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# Serial effects in choice and confidence modulate each other: Evidence from 26 experiments

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ABSTRACT

Perception and memory at timepoint N are biased by the timepoint N-1 decision, a phenomenon known as serial dependence. A similar dependence has been found for confidence ratings, a phenomenon known as "confidence leak." These two types of serial effects have mostly been assumed to be independent and have typically been attributed to distinct explanatory mechanisms. Here, using data from 26 experiments (total $N = 1876$), we show that choice and confidence serial effects are strongly associated and even modulate each other. We first confirm that choice and confidence serial effects are robustly present in both perception (16 experiments) and memory (10 experiments) tasks. Critically, we find that choice serial effects and confidence leak interact with each other in all 26 experiments. Specifically, switching the perceptual or memory choice substantially weakens confidence leak. What is more, switching the confidence rating not only attenuates but in fact reverses the choice serial effect. Further, we show that manipulating the choice on a trial-by-trial basis by interleaving stimulus categories modulates confidence leak. Finally, we found that subjects who exhibit stronger choice serial effects also exhibit stronger confidence leak. These results demonstrate that serial effects in choice and confidence are strongly related and suggest the possibility of common mechanisms underlying different serial effects.

## 1. Introduction

Much previous research has demonstrated the ubiquity of serial effects in decision-making. Serial effects in the decision, that is, the attraction of the response to the previous trial, is prominent in both continuous reproduction tasks (Cicchini et al., 2017; Cicchini et al., 2024; Fischer & Whitney, 2014; Liberman et al., 2014; Manassi et al., 2023; Pascucci et al., 2023) and discrete choice tasks such as numerosity estimation (Fornaciai & Park, 2020; Morimoto & Makioka, 2022), x-ray image perception (Manassi et al., 2019), and dermatological judgments (Ren et al., 2023). Independently, the autocorrelation of confidence judgments across trials – a phenomenon known as "confidence leak" (Rahnev et al., 2015) – has been shown in a variety of psychophysical tasks (Aguilar-Lleyda et al., 2021; Bocheva & Rahnev, 2025; Kantner et al., 2019; Mei et al., 2023; Ng et al., 2021), including interleaving cognitive domains (Kantner et al., 2019). However, to date, those two types of serial effects have mostly been studied separately.

Serial effects in the decision have primarily been studied in continuous tasks (Cicchini et al., 2017; Cicchini et al., 2024; Fischer & Whitney, 2014; Liberman et al., 2014; Manassi et al., 2023; Pascucci et al., 2023). However, here we are interested in the degree to which serial effects occur in discrete (binary) perceptual and memory decisions. A rich literature has examined related phenomena in the context of priming in perception and memory (Fazio et al., 1986; Ratcliff & McKoon, 1988; Schacter & Buckner, 1998; Tulving & Schacter, 1990), where an immediately preceding stimulus either facilitates or impairs recognition (Meyer & Schvaneveldt, 1971; Warren & Morton, 1982), categorization (Herr, 1986; Higgins et al., 1985), perception (Cheesman & Merikle, 1984; Marcel, 1983; Wiggs & Martin, 1998), motor action (Tucker & Ellis, 2004), and response time (Fazio et al., 1986; Frings et al., 2015; Tipper, 1985). Regardless of whether the task is continuous or discrete, there is substantial debate on whether serial effects occur primarily at the sensory level (Cicchini et al., 2024; Fischer & Whitney, 2014; Liberman et al., 2014; Manassi & Whitney, 2024), the decisional level (Bae & Luck, 2020; Bliss et al., 2017; Czoschke et al., 2019; Fornaciai & Park, 2020; Morimoto & Makioka, 2022, 2024; Sadil et al., 2024; Sheehan et al., 2024; Zhang & Lewis-Peacock, 2024), or both (Zhou et al., 2024). Nevertheless, there is strong consensus that choice serial effects arise from the fact that content in the environment is

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autocorrelated. That is, objects in the world don't just randomly appear and disappear, and so perceiving an object at one time point should optimally bias you towards perceiving it at the next time point.

Similar to choice serial effects, confidence leak has been shown to occur across many perceptual tasks, such as feature dominance and orientation discrimination (Mei et al., 2023; Mueller & Weidemann, 2008; Rahnev et al., 2015). For example, confidence leak appears for decisions related to separate features within the same task, such as the dominant color and the dominant letter identity of an ensemble of O's and X's (Rahnev et al., 2015). This result was further replicated in a study involving continuous confidence judgments (Aguilar-Lleyda et al., 2021). In a different study, manipulating the difficulty of the preceding trial was able to predict confidence in the current trial (Ng et al., 2021), where an easy previous trial resulted in higher confidence in the current trial. The confidence serial effect is thought to arise from the fact that difficulty – rather than content – is autocorrelated (Rahnev et al., 2015). For example, a foggy day will make all perceptual tasks more difficult independently of the content in the environment.

Even though serial effects in choice and confidence have generally been studied separately, a single previous paper has suggested that they are not independent (Kantner et al., 2019). Kantner et al. analyzed two existing datasets with memory judgments and performed a new experiment that interleaves high-level perceptual and memory tasks. The authors found that confidence leak is stronger for repeated choices across all three experiments. While Kantner et al.'s work broke new ground by suggesting that choice and confidence serial effects are not independent (as had been previously assumed), their paper didn't attempt to comprehensively examine the interactions between choice and confidence serial effects. For example, Kantner et al. showed an interaction for two standard memory tasks and one study where perception and memory tasks are interleaved but did not sample a larger set of perception and memory experiments. Further, while Kantner et al. demonstrated that confidence leak increases for repeated choices, they didn't examine how choice serial effects change for repeated confidence judgments. Critically, Kantner et al. didn't examine whether the interaction between choice and confidence serial effects is subject to experimental manipulation, such that manipulating the strength of one serial effect would affect the strength of the other. Finally, Kantner et al.'s work leaves it open whether there are stable individual differences in the propensity to exhibit strong serial effects.

Here, we aimed to comprehensively examine the interactions between choice and confidence serial effects across a wide variety of tasks and experiments. We examined the strength of choice and confidence serial effects, as well as their interaction in 26 experiments (16 perceptual and 10 memory) from the Confidence database (Rahnev et al., 2020). We found positive choice and confidence serial effects in all 26 experiments with both the choice and confidence serial effects being stronger in the perception than the memory experiments. Similar to Kantner et al.'s findings, switching the main decision weakened the confidence leak effect. Crucially, we also observed a new effect where switching the confidence judgment reversed the choice serial effect into a repulsive bias. Further, we showed that manipulating the choice on a trial-by-trial basis by interleaving stimulus categories modulates confidence leak. Finally, our data allowed us to examine whether serial effects represent a source of individual differences. Indeed, we found that participants who have stronger confidence leak also exhibit stronger choice serial effects. Together, these results robustly demonstrate the ubiquity of the interrelation between choice and confidence serial effects across different tasks and domains.

## 2. Methods

### 2.1. Dataset selection

We reanalyzed data from 26 existing datasets (16 perceptual and 10 memory) from the Confidence Database (CDB) (Rahnev et al., 2020). The total N of subjects was 1188 for perception and 688 for memory tasks, respectively. We selected datasets that meet the following selection criteria: (1) the datasets had to include a binary discrimination decision (e.g., left- vs right-oriented Gabor patch) and a confidence rating (datasets that asked for visibility ratings were excluded), (2) the confidence rating had to be given on each trial and feature a discrete scale with a minimum of 3 (to allow for greater sensitivity in confidence ratings) and maximum of 6 options (to provide enough power for the comparison between repeat and switch confidence trials), (3) the experiments had to feature visual perception or old/new memory tasks only ("mixed" experiments that had both a perception and memory component or tasks that were not purely perceptual or memory-related were excluded), (4) responses had to be given with the same hand (experiments that required hand switching were excluded to avoid additional noise when comparing consecutive trials on the basis of other variables), (5) the confidence response cannot be given before the decision, (6) the experiment did not involve TMS perturbations or conditions with speed focus, and (7) the datasets had to feature less than 5% missing data points in either the stimulus, response, or confidence values. Details related to the number of subjects, trials per subject, confidence scale, and task specifics for each of the selected experiments can be seen in Table 1. These data were downloaded in May 2025 and will not include any dataset added to the Confidence Database at a later point.

In addition to these 26 datasets, we selected 7 more experiments that included a task difficulty manipulation (stimulus contrast) for the purpose of assessing the effects of repeating and switching difficulty on choice serial effects. Due to the relatively low number of datasets in CDB that manipulated task difficulty, we selected data using criteria (1), (6) and (7) above, as well as the additional criterion that the dataset had to feature a difficulty manipulation. We further excluded datasets that used continuous contrast or difficulty. All 7 datasets were Gabor patch discrimination experiments. Details related to the number of subjects, trials per subject, confidence scale and number of contrast levels can be seen in Table 2.

### 2.2. Stimuli and procedure

The stimulus contents of the different datasets differed substantially (e.g., Gabor patch discrimination, random dot motion, face discrimination) (Table 1). The most common type of perceptual task was Gabor patch discrimination (Fig. 1A), where subjects were required to discriminate between left- and right-oriented Gabor patches. Note that perceptual choices (e.g., left- vs. right-tilted Gabor) were grouped with other perceptual choices (e.g., male vs. female face) based only on which response happened to be mapped to a left vs. right button press, thereby making the grouping arbitrary. The most common type of memory task was recognition memory for words where subjects were required to categorize words as old or new (Fig. 1B). In all experiments, subjects provided responses using a keyboard with the main decision and confidence being given with separate button presses. The confidence scale used differed across experiments. Twelve of 16 perceptual tasks used a 4-point confidence scale, where 1 indicates the least confident and 4 indicates the most confident (Fig. 1A). By contrast, the 3-point confidence scale (1 indicates the least confident, 3 indicates the most confident) was most common in memory tasks (Fig. 1B). Inter-trial intervals varied between 500 and 1500 ms.

### 2.3. Analyses

To ensure the validity of our serial effect analyses, we first checked that stimulus presentations across tasks and subjects were fully randomized by comparing the probability of a stimulus repeat and a stimulus switch on two consecutive trials, with the expectation that those would be equal. In addition, we compared the probability of repeating a stimulus with the probability of repeating either the main choice or the

**Table 1**
Analyzed datasets. Experiments are organized in descending order in terms of # subjects.

| Study # | Experiment | N | # trials/subj | Conf scale | Stimuli |
|---|---|---|---|---|---|
| Perception 1 | Haddara & Rahnev, 2022 (Expt 1) | 443 | 480 | 4 | Letters and colors |
| Perception 2 | Bang et al., 2019 (Expt 2) | 201 | 200 | 4 | Gabor patches |
| Perception 3 | Desender et al., 2022 (Expt 2B) | 99 | 500 | 6 | Random dot motion |
| Perception 4 | Haddara & Rahnev, 2022 (Expt 2) | 75 | 3350 | 4 | Letters |
| Perception 5 | Hainguerlot et al., 2018 | 65 | 512 | 6 | Gabor patches |
| Perception 6 | Bocheva & Rahnev, 2025 (Expt 2) | 51 | 1000 | 4 | Gabor patches |
| Perception 7 | Bocheva & Rahnev, 2025 (Expt 1) | 45 | 1000 | 4 | Gabor patches |
| Perception 8 | Yeon et al., (unpub) (Expt 2) | 37 | 880 | 4 | Random dot motion |
| Perception 9 | Maniscalco et al., 2017 (Expt 1) | 30 | 1000 | 4 | Gabor patches |
| Perception 10 | Rausch et al., 2020 | 25 | 1000 | 4 | Gabor patches |
| Perception 11 | Wang, 2018 | 24 | 504 | 3 | Ambiguous faces |
| Perception 12 | Yeon et al. (unpub) (Expt 1) | 24 | 840 | 4 | Random dot motion |
| Perception 13 | Gajdos et al., 2019 | 22 | 699 | 4 | Gabor patches |
| Perception 14 | Sherman et al., 2016 | 18 | 768–3264 | 4 | Gabor patches |
| Perception 15 | Filevich & Fandakova (unpub) | 17 | 600 | 6 | Gabor patches |
| Perception 16 | Bang et al., 2019 (Expt 1) | 12 | 3434–3679 | 4 | Gabor patches |
| Memory 1 | Kantner & Lindsay, 2012 (Expt 3) | 147 | 192–384 | 3 | Words and paintings |
| Memory 2 | Chandravadia et al., 2020 | 87 | 100 | 3 | Images |
| Memory 3 | Kantner & Lindsay, 2014 (Expt 1) | 87 | 192 | 3 | Paintings |
| Memory 4 | Kantner & Lindsay, 2014 (Expt 2) | 74 | 172 | 3 | Words and faces |
| Memory 5 | Schurgin et al., 2020 | 70 | 300 | 6 | Colors |
| Memory 6 | Kantner & Lindsay, 2012 (Expt 4) | 51 | 96 | 3 | Words |
| Memory 7 | Sadeghi et al., 2017 | 50 | 200 | 6 | Words |
| Memory 8 | Kantner & Lindsay, 2012 (Expt 2) | 46 | 192 | 3 | Words |
| Memory 9 | Kantner & Lindsay, 2012 (Expt 1) | 41 | 192 | 3 | Words |
| Memory 10 | Hu et al., 2017 | 35 | 150 | 6 | Words |

confidence (see Lueckmann et al., 2018).

We quantified serial effects in choice and confidence in two ways. First, we computed the probability of a choice on $t$ conditioned on the previous choice $t-1$. Specifically, we checked whether the probability of response "1" was significantly higher than the probability of response "2" when the previous response was "1". Similarly, we checked whether the probability of a response "2" was significantly higher than the probability of response "1" when the previous response was "2". To

**Table 2**
Analyzed datasets that included a difficulty (contrast) manipulation. Experiments differ by the type of confidence scale and the number of difficulty (contrast) levels.

| Experiment | N | # trials/subj | Conf scale | Contrast levels |
|---|---|---|---|---|
| Bocheva & Rahnev, 2025 (Expt 2) | 51 | 1000 | 4 | 2 |
| Bocheva & Rahnev, 2025 (Expt 1) | 45 | 1000 | 4 | 2 |
| Rausch & Zehetleitner, 2016 | 20 | 420 | −12 to 12 (continuous) | 6 |
| Shekhar & Rahnev, 2021 | 20 | 2800 | 50 to 100 (continuous) | 3 |
| Adler & Ma, 2018 (Expt 3) | 15 | 3240 | 4 | 6 |
| Adler & Ma, 2018 (Expt 1) | 11 | 4320 | 4 | 6 |
| Adler & Ma, 2018 (Expt 2) | 8 | 2592–4390 | 4 | 6 |

achieve this, we subtracted the probabilities for each of the two choices based on the previous choice: $P(choice(t) = 1 \mid choice(t-1) = 1) - P(choice(t) = 2 \mid choice(t-1) = 1)$ and $P(choice(t) = 2 \mid choice(t-1) = 2) - P(choice(t) = 1 \mid choice(t-1) = 2)$), where "1" and "2" are the two stimulus categories and compared their difference to 0. For this analysis, we excluded subjects who did not use both responses (1 perception subject excluded). To quantify serial effects in confidence, we checked whether giving a certain confidence rating on trial $t-1$ increased the probability of giving the same confidence rating and the adjacent confidence rating on trial $t$. To check whether a certain confidence rating on trial $t-1$ increased the probability of giving an adjacent confidence rating on trial $t$, we excluded all confidence repeats. We then subtracted the base probabilities of confidence ratings from each subject's confidence on trial $t$ as a function of their confidence on trial $t-1$. Then, we subtracted the by-subject probabilities of the neighboring confidence ratings on trial $t$ as a function of confidence on trial $t-1$, and we tested their average difference against 0:

$$d1 = P(conf(t) = 2)|conf(t-1) = 1) - P(conf(t) = 3)|conf(t-1) = 1)$$

$$d2 = P(conf(t) = 3)|conf(t-1) = 2) - P(conf(t) = 4)|conf(t-1) = 2)$$

$$d3 = P(conf(t) = 2)|conf(t-1) = 3) - P(conf(t) = 1)|conf(t-1) = 3)$$

$$d4 = P(conf(t) = 3)|conf(t-1) = 4) - P(conf(t) = 2)|conf(t-1) = 4)$$

For this analysis, we excluded subjects who did not have consecutive trials of a given pair of adjacent confidence ratings when excluding confidence repeats (11% of perception and 18% of memory subjects excluded).

To account for possible biases in the aggregation process across subjects, we conducted a separate analysis where we subtracted the overall probabilities of giving a certain confidence rating (expected distribution) from each subject's confidence rating probabilities conditioned on trial $t-1$ (conditioned distribution). This analysis allowed us to obtain an unbiased estimate of confidence leak quantified by response probabilities.

Second, we quantified serial effects by regressing the regular time series of choices on their lagged ($t-1$) version on the subject and on the experimental level, where the strength of the serial effect was quantified by the beta (slope) value of the type-1 ordinary least squares (OLS) regression. As above, we excluded one subject who did not use both responses. Similarly, we quantified confidence leak by regressing confidence ratings on their lagged ($t-1$) version for each subject and each experiment separately. Once again, the strength of confidence leak was

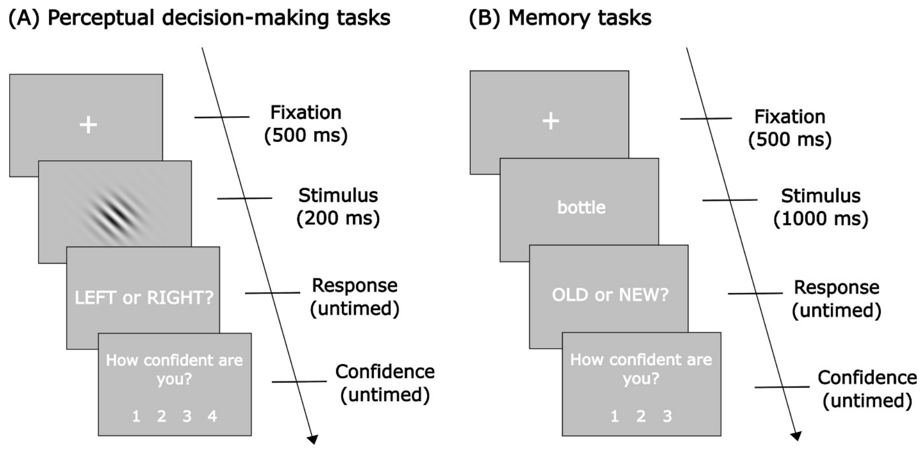


**Fig. 1.** Examples of perception and memory tasks that require a discrete choice. A) An example of a standard perceptual decision-making task where subjects are required to discriminate between left- and right-tilted Gabor patches (8 out of 16 analyzed perceptual tasks). Task timings were taken from Bocheva and Rahnev (2025). B) An example of a recognition memory task where subjects are required to indicate whether the item was presented during a learning phase. Task specifics were taken from Kantner and Lindsay (2012).

measured by the beta (slope) value of the linear regression. To test how different variables contributed to the serial effects, we included stimulus, response, and confidence on trial $t-1$ and confidence on trial $t$ as predictors of the response on trial $t$ in a multiple linear regression. Separately, included stimulus, response, and confidence on trial $t-1$ and response on trial $t$ as predictors of the confidence on trial $t$. We then tested the beta coefficients of each term against 0. We ran the same analyses using a type-2 linear regression and found the same effects. Note that, for both multiple regressions, we computed a Variance Inflation Factor (VIF) to ensure that none of the predictors' variance coefficients were being artificially inflated due to multicollinearity between predictors.

For each type of quantification of the choice and confidence serial effect strengths, we compared the strength of serial effects in perception and memory. To do so, we compared the experiment-level beta values across the two domains using independent samples *t*-tests.

Given the robustness of serial effects in behavioral tasks, we were interested in how one type of serial effect might modulate a different type of serial effect. We first examined how the strength of choice serial effects differed based on repeating or switching the confidence judgment. We regressed the regular time series of the choice on its lagged ($t-1$) version separately in cases where the confidence rating on $t$ and $t-1$ was repeated or switched. We then compared the beta values on the subject and the experimental level using a paired samples t-test. To assess how the strength of confidence leak differed based on repeating or switching the main choice, we regressed the regular confidence time series on its lagged ($t-1$) version separately for trials where the response on $t$ and $t-1$ was repeated or switched. Again, we compared the subject-level and experiment-level beta values using a paired samples *t*-test. For these analyses, we excluded subjects who only used one response in repeat-confidence trials (5 memory subjects excluded), as well as subjects who only gave one confidence rating in repeat-choice trials (3 perception and 7 memory subjects excluded). We ran the same analysis for 5 trials and 10 trials back and compared the differences between repeat- and switch-responses using paired *t*-tests.

We further investigated whether we could modulate serial effect strength via different manipulations. To quantify the effect of experimental manipulation on serial effects, we compared how confidence leak strength is affected by change in the choice serial effect induced by repeating or switching the stimulus category, and how choice serial effect strength is affected by change in confidence leak induced by repeating or switching the task difficulty. For these analyses, we excluded subjects who were lacking one of the two responses in repeat-stimulus trials (2 perception and 6 memory subjects excluded), as well as subject who only gave one confidence rating in repeat-difficulty trials (1 subject excluded).

In datasets including a difficulty manipulation (Table 2), we further assessed whether the contrast on trial $t-1$ and trial $t$ contributed to serial effects by fitting them as predictors in a multiple linear regression alongside the rest of the control variables we included in the main multiple regression for the Table 1 datasets. We then tested the beta coefficients of each term against 0.

The modulation of confidence leak by repeating or switching the choice and the modulation of choice serial effects by repeating or switching confidence might be idiosyncratic. Namely, subjects who are more prone to switching responses in general (i.e., "alternators") might exhibit a stronger repulsive choice serial effect in switch confidence trials compared to repeat confidence trials. Similarly, subjects who are more prone to repeating choices in general ("repeaters") might exhibit a stronger attractive choice serial effect for repeat vs switch confidence. To explore such effects, we computed choice serial effects and confidence leak for repeat and switch trials separately for subjects who repeated their response in 2 consecutive trials in more than 50% of the experiment, and for subjects who switched their response in 2 consecutive trials in more than 50% of the experiment. Then, we compared the beta coefficient differences of repeat and switch trials between "repeaters" and "alternators" using an independent sample t-test. Lastly, we checked whether the choice serial effect in switching confidence (or confidence leak in switching the choice) in "repeaters" was larger than the choice serial effect in switching confidence (or confidence leak in switching the choice) in "alternators" using an independent sample t-test.

Finally, we investigated whether serial effect correlations generalize across subjects within a given experiment. To assess the inter-subject correlation of choice serial effects and confidence leak, we ran a random-effects model with Fisher z-transformation to pool correlation coefficients across experiments separately for perception and memory. In addition, we correlated the subject-level beta (slope) values for the choice serial effect with the subject-level beta (slope) values for confidence leak and tested the aggregated *r* values within each experiment against 0.

All *p*-values across all analyses were Bonferroni-corrected based on the number of comparisons. Specifically, we corrected for the number of tests within a single analysis type (e.g., if a given analysis involved three tests for perception and three tests for memory, we corrected for six tests). When analyzing data at the experiment level, we corrected for the presence of 16 perception experiments and separately for the presence of 10 memory experiments.

### 2.4. Data and code

All data and code are available at https://osf.io/yns96/.

## 3. Results

### 3.1. Manipulation checks

First, we confirmed that stimulus presentation was randomized by computing the probabilities of a stimulus switch and a stimulus repeat for each experiment. We found that the probability of a stimulus repeat was not different from the probability of a stimulus switch in perception (P(stimulus repeat) = 0.48, t(15) = −0.89, $p > .9$) or memory experiments (P(stimulus repeat) = 0.49, t(9) = −2.35, $p = .17$). In addition, we confirmed that the probability of repeating a response did not correlate with the probability of repeating a stimulus across subjects in perception ($p = .18$) and memory tasks (p > .9). Finally, we confirmed that the probability of repeating a confidence rating did not correlate with the probability of repeating a stimulus across subjects in perception (p > .9) and memory tasks ($p = .68$). These results demonstrate that the analyzed experiments had randomized stimulus presentations.

### 3.2. Robust choice serial effects in perception and memory

We first examined the strength of choice serial effects in perception and memory when combining across all experiments. Although stimuli differed greatly across tasks (e.g., Gabor patches, images, words), all tasks required a binary choice decision – what we universally refer to as Category 1 and Category 2 (e.g., left vs. right-tilted Gabor patches or male vs. female faces, where the categories simply reflected the mapping to left vs. right keys). Across all perceptual experiments, making a “Category 1” decision at time $t-1$ made subjects 5% more likely to select “Category 1” at time $t$ (52.6% vs. 47.3%; t(1184) = 9.06, $p = 3.3 \times 10^{-18}$, Cohen's $d = 0.26$; Fig. 2A). Similarly, making a “Category 2” decision at time $t-1$ made subjects 5% more likely to select “Category 2” at time $t$ (52.4% vs. 47.5%; t(1184) = 8.27, $p = 2 \times 10^{-15}$, Cohen's $d = 0.24$). Overall, subjects exhibited a strong tendency to repeat the same perceptual decision (t(1186) = 14.48, $p = 4.2 \times 10^{-43}$, Cohen's $d = 0.42$).

Just like in perception, our memory tasks differed in content (e.g., images and words), but required a binary choice decision – old vs new. Overall, there was again a significant tendency to repeat the same memory decision (t(684) = 9.07, $p = 7.2 \times 10^{-18}$, Cohen's $d = 0.35$). Nevertheless, there was a difference between old and new judgments. Specifically, making an “old” decision at time $t-1$ did not affect the likelihood of selecting “old” at time $t$ (49.6% vs. 50.3%; t(684) = 0.68, p > .9; Fig. 2A) but making a “new” decision at time $t-1$ made subjects 8% more likely to select “new” at time $t$ (54.0% vs. 45.9%; t(684) = 9.61, $p = 8 \times 10^{-20}$, Cohen's $d = 0.37$). A direct comparison of the strength of the choice serial effects confirmed that they differed across perception and memory (t(1868) = 2.48, $p = .01$, Cohen's $d = 0.12$).

We further computed the strength of serial effects by conducting a regression analysis for each subject separately. We found strong choice serial effects in perceptual tasks (average β = 0.05, t(1184) = 14.48, $p = 5.5 \times 10^{-43}$, Cohen's $d = 0.42$), and smaller but still significant choice serial effects in memory tasks (average β = 0.03, t(684) = 9.07, $p = 9.6 \times 10^{-18}$, Cohen's $d = 0.35$).

Since the above results are based on combining across experiments,

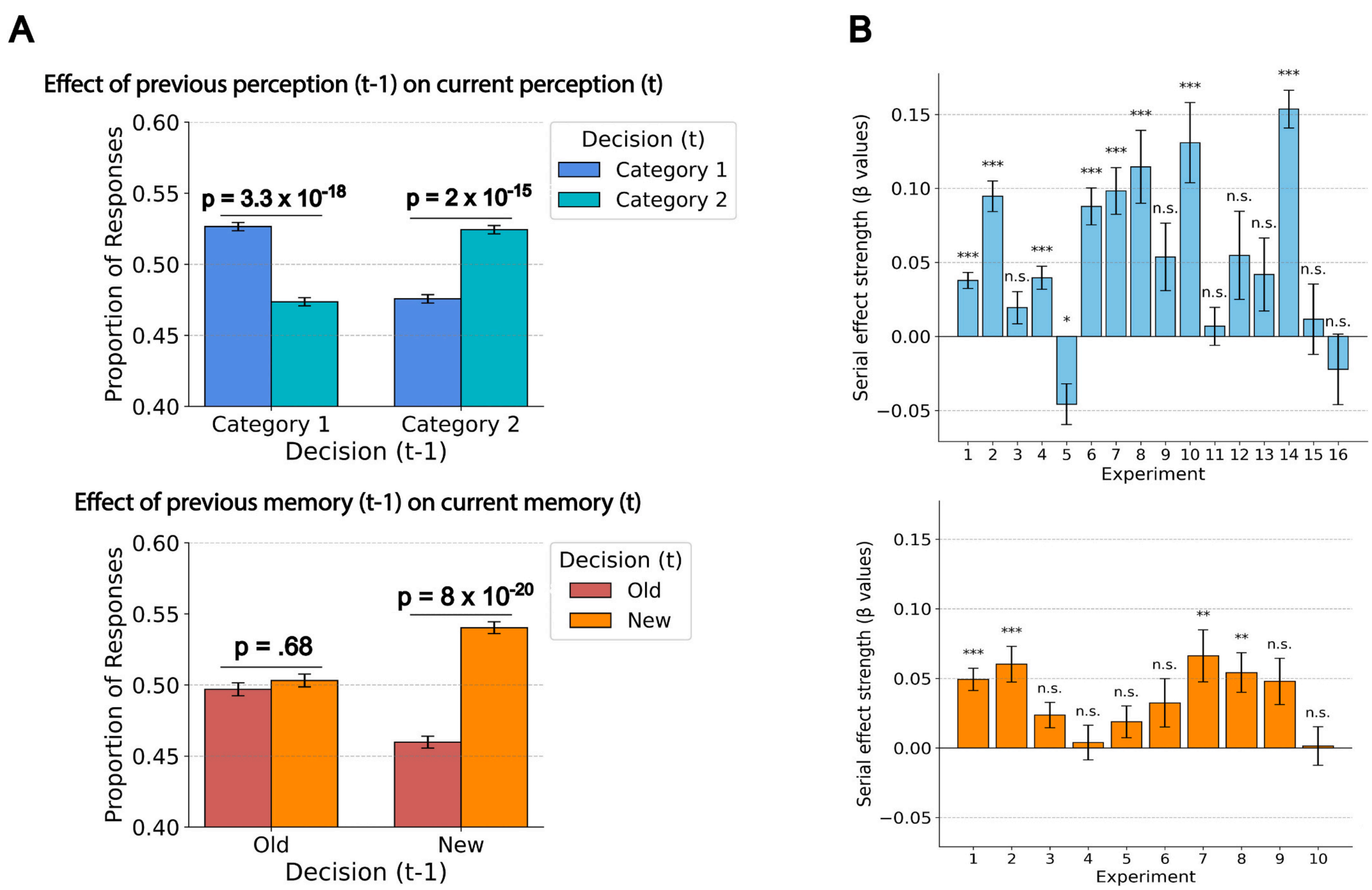


**Fig. 2.** Choice serial effects. A) The probability of repeating the preceding choice was higher across a variety of perceptual and memory tasks. B) Strength of choice serial effects across experiments quantified as the beta value of the regression (trial-by-trial choices regressed on their N-1 lagged version). Subject-level beta values within each experiment were tested against 0. Error bars depict SEM. ***, $p < .001$; **, $p < .01$; *, $p < .05$; n.s., not significant.

we further analyzed the choice serial effects within each experiment. We found that 8 of the 16 perceptual experiments showed a significant choice serial effect ($p < .05$) (with one of the experiments exhibiting a significant negative bias), but this was true for only 4 of the 10 memory experiments (Fig. 2B). We then conducted the same analyses by averaging on the experimental level and obtaining a single beta value per experiment for perceptual (average $\beta = 0.05$, $t(15) = 3.95$, $p = .01$, Cohen's $d = 0.99$) and memory tasks (average $\beta = 0.03$, $t(9) = 4.9$, $p = .006$, Cohen's $d = 1.55$). Choice serial effects quantified by the regression slope did not differ significantly for perception and memory ($t(24) = 1.03$, $p = .31$).

Finally, we conducted the same analyses by examining lag-5 and lag-10 effects. We indeed found that the choice serial effects diminished substantially with increasing the lag (Supplementary Fig. 1), suggesting that lag-1 analyses above reflect genuine serial effects.

### 3.3. Robust confidence leak in perception and memory

Having established the existence of robust choice serial effects, we examined the presence of confidence serial effects (i.e., confidence leak). We found that giving a specific confidence rating at time $t-1$ led to a higher probability of choosing the same confidence rating at time $t$ for both the perception and memory experiments ($p < .05$ for all pairwise comparisons in the perception experiments and the 3-choice memory experiments; Fig. 3 A). However, the results in Fig. 3A may be the product of idiosyncratic biases in response or key preferences (e.g., a bias in giving confidence = 3 on a disproportionate number of trials). Aggregating idiosyncratic biases across subjects may produce a

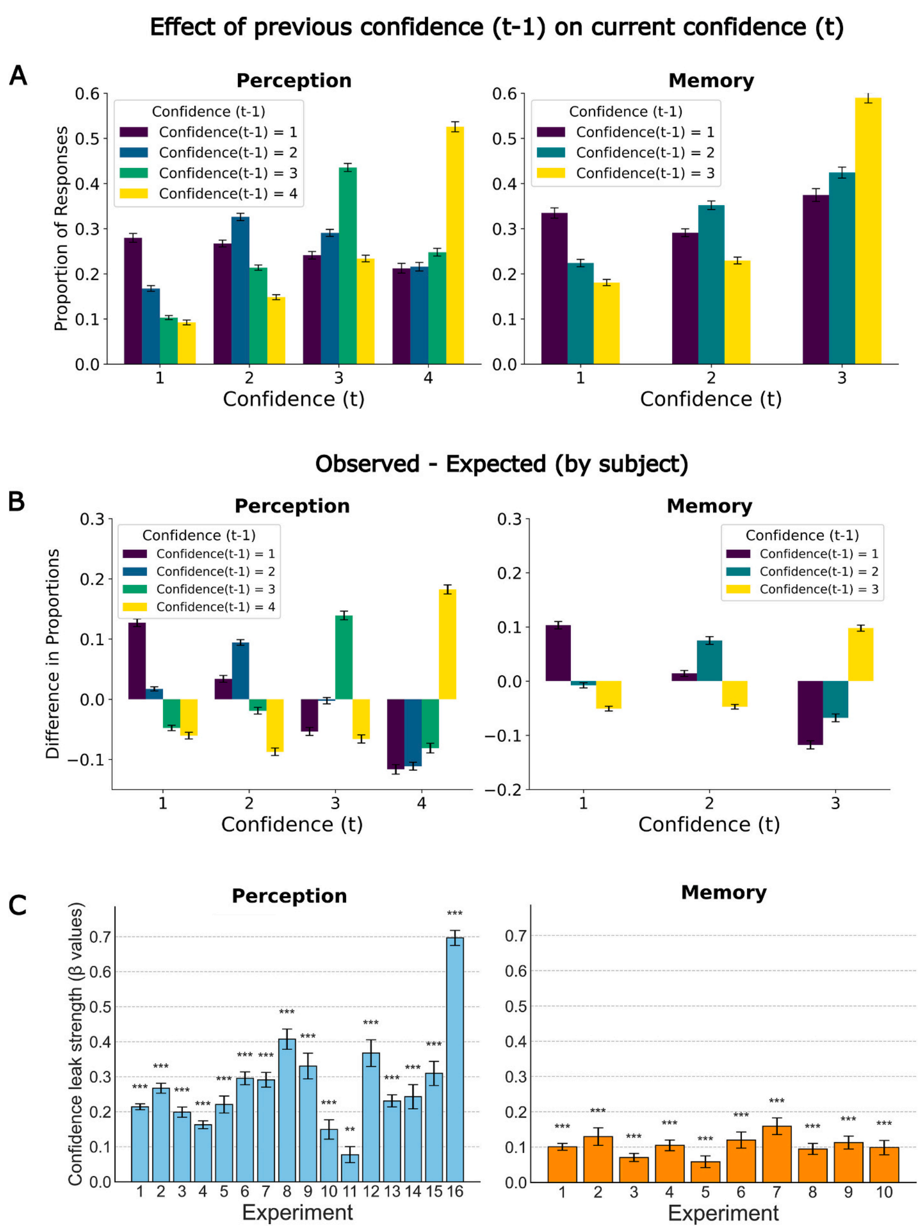


**Fig. 3.** Serial effects in confidence judgments (confidence leak). A) Subjects were more likely to repeat the previous confidence judgment across a variety of perceptual and memory tasks. The perception plot on the left shows combined data from all 12 perceptual experiments that included a 4-point confidence scale. The memory plot on the right shows combined data from the seven memory experiments with 3-point confidence scales since the 3-point confidence scale was most prevalent in memory tasks. B) Confidence leak is present when accounting for individual response biases. We subtracted the overall by-subject distribution of confidence responses (expected distributions) from the by-subject distributions depicted in A (observed distributions). C) Confidence leak strength on the experimental level quantified by the beta value of the regression (trial-by-trial confidence responses regressed on their N-1 lagged series). The within-experiment subject-level beta values were tested against 0. Error bars depict SEM. ***, $p < .001$; **, $p < .01$.

confidence trend similar to the one in Fig. 3A, without confidence leak actually being present. To test for this possibility, we accounted for such biases by subtracting the overall bias from the distributions of choices conditioned on the confidence given at time $t-1$. Specifically, for each subject, we subtracted the overall probability of each confidence response (expected distribution) from the probability of each confidence response conditioned on the previous confidence (observed distribution): $P(Conf(t)\,|Conf(t-1)) - P(Conf(t))$. We found that the same qualitative pattern emerged, such that giving a specific confidence rating at time $t-1$ led to a higher probability of choosing the same confidence rating at time $t$ for both the perception and memory experiments ($p < .05$ for all pairwise comparisons; Fig. 3B). Further, we conducted a repeated-measures ANOVA and found a significant interaction between previous and current confidence for both perception (F(9,10,683) = 536.98, $p < 1 \times 10^{-80}$, $\eta_p^2 = 0.31$) and memory experiments (F(9, 6183) = 322.51, $p < 1 \times 10^{-80}$, $\eta_p^2 = 0.31$), demonstrating a robust confidence leak effect when accounting for idiosyncratic biases in response or key preferences.

We further analyzed the strength of confidence leak by conducting a regression analysis where confidence on the previous trial was used to predict confidence on the current trial. We found robust confidence leak across the perceptual tasks (average β = 0.24, t(1184) = 45.87, $p = 5 \times 10^{-264}$, Cohen's $d = 1.33$). Like choice serial effects, confidence leak was weaker but still highly significant in the memory tasks (average β = 0.10, t(684) = 19.13, $p = 9.1 \times 10^{-65}$, Cohen's $d = 0.73$). Once again, we averaged the by-subject beta values within each experiment to obtain a single beta value per experiment. We found significant confidence leak ($p < .05$) in all 26 studies across perception and memory. At the experiment level, these beta values were significantly positive for perceptual (average β = 0.27, t(15) = 7.95, $p = 7.4 \times 10^{-6}$, Cohen's $d$ = 1.99) and memory tasks (average β = 0.10, t(9) = 11.84, $p = 6.9 \times 10^{-6}$, Cohen's $d = 3.75$) (Fig. 3C). Critically, a direct comparison between the strengths of confidence leak in perception and memory yielded a significant difference (t(24) = 3.89, $p = 6.8 \times 10^{-4}$, Cohen's $d = 1.57$) with confidence leak in perceptual tasks being stronger. Note that while most perceptual experiments used a 4-point confidence scale, most memory experiments used a 3-point confidence scale. However, we confirmed that the average slope did not substantially change in the memory experiments based on the scale (both the seven 3-point confidence experiments and the three 6-point confidence experiments had average β = 0.10).

As with the choice serial effects, we conducted the same analyses by examining lag-5 and lag-10 effects for confidence. We found that confidence leak diminished substantially with increasing the lag (Supplementary Fig. 1), suggesting that lag-1 analyses above reflect genuine serial effects on confidence.

The results in Fig. 3A and B raise the possibility that the confidence leak effect is solely driven by confidence repeats. That is, the effect might disappear when we account for people's tendency to repeat their confidence ratings. To test this possibility, we excluded all confidence repetitions from our data. Then, we subtracted the by-subject probabilities of the neighboring confidence ratings on trial $t$ as a function of confidence on trial $t-1$. In other words, we computed the differences, $d_i$, that quantify how much more likely it is that a confidence $i$ on trial $t-1$ is followed by a nearby confidence ($i+1$ or $i-1$) than a confidence that is farther away ($i+2$ or $i-2$) in the same direction. Specifically, we did not compare adjacent confidence ratings in different directions (e.g., 1 and 3 for a rating of 2 on the previous trial) because the base rate of confidence ratings varies substantially, and the comparison between confidence ratings that are not in the same direction would therefore be noisy. We then tested the average of the four difference values against 0 (see Section 2.3 for more details). We found that these different values were significantly positive in perception (t(1053) = 31.46, $p = 2.07 \times 10^{-153}$, Cohen's $d = 0.97$) but marginally negative in memory experiments (t(559) = −2.28, $p = .04$, Cohen's $d = 0.11$), demonstrating that each confidence rating increased the probability of giving the neighboring confidence rating in the subsequent trial in perception, but not in memory experiments. Confidence leak to neighboring responses was significantly stronger in perception compared to memory experiments (t(1612) = 17.21, $p = 4.02 \times 10^{-61}$, Cohen's $d = 0.9$). Overall, these analyses show that confidence leak is not solely driven by confidence repeats.

### 3.4. Choice serial effects and confidence leak are robust when controlling for other factors

The analyses above focused on testing the effect of either choice or confidence in a previous trial on choice or confidence in the current trial. Here, we test for the robustness of these effects by including additional factors using multiple regression analyses. Specifically, we included the stimulus, response, and confidence on the previous trial, as well as the confidence or choice on the current trial as predictor for choice or confidence on the current trial, respectively. Importantly, we ensured that predictors did not suffer from excessive multicollinearity (Supplementary Tables 1 and 2). We found that the choice on trial $t-1$ still predicted the choice on trial $t$ in perception (β = 0.06, t(1184) = 17.94, $p = 6 \times 10^{-63}$, Cohen's $d = 0.52$) and memory (β = 0.04, t(684) = 10.14, $p = 1 \times 10^{-21}$, Cohen's $d = 0.39$) (Supplementary Fig. 2). This was also true on the experiment level in perception (β = 0.06, t(15) = 4.98, $p$ = .001, Cohen's $d = 1.25$) and memory (β = 0.04, t(9) = 5.64, p = .001, Cohen's $d = 1.79$). The same was true for confidence leak: confidence on trial $t-1$ predicted confidence on trial $t$ in perception (β = 0.24, t(1184) = 46.23, $p = 1.3 \times 10^{-266}$, Cohen's $d = 1.34$) and memory (β = 0.10, t(684) = 19.82, $p = 1.6 \times 10^{-68}$, Cohen's $d = 0.76$). Examining the other predictors, we found the stimulus on trial $t-1$ negatively predicted the current choice in perception (β = −0.02, t(1184) = −10.02, $p = 7.7 \times 10^{-22}$, Cohen's $d = -0.29$) and memory (β = −0.01, t(684) = −3.68, $p = .002$, Cohen's $d = -0.14$), a result consistent with the idea that there could be an adaptation-based repulsive effect of the stimulus on the response in the following trial (Sheehan & Serences, 2022).

### 3.5. Switching the confidence judgment creates a repulsive choice bias

The ubiquitous existence of choice serial effects and confidence leak posits the question of whether and how the two modulate each other. Specifically, to what extent does a repeat of the same choice or confidence affect the strength of confidence or choice serial dependence, respectively. In this section we first focus on how switching confidence affects choice serial effects.

To examine how switching confidence affects choice serial effects, we estimated the strength of the choice serial effect for each subject separately for cases where the confidence ratings were the same or different on two consecutive trials. We found that repeating the same confidence was accompanied by strong positive choice serial effects in both perception (average β = 0.15; t(1184) = 25.62, $p = 2.19 \times 10^{-114}$, Cohen's $d = 0.74$ and memory experiments (average β = 0.13; t(684) = 17.89, $p = 8.15 \times 10^{-58}$, Cohen's $d = 0.68$). Critically, switching the confidence judgment was associated with a reversed choice serial effect in perception (average β = −0.06; t(1184) = −12.44, $p = 2.7 \times 10^{-32}$, Cohen's $d = 0.36$) (Supplementary Fig. 3) and memory (average β = −0.07; t(679) = −11.33, $p = 3.56 \times 10^{-26}$, Cohen's $d = 0.43$). The difference between the choice serial effect for repeating vs. switching confidence was highly significant (perception: t(1184) = 25.5, $p = 1.52 \times 10^{-113}$, Cohen's $d = 0.74$; memory: t(679) = 18.68, $p = 5.97 \times 10^{-62}$, Cohen's $d = 0.71$).

To assess the strength of the effect on the experiment level, we averaged the by-subject beta coefficients to obtain a single beta value per experiment. We then compared choice serial effect beta values for repeating and switching confidence. We again found that choice serial effects were significantly higher for repeated confidence vs. switched confidence in both perception (average repeat β = 0.14; average switch β = −0.04; t(15) = 7.25, $p = 4.52 \times 10^{-5}$, Cohen's $d = 1.75$) and memory (average repeat $\beta = 0.13$; average switch $\beta = -0.07$; $t(9) = 5.36$, $p = .007$, Cohen's $d = 1.49$) (Fig. 4A). Further, this difference was significant ($p < .05$) for 15 out of the 16 perception experiments and for 9 of the 10 memory experiments. The strength of confidence modulation was not significantly different for perception and memory ($t(24) = 0.64$, $p = .53$).

To further assess how repeating the confidence response affects the choice serial effect, we examined whether this effect occurs for lag-5 and lag-10. We found a difference in choice serial effect strength based on repeating or switching the confidence rating for 5 trials back in perception ($t(15) = 4.77$, $p = 7.3 \times 10^{-4}$, Cohen's $d = 1.19$) but not in memory ($t(9) = -0.44$, $p > .9$) (Fig. 5). For 10 trials back, there was no modulation in either perception ($t(15) = 1.39$, $p = .55$) or memory ($t(9) = 1.03$, $p > .9$). Importantly, the difference between repeat and switch confidence was much smaller for 5 trials back compared to 1 trial back in both perception ($t(15) = 7.04$, $p = 1.19 \times 10^{-5}$, Cohen's $d = 1.76$) and memory ($t(9) = 5.09$, $p = .001$, Cohen's $d = 1.61$). These results suggest that the effect of repeating confidence on the direction of the choice serial effect is due to the influence of the previous trial instead of slow drifts in choice and confidence biases throughout the experiment.

### 3.6. Switching the choice weakens confidence leak

Having established that confidence switches reverse the choice serial effect, we investigated how choice switches affect confidence leak. Similar to above, we estimated the strength of confidence leak for each subject separately for cases where the main decision was either repeated or switched. We found that confidence leak remained significantly positive regardless of whether the main decision was repeated or switched (all p's $< 0.05$). Critically, however, switching the main decision weakened confidence leak in perception (average repeat $\beta = 0.32$; average switch $\beta = 0.13$; $t(1181) = 27.2$, $p = 1.05 \times 10^{-125}$, Cohen's $d = 0.79$) and memory experiments (average repeat $\beta = 0.17$; average switch $\beta = -0.004$; $t(677) = 15.88$, $p = 2.49 \times 10^{-47}$, Cohen's $d = 0.61$). Note that confidence leak in these switched memory choices did not differ from zero, despite the negative average β values ($t(677) = -0.637$, $p > .9$, Cohen's $d = -0.02$). The same results appeared at the experiment level: switching the main decision substantially weakened the confidence leak effect in perception (average repeat $\beta = 0.35$; average switch $\beta = 0.18$; $t(15) = 7.03$, $p = 6.44 \times 10^{-5}$, Cohen's $d = 1.75$) and memory experiments (average repeat $\beta = 0.17$; average switch $\beta = -0.001$; $t(9) = 4.72$, $p = .01$, Cohen's $d = 1.49$) (Fig. 4B). Further, this difference was

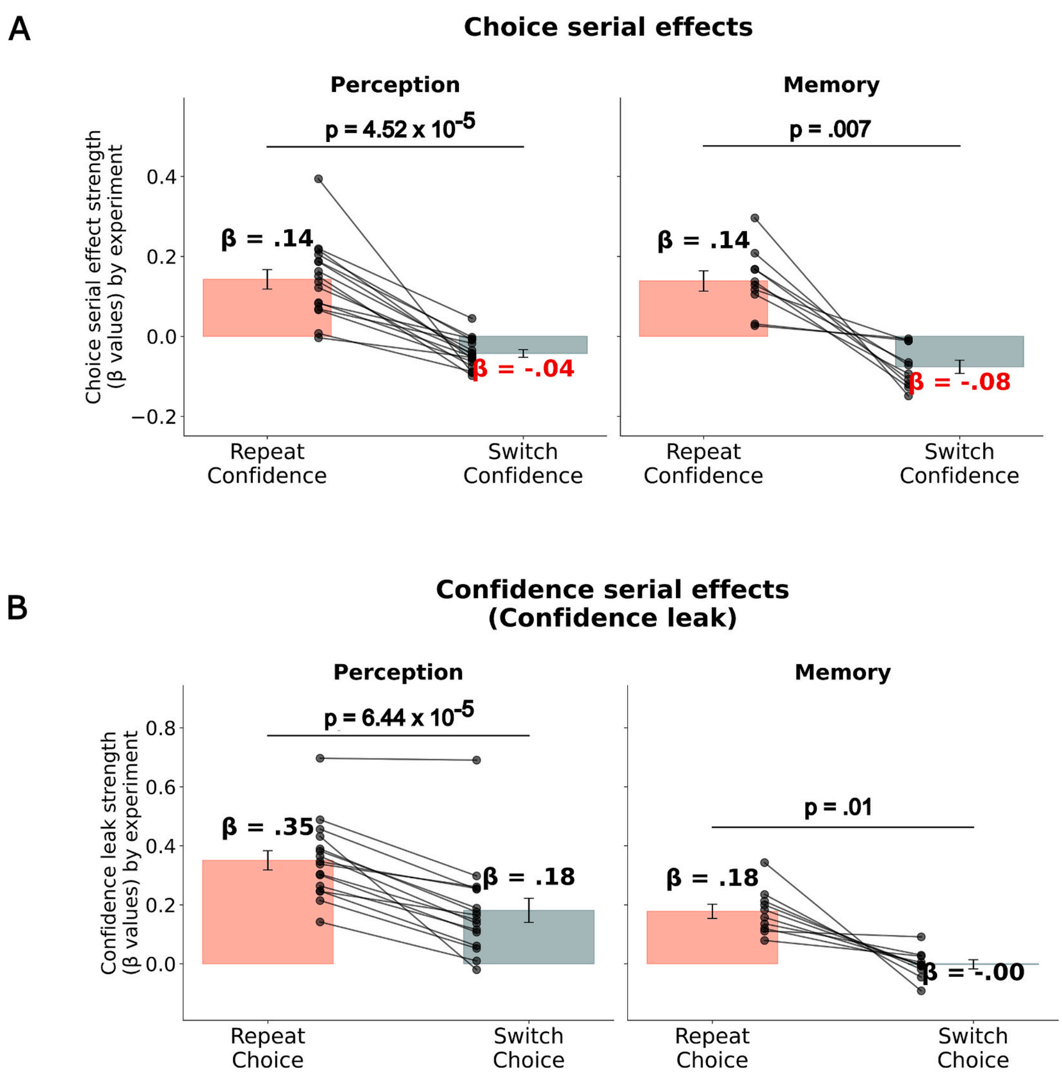


**Fig. 4.** Choice serial effects are reversed after a confidence switch and confidence leak is diminished after a choice switch. A) Switching the confidence rating was associated with a tendency of making a different perceptual judgment relative to the previous trial. However, switching the perceptual judgment only weakened the (positive) confidence leak effect. B) Switching the confidence rating was also associated with a different memory decision. A different memory decision relative to the previous trial was linked to a change of confidence. Each data point (beta value) represents the averaged by-subject beta values within a single experiment. Error bars depict SEM.

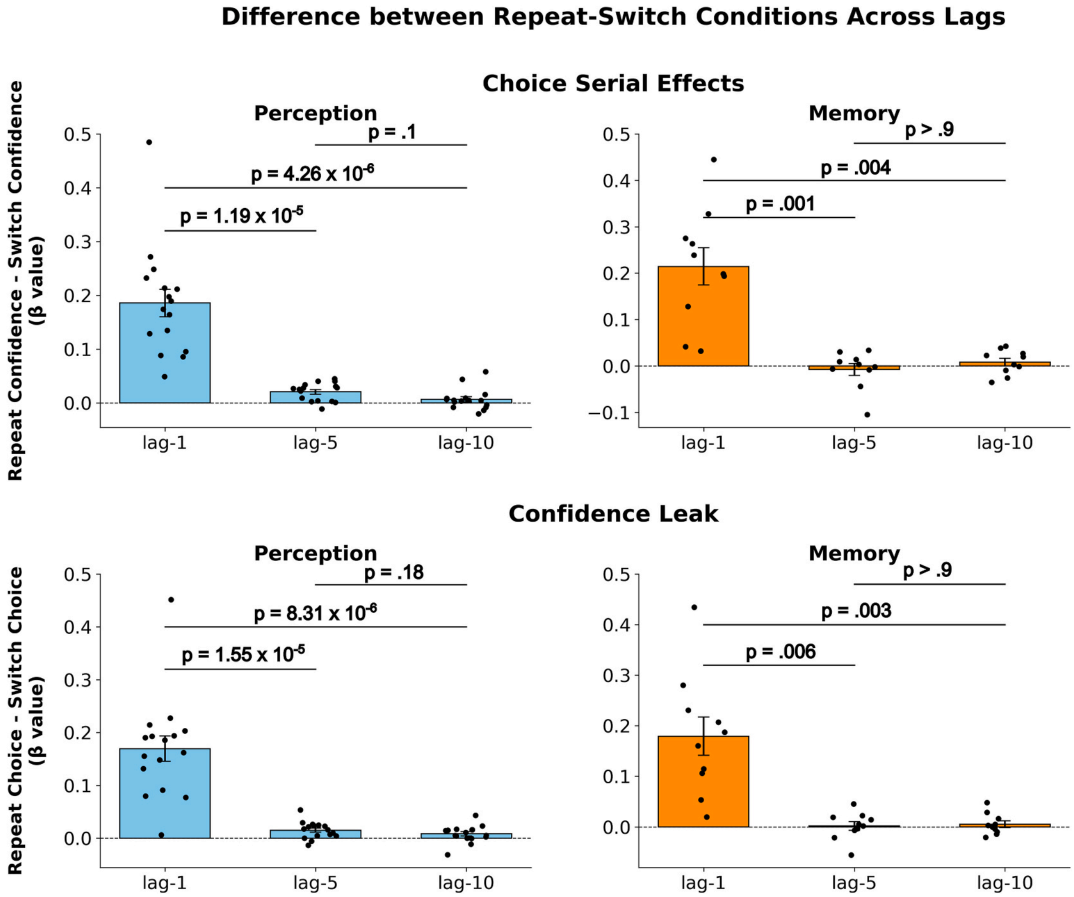


**Fig. 5.** The difference in choice serial effect and confidence leak strength for repeats and switches diminishes with time. A) Switching the confidence rating modulated choice serial effects for lag-1 analysis, but the modulation was significantly weaker for lag-5 and lag-10 analyses, suggesting that the interaction between confidence and the choice serial effect is not a function of slow decisional drifts throughout the experiment. B) Switching the choice modulated confidence leak for lag-1 analysis, but the modulation was significantly weaker for lag-5 and lag-10 analyses, suggesting that the interaction between choice and confidence leak is not a function of slow decisional drifts throughout the experiment. Each data point represents the averaged by-subject beta value differences within a single experiment. Error bars depict SEM.

significant ($p < .05$) for 15 of the 16 perception experiments and for 9 of the 10 memory experiments. The choice modulation of confidence leak did not differ in strength for perception and memory ($t(24) = 0.23$, $p = .82$).

To assess how repeating the choice affects confidence leak beyond the previous trial, we examined whether the interaction between choice serial effects and confidence leak occurs for lag-5 and lag-10. Namely, we checked whether repeating and switching the main choice modulated confidence leak for 5 and 10 trials back (Fig. 5B). We found a difference in confidence leak strength based on repeating or switching the choice for 5 trials back in perception ($t(15) = 3.76$, $p = .005$, Cohen's $d = 0.94$) but not for memory ($t(9) = 0.26$, $p > .9$). For 10 trials back, there was no modulation in either perception ($t(15) = 1.95$, $p = .2$) or memory ($t(9) = 0.68$, $p > .9$). Importantly, the difference between repeat and switch choice was significantly smaller for 5 trials back compared to 1 trial back in perception ($t(15) = 6.89$, $p = 1.55 \times 10^{-5}$, Cohen's $d = 1.72$) and for memory ($t(9) = 4.22$, $p = .006$, Cohen's $d = 1.33$). Again, these results suggest that the effect of repeating the main choice on confidence leak is due to the influence of the previous trial and gradually disappears throughout the experiment.

### *3.7. Manipulating choice serial effect strength modulates confidence leak strength and vice versa*

Our results so far establish that choice and confidence serial effects robustly interact. However, it remains an open question whether manipulations that directly affect one type of serial effect would modulate the strength of the other type of serial effect.

We first assessed how a manipulation that influences the propensity to repeat one's choice affects confidence leak strength. The manipulation we focus on was whether the stimulus category on two consecutive trials was repeated or not. We chose this manipulation because repeating the stimulus category would naturally lead to repeated responses, whereas switching the stimulus category would naturally lead to switched responses. Indeed, we confirmed that repeating vs. switching the stimulus led to a strong positive vs. negative choice serial effect (perception: average betas = 0.37 vs. -0.25, $t(1184) = 57.08$, $p = 1 \times 10^{-308}$, Cohen's $d = 1.65$; memory: average betas = 0.34 vs. -0.26, $t(684) = 38.99$, $p = 4.6 \times 10^{-175}$, Cohen's $d = 1.49$). This difference also appeared on the experiment level (perception: $t(15) = 14.84$, $p = 1.8 \times 10^{-9}$, Cohen's $d = 3.7$; memory: $t(9) = 6.66$, $p = 7.4 \times 10^{-4}$, Cohen's $d = 2.1$).

Critically, we examined whether repeating vs. switching the stimulus also modulates the confidence leak strength. Indeed, we found that confidence leak was weaker when stimuli switched in two consecutive trials for both perception (average betas = 0.30 vs. 0.18, $t(1183) = 24.2$, $p = 4.9 \times 10^{-105}$, Cohen's d = 0.7) and memory (average betas = 0.16 vs. 0.03, $t(678) = 16.66$, $p = 6.8 \times 10^{-52}$, Cohen's $d = 0.63$) (Supplementary Fig. 4). The same result appeared on the experiment level (perception: $t(15) = 6.08$, $p = 1.5 \times 10^{-4}$, Cohen's $d = 1.62$; memory: $t(9) = 8.24$, $p = 7 \times 10^{-5}$, Cohen's $d = 2.6$) (Fig. 6). These findings demonstrate that a manipulation that directly affects the strength of the choice serial effect modulates the strength of confidence leak.

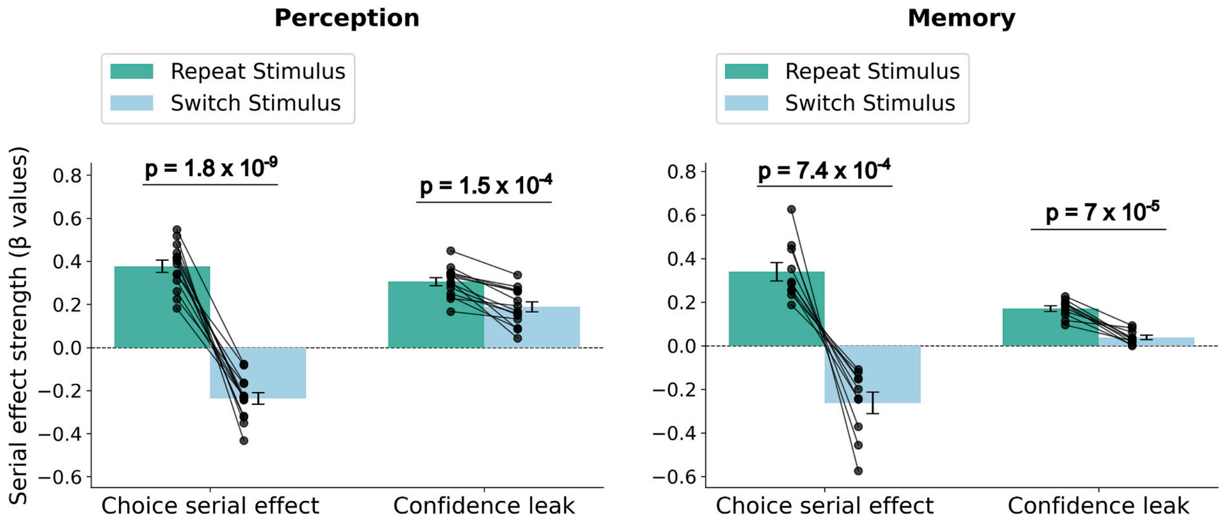


**Fig. 6.** Manipulation that affects the choice serial effect weakens confidence leak. Given the above-chance accuracy in all experiments, switching the stimulus naturally switched the choice, resulting in a repulsive bias. Importantly, switching the stimulus also weakened confidence leak. This was true for both perception and memory experiments. Each data point (beta value) represents the averaged by-subject beta values within a single experiment. Error bars depict SEM.

Having examined how a manipulation that affects choice serial effect strength modulates the confidence leak, we assessed the opposite direction, namely how a manipulation that affects confidence leak strength modulates choice serial effect strength. The manipulation we focused on was whether the task difficulty on two consecutive trials was repeated or not. We chose this manipulation because repeating task difficulty would naturally lead to repeated confidence, whereas switching task difficulty would naturally lead to switched confidence. To assess the effect of switching task difficulty on choice serial effects, we reanalyzed data from seven studies that included a difficulty manipulation (in all cases, by manipulating stimulus contrast).

We started by confirming that repeating vs. switching the task difficulty led to a change in the strength of confidence leak. Indeed, we found that both at the level of individual subjects (average betas for repeating vs. switching difficulty = 0.40 vs. 0.20, $t(168) = 10.44$, $p = 1.1 \times 10^{-19}$, Cohen's $d = 0.8$). Critically, we examined whether repeating vs. switching task difficulty also modulates the choice serial effect strength. Indeed, we found that switching task difficulty diminished the strength of choice serial effects at the level of individual subjects (average betas for repeating vs. switching difficulty = 0.11 vs. 0.09, $t(168) = 4.26$, $p = 6.6 \times 10^{-5}$, Cohen's $d = 0.32$). These effects were in the same direction but marginally significant at the experiment level: repeating confidence did not significantly affect either confidence leak ($t(6) = 2.92$, $p = .05$) or choice serial effect ($t(6) = 2.52$, $p = .09$). Note that these latter analyses would have been significant without correcting for multiple comparisons and were underpowered given that we only had seven experiments. Overall, these findings suggest that a manipulation that affects confidence leak strength modulates the strength of choice serial effects, although this effect is weaker compared to the modulation of confidence leak by the manipulation targeting choice serial effects.

### *3.8. The interaction between choice serial effects and confidence leak for choice "repeaters" vs. "alternators"*

Considering the idiosyncratic nature of serial effects, it is an open question whether we would also observe idiosyncratic differences in the interaction between serial effects based on how prone the subject is to repeating a choice in two consecutive trials. We checked whether the repeat-switch confidence modulation of choice serial effects differed across subjects based on whether they were more prone to repeating ("repeaters") or switching ("alternators") their responses in 2 consecutive trials (Fig. 7). We found that the difference of the choice serial effect in repeating and switching confidence for "repeaters" was larger than the difference of the choice serial effect in repeating and switching confidence for "alternators" in perception ($t(1183) = 5.53$, $p = 1.7 \times 10–7$, Cohen's d = 0.32) and memory ($t(678) = 3.8$, $p = 6.7 \times 10^{-4}$, Cohen's d = 0.3). These differences were marginal on the experiment level for perception ($t(14) = 2.56$, p = .09) and memory ($t(9) = 2.54$, $p = .07$). Importantly, choice serial effects in switch-confidence trials were repulsive and stronger for "alternators" compared to switch-confidence trials for "repeaters" in both perception ($t(1183) = 12.48$, $p = 2.7 \times 10^{-32}$, Cohen's d = 0.7) and memory ($t(678) = 7.82$, $p = 1.9 \times 10–13$, Cohen's d = 0.61). This was also true on the experiment level in both perception ($t(14) = 10.11$, $p = 3.2 \times 10^{-7}$, Cohen's $d = 2.61$) and memory ($t(9) = 6.61$, $p = 3.8 \times 10^{-4}$, Cohen's $d = 2.09$).

Similarly, we found that the difference of confidence leak in repeating and switching choices for "repeaters" was larger than the difference of confidence leak in repeating and switching choices for "alternators" in perception ($t(1180) = 5.34$, $p = 4.7 \times 10^{-7}$, Cohen's d = 0.31) and memory ($t(676) = 2.65$, $p = .03$, Cohen's $d = 0.21$; Fig. 7). However, confidence leak in switch-choice trials for "alternators" did not differ from confidence leak in switch-choice trials for "repeaters" in neither perception ($t(1182) = 0.102$, $p > .9$) nor memory ($t(679) = -0.05$, $p > .9$).

### *3.9. Serial effect strength in choice correlates with confidence leak strength*

Finally, we examined whether the within-subject interaction between choice and confidence serial effects generalizes to an across-subject relationship. Specifically, we estimated the strength of choice and confidence serial effects for each subject and correlated these strengths across subjects for each experiment. To account for the variability across datasets, we used a random-effects model to estimate the pooled correlation coefficient separately for perception and memory. We found a significant correlation between the strength of choice and confidence serial effects in both perception ($r = 0.144$ [95% CI 0.052, 0.235]) and memory ($r = 0.310$ [95% CI 0.155, 0.449]) experiments. At the experiment-level, all 16 perception experiments exhibited positive correlations (average $r = 0.20$), with eight of them being significant on their own ($p_{uncorrected} < 0.05$). Similarly, 8 of the 10 memory experiments exhibited positive correlations (average $r = 0.26$), with six of them being significant on their own ($p_{uncorrected} < 0.05$).

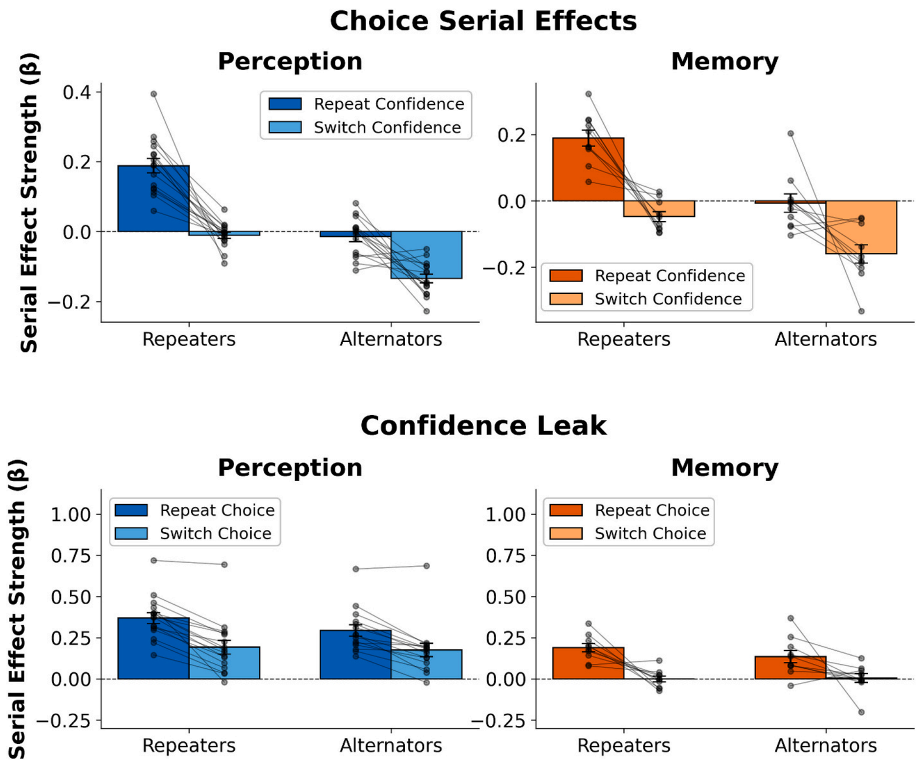


**Fig. 7.** Choice serial effects turn repulsive for "alternators" in switch-confidence trials. The interaction between choice and confidence serial effects depends on whether the subject is more prone to repeating or switching responses on two consecutive trials. While "repeaters" exhibit a positive choice serial effect in repeat confidence trials, "alternators" do not. Rather, "alternators" exhibit a negative choice serial effect in switch-confidence trials. However, this difference is not present for confidence leak. Error bars depict SEM.

## 4. Discussion

Choice serial effects (the tendency towards repeating perceptual choices) and confidence leak (the tendency towards repeating confidence judgments) have mostly been studied separately from each other. Here, we showed that choice serial effects and confidence leak modulate each other. Namely, switching the main choice weakened confidence leak and switching the confidence rating reversed the choice serial effect bias. We further demonstrated that manipulations that affect choice serial effects also modulate confidence leak and vice versa. Finally, we found that individual differences in the choice serial effect strength are related to individual differences in confidence leak strength. Together, these results demonstrate that choice serial effects and confidence leak strongly modulate each other. Moreover, our findings suggest that different types of serial effects generalize to a wide variety of perceptual and memory tasks and possibly share a common mechanism.

An interaction between choice and confidence serial effects was previously shown by Kantner et al. (2019). In their paper, the authors demonstrated that confidence leak is stronger for repeated responses compared to changed responses in the context of memory judgments. In addition, Kantner et al. showed that this type of effect generalizes for how interleaved perceptual judgments influence memory decisions. Here, we replicated Kantner et al.'s results by showing that confidence leak is modulated by the main choice in both the perception and the memory domain, with repeated choices eliciting stronger confidence leak. Critically, our findings go beyond Kantner et al.'s in several ways. First, we demonstrated that confidence modulates serial effects in the choice such that switching the confidence judgment predicted a reversed choice serial effect. In other words, a change in confidence was robustly associated with a switched perceptual or memory decision, rather than just a weaker positive choice serial effect. Second, we showed that confidence leak extends to neighboring confidence judgments, such that giving a certain confidence rating increases the probability of giving the neighboring confidence rating as opposed to a confidence rating that is farther away. Third, we demonstrated that modulating the strength of one type of serial effect affects the other type of serial effect. Specifically, stimulus repeats (a modulator of choice serial effect strength) modified confidence leak strength, and difficulty repeats (a modulator of confidence leak strength) modified choice serial effect strength. Finally, we showed the existence of robust individual differences where people exhibiting stronger confidence leak also exhibit stronger choice serial effects. Thus, these results go beyond the Kantner et al.'s findings by painting a comprehensive picture of the interaction between choice and confidence serial effects.

A major question about the nature of choice serial effects and confidence leak is the extent to which they are driven by the decision, the stimulus, or other variables tightly correlated with the decision and the stimulus. Specifically, a fundamental question in the serial dependence literature is whether serial dependence manifests on the perceptual or post-perceptual level (e.g., Cicchini et al., 2024; Pascucci et al., 2023). The present study is not designed to answer this question. However, within our context of the two-choice perceptual and memory tasks examined here, we can test the relative predictive strength of previous decisions compared to the relative predictive strength of the previous stimulus – whose variance can be differentiated in incorrect trials. To address this question of relative prediction, we used the stimulus, the choice and the confidence on trial $t-1$ while controlling for the confidence on trial $t$ to predict the choice on trial $t$. For both choice serial effects and confidence leak, we showed that the relevant decision on the previous trial was the only variable that positively predicted the current decision. Separately, using the datasets that included a difficulty manipulation (Table 2), we showed that contrast on the previous trial failed to predict current choice or confidence when accounting for the rest of the variables. These results suggest that, at least when it comes to two-choice perceptual decision-making tasks like the ones we analyze here, serial effects are likely driven by higher-order cognitive processes.

Our results have strong implications for existing theories of choice and confidence serial effects. One common view is that choice serial effects, at least in the context of memory judgments, are caused by fatigue or inattentiveness (Annis & Malmberg, 2013; Malmberg & Annis, 2012). While fatigue or inattentiveness could indeed contribute to serial effects, our findings that switching the stimulus affects confidence leak strength and switching contrast affects choice serial effect strength demonstrate that serial effects in both perception and memory go well beyond mere fatigue. Our results also have implications about the first formal model of confidence leak, which explained the phenomenon as arising from expanding and shrinking of the confidence criteria (Rahnev et al., 2015). Indeed, that model does not account for the robust interaction between serial effects in choice and confidence. Instead, our results fit better with Kantner et al. (2019) "sticky evidence" model where the strength of evidence carryover is a function of the distance (similarity) between the evidence values on trials $t-1$ and $t$.

Our results demonstrate that serial effect modulations are asymmetrical. Namely, while switching the choice simply weakens confidence leak, switching the confidence rating reverses the choice serial effect. One possibility for this effect is that it is simply explained by the strength of the original effects. Specifically, confidence leak is extremely strong and therefore any manipulation that affects it is likely to simply weaken it without being able to fully reverse it. In contrast, choice serial effects in our two-choice experiments are comparatively weaker, and thus it is easier for them to be reversed instead of just weakened. Nevertheless, this possibility remains speculative and should be tested empirically in future research.

Our results suggest practical interventions for diminishing the negative consequences of serial effects in real-world decision making. For example, it has been repeatedly demonstrated that choice serial effects appear in the decisions of doctors (e.g., when judging the presence or the absence of a tumor using an x-ray), which diminishes the overall accuracy of the diagnoses made by medical personnel (Manassi et al., 2019; Manassi et al., 2021; Ren et al., 2023). Here we showed that switching the difficulty of the decision across consecutive trials weakens choice serial effects. This result suggests that as long as individual cases can be first sorted by difficulty, then arranging the cases in a way that interleaves the difficulty could improve the overall accuracy rate of diagnoses. The same technique can be used across a wide variety of contexts.

Another novel finding of our work is that serial effects tend to be stronger in perception compared to memory. We found this to be true for both choice serial effects (Fig. 2) and confidence leak (Fig. 3). It is currently unclear what drives this difference. One possibility is that the strength of serial effects is domain specific. Another possibility is that there are differences between these studies – such as in overall accuracy or reaction time – that drive the domain differences in serial effect strength. Still another possibility is that the difference is driven by the fact that the perception datasets we used are based on discrimination tasks, whereas the memory datasets are based on detection tasks. It is also known that memory judgments based on detection result in internal representations of unequal variance (i.e., distributions for "old" tend to have higher variance than distributions for "new") (Mickes et al., 2007; Wixted, 2007), while the differences in variance for perceptual discrimination judgments are smaller (Rahnev, 2021). Further, confidence in discrimination and detection tasks may be based on different computations (Mazor et al., 2023), which might in turn affect the difference in serial effect strength we observe between perception and memory for confidence leak. Future research will need to distinguish between these possibilities.

In conclusion, we found that choice and confidence serial effects interact with each other. Specifically, switching the decision in two consecutive trials weakened confidence leak, whereas switching the confidence judgment reversed the choice serial effect into a repulsive bias. Further, we showed that manipulating the variable associated with one serial effect modulates the strength of the other serial effect. Finally, we found that individual differences in the choice serial effect strength are related to individual differences in confidence leak strength. These results demonstrate that serial effects in choice and confidence are strongly related, suggesting the possibility of common mechanisms underlying different serial effects. Importantly, these findings could be used to develop new approaches for diminishing the adverse nature of serial effects.

## CRediT authorship contribution statement

**Michaela Bocheva:** Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Kai Xue:** Methodology, Formal analysis. **Dobromir Rahnev:** Writing – review & editing, Supervision.

## Declaration of competing interest

The authors have no competing interests to declare that are relevant to the content of this article.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2026.106643.

## Data availability

Data is available in an online repository (linked in the main text).

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