Could Serial Dependence Account for Blown Calls in Baseball/Softball?

Hadley Rogers

Thesis Submitted in Partial Fulfillment of the Requirements

for the Bachelor of Arts Degree at Hamilton College

December 13, 2025

Advisor: Professor Alexandra List

Abstract

In baseball and softball, batters perceive many pitches back-to-back, making quick decisions based on what they see. Even the best batters and umpires sometimes err by swinging at a bad pitch or blowing a call. Recent research suggests that previous stimuli and decisions bias current perceptual judgments. Here, I investigated whether this bias, called serial dependence, may explain players' and officials' errors. In this study, participants completed two tasks in which they watched 100 repetitions of a dot simultaneously growing and moving downward at various trajectories, mimicking a pitch's movement. After each repetition, participants were asked to click on the dot's final location (localization task), or to indicate whether the dot landed inside or outside of a previously shown rectangle (2AFC task). Localizations were repulsed from the previous dot's final location, whereas 2AFC responses were attracted toward the previous response. Taken together, these results indicate a push-pull effect of serial dependence on participants' perceptual judgments, with current perceptions being simultaneously repulsed from and attracted toward previous stimuli and responses, respectively. Using these findings, I hypothesize that attractive serial dependence would be observed in baseball/softball games, potentially informing in-game strategy and umpire training.

Keywords: serial dependence, visual perception, localization, binary choice, decision making, baseball/softball

Could Serial Dependence Account for Blown Calls in Baseball/Softball?

Down to the final out in a tight game five of the 1997 National League Championship Series (NLCS), Fred McGriff struck out looking, handing the Miami Marlins the victory over McGriff's Atlanta Braves by one run. A disappointing outcome regardless, McGriff and the Braves' frustration was amplified by the fact that the final pitch, called a strike, was high, outside, and clearly out of the strike zone. Had the correct call been made, McGriff would have been on first with the go-ahead run at the plate. A glaring instance of umpire error, what could have led Eric Gregg, the home-plate official, to make such a consequential mistake? Could the previous pitch, a ball way off the plate, have made Gregg more inclined to call the final pitch a strike? Could the final pitch being less outside than the previous pitch have made an impact on Gregg's perception and judgment on the final call? Although we will never know what the outcome of the 1997 NLCS game five could have been had the right call been made, we can dig deeper into why Gregg may have blown the call.

Whether officiating a baseball game or making sense of what direction a car is moving, we are constantly making perceptual judgments in an unstable, ever-changing visual world. Although we may not all be dealing with rowdy fans and staggering curveballs, we are all also dealing with constant interruptions to vision (e.g., blinking, moving objects that temporarily occlude other objects). Despite these interruptors, we are still able to perceive a stable, continuous visual world. This consistency stems, in part, from the visual system's use of the recent past to perceive and interpret the present (Girshick et al., 2011). When similar stimuli are viewed in sequence, perceptions and judgments of present stimuli result from both past and present visual information (Fischer & Whitney, 2014). For example, when determining the color of sequentially presented stimuli, reports of a given stimulus's color are biased toward the color of the previously presented stimulus, as long as both colors are sufficiently similar (Barbosa & Compte, 2020). The influence of recent stimuli on current perception is called serial dependence (Fischer & Whitney, 2014).

In addition to color, visual serial dependence occurs across various stimuli and features, including orientation (Kim et al., 2020), position (Manassi et al., 2018), and faces (Liberman et al., 2014). Across these different stimuli and features, visual serial dependence is characterized by attentional, spatial, temporal, and featural tuning (Manassi & Whitney, 2024), with attended-to stimuli or stimuli closer together in time, space, and appearance exhibiting the greatest perceptual smoothing. The attentionally-, spatially-, temporally-, and featurally-tuned fields in which serial dependence occurs are referred to as “continuity fields” (Manassi & Whitney, 2024). Within continuity fields, perception is smoothed using implicit knowledge of typical autocorrelations, or experience-driven assumptions that stimuli present moments ago are likely to still be present.

Although it is usually safe to assume that the world around us is autocorrelated, it is not always (Zavagno et al., 2015). Thus, serial dependence, while often helpful, can lead to errors in perception and judgment, errors that may be particularly pronounced and consequential for people whose daily tasks involve sequential visual analysis tasks. For example, visual serial dependence is evident in radiologists’ interpretations of sequentially viewed medical scans, with the perception of a lesion’s shape in a given mammogram being systematically attracted toward the shape of previously seen lesions (Manassi et al., 2021). Similarly, dermatologists’ perceptual judgments of sequentially viewed skin lesions as benign or malignant are biased by previous perceptual judgments (Ren et al., 2023). Even minor errors in both of these fields could lead to major consequences such as misdiagnosis and inappropriate treatment. Though less consequential for people's health, batters and umpires are asked to perform similar sequential visual perception and judgment tasks where minor errors can have significant consequences on game outcomes, making the baseball/softball context an interesting area for studying serial dependence and its mechanisms.

Although we continue to learn about serial dependence in different settings, research has yet to resolve an existing debate. Namely, the extent to which visual serial dependence occurs at a low-level, purely perceptual stage of visual processing versus a high-level, cognitive/decision stage remains unclear. Initial research argued for serial dependence as occurring on a perceptual level, directly altering what we see (Fischer & Whitney, 2014). However, research has since emerged complicating this view, suggesting that serial dependence may be due, instead, to errors in decision making (Pascucci et al., 2019).

Evidence for serial dependence as a low-level, perceptual process stems from the hypothesized role of neural traces in biasing perception (Murai & Whitney, 2021). Fischer and Whitney (2014) proposed that neural changes due to previous activation may impact how the current stimulus is processed, biasing perception toward previously seen stimuli. Thus, changes in neural responsiveness, not later decisions, are what lead to the observed serial dependence effect. Murai and Whitney (2021) provided support for this idea by asking participants to judge whether a certain Gabor patch was present or absent in a noisy image and, in a second task, to determine whether a Gabor patch was tilted clockwise or counterclockwise. Both of these tasks involve only simple detection, requiring no maintenance, rehearsal, or retrieval of previously seen stimuli. Thus, any observed attractive serial dependence, the authors argued, could be attributed to changes in low-level perceptual templates directly. In line with the perceptual account of serial dependence, participants' responses indicated that perceptions of a given

Gabor’s presence/absence and orientation were drawn toward previous inducer orientations (i.e., attractive serial dependence).

Serial dependence in low-level, perceptual tasks, however, does not consistently elicit attractive serial dependence. Rather, some studies indicate that current perceptions are biased away from previously seen stimuli in such tasks. Pascucci et al. (2019), for example, found that reports of a given Gabor’s orientation were repulsed from that of previous stimuli. Likewise, when asked to report which of two simultaneously presented stimuli was more clockwise, Fritsche et al. (2017) found that participants’ perceptions were repulsed from previous stimuli. Thus, evidence supporting serial dependence as operating on low-level processes is inconsistent, with some research suggesting that serial dependence biases perception attractively, whereas other research suggests that serial dependence biases perception repulsively.

Studies investigating the role of later processes, such as working memory, in serial dependence caution us away from understanding this bias as a solely perceptual process (Chen et al., 2023). Rather than sequential stimuli appearing more similar due to serial dependence, the decision-based view posits that we, instead, only make similar decisions about successive stimuli. For example, Schlunegger and Mast (2023) demonstrated that, when asked to discriminate motion in random dot displays as either leftward, rightward, upward, or downward, participants’ prior responses, rather than prior stimuli, predicted responses in future trials. Other studies have replicated these findings (Moon & Kwon, 2022; Pascucci et al., 2019), suggesting that serial dependence relies more on past choices than actual input statistics. As opposed to the mix of attractive and repulsive effects observed in lower-level perceptual tasks, perceptual decisions are consistently biased toward previous stimuli (Fritsche et al., 2017; Moon & Kwon, 2022; Pascucci et al., 2019; Schlunegger & Mast, 2023).

The resolution of this debate probably falls somewhere in the middle of these two positions. A third, two-factor model posits that serial dependence is better understood as a hierarchy of push and pull factors, integrating both low-level and high-level processes. Importantly, this model accounts for the existence of both attractive and repulsive serial dependence effects, positing that serial dependence is characterized by a simultaneous repulsion from previous stimuli and attraction to previous responses (Fritsche et al., 2017). Murai and Whitney's (2021) aforementioned findings that current perceptions were attracted toward previous perceptions, at first glance, do not fit with this model. However, by asking participants to make binary decisions about whether a stimulus was present/absent or clockwise/counterclockwise, the two-factor model suggests, may have led the authors to find attractive serial dependence. Using a two-alternative forced choice (2AFC) structure makes the act of decision-making more salient to participants as opposed to a free-response task, potentially facilitating decision bias (Treviño et al., 2020). Thus, the attractive bias observed by Murai and Whitney is likely better explained as an attraction to the previous decision, not an attraction to the previous stimulus.

Fritsche et al. (2017) were the first to parse out the effects of previous stimuli versus responses using a series of similar tasks, one involving the reproduction of a Gabor's orientation and two involving comparing perceptual features of a pair of Gabors. The reproduction task, because it forces participants to store the previously seen orientation in working memory and decide how to adjust a subsequently presented Gabor to match, engages higher-level decision-making and working-memory processes. On the other hand, the authors reasoned that asking participants to make an immediate comparison between two Gabors reduced the potential influence of post-perceptual, decision-making processes, allowing any bias to be attributed to changes in stimulus perception directly. In the reproduction task, designed to measure decision bias, reported orientations were biased toward previously seen orientations. In the two comparison tasks, designed to measure perceptual bias, participants' responses were repulsed from previous stimuli. Thus, by engaging participants in a task that required perceptual, rather than decisional, processes, a repulsive serial dependence effect occurred. A task more taxing on participants' decision-making processes, on the other hand, yielded the expected attractive serial dependence effect.

Together, repulsion from previous stimuli and attraction to previous decisions make up a two-factor model of serial dependence that integrates both low-level and high-level processes and is supported by novel statistical modeling approaches (Pascucci et al., 2019; Sadil et al., 2023). At the same time that perceptions of previous stimuli promote sensitivity to change through repulsive serial dependence, previous responses create consistency via attractive serial dependence, striking an important balance. The coexistence of these two mechanisms is evident in Sadil et al.'s (2023) statistical analysis of previously performed serial dependence studies, because a two-factor model based on both prior stimuli and prior responses fit the data better than a one-factor model using either prior stimuli or prior responses. Visual experience, then, may be the result of previous stimuli, previous decisions, and the corresponding biases that provide us with both stability and sensitivity to change.

The two-factor model of serial dependence, however, is not without its limitations. The main weakness with this view is the difficulty associated with isolating perceptual and decision effects, because both are tightly intertwined in the process of perceiving and understanding our visual world. Even in experiments purportedly only measuring changes in perception, participants are asked to make decisions based on what they saw. Thus, assuming that perceptions of current stimuli are repulsed from previous stimuli neglects the role that decision-making still plays in executing perceptual tasks. A common strategy to combat this confound involves randomly intermixing response trials with trials that do not require participants to make a response (Fischer & Whitney, 2014). Studies employing this strategy have found that serial dependence is unaffected by the lack of a decision on a previous trial (Liberman et al., 2014; Manassi et al., 2017; Xia et al., 2016), suggesting that serial dependence occurs at the level of perception regardless of whether or not a participant is asked to make a decision.

Including no-response trials, though, does not eliminate the possibility of participants making implicit perceptual decisions. Even if they are not explicitly asked to decide whether a stimulus is oriented clockwise or counterclockwise in a given trial, participants may still make implicit decisions due to the expectation of a future response requirement. Therefore, including no-response trials may not be sufficient to disentangle perceptual and decisional processes. Though it complicates inferences that can be drawn from serial dependence studies, the intimate interlacing of previous stimuli and responses supports the use of a two-factor model.

To best understand the role of serial dependence in specific contexts, it is necessary to consider both previous stimuli's and previous responses' effects on current perceptions. In this study, I employ two perceptual judgment tasks akin to those performed by umpires and batters, who perform precise back-to-back visual perception and judgment tasks, to ascertain how serial dependence may be at play on the baseball/softball field. In one task, participants are asked to localize pitch endpoint (measuring perceptual bias). In the second task, participants are asked to determine whether a simulated pitch falls inside or outside of the "strike zone" (measuring decision bias). The use of these specific tasks, never before used in serial dependence research, allows for a better understanding of serial biases in both a novel context and using novel stimuli.

Consistent with the two-factor model of visual serial dependence in visual perception, I hypothesized that (1) reported pitch location in a given trial would be repulsed from pitch location of the previous trial, and (2) reports of whether a pitch fell inside or outside of the strike zone would be attracted toward the previous reported location.

Method

Participants

Twenty-six students (18 cisgender female, 7 cisgender male, 1 non-binary/genderfluid/genderqueer) at Hamilton College participated in the experiment. Participants ranged in age from 19 to 22 years (M = 20.04, SD = 1.02). All participants were told that the purpose of the study was to examine how what we see is impacted by both prior experience and how we are asked to respond to what we see. Participants gave informed consent to take part in the study and were compensated with extra credit. The experimental procedures were approved by the Hamilton College Institutional Review Board (ID#: F25-038).

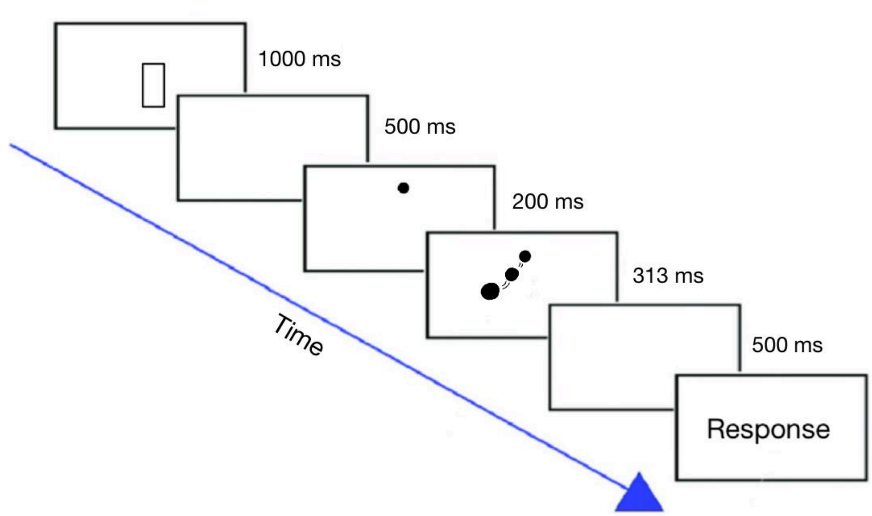
Stimuli

Experimental stimuli, shown in Figure 1, were programmed using PsychoPy. The initial stimulus consisted of a black outline of a 6 x 4 cm (θ_{width} = 6.74°, θ_{height} = 4.49°) rectangle presented 1.32 cm (θ_{offset} = 1.48°) below the center of an LCD monitor (4480 x 2520 resolution at 218 pix/inch, 60 Hz, Apple iMac). After 1000 ms, the rectangle disappeared and was replaced by a blank screen for 500 ms. Then, a black dot with a 0.52 cm diameter appeared centered at the top of the screen ($\theta_{eccentricity}$ = 14.80°) . Following 200 ms of stillness, the dot's diameter grew to 1.06 cm while simultaneously moving downward at 25.95 cm/sec to simulate a three-dimensional object approaching the viewer. The dot moved downward at one of the following angles, selected randomly for each trial: ±30°, ±25°, ±20°, ±15°, ±10°, ±5°, and 0°.

Negative angles indicate leftward motion, whereas positive angles indicate rightward motion. Each angle was accompanied by a random curvature value selected from the following: 0, ±0.01, ±0.02, and ±0.025. Positive curvature values curve the dot's path to the right, and negative curvature values do the opposite. Greater curvature absolute values bend the dot's path more strongly. Random angle and curvature pairs on each trial mimic different pitch trajectories. Due to the dot's variable trajectory, it ended at different horizontal locations on the screen in each trial. Once the dot moved halfway down the screen at the given angle/curvature, it disappeared. The screen then remained blank for 500 ms before participants were asked to provide a response. After responding, participants viewed a blank screen for 500 ms before the next trial began.

Figure 1

Event Sequence



Note. General event sequence for both experimental tasks. Response mode varied depending on whether participants were completing the localization or 2AFC task.

Procedure

The experiment was conducted in a regularly lit testing room. Participants were seated in front of a computer, 50 cm from the screen, and instructed to perform all tasks as accurately as possible. Participants performed two tasks, the order of which was counterbalanced across participants. In the localization task, participants were instructed to, after viewing the event sequence, click the dot's final location on the screen. In the 2AFC task, participants were instructed to, after viewing the same event sequence, indicate whether the dot's final position would have fallen inside or outside of the initially shown rectangle. Participants were instructed to press "i" if they thought the dot would have landed inside of the rectangle and "o" if they thought it would have landed outside. Participants completed 100 trials of each task with breaks offered about every five minutes. After finishing all trials, participants answered a series of demographic questions and were thanked for their time.

Data Analysis

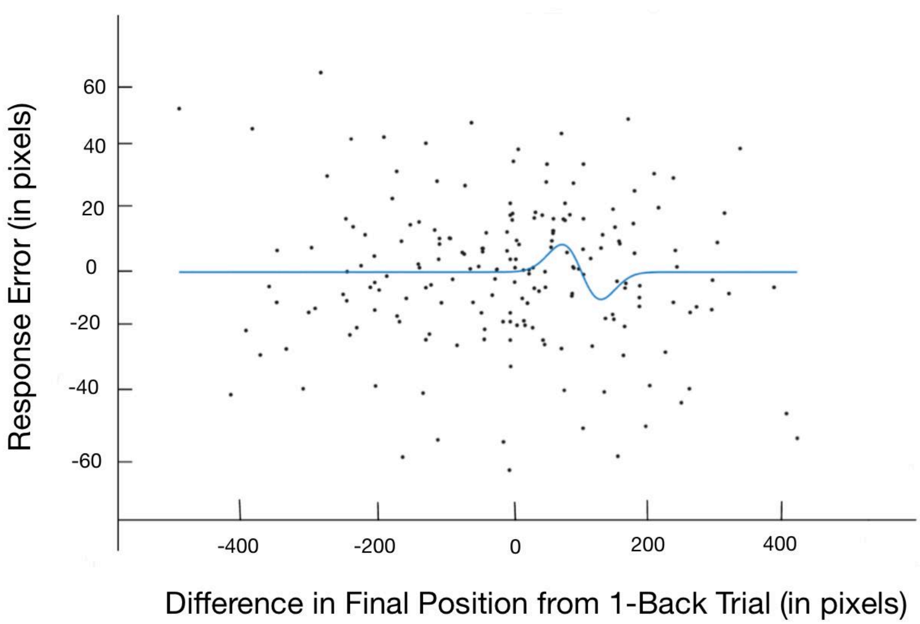
Consistent with previous serial dependence research (Fischer & Whitney, 2014; Fritsche et al., 2020; Manassi et al., 2017, 2018) , I calculated bias in the localization task by fitting a derivative of Gaussian (DoG) curve to each participant's data. Before fitting the DoG curve, I calculated how much the final dot position in a given trial differed from the final dot position in the previous trial (in pixels). For each trial, I also calculated participants' response error, defined as the distance between reported final dot position and true final dot position (in pixels). Data points were then plotted for each trial with the difference between sequential final positions as the x-value and response error as the y-value. Zero on the x-axis means sequential final positions were identical; zero on the y-axis indicates perfect performance at identifying the dot's final position. The simplest DoG curve of the form seen in (1) was fit to the data points (Figure 2), with a separate curve fit for each participant's data. I then measured serial dependence as half of

$$y = A(-(x - \mu)/\sigma^2 e^{(-(x-\mu)^2/(2\sigma^2))} \tag{1}$$

the DoG curve's peak-to-trough amplitude with positive values indicating attractive bias and negative values indicating repulsive bias.

Figure 2

Gaussian Derivative Fit to Participant X's Data



Note. Best fit Gaussian derivative for Participant X's data. Participant X's data fit particularly well with the derivative of Gaussian function. Response error reflects the difference between the participant's reported final dot location and the true final dot location. Difference in final position was calculated by subtracting the dot's location in the previous trial from the dot's location in the current trial.

An alternative method of data analysis was used to test for serial dependence in the inside-outside task, consistent with prior serial dependence research involving binary decisions (Zhang & Alais, 2020; Ren et al., 2023). I used metrics from signal detection theory to measure bias in this task. For each participant, I first separated trials preceded by an outside response from those preceded by an inside response. Given all trials preceded by an outside response, hit rate was calculated as the number of correctly-identified inside landings divided by the total number of true inside landings. False alarm rate was calculated as the number of outside landings incorrectly identified as inside divided by the total number of true outside landings. Once I obtained the hit rate and false alarm rate for the given participant, each value's z-score was computed. Using the two obtained z-scores, I computed the criterion using (2). This

$$C = -((Z(HR) + Z(FAR))/2) \tag{2}$$

process was then repeated with all trials preceded by an inside response, yielding a C_{outside} and C_{inside} value for each participant. A serial dependence index for each participant was then calculated as $C_{\text{outside}} - C_{\text{inside}}$, with positive values indicating attractive bias and negative values indicating repulsive bias.

Results

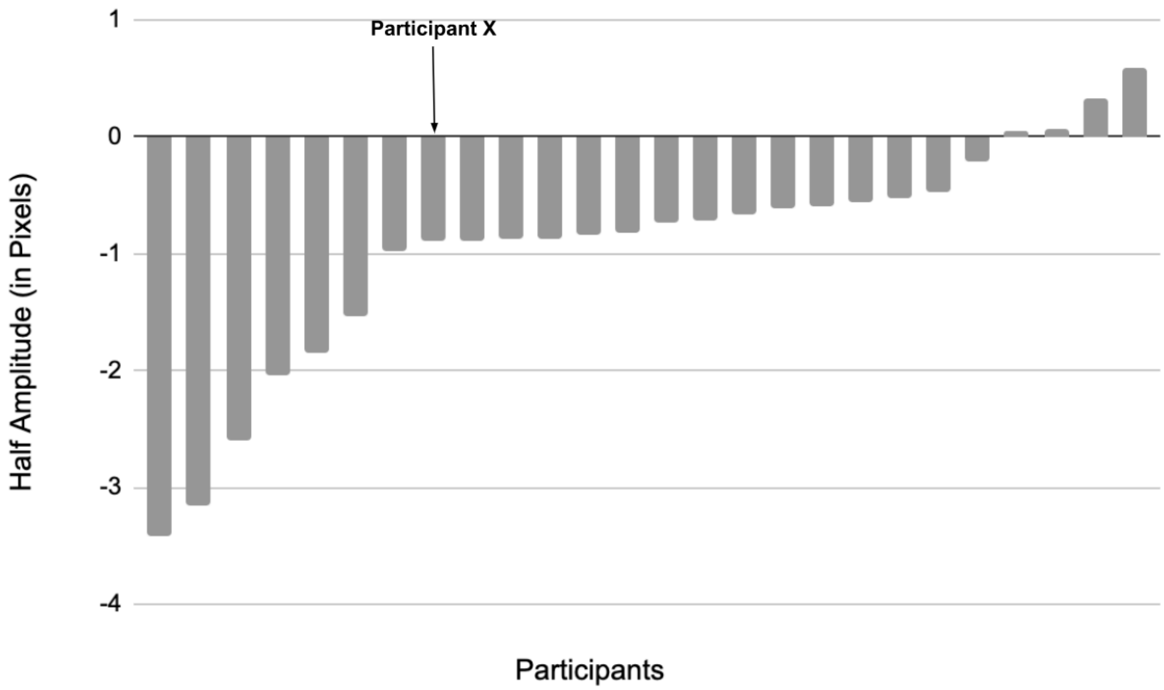
Localization Task

Response error for each trial was calculated as the distance between the participant's reported final location and the true final location of the moving dot (*M* = 20.03 pix, *SD* = 18.90). For each participant, trials were considered lapses and excluded if errors exceeded three standard deviations from the given participant's average error. No more than three trials were excluded for each participant (*M* = 1.27 trials, *SD* = 0.92).

As hypothesized, the simplest derivative of Gaussian curve fit to 22 out of 26 participants' data reached peak half-amplitude in the curve's negative lobe (Figure 3; $M = -0.95$ pix, $SD = 0.97$), indicating that perceived final location on a given trial was significantly repulsed from final location on the previous trial, $t(25) = -3.77$, $p < .001$, $d = -0.74$.

Figure 3

Peak Half-Amplitudes of Fit Gaussian Derivatives



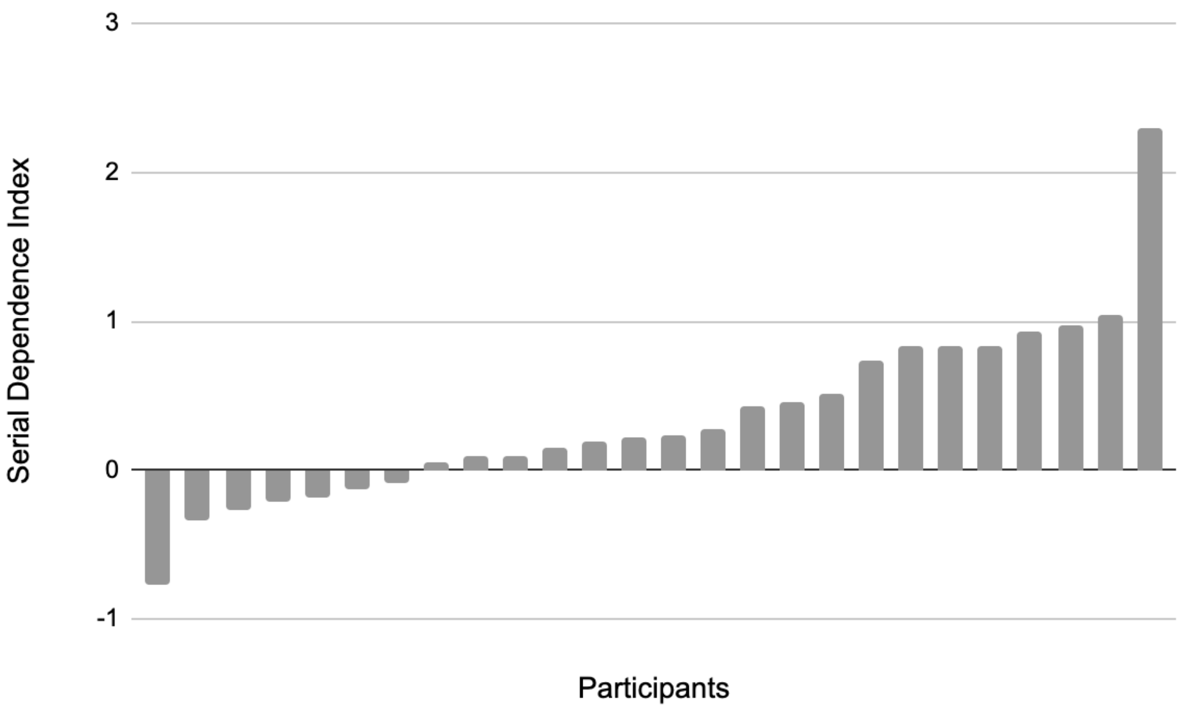
Note. Peak half-amplitude of the Gaussian derivatives fit to each participant's data from the localization task ($N = 26$). Negative values indicate that peak half-amplitude was observed in the curve's negative lobe, indicating a repulsive effect.

2AFC Task

As hypothesized and shown in Figure 4, 21 out of 26 participants' serial dependence indices ($M_{Criterion} = 0.35$, $SD_{Criterion} = 0.61$), calculated using signal detection theory, were positive, indicating that participants' inside/outside response on a given trial was significantly attracted toward their inside/outside response on the previous trial, $t(25) = 2.95$, $p = .007$, $d = 0.58$.

Figure 4

Serial Dependence Indices for 2AFC Task



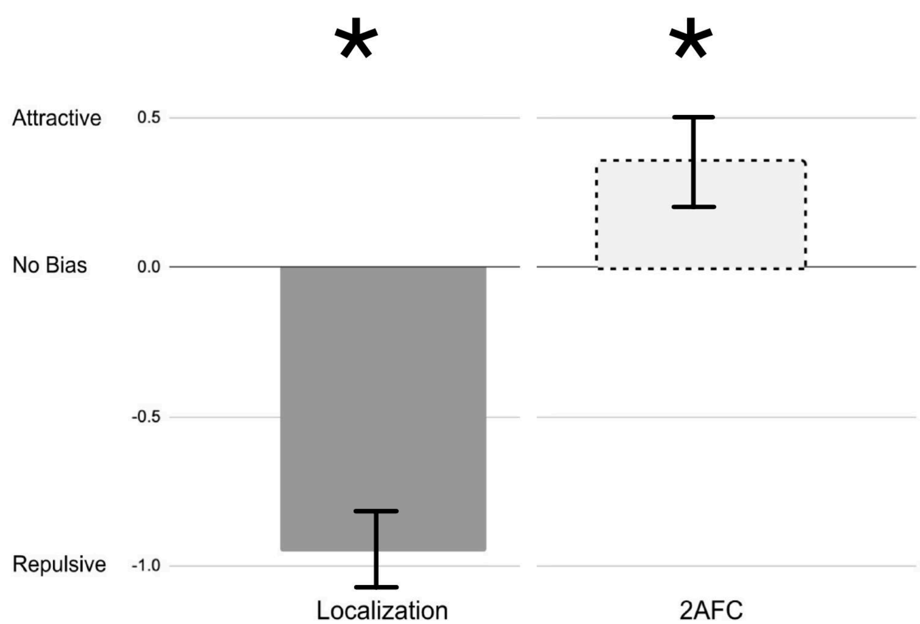
Note. Serial dependence indices for each participant in the 2AFC task ($N = 26$). Positive values indicate an attractive effect.

Discussion

In a chaotic sensory world, we must balance sensitivity to both patterns and change to make sense of our environment. To achieve this balance, serial dependence is hypothesized to operate in different directions on previous stimuli and previous decisions to shape visual experiences, biasing perceptual judgments away from previous stimuli and toward previous decisions (Fritsche et al., 2017; Murai & Whitney, 2021; Pascucci et al., 2019). To investigate the opposing influences of attractive and repulsive serial dependence, I used two tasks–one localization and one 2AFC task. In the localization task, participants' reports of a moving dot's final location showed repulsive serial dependence; reported final dot location on a given trial was repulsed from the dot's final location in the preceding trial (Figure 5). In the 2AFC task, participants displayed attractive serial dependence; decisions about whether a moving dot would have fallen inside or outside of a given box were significantly biased toward decisions made on the previous trial (Figure 5).

Figure 5

Serial Dependence in Localization and 2AFC Tasks



Note. Average serial dependence scores for localization and 2AFC tasks. Localization bar represents average DoG peak half-amplitude across participants. 2AFC bar represents average

serial dependence index ($C_{\text{outside}} - C_{\text{inside}}$) across participants. For both tasks, negative values indicate repulsive serial dependence, and positive values indicate attractive serial dependence.
* $p < .05$.

The repulsive bias in the localization task is consistent with previous findings regarding serial dependence in low-level perceptual tasks (Fritsche et al., 2017; Moon & Kwon, 2022). By asking participants only to indicate a moving dot's final location (and not to determine whether that location would have fallen inside or outside of a certain area), the localization task was a lower-level task compared to the 2AFC task. Although both tasks required participants to briefly hold the previous dot's end point in working memory, only the 2AFC task additionally required participants to hold the rectangle's initial location in working memory. As in Fritsche et al. (2017), increasing the amount of information participants had to store activated higher-level cognitive processes. When asked to attend to the stimulus' location only (in the localization task), participants made a simpler perceptual judgment. Because repulsive serial dependence occurred on the lower-level perceptual task and not the more cognitively taxing one, the current results are consistent with the two-factor model.

On the perceptual level, sensory neurons adapt and become more sensitive to changes in the environment (Moon & Kwon, 2022). Because sensory neurons are highly attuned to changes in our environment, minor changes then appear more drastic than they really are (Webster, 2016). This adaptation-induced visual change-sensitivity effectively repels current perceptions from those of the recent past. The speed with which dots moved across the screen in my study lends support to the role of neuronal adaptation in response to even briefly (313 ms) presented stimuli, in contrast with the prolonged exposure techniques used in much of the extant literature (Manassi et al., 2021; Moon & Kwon, 2022; Ren et al., 2023; Shan & Postle, 2022). The repulsive serial dependence I observed here in participants' performance on the localization task, therefore, likely reflects heightened change sensitivity due to adaptation on the neural level.

The reported attractive bias in the 2AFC task, on the other hand, is consistent with previous research exploring the role of serial dependence in higher-level cognitive tasks (Collins et al., 2024; Manassi et al., 2021; Ren et al., 2023). To perform the 2AFC task, participants were required to hold both the dot's final location and the dimensions/location of the previously presented rectangle in working memory before deciding whether the dot would have fallen inside or outside of the given rectangle. When faced with a more taxing cognitive task, participants reverted, albeit implicitly, to assuming consistency in their environment. This strategy may stem from the many reliable autocorrelations in the visual world. Through extensive visual experience, perceivers come to understand and expect certain perceptual patterns. For example, even if a person's perception of someone standing across the street is momentarily occluded by a passing bus, they probabilistically infer that the person is still standing across the street. Participants may have similarly assumed this same consistency in the 2AFC task, leading to a bias toward reporting "inside" if they reported "inside" on the previous trial, and "outside" if they reported "outside" on the previous trial.

Attractive serial dependence may result from increased engagement of working memory. In the present study, attractive serial dependence was evident only when participants had to store more information in working memory. Similarly, only when Fristche et al. (2017) increased the demand on participants' working memory by having them store characteristics of the previous stimulus in memory did they find attractive serial dependence. The importance of working memory in serial dependence has been highlighted by other research, as well. For example, Markov et al. (2024) found that high working memory load at the time of response increased attractive serial dependence. Thus, the heightened role of working memory in the 2AFC task may explain attractive serial dependence in this task, but not the localization task.

By using the same stimuli and only changing the task, I demonstrated the coexistence of both attractive and repulsive serial dependence effects in visual perception. The findings are consistent with the two-factor model originally proposed by Fritsche et al. (2017), suggesting that the visual system optimizes both sensitivity and stability by balancing repulsion at the perceptual level (as seen in the localization task) with attraction at the decision level (as seen in the 2AFC task). Serial dependence, thus, may be better understood as context dependent, repulsing current perceptions when a situation requires low-level perceptual judgments and attracting current perceptions when a situation is more cognitively taxing on processes such as working memory.

It is difficult, however, to fully isolate decision and perceptual processes and their corresponding biases. For one, I cannot conclude that repulsive serial dependence is specific to perceptual processes because tasks used to measure perceptual bias, in this study and the existing literature, have inherently involved decision-making processes. For example, in backing their two-factor model of serial dependence, Fritsche et al. (2017) argue that indicating whether two Gabor gratings' orientations are the same or different is a sufficient measure of perceptual bias. However, this task also requires participants to make a decision about the two Gabors. Although I attempted to limit the overlap between decision and perceptual processes in the experimental design, I acknowledge that my localization task, meant to measure perceptual bias, still required participants to make a decision about where a moving dot ended. Despite this overlap, the structure of my tasks allowed me to better isolate the influence of decisional processes on serial dependence. By using identical stimuli in both tasks and having one task recruit slightly more cognitive resources than the other, I was able to draw conclusions about how higher level processes affect serial dependence.

My findings from both tasks, designed to mimic the task performed by home plate umpires and batters, shed light on the neural processes involved in officiating and partaking in a baseball/softball at-bat. As pitches are thrown, batters make their best guess about the ball's final position to determine whether they will swing or not. Umpires, on the other hand, determine whether the pitched ball's final position falls inside or outside of the strike zone. Given my findings, I argue that players' and officials' perceptions of a pitch's location are likely influenced by serial dependence.

Because both batters and umpires are tasked with determining a ball's expected or true final position and then making a decision given that final position (swinging or not swinging vs. calling a ball or calling a strike), I would expect players' decisions and umpires' calls to be more in line with the serial dependence effect observed in the 2AFC task (versus the localization task). Thus, both umpires and batters should show a bias toward deciding a pitch was outside when the previous pitch was determined to be outside, and a bias toward deciding a pitch was inside if the previous pitch was determined to be inside.

Because athletes and officials are making judgments based on their perception of a moving ball's location, one might expect a given pitch's (expected) final location to be repulsed from the previous pitch's (expected) final location. However, I would not expect this bias to be apparent in baseball/softball games because players and umpires are tasked with perceiving a moving pitch and then making a decision based on its final location, a task far beyond perception alone. Therefore, I would expect any repulsive serial dependence effects to be overshadowed by attractive bias because of the higher-level decisions players and umpires make.

Discrepancies between players' and officials' perceptions and judgments may stem from the slightly different tasks the two groups are asked to perform. Umpires, on one hand, are able to see the pitch's final location as it is caught by the catcher. After seeing where the pitch lands, umpires determine whether that landing point falls inside or outside of the strike zone. Batters, on the other hand, must determine whether they expect the pitch to land inside or outside of the strike zone before the pitch actually reaches its final position (so they have enough time to swing). Because they are being asked to make a faster decision and, potentially, to execute the motor process of swinging a bat, a player's task is likely more cognitively demanding than an umpire's. Given that they must make more/faster inferences and decisions than umpires, I would expect players' decisions to be affected by attractive serial dependence to a greater extent than umpires'. This discrepancy suggests that players may be more likely than umpires to erroneously deem a pitch outside if the previous pitch was outside, leading to frustration if the batter determined the pitch to be a ball and the umpire determined the same pitch to be a strike.

Knowing that batters' and umpires' perceptions and decisions are susceptible to serial dependence could be exploited by opposing pitchers. For example, knowing that a previous pitch landed inside the strike zone, the pitcher may decide to throw the next pitch just outside the strike zone in hopes that the batter will swing, mistakenly determining that pitch to be inside the strike zone, as well. Even if the player opts not to swing at the pitch, the umpire may succumb to attractive bias and call the pitch a strike even though it was slightly outside the strike zone.

Any of the proposed effects of serial dependence in an actual baseball/softball game proposed here are only speculations because my tasks did not specifically mention baseball/softball when participants completed them. Although I expect that my findings are strong enough to generalize to real game settings, my study lacks the ecological validity to make these inferences. I was hesitant to make my tasks overly sport-specific because this would have narrowed my participant pool to people with sufficient baseball/softball experience and, thus, reduced overall generalizability. By including a variety of baseball/softball experience in my participant base, I was able to make greater generalizations about the mechanisms underlying and the consequences of serial dependence in different situations.

Future research may explore whether my findings and hypothesized in-game consequences are accurate. I am interested in the use of quasi-experimental methods to analyze pitch locations and decisions made in recorded Major League Baseball and Athletes Unlimited Softball League games. Future research is also needed to better understand the role of higher-level cognitive processes in influencing the direction of serial dependence. For example, is there a threshold of working memory activation required to elicit attractive, as opposed to repulsive, serial dependence? This potential line of research will also predict which situations elicit different directions of serial dependence.

Conclusion

Consistent with a two-factor model of serial dependence, participants' perceptions showed serial dependence in opposite directions for prior stimuli versus prior responses. In a design created to roughly simulate a batter or umpire's experience at/behind the plate, I found that, in a localization task, reported dot location was repulsed from the dot's location in the previous trial. However, when asked to indicate whether a dot would have landed inside or outside of a previously shown box, participants' perceptions were biased toward the decision made on the previous trial. The coexistence of these two opposing processes in visual perception allows for sensitivity to both patterns and change. The current results shed light on patterns likely present in sports games, as well as in day-to-day visual perception.

References

Barbosa, J., & Compte, A. (2020). Build-up of serial dependence in color working memory. *Scientific Reports, 10*(1), 10959. https://doi.org/10.1038/s41598-020-67861-2

Chen, S., Wang, T., & Bao, Y. (2023). Serial dependence in timing at the perceptual level being modulated by working memory. *PsyCh Journal, 12*(6), 774-786. https://doi.org/10.1002/pchj.653

Fischer, J., & Whitney, D. (2014). Serial dependence in visual perception. *Nature Neuroscience, 17*(5), 738-743. https://doi.org/10.1038/nn.3689

Fritsche, M., Mostert, P., & de Lange, F. P. (2017). Opposite effects of recent history on perception and decision. *Current Biology, 27*(4), 590-595. https://doi.org/10.1016/j.cub.2017.01.006

Girshick, A. R., Landy, M. S., & Simoncelli, E. P. (2011). Cardinal rules: Visual orientation perception reflects knowledge of environmental statistics. *Nature Neuroscience, 14,* 926-932. https://doi.org/10.1038/nn.2831

Kim, S., Burr, D., & Alais, D. (2019). Attraction to the recent past in aesthetic judgments: A positive serial dependence for rating artwork. *Journal of Vision, 19*(12), 1-17. https://doi.org/10.1167/19.12.19

Kim, S., Burr, D., Cicchini, G. M., & Alais, D. (2020). Serial dependence in perception requires conscious awareness. *Current Biology, 30*(6), R257-R258. https://doi.org/10.1016/j.cub.2020.02.008

Liberman, A., Fischer, J., & Whitney, D. (2014). Serial dependence in the perception of faces. *Current Biology, 24,* 2569-2574. https://doi.org/10.1016/j.cub.2014.09.025

Manassi, M., Liberman, A., Chaney, W., & Whitney, D. (2017). The perceived stability of scenes: Serial dependence in ensemble representations. *Scientific Reports, 7,* 1971. https://doi.org/10.1038/s41598-017-02201-5

Manassi, M., Liberman, A., Kosovicheva, A., Zhang, K., & Whitney, D. (2018) Serial dependence in position occurs at the time of perception. *Psychonomic Bulletin and Review, 25,* 2245-2253. https://doi.org/10.3758/s13423-018-1454-5

Manassi, M., Ghirardo, C., Canas-Bajo, T., Ren, Z., Prinzmetal, W., & Whitney, D. (2021). Serial dependence in the perceptual judgments of radiologists. *Cognitive Research: Principles and Implications, 6*(65). https://doi.org/10.1186/s41235-021-00331-z

Manassi, M., & Whitney, D. (2024). Continuity fields enhance visual perception through positive serial dependence. *Nature Reviews Psychology, 3,* 352-366. https://doi.org/10.1038/s44159-024-002797-x

Markov, Y. A., Tiurina, N. A., & Pascucci, D. (2024). Serial dependence: A matter of memory load. *Heliyon, 10*(13), e33977. https://doi.org/10.1016/j.heliyon.2024.e33977

Moon, J., & Kwon, O. S. (2022). Attractive and repulsive effects of sensory history concurrently shape visual perception. *BMC Biology, 20*, 247. https://doi.org/10.1186/s12915-022-01444-7

Murai, Y., & Whitney, D. (2021). Serial dependence revealed in history-dependent perceptual templates. *Current Biology, 31*(14), 3185-3191. https://doi.org/10.1016/j.cub.2021.05.006

Pascucci, D., Mancuso, G., Santandrea, E., Della Libera, C., Plomp, G., & Chelazzi, L. (2019). Laws of concatenated perception: Vision goes for novelty, decisions for perseverance. *PLoS Biology, 17*(3), e3000144. https://doi.org/10.1371/journal.pbio.3000144

Ren, Z., Li, X., Pietralla, D., Manassi, M., & Whitney, D. (2023). Serial dependence in dermatological judgments. *Diagnostics, 13*(10), 1775.

https://doi.org/10.3390/diagnostics13101775

Sadil, P., Cowell, R. A., & Huber, D. E. (2023). The push-pull of serial dependence effects: Attraction to the prior response and repulsion from the prior stimulus. *Psychonomic Bulletin and Review, 31,* 259-273. https://doi.org/10.3758/s13423-023-02320-3

Schlunegger, D., & Mast, F. W. (2023). Probabilistic integration of preceding responses explains response bias in perceptual decision making. *iScience, 26*(7), 107123. https://doi.org/10.1016/j.isci.2023.107123

Shan, J., & Postle, B. R. (2022). The influence of active removal from working memory on serial dependence. *Journal of Cognition, 5*(1), 1-18. https://doi.org/10.5334/joc.222

Treviño, M., Medina-Coss y León, R., & Haro, B. (2020). Adaptive choice biases in mice and humans. *Frontiers in Behavioral Neuroscience, 14*, 99. https://doi.org/10.3389/fnbeh.2020.00099

Webster, M. A. (2016). Visual adaptation. *Annual Review of Vision Science, 1*, 547-567. https://doi.org/10.1146/annurev-vision-082114-035509

Xia, Y., Yamanashi Leib, A., & Whitney, D. (2016). Serial dependence in the perception of attractiveness. *Journal of Vision, 16*(15), 28. https://doi.org/10.1167/16.15.28

Zavagno, D., Daneyko, O., & Actis-Grosso, R. (2015). Mishaps, errors, and cognitive experiences: On the conceptualization of perceptual illusions. *Frontiers in Human Neuroscience, 9,* 190. https://doi.org/10.3389/fnhum.2015.00190

Zhang, H., & Alais, D. (2020). Individual difference in serial dependence results from opposite influences of perceptual choices and motor responses. *Journal of Vision, 20*(8), 1-14. https://doi.org/10.1167/jov.20.8.2