# False contingency knowledge reverses the color-word contingency learning effect

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## Abstract

In learning research, there is an ongoing debate about the role of awareness in human contingency learning. While a large part of the contingency learning (CL) effect actually reflects episodic retrieval of previous responses (Giesen et al., 2020; Schmidt et al., 2020), a significant residual CL effect remains, which reflects a genuine impact of global contingencies on behavior (Rudolph & Rothermund, 2024; Xu & Mordkoff, 2020). In a highly-powered (*N* =120) pre-registered study, we tested the influence of contingency awareness on the genuine CL effect by giving true or false instructions about the existing color-word contingencies. We found that the genuine CL effect is modulated by awareness, as true (false) instructions amplified (reduced) the residual CL effect (see also Schmidt & De Houwer, 2012). Further, participants who maintained the belief in the falsely instructed contingencies until the end of the experiment actually showed a reversed genuine CL effect, characterized by faster responses in low contingency trials that corresponded to the falsely instructed color-word combination. In sum, our findings suggest that genuine human CL, which is free from the influence of episodic retrieval, reflects propositional beliefs rather than association formation.


Keywords*: Contingency learning, contingency awareness, episodic retrieval, propositional learning*

How organisms learn the relationships (contingencies) between events, actions, and their consequences is a central question in cognitive research (e.g., Allan, 2005; De Houwer & Hughes, 2017; Garner, 2014; Shanks, 2010). A valuable experimental framework for investigating the cognitive mechanisms that underlie human contingency learning is the color-word contingency learning paradigm (Schmidt et al., 2007): In this paradigm, participants have to categorize the colors of neutral adjectives, which are presented with varying frequencies in certain colors, creating high-contingency combinations (frequent color-word pairings) and low-contingency combinations (infrequent color-word pairings). Even though the words are irrelevant for the task (distractors), the contingencies between words and colors impact performance, resulting in a global contingency learning (CL) effect, which is characterized by better performance (i.e., faster RT and lower error rates) in high compared with low contingency trials.

Prior findings suggest that episodic retrieval of previously executed responses explain a large part of the CL effect (Giesen et al., 2020; Rudolph & Rothermund, 2024; Schmidt et al., 2020; Xu & Mordkoff, 2020). By stimulus-based retrieval, the response which was bound to the distractor stimulus during its last occurrence becomes reactivated (i.e., the word “klein” *retrieves* the color “red” and/or the corresponding response). Due to the confounding of contingencies with retrieval (highly frequent color-word combinations typically retrieve a matching response whereas low frequency combinations typically retrieve a mismatching response; Giesen et al., 2020; Schmidt et al., 2020), episodic retrieval accounts for a large portion of the CL effect. After controlling for episodic retrieval of previous responses, however, some studies still reported a significant *residual* CL effect (Rudolph & Rothermund, 2024; Xu & Mordkoff, 2020). This residual (i.e., retrieval-adjusted) CL effect can be considered as genuine contingency learning, as it reflects the impact of global contingencies on behavior after controlling for the effect that is due to retrieving the single most recent episode in which the distractor had been presented.

Within the existing literature, there are two popular theoretical accounts that aim to explain how global contingencies guide behavior, namely associative learning and propositional learning. The associative learning account postulates the automatic formation of links between mental representations of stimuli and responses through repetition and co-occurrence (Pavlov, 1927; Rescorla, 1972). Accordingly, the CL effect results from the gradual emergence of an associative relation between an irrelevant attribute and the color and/or response with which it co-occurred most of the time (Miller, 1987; Mordkoff, 1996; Schmidt et al., 2007; Schmidt & De Houwer, 2016a, 2016b; Xu & Mordkoff, 2020). Once such an associative link is formed, the presentation of the stimulus automatically activates the corresponding stimulus and/or response representation, which then facilitates responding in high compared to low contingency trials. Associative learning is characterized as an automatic process, as it operates unconsciously and requires no cognitive engagement (Bargh, 1994; De Houwer, 2009; McLaren et al., 1994).

Propositional learning, in turn, involves the strategic testing of hypotheses concerning relational information and results in declarative knowledge of the present contingencies between words and colors and/or responses (Mitchell et al., 2009). Thus, the propositional learning account predicts that the CL effect depends on participants becoming *aware* of the color-word contingencies and applying their knowledge about the contingencies in their behavioral decisions.

While earlier findings suggest that CL can occur in the absence of awareness (Schmidt et al., 2007), other studies have demonstrated that the CL effect is modulated by awareness: That is, awareness of the word-color contingencies is typically accompanied by larger CL effects, and instructing participants about the correct/true (vs. incorrect/false) color-word contingencies amplifies (vs. reduces) the CL effect (Schmidt & De Houwer, 2012). Analogous results of an influence of contingency awareness on CL effects have recently been reported in related paradigms (Arunkumar et al., in press; 2022; 2023; Rothermund et al., 2024).

Within these early studies investigating the relationship of CL and contingency awareness (Schmidt et al., 2007; Schmidt & De Houwer, 2012), however, episodic retrieval was not taken into account. In a more recent study (Rudolph & Rothermund, 2024), the *residual* (retrieval-adjusted) CL effect was always accompanied by contingency awareness, meaning that genuine CL effects were only observed if participants were aware of the respective color-word contingency they experienced during the experimental task. However, since the authors did not manipulate contingency awareness experimentally, it remains unclear whether contingency awareness plays a causal role in the manifestation of the CL effect. Alternatively, it remains possible that associative learning is the precondition for contingency awareness to emerge (rendering the latter as a result, rather than a cause of learning). This reasoning would imply that associative learning might also be the underlying cause of the genuine CL effect.

**The present study**

The primary goal of the present study is to clarify the cognitive source of the genuine (i.e., retrieval-adjusted) CL effect. By employing strong contingencies, we wanted to provide optimal conditions for finding a robust residual CL effect that is significant even after controlling for retrieval effects of the most recent episodes in which the word had been presented (Rudolph & Rothermund, 2024; Xu & Mordkoff, 2020). Furthermore, the major aim of this study was to test the causal effect of contingency awareness on genuine CL. To achieve this, the present study endorsed an experimental manipulation of awareness by instructing correct (i.e., true) and incorrect (i.e., false) contingencies. Importantly, the associative and the propositional learning account make different predictions about the impact of these instructions on CL: If the genuine CL effect reflects associative learning, it should not be affected by verbal instructions. Instead, the *actual contingencies* (i.e., the frequency of the experienced color-word pairings) should determine the size and direction of the CL effect. If, however, the residual CL effect is propositional in nature, then true (false) instructions should amplify (reduce) the CL effect – independently of the actual contingencies. Hence, *contingency awareness* should determine the size and direction of the CL effect, regardless of the actual contingencies (see also Mitchell et al., 2009).

To manipulate contingency awareness, each participant received one true (i.e., an instruction that matched the actual contingencies) and one false instruction (i.e., an instruction that mismatched the actual contingencies) about the color-word contingencies in the experimental task. By manipulating – rather than just measuring – contingency awareness, while simultaneously controlling for effects of episodic retrieval, the present study is the first to investigate the causal role of contingency awareness for genuine CL effects.

In addition to the experimental awareness manipulation, contingency awareness was also measured. To determine awareness of color-word contingencies separately for each word within each participant, we employed a forced choice recognition task at the end of the experiment (see Hirshman, 1995; Shanks & John, 1994; Stahl & Bading, 2020; Stahl et al., 2016).

### Hypotheses

First, we predicted a robust residual CL effect, specified through faster responding in high compared to low contingency trials, even after controlling for response retrieval of the most recent occurrence of the distractor word. Second, we expected that the residual CL effect is modulated by instructions, that is, true (false) instructions should amplify (reduce) the residual CL effect. Third, we hypothesized that the direction of the residual CL effect is affected by contingency awareness (i.e., participants who display belief in the falsely instructed contingencies should show a *reversed* CL effect, characterized by faster responses in low contingency trials).

## Method

### Ethics vote, pre-registration, and open access

Ethical approval was granted by the Ethics Committee of the FSU Jena (FSV 23/071). Prior to data collection, the exact method, design, hypotheses, data preparation, and planned analyses were pre-registered online (https://aspredicted.org/vz9ar.pdf). All data and analyses scripts are available at https://osf.io/byqhx/.

### Required sample size and a priori power calculations

We conducted an independent pilot study on Prolific (which is not part of the present study) and ran a power analysis based on the observed effects using *G*Power* 3.1.9.7 (Faul et al., 2007). The results indicated that we need $N = 116$ participants to detect an interaction effect ($d_z = 0.465$) between genuine CL effects (after controlling for episodic retrieval effects) and contingency awareness with a power of $1\text{-}ß = .80$ in a hierarchical multilevel analysis.

### Participants

A total of $N = 120$ psychology students of the FSU Jena (17 male, 102 female, 1 diverse) with a mean age of 20.31 ($SD = 2.66$) took part in the experiment, which was conducted in presence (maximum number of 15 participants per session seated at isolated workplaces) in a lab at the FSU Jena. All participants had a mean error rate below 20% in the training block and within the experimental blocks, and successfully remembered the instructed contingencies when probed in an incidental instruction check before the main experimental task started. Hence, the data of all participants could be processed. All participants were native German speakers. They gave their informed consent prior to participation in the study and received a partial course credit for participation. The experiment lasted approximately 30 minutes.

### Design

The experiment comprised a 2 (contingency: high vs. low frequency combination of color and word) x 2 (response relation between the present response and the response of the last occurrence of the same word: same vs. different response) x 3 (contingency instructions: true vs. false vs. none) repeated measures design, with all factors being manipulated within participants (see Figure 1 for an illustration of the contingency and response relation factor). The factors contingency and instructions were counterbalanced across stimuli, resulting in 3 x 3 = 9 unique conditions that participants were randomly assigned to. Reaction times (RT) functioned as the dependent variable of interest.

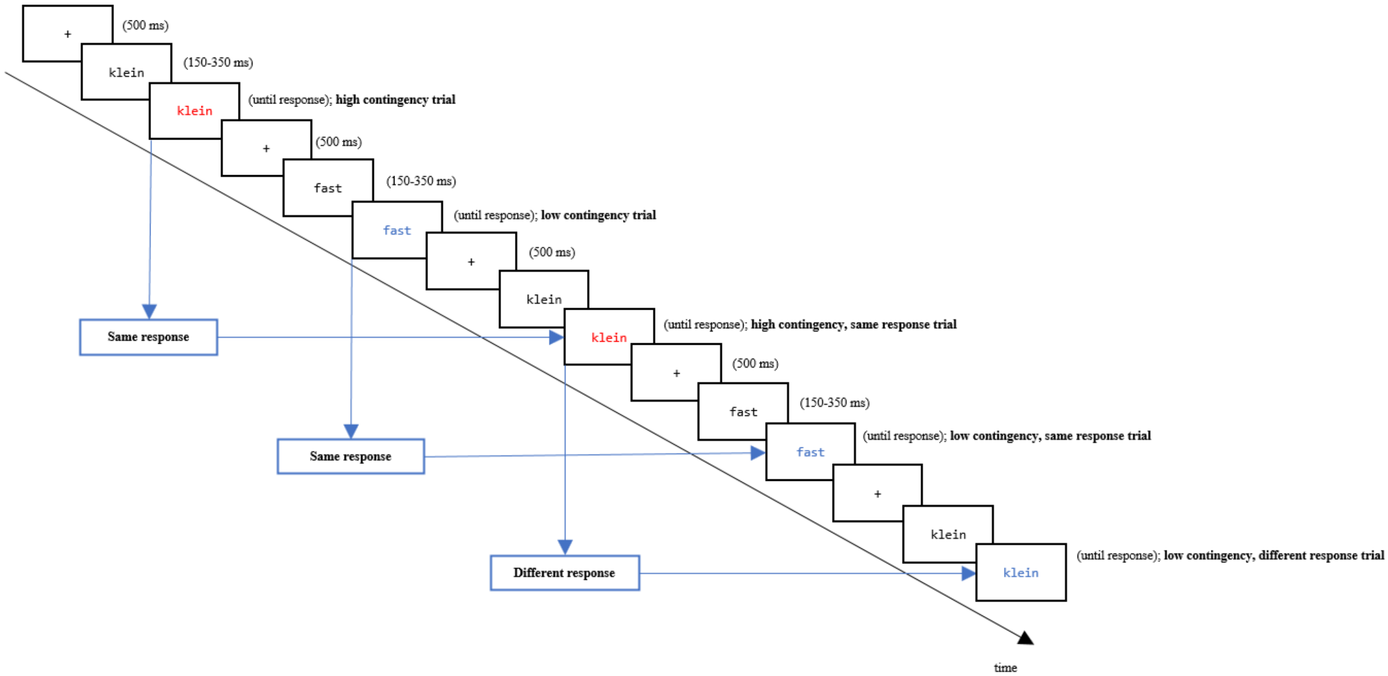


***Figure 1.*** Schematic trial procedure in the color classification task. Trials are classified as high contingency (e.g., 'klein' in red font) and low contingency trials (e.g., 'klein' in blue font). Arrows illustrate different types of response relations between the current trial and the last occurrence of the same distractor word (same response, different response).

To manipulate color-word contingency, we created two conditions depending on the frequency of the color-word combinations: In the high contingency (hc) condition, words are presented with colors that are assigned to a response that is frequently combined with this word (4 out of 6 occurrences), whereas for the two low contingency (lc) conditions, words are presented with colors that are seldomly combined with this word (two word-color combinations presented 1 out of 6 occurrences, see Table 1). In addition, each trial can be categorized as to whether during the last occurrence of the distractor word the same or a different response was required (factor "response relation"; see Fig. 1). Although hc and lc trials predominantly have last occurrences with same or different responses, respectively (Giesen et al., 2020; Schmidt et al., 2020), the reverse combinations (hc – different response, lc – same response) are also possible and occur with sufficient frequency to disentangle the effects of these factors, and to estimate residual effects of contingency after controlling for the influence of response relation (e.g., Rudolph & Rothermund, 2024).

**Table 1**

*Color-word contingency manipulations in the color classification task*

| Target (color) | Correct Response | Distractor (word) | | |
|---|---|---|---|---|
| | | klein | ganz | fast |
| red | left | 2/3 (hc) | 1/6 (lc) | 1/6 (lc) |
| blue | middle | 1/6 (lc) | 2/3 (hc) | 1/6 (lc) |
| yellow | right | 1/6 (lc) | 1/6 (lc) | 2/3 (hc) |

*Note.* hc, high contingency color-word combinations; lc, low contingency color-word combinations. The specific assignment of words to colors represents only one instance of the counterbalanced design.

## Apparatus and Stimuli

The experiment was programmed with *E-Prime 3.0*. Stimuli were three neutral German adjectives (klein [small], ganz [whole], fast [almost]) which appeared in one of three colors (red, blue, yellow), resulting in 3 x 3 = 9 color-word combinations. Stimuli were presented in Consolas font (18 pts.) on a black background. The keyboard served to collect responses. Each of the three target colors was assigned to one response key. Specifically, participants should use their index, middle, and ring fingers of their dominant hand to press the "g" (left), "h" (middle) and "j" (right) keys to classify the colors of the words (see Figure 2).

## Procedure

Participants were first semester psychology students who were given the chance to participate in the study to receive partial course credit. Upon their arrival in the laboratory, participants were told to sit in front of a computer. Via the screen, they received information about procedure, duration, and data collection of the experiment. Demographic information (gender, age, handedness) was gathered at the beginning of the experiment, followed by the consent page. If participants consented to participate, instructions were given; otherwise, the study was terminated.

Participants were informed that they would see words in different colors and that their task was to categorize the color of the words. After providing an example for the task, participants were asked to keep their index, middle, and ring finger above the response keys and to react as fast and correct as possible. Then, participants worked through a training block consisting of 12 trials containing words which were presented in one of the three colors (red, blue, yellow). The words in the training block differed from the word stimuli in the experimental blocks and no color-word contingency was present. Participants had to repeat the training block if they committed more than 20% errors. If the error rates still exceeded 20% after the repetition, the experiment was aborted.

After completing the training block, each participant received one true and one false instruction about the color-word contingencies (English translation; unbeknownst to participants, the first part of the instruction always reflected a true contingency, whereas the second part always reflected a false contingency):

> "IMPORTANT! Some words in the experiment are presented most often in a certain color. Knowing which word is presented in which color can help you. Specifically: The word 'klein' appears most often in red. The word 'ganz' appears most often in yellow. Remember these color-word relationships as you perform the task."

Note that the exact instructions (i.e., words and colors) differed depending on the counterbalancing condition each participant was assigned to. After each instruction, the word stimulus was displayed in the respective color. No instructions were given about the remaining third color and third word. After reading the instructions, participants were asked to indicate the instructed color of the two words via keypress (1-3). Participants had to indicate both colors correctly, otherwise the instructions were shown again, and the questions were repeated. If they committed an error during the repetition, the experiment was aborted.

After the training block, participants worked through eight experimental blocks. Each block consisted of 72 color-word combinations. Every trial started with a fixation cross (500 ms) followed by a short presentation of the distractor (word in white). The duration was randomly selected from one out of five possible values (150, 200, 250, 300 or 350 ms) after which the final color-word combination appeared until key press. Incorrect responses elicited the feedback “Error – be more accurate! Continue with space-bar...”. Feedback was displayed in white font on red background until key press. Afterwards, the next trial started immediately. Throughout the experiment, the assignment of colors to corresponding responses (left, middle or right) was displayed[1] on the upper left, middle and right side of the screen (see Figure 2).

[1] Note that while displaying the assignment of colors to the corresponding responses is standard in color-word contingency learning experiments, experiments using the Stroop task are typically conducted without presenting this assignment throughout the study. This should be considered when discussing findings from the Stroop literature from the perspective of contingency learning.

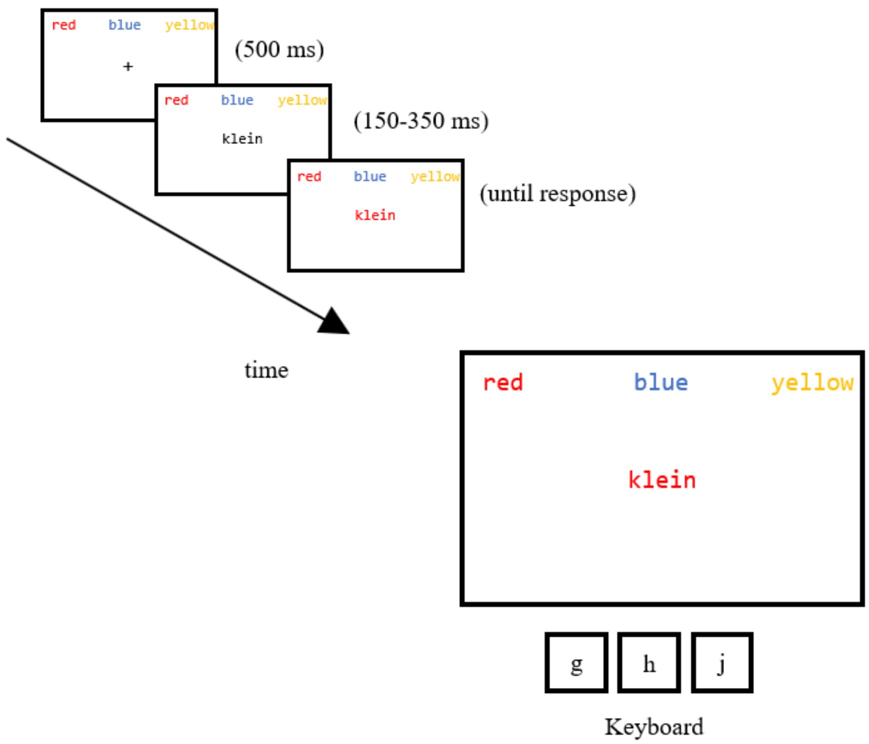


***Figure 2***. Exemplary trial sequence in the color classification task. In the original study, the color labels were printed in German.

After working through the eight experimental blocks, participants completed the contingency awareness assessment (see Figure 3). Participants were asked to give their answers based on the impression during the task. They had to indicate via key press in which color the displayed distractor word was presented most often (forced choice). The assignment of the three possible colors to the response keys (1-3) was randomized for each word. Responses were coded separately for each word within each participant as being either correct (correct color in which the word had been presented most often = contingency aware) or incorrect (false color that was assigned to a different key = contingency unaware). After the assessment, the experiment ended and participants were given a code that served as a proof for successful completion.

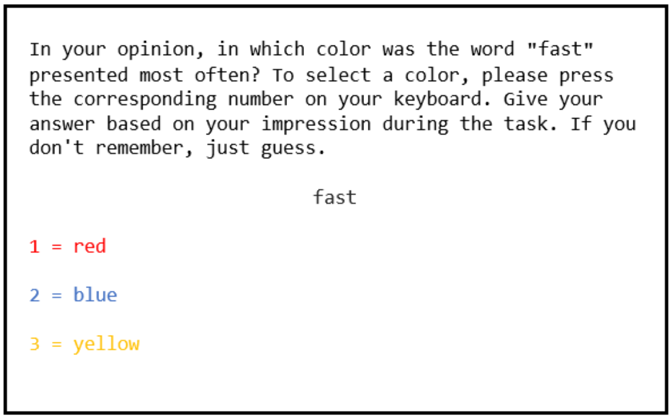


***Figure 3***. Exemplary question of the contingency awareness assessment (English translation).

**Data preparation**

Prior to analysis, the first trials of each block (1.4%) and trials with erroneous responses (1.8%) were excluded. Next, we excluded all trials that were preceded by trials with erroneous responses during the last occurrence of the same word (4.4%). Finally, we eliminated outliers by removing all trials with RTs that were below 250 ms or that were more than 3 interquartile ranges above the third quartile of the individual RT distribution (1.7%; “far out values” according to Tukey, 1977). The practice block was omitted from the analysis.

## Results

We conducted a series of hierarchical multi-level analyses based on individual trials, treating trials as nested within subjects, while allowing for random intercepts to control for differences in response speed between participants. RT was the dependent variable of interest. Predictors were successively added to the models. All predictors indicating a contrast between two conditions (e.g., Contingency learning [CL], response retrieval [RR], instruction [INS], and contingency awareness [CA]) were coded to have a mean of zero across all trials within the analysis and a difference of 1 between the two weights. Thus, the resulting regression coefficient reflects the difference in average response times between the two conditions (in milliseconds). To assess contingency effects, we focus on the contrast between high contingency (hc, coded as +.33) vs. low contingency trials (lc, coded as -.67), as this corresponds to conventional CL effects. For better readability, the results of our analyses are presented in Table 2. The means for all experimental conditions can be found in the Appendix (Table A1).

**Simple contingency learning effects (Model 1)**

In a first step, we tested the effects of contingencies without controlling for retrieval. Including contingency as the only level 1 predictor yielded a highly significant CL effect: On average, participants responded 36 ms faster in high compared to low contingency trials.

**CL effects after controlling for episodic retrieval (Model 2)**

In a second step, we entered episodic retrieval of previous stimulus-response (S-R) information from the last prior occurrence of the same word (matching episode) as an additional predictor to the regression model. Response retrieval was coded as +.5 if the probe word was presented in a color that shared the *same response* key for this word during its last occurrence, and as -.5 if the word was presented in a color that was assigned to a *different response* key during its last occurrence. Adding response retrieval as an additional level 1 predictor yielded a large and highly significant effect for this variable, indicating faster response times if the response of the last matching episode was the same as the response required in the current trial. Controlling for response retrieval reduced the CL effect substantially (from 36 ms to 14 ms), indicating that episodic retrieval of previous responses explains a large part of the CL effect. Importantly, however, the CL effect was still significant after controlling for episodic retrieval, indicating a robust residual CL effect of the global contingencies[2].

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[2] As suggested by a reviewer, we tested whether CL and response retrieval effects are altered by the duration in which a word appears in white before the final color-word combination (i.e., the target color) is presented (that is, the word-color SOA). Longer word-color SOAs reduced RTs, but we found no significant interaction between word-color SOA and CL or response retrieval. Hence, the duration in which a word was presented in white (150-350 ms) before the final color-word combination appeared did not alter CL or response retrieval effects.

**Table 2**

*Results of a stepwise multi-level regression analysis predicting trial RT based on contingency learning (high vs. low frequency), episodic response retrieval (retrieval of a same/different response), instructions (coded as true vs. no and false vs. no) and their interactions with contingency learning*

| Predictor | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| Intercept | 563.51***<br>[549.72, 577.31] | 563.71***<br>[549.92, 577.49] | 563.72***<br>[549.93, 577.51] |
| CL (HC vs. LC) | -36.43***<br>[-38.99, -33.86] | -14.22***<br>[-17.11, -11.34] | -14.25***<br>[-17.14, -11.37] |
| Response retrieval (RR) | | -44.46***<br>[-47.17, -41.74] | -44.42***<br>[-47.14, -41.71] |
| TINS (TRUE vs. NO) | | | -5.89***<br>[-9.28, -2.51] |
| FINS (FALSE vs. NO) | | | 2.38<br>[-1.01, 5.76] |
| TINS (TRUE vs. NO) x CL | | | -22.43***<br>[-29.63, -15.22] |
| FINS (FALSE vs. NO) x CL | | | 12.49***<br>[5.30, 19.68] |
| BIC | 809891 | 808878 | 808859 |
| Δ BIC | – | -1013 | -19 |
| $\chi^2$ | – | 1021.50*** | 49.29*** |

*Note*. ***p < 0.001. CL, contingency learning. HC, high contingency trials. LC, low contingency trials. TINS/FINS/NO, true/false/no instructions. BIC, Bayesian information criterion. $\chi^2$, Chi-squared test statistic. We implemented a person specific intercept ($df$ = 119) to control for individual differences in RTs. All other variables were implemented on a trial level ($df_{Trial}$ = 62550). Values in brackets indicate the 95% confidence interval (lower and upper limit) for each regression weight. Regression weights (*ß*) reflect the difference in milliseconds between the conditions that define a contrast.

**The modulation of contingency learning by instructions (Model 3)**

True instructions (coded as +.5 if *true* instructions were given about the frequent [hc] word-color combination; coded as -.5 if no instructions were given about the word-color contingency of the distractor word) and its interaction with CL were entered as additional predictors to the model. Importantly, the interaction term of true instructions with CL was highly significant, indicating that true instructions amplified the residual CL effect. Adding false instructions (coded as +.5 if *false* instructions were given about the word-color contingency of the distractor word; coded as -.5 if no instructions were given about the frequent [hc] word-color combination) and its interaction with CL also yielded a highly significant effect. Note that the regression weight is positive, indicating that false instructions about the contingency reduced the magnitude of the residual CL effect.

**Model comparison**

To evaluate model fit, we used the Bayesian information criterion (BIC) and Chi-squared tests, which are reported in Table 2. Descriptively, the change in the BIC value from Model 1 (with CL as the single predictor) to Model 2 (with response retrieval as additional predictor) indicates that adding response retrieval as a predictor improved model fit. The Chi-squared test suggests that Model 2 explains the data significantly better than Model 1, $\chi^2(1) = 1021.5$, $p < 0.001$. The change in BIC values from Model 2 (with CL and response retrieval) to Model 3 (with the main effects of instructions and their interactions with CL as additional predictors) indicates that adding the respective predictors results in a better model fit. Accordingly, the Chi-squared test suggests that Model 3 explains the data significantly better than Model 2, $\chi^2(4) = 49.29$, $p < 0.001$.

***Residual CL effects within each instruction condition***

To follow-up on the significant interaction terms between CL and true/false instructions, we analyzed the strength of the residual CL effect separately for each instruction condition. Participants who received no/false instructions about the existing color-word contingency might have identified the existing actual contingency over the course of the experiment through experience. Thus, we included contingency awareness and its interaction with CL to the models. The results are presented in Table 3.

Within the true and the no instruction conditions, contingency awareness was coded in an identical way (the contrast was coded as +.3 if participants reported the correct color in the contingency awareness assessment; coded as -.7 if participants reported the false color). For both conditions, the CA contrast and its interaction with CL were entered as additional predictors to the models. In both conditions, the interaction terms of contingency awareness (CA1: correct color [CC] vs. false color [FC]) with CL are statistically significant (true instruction condition: $M$ = -24.82 ms, $t$[20749] = -5.06, $p$ < .001; no instruction condition: $M$ = -10.41 ms, $t$[20874] = -2.15, $p$ = .031), indicating that awareness of the existing color-word contingencies amplifies the CL effect.

Within the false instructions condition, participants could either recognize the actual *correct color* (CC) in which a word was presented most often during the task or report the *falsely instructed color* (FIC) from the beginning of the experiment, which contained contingency information that mismatched the actual contingencies. Further, they could report the *remaining color* (RC) which was neither correct nor instructed. Hence, within the false instructions condition, we split the contingency awareness factor into two contrasts: One contrast (CA2: CC vs. RC) was coded as +.15 if participants report the actual *correct color* in the contingency awareness assessment and coded as -.85 if participants report the *remaining color*. The other contrast (CA3: FC vs. RC) was coded as +.4 if participants report the *false color* that was originally instructed and coded as -.6 if participants report the *remaining color*[3].

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[3] The regression weights for the contrasts were computed in such a way that (a) the resulting contrast had a mean of zero, and that (b) the difference between the regression weights for the two conditions of the contrast was 1. The specific weights then depend on the frequency with which each condition appears in the data set: $w_1 = \frac{f_2}{(f_1+f_2)}$ and $w_2 = \frac{-f_1}{(f_1+f_2)}$. Equal trial frequencies in each condition will result in a contrast coding of $w_1$ = .5 and $w_2$ = -.5. If the frequencies are unequal, however, this will result in unequal weights, so that the condition with the higher frequency receives a lower (absolute) weight (and vice versa). Thus, the resulting regression coefficient reflects the difference between the two conditions (in milliseconds), and the main effects and interactions of the predictors can be interpreted simultaneously.

Adding the first contrast of contingency awareness (CA2: CC vs. RC) and its interaction with CL yields a highly significant interaction effect (*M* = -63.14 ms, *t*[20697] = -6.372, *p* < .001), indicating stronger CL effects if participants are aware of the respective actual color-word contingency. Adding the second contrast (CA3: FIC vs. RC) and its interaction with CL yields also a highly significant product term (*M* = 74.38 ms, *t*[20697] = 6.277, *p* < .001), suggesting that the CL effect is substantially reduced if participants are not aware of the color-word contingencies; effectively, the residual CL effect was reversed.

**Table 3**

*Results of a multi-level regression analysis predicting trial RT within each instruction condition based on contingency learning (high vs. low frequency), episodic response retrieval (retrieval of a same/different response), and contingency awareness (correct vs. false color identified) and its interaction with CL*

| Instructions | true | no | false |
|---|---|---|---|
| Intercept | 561.08***<br>[547.63, 574.53] | 565.18***<br>[551.76, 578.61] | 565.00***<br>[550.13, 579.87] |
| CL (HC vs. LC) | -25.62***<br>[-30.61, -20.64] | -10.14***<br>[-15.14, -5.15] | -6.87**<br>[-11.84, -1.90] |
| Response retrieval (RR) | -42.81***<br>[-47.50, -38.13] | -43.60***<br>[-48.31, -38.90] | -46.40***<br>[-51.09, -41.70] |
| CA1 (CC vs. FC) | -38.75*<br>[-68.33, -9.17] | -13.75<br>[-42.60, 15.10] | |
| CA1 (CC vs. FC) x CL | -24.82***<br>[-34.44, -15.20] | -10.41*<br>[-19.89, -0.94] | |
| CA2 (CC vs. RC) | | | -47.20<br>[-112.73, 18.34] |
| CA2 (CC vs. RC) x CL | | | -63.14***<br>[-82.56, -43.72] |
| CA3 (FIC vs. RC) | | | 20.33<br>[-58.70, 99.36] |

| | |
|---|---|
| CA3 (FIC vs. RC) x CL | 74.38***<br>[51.15, 97.60] |

*Note*. *p < 0.05, **p < 0.01, ***p < 0.001. CL, contingency learning. HC, high contingency trials. LC, low contingency trials. CA, contingency awareness. CC, correct color. FC, false color. FIC, falsely instructed color. RC, remaining color. We implemented a person specific intercept (*df* = 119) to control for individual differences in RTs. All other variables were implemented on a trial level. Values in brackets indicate the 95% confidence interval (lower and upper limit) for each regression weight. Regression weights (*ß*) reflect the difference in milliseconds between the conditions that define a contrast.

### *Residual CL effects within each instruction condition, depending on awareness of the contingencies*

To follow-up on the significant interaction terms between CL and contingency awareness, we analyzed the residual CL effects within each instruction condition while taking the role of contingency awareness into account. On average, 70% of the actual color-word combinations were recognized correctly, which significantly exceeds the chance level of 33%, $t[359] = 15.14$, $p < 0.001$, but is still far from being perfect. Participants displayed similar levels of contingency awareness in the three instruction conditions (true instructions: 70.5%, false instructions: 70.5%, no instructions: 68.4%), indicating that instructed contingency beliefs did not last until the end of the experiment for most participants, but were overwritten by experiencing the actual color-word contingencies during the task. The results of the regression analysis are presented in Table 4 (true and no instruction conditions) and Table 5 (false instruction condition).

If participants received true or no instructions about the present color-word contingencies, a residual CL effect occurred only if participants identified the correct color of the word at the end of the experiment (true instructions: -33.92 ms, $t[14633] = -11.85$, $p < .001$; no instructions: $M = -12.44$ ms, $t[14281] = -4.11$, $p < .001$). If participants reported the false color at the end of the experiment, no residual CL effect remained after controlling for response retrieval (true instructions: -6.29 ms, $t[6114] =$

-1.20, $p$ = .230; no instructions: $M$ = -4.70 ms, $t$[6591] = -1.00, $p$ = .317). Hence, there was no residual CL effect for those trials for which the respective participant was unable to recognize the contingency.

**Table 4**

*Residual CL effects for trials in which true or no color-word contingency instructions were given, depending on the awareness of the respective contingency*

| Instructions | true | | none | |
|---|---|---|---|---|
| CA | CC | FC | CC | FC |
| Intercept | 549.38***<br>[535.27, 563.49] | 588.14***<br>[557.18, 619.09] | 561.04***<br>[546.34, 575.74] | 574.77***<br>[546.61, 602.93] |
| CL (HC vs. LC) | -33.92***<br>[-39.53, -28.31] | -6.29<br>[-16.57, 3.98] | -12.44***<br>[-18.38, -6.51] | -4.70<br>[-13.91, 4.51] |
| RR | -41.20***<br>[-46.47, -35.93] | -46.75***<br>[-56.41, -37.08] | -45.28***<br>[-50.88, -39.69] | -39.96***<br>[-48.63, -31.30] |

*Note.* ***p < 0.001. CL, contingency learning. HC, high contingency trials. LC, low contingency trials. RR, response retrieval. CA, contingency awareness. CC, correct color. FC, false color. Values in brackets indicate the 95% confidence interval (lower and upper limit) for each regression weight. Regression weights ($\beta$) are reported in milliseconds.

Within the false instructions condition, participants who corrected the falsely instructed contingency and reported the correct color of the word at the end of the experiment displayed a highly significant residual CL effect ($M$ = -15.48 ms, $t$[14609] = -5.40, $p$ < .001) that corresponds to the actual contingencies, if participants develop awareness of these actual contingencies. No residual CL effect was present if participants reported the remaining color in the contingency awareness assessment ($M$ = 3.87 ms, $t$[2488] = 0.42, $p$ = .677). If participants reported the falsely instructed color in the contingency awareness assessment (i.e., if they maintained the belief in the falsely instructed contingency until the end of the experiment), the residual CL effect was significant, but *reversed* ($M$ = 21.05 ms, $t$[3595] = 3.53, $p$

< .001), indicating faster responses in low contingency trials (i.e., trials that matched the false contingency instruction). Hence, for these participants, the CL effect corresponded to the falsely instructed contingency relation (and thus did not correspond to the actually experienced word-color contingencies).

**Table 5**

*Residual contingency learning effects for trials in which the false color-word contingency was instructed, depending on the awareness of the respective contingency*

| | Contingency awareness | | |
|---|---|---|---|
| | CC | RC | FIC |
| Intercept | 558.14***<br>[544.48, 571.80] | 593.30***<br>[526.14, 660.47] | 573.34***<br>[528.18, 618.50] |
| CL (HC vs. LC) | -15.48***<br>[-21.09, -9.86] | 3.87<br>[-14.36, 22.10] | 21.05***<br>[9.35, 32.74] |
| RR | -47.57***<br>[-52.86, -42.28] | -47.90***<br>[-65.14, -30.67] | -40.81***<br>[-52.02, -29.60] |

*Note.* ***p < 0.001. CL, contingency learning. HC, high contingency trials. LC, low contingency trials. RR, response retrieval. CC, correct color. FIC, falsely instructed color. RC, remaining color. Values in brackets indicate the 95% confidence interval (lower and upper limit) for each regression weight. Regression weights (*β*) are reported in milliseconds.

## Discussion

The primary goal of the present study was to investigate the cognitive source of genuine CL effects. While original studies suggest that CL occurs in the absence of awareness (Schmidt et al., 2007), subsequent investigations have shown that the CL effect is modulated by participants' awareness of the color-word contingencies (Schmidt & De Houwer, 2012). In the present study, we observed a substantial genuine CL effect, reflecting an effect of global contingencies that remained significant even after controlling for stimulus-based episodic retrieval of previous responses. Second, this genuine CL effect was modulated by instructions, as true (false) instructions amplified (reduced) the observed effect. Third, the direction of the residual CL effect was altered by contingency awareness, as maintained false contingency knowledge resulted in a *reversed* CL effect.

**Propositional knowledge as the primary source of genuine contingency learning**

Consistent with previous findings that focused on confounded CL effects (Schmidt & De Houwer, 2012), the genuine CL effect in our study was modulated by instructions about the present contingencies: We observed stronger genuine CL effects if the high contingency color-word combination was correctly instructed, while CL was reduced if participants received incorrect information about the color-word contingency. We did not find convincing evidence for genuine CL effects in the absence of awareness (i.e., no genuine CL effect occurred if participants reported the false color [true and no instructions condition] or the remaining color [false instructions condition] in the contingency awareness assessment). Hence, CL depends on participants becoming aware of and utilizing the relevant contingencies in their behavior (Rudolph & Rothermund, 2024; for a similar rationale, see Hughes et al., 2023).

Further on, the direction of the residual CL effect was determined by contingency awareness: If participants identified the contingencies correctly (that is, in line with the actual contingencies), a typical CL effect emerged, characterized by faster responding in high compared to low contingency trials. If, however, participants reported the falsely instructed contingency in the awareness assessment, a *reversed* CL effect was observed. That is, participants responded *faster* in *low contingency trials*, i.e., in trials that corresponded to the falsely instructed color-word combination. Consequently, not the experienced frequency of a certain color-word combination, but the *contingency awareness*, that is, the propositional belief that participants held about the contingencies, determined the size and direction of the residual CL effect in the present study.

Several aspects of these findings are noteworthy. The associative learning account would predict that the residual CL effect reflects differences in the amount of exposure to actual color-word combinations, regardless of any (true or false) prior instructions. However, the present findings contradict this prediction: we found that even if instructions oppose the actual contingencies, participants hold on to these instructed beliefs (that is, some sort of ostensible contingency awareness), and this awareness then drives responding. Participants who display belief in the false instructions seem to use their (ostensible) contingency knowledge to make predictions about the required response – irrespective of its validity. Consequently, participants are suddenly faster in responding to low contingency trials – that is, in those trials that correspond to the falsely instructed color-word combination, because in these trials, their knowledge is applicable and leads to fast responses. In the actual high contingency trials, however, the word appears in a color which deviates from the prediction based on the false belief, requiring them to correct the predicted response, thus consuming more time. In combination, this resulted in a *reversed* CL effect.

Taken together, our findings provide strong evidence for the propositional account of human contingency learning, as (1) genuine CL effects were modulated by instructions, (2) we did not find any evidence for CL in the absence of awareness, and (3) false contingency knowledge caused the CL effect to reverse. Associative learning theory predicts that CL is not altered by verbal instructions, occurs even in the absence of awareness, and is influenced by the actually experienced contingencies. However, within the current investigation, contingency awareness which resulted from prior instructions was the crucial factor underlying the manifestation of the CL effect.

**Limitations and future research**

Importantly, our findings do not question that the CL effect results to a large part from an automatic cognitive process, as we acknowledge that CL primarily stems from retrieval of the most recent matching episode (the "law of recency", Giesen et al., 2020). However, the present study goes beyond these prior findings and is interested in the part of the CL effect that cannot be explained by automatic response retrieval. Still, after taking episodic retrieval into account, the present results suggest that the genuine CL effect is bound to and caused by (ostensible) contingency awareness.

In the present experimental design, the precise mechanisms underlying the formation of propositional contingency beliefs remain partly unexplained: On the one hand, we established propositional knowledge by *instructing* participants about the contingencies, either correctly or incorrectly. This had an influence on the resulting residual CL effect, indicating that propositional beliefs about contingencies can be established in the absence of actual evidence and experience by mere instructions. Yet, contingency awareness measured at the end of the experiment did not differ systematically between the three instruction conditions. Thus, the expectations that were induced by the instructions did not last until the end of the experiment for most participants, but were overwritten by experiences made during the task, indicating that *experience* can also induce or cause a change in propositional beliefs. Interestingly, however, these changes in beliefs cannot easily be explained by a passive accumulation of evidence. That is because even within the false instruction condition, some participants still reported the falsely instructed contingencies at the end of the study and demonstrated residual CL effects in accordance with their false beliefs, despite continuously encountering opposing evidence.

Previous research demonstrated that a specific form of attention is needed to transform the actual experience of contingencies into respective knowledge: Logan and Etherton (1994) demonstrated that learning about the repeated co-occurrence of two stimuli requires divided attention on both stimuli (i.e., in our case, words and colors), while attending to one stimulus alone is insufficient to produce sustainable CL effects. From this perspective, our findings suggest that propositional contingency knowledge can emerge via (1) explicit instructions and/or (2) evidence of co-occurrence, with attention directed to both co-occurring stimuli as a prerequisite.

The main goal of the present study was to examine the influence of verbal instructions on the genuine CL effect. Thus, the study aimed to establish a causal effect of propositional beliefs on CL effects that is not mediated by associative learning, rather than to clarify the emergence and change of propositional beliefs. Importantly, we also do not claim that the process of belief formation is limited to the last episode and, thus, somewhat resistant to or separate from cumulative experience (the "law of recency" principle [Giesen et al., 2020] only holds for the process of episodic response retrieval, and thus is unrelated to the formation of beliefs). Instead, we admit that this question goes beyond the present study and that systematic future research is needed to make progress in this direction. Manipulating attention seems to be a promising route to identify what is needed to transform repeated experiences of co-occurrence into propositional beliefs about contingencies (Logan & Etherton, 1994).

Another unresolved issue is how interindividual differences in contingency awareness precisely affected the learning phenomenon (i.e., the CL effect). One possibility is that some participants might have been more motivated to extract and remember contingency knowledge in the experimental trials, which then resulted in the observed differences in the CL effect. Alternatively, it could be hypothesized that differences in both, contingency awareness and CL, originate from differences in associative learning abilities. From this perspective, some participants might acquire contingencies more effectively than others, which in turn would produce differences in contingency awareness and in CL effects. Given the current experimental design, it is not possible to empirically dissociate which of these causal explanations is correct. Specifically, discerning whether changes in contingency awareness precede changes in the CL effect (or vice versa), is a question for future research (for a similar argument, see Kurdi et al., 2024). A promising approach to disentangle the two possibilities might be to assess contingency awareness repeatedly throughout the experiment (e.g., Giesen & Rothermund, 2015) in order to test whether it causally predicts subsequent changes in residual CL effects – or whether it rather is influenced by preceding changes in CL, indicating that it is a result of associative learning.

A broad range of literature suggests that human (and even non-human) learning is strongly governed by initial hypothesis and propositional beliefs, and can be quite resistant to actual contingencies (e.g., Beckers et al., 2006; De Houwer, 2009; Krechevsky, 1932; Levine, 1971; Mitchell et al., 2009). Accordingly, our results demonstrate that both, correct and false instructions, are effective in shaping the genuine CL effect. Further, the finding that some participants endorsed a belief that reflected the falsely instructed contingencies even at the end of the experiment, despite having been exposed to massive amount of contradicting evidence, and still showed a residual CL effects in opposition to the actual contingencies of the experiment, is difficult to reconcile with an account of learning in terms of a passive accumulation of evidence. Hence, we feel safe to conclude that the observed differences in genuine CL originate from differences in the propositional beliefs of the participants.

Furthermore, the instruction manipulation did not affect contingency awareness measured at the end of the experiment. Future studies could employ the contingency instructions within a shorter experiment to create measurable differences in overall contingency awareness, or implement different experimental manipulations, such as the alteration of the available cognitive resources (e.g., by increasing the number of rules to be learned or implementing a second task with alternating difficulty). If the residual CL effect reflects propositional reasoning, it should be sensitive to the amount of available cognitive resources (i.e., high cognitive load should reduce the residual CL effect).

## Conclusion

The present study provides new insights about the cognitive sources of human contingency learning. We observed a substantial residual CL effect that reflects the impact of global contingencies beyond mere retrieval of previous, single episodes. This genuine CL effect was modulated by contingency awareness, as true (false) instructions amplified (reduced) the observed effect. Further, the direction of the genuine CL effect was determined by contingency awareness, as false contingency knowledge caused the

CL effect to reverse. In sum, our findings add further evidence to the existing literature underlining the propositional nature of human contingency learning.

**Declaration of conflicting interests**

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**Notes**

Experiment, data and R scripts are publicly available on the Open Science Framework: https://osf.io/byqhx/. More information is available from the lead author on request.

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## Appendix

**Table A1**

*Mean reaction times and standard deviations in milliseconds for trials in which true, no, or false color-word contingency instructions were given, depending on contingency (high vs. low frequency) and episodic response retrieval (retrieval of a same/different response)*

| | | Episodic retrieval | | |
|---|---|---|---|---|
| Instructions | Contingency | SR | DR | ER effect |
| true | HC | 532 (162) | 572 (171) | -40 (236) |
| | LC | 541 (162) | 602 (182) | -61 (244) |
| | CL effect | -9 (229) | -30 (250) | |
| no | HC | 540 (170) | 582 (167) | -42 (238) |
| | LC | 549 (173) | 594 (170) | -45 (243) |
| | CL effect | -9 (243) | -12 (238) | |
| false | HC | 539 (172) | 585 (180) | -46 (249) |
| | LC | 541 (160) | 595 (172) | -54 (235) |
| | CL effect | -2 (235) | -10 (249) | |

*Note.* HC, high contingency. LC, low contingency. SR, same response. DR, different response. Standard deviations are reported in parenthesis. CL effect: $RT_{HC} – RT_{LC}$; ER effect: $RT_{SR} – RT_{DR}$