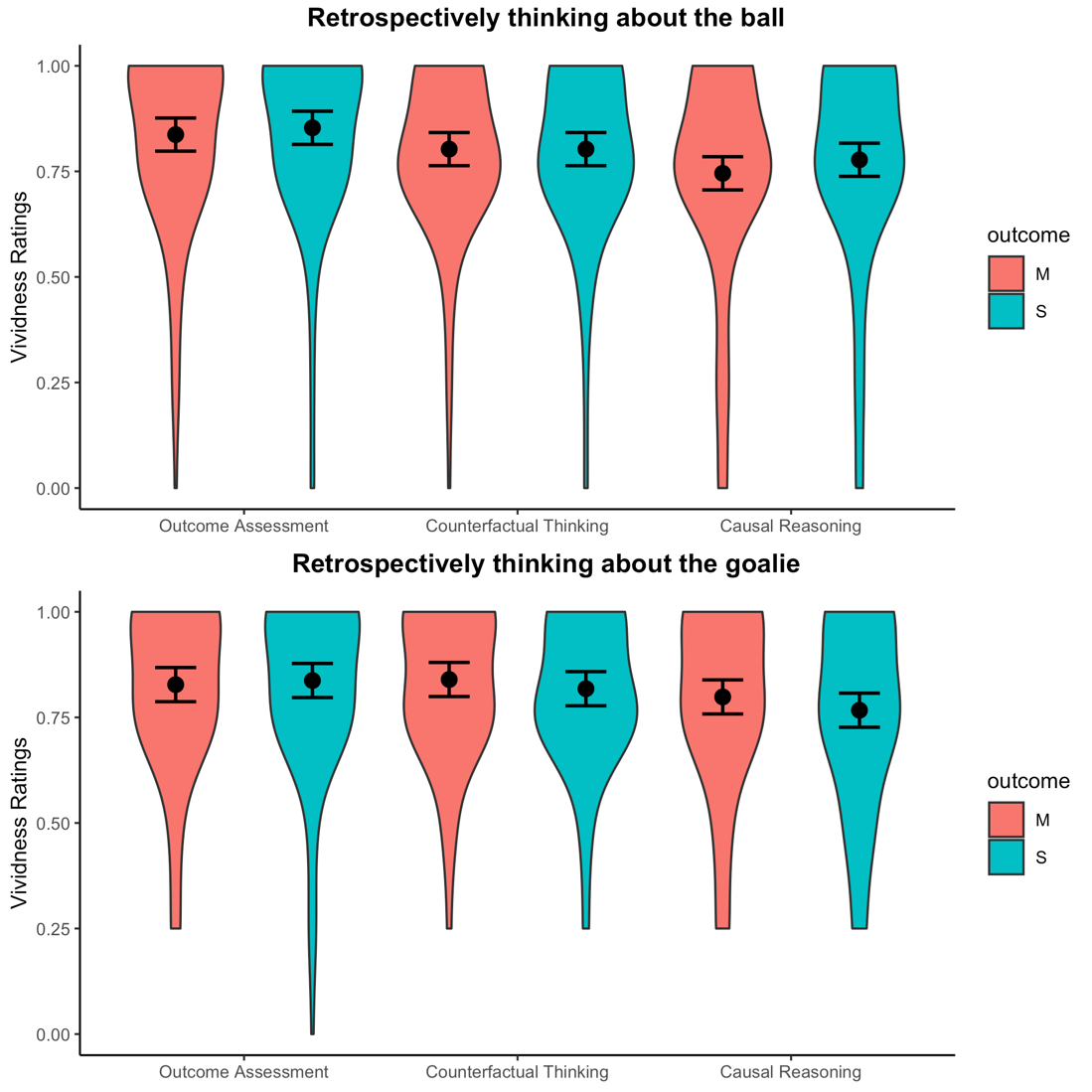
**Behavioral Pilot**

We conducted an online, behavioral pilot study (N = 250) using Amazon Mechanical Turk. Participants were randomly assigned to the personal perspective or impersonal perspective conditions. A total of 16 personal and 22 impersonal participants were removed for failing at least one of two questions used to gauge participants’ engagement and compliance (final N = 212). Participants in this pilot only viewed the upward display orientation and completed 6 trials (a score and miss trial for each thought type, randomized).

**Vividness.** We first assessed whether the vividness of mental simulation varied across the type of retrospective thought, the success of the outcome, and/or the perspective of the mental simulation. Ratings of vividness (1-5) were normalized on a 0-1 range. Using the *lme4* package in R (Bates, Mächler, Bolker, & Walker, 2015), we then conducted a mixed-effect linear regression analysis that modeled *vividness* as a *thought* (three levels: outcome assessment [reference group], counterfactual thinking, and causal reasoning) by *perspective* (personal [reference group] and impersonal) by *outcome* (two levels: miss [reference group] and score) three-way interaction with *participant* as a random effect.

Findings from the full model are reported in **Table 2.** As illustrated in **Figure 2,** post-hoc comparisons using the *emmeans* package in R (Lenth, 2017)[[1]](#footnote-1) showed that participants reported more vivid mental simulations for outcome assessment than counterfactual thinking (*B* = .04, *SE* = .01, *p* = .004) but only when participants were focused on the ball (personal perspective). Those who were focused on the goalie (impersonal perspective) reported similar vividness ratings for outcome assessment and counterfactual thinking (*B* = .00, *SE* = .02, *p* = .809). Mental simulations for outcome assessment were more vivid than for causal reasoning regardless of whether participants were focused on the ball (*B* = .08, *SE* = .01, *p* < .001) or the goalie (*B* = .05, *SE* = .02, *p* = .001). Further, mental simulations for counterfactual thinking were reported as more vivid than causal reasoning again regardless of whether participants were focused on the ball (*B* = .04, *SE* = .01, *p* = .005) or the goalie (*B* = .05, *SE* = .02, *p* = .002)

These findings indicate that the vividness of mental images evoked during retrospective thinking varied across thought type. This, along with our prediction that the vividness of mental simulation might impact any percept-related event judgments from retrospective thinking, we included vividness ratings as a variable in analyses investigating event ratings (described next).



**Figure 2.** Estimated marginal means and standard errors for normalized ratings indicating the vividness of mental images evoked during retrospective outcome assessment, counterfactual thinking, and causal reasoning.

*Table 2.* *Test statistics for all variables in the regression models predicting the vividness of mental simulations*

|  |  |  |  |
| --- | --- | --- | --- |
| **Predictors** | ***B*** | ***95% CI*** | ***p*** |
| (Intercept) | **.837** | **.798 –.876** | **< .001** |
| Outcome [score] | .02 | -.03 – .06 | .338 |
| Thought [counterfactual thinking] | -.03 | -.08 – .01 | **.097** |
| Thought [causal reasoning] | **-.09** | **-.13 – -.05** | **< .001** |
| Perspective [goalie] | -.01 | -.07 – .05 | **.741** |
| Outcome [score] \* Thought [counterfactual thinking] | -.02 | -.07 – .04 | .584 |
| Outcome [score] \* imagination [causal reasoning] | .02 | -.04 – .07 | .584 |
| Outcome [score] \* Perspective [goalie] | -.01 | -.07 – .05 | .831 |
| Thought [counterfactual thinking] \* Perspective [goalie] | .05 | -.01 – .11 | .117 |
| Thought [causal reasoning] \* Perspective [goalie] | **-.06** | **.00 – .12** | **.035** |
| (Outcome [score] \* Thought [counterfactual thinking]) \* Perspective [goalie] | -.02 | -.10 – .07 | .712 |
| (Outcome [score] \* Thought [causal reasoning]) \* Perspective [goalie] | -.06 | -.14 – .03 | .173 |
| **Random Effects** | | | |
| σ2 | .02 | | |
| τ00 id | .02 | | |
| ICC | .46 | | |
| N id | 212 | | |
| Observations | 1272 | | |
| Marginal R2 / Conditional R2 | .02 / .48 | | |

*Note.* *B* = unstandardized coefficients; *CI* = confidence interval; Boldface text indicates *p* < .05; Created with the *sjPlot* package in R (Lüdecke, 2020)

**Predicting causal judgments from internal thoughts.** We next assessed the extent to which participants relied on outcome assessment and counterfactual thinking for causal reasoning. To assess this, we first conducted two linear mixed-effect analyses to separately model event judgements for outcome assessment (model 1) and counterfactual thinking (model 2) as a *perspective* (personal [reference group] and impersonal) by *outcome* (two levels: miss [reference group] and score) by *vividness* three-way interaction with *participant* as a random effect.

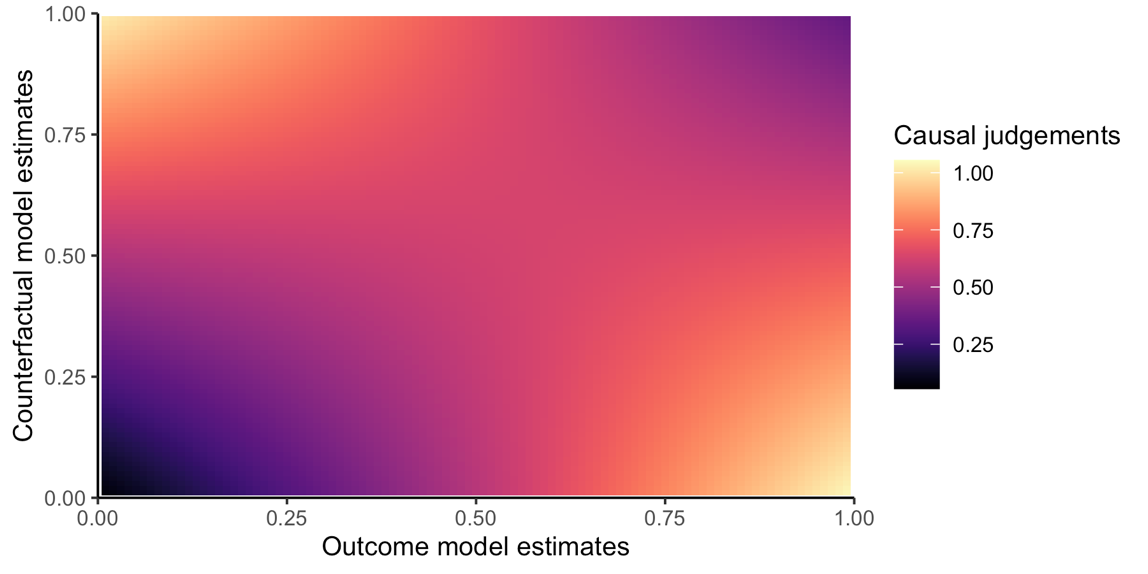
The results from these models are reported in **Table 3**. In both of these models showed that vividness was a significant predictor of event judgements, although this main effect was characterized by an outcome by vividness interaction. Specifically, the vividness of mental simulations for miss trials (*B* = -.34, *SE* = .10, *CI* = -.53 – -.15) negatively predicted outcome judgements but vividness for score trials (*B* = .25, *SE* = .10, *CI* = .06 – .44) *positively* predicted outcome judgements. A post-hoc comparison suggests that these effects were significantly different; *B* = -.58, *SE* = .14, *p* < .001. This pattern of results was reversed for counterfactual judgments. That is, the vividness of mental simulations for miss trials (*B* = .39, *SE* = .12, *CI* = .16 – .62) positively predicted counterfactual judgements but vividness for score trials (*B* = -.34, *SE* = .11, *CI* = -.56 – -.12) *negatively* predicted counterfactual judgements. A post-hoc comparison suggests that these effects were significantly different; *B* = .73, *SE* = .16, *p* < .001.

*Table 3.* *Test statistics for all variables included in the regression models predicting event judgements for outcome assessment and counterfactual thinking*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Model 1: Outcome assessment** | | | **Model 2: Counterfactual thinking** | | |
| *Predictors* | *B* | *95% CI* | *p* | *B* | *95% CI* | *p* |
| (Intercept) | **.48** | **.26 – .70** | **<.001** | **.53** | **.28 – .79** | **< .001** |
| Outcome [score] | .26 | -.06 – .58 | .105 | -.08 | -.43 – .26 | .640 |
| Perspective [impersonal] | .14 | -.18 – .46 | .400 | -.00 | -.39 – .38 | .982 |
| Vividness | **-.26** | **-.51 – -.00** | **.050** | **.40** | **.09 – .71** | **.011** |
| Outcome [score] \* Perspective [impersonal] | -.259 | -.72 – .20 | .268 | .28 | -.25 – .81 | .295 |
| Outcome [score] \* Vividness | **.43** | **.06 – .80** | **.022** | **-.56** | **-.98 – -.14** | **.009** |
| Perspective [impersonal] \* Vividness | -.17 | -.54 – .21 | .384 | -.02 | -.47 – .44 | .949 |
| (Outcome [score] \* Perspective [impersonal]) \* Vividness | .31 | -.22 – .84 | .251 | -.34 | -.97 – .29 | .290 |
| **Random Effects** | | | | | | |
| σ2 | .08 | | | .09 | | |
| τ00 | .00 id | | | .00 id | | |
| N | 212 id | | | 212 id | | |
| Observations | 424 | | | 424 | | |
| Marginal R2 / Conditional R2 | .56 / NA | | | .46 / NA | | |

*Note.* *B* = unstandardized coefficients; *CI* = confidence interval; Boldface text indicates *p* < .05;

We next conducted a mixed-effect linear regression analysis that modeled causal judgements as a *model 1* by *model 2* interaction with *participant* as a random effect. These findings showed that model 1 (*B* = 1.00, *SE* = .28, *p* < .001) and model 2 (*B* = .97, *SE* = .29, *p* = .001) were significant predictors of causal judgments, but these main effects were characterized by a significant interaction; *B* = -1.69, *SE* = .39, *p* < .001. As illustrated in **Figure 3**, causal judgements were greatest when outcome model estimates were high and counterfactual model estimates were low as well as when counterfactual model estimates were high and outcome model estimates were low. This finding suggests that outcome assessment and counterfactual thinking predicted causal judgements, supporting counterfactual theories of causal reasoning.



**Figure 3.** Causal judgements as predicted by outcome model estimates and counterfactual model estimates.

**Discussion.** [include after feedback, framed how the intro pans out]

**Eye tracking pilot**

**Proposed analyses and anticipated results**

**Discussion**

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1. Comparisons were adjusted using the Tukey method for multiple comparisons. [↑](#footnote-ref-1)