

**Serial Dependence Compared on Responses Given With and Without Visual Feedback**

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**Abstract**

Despite the highly variable input that the human perceptual system receives from the external world, the experienced perception is stable and smooth. The continuity field is one of the psychological mechanisms that create this perceptual stability by integrating the sensory evidence spatiotemporally. The way to quantify this continuity field is serial dependence between successive stimuli, a general phenomenon that increases the signal-to-noise ratio in the visual system. Since the literature suggests it as a general processing mechanism, it is expected that serial dependence will not depend on the response type. Therefore, in the current study, it was hypothesized that serial dependence would be comparable when the responses are given in the presence and absence of visual feedback. To test the generalizability of serial dependence, a sample of 14 participants completed an orientation judgment task in two conditions. In the visual feedback condition, responses were given manually by a lever whose orientation was shown via visual feedback on the screen. In the no-visual feedback condition, responses were also given by adjusting the lever, but there was no visual feedback on the screen. Results show that the strength of serial dependence is significantly smaller when the response is given without visual feedback, compared to the with-visual-feedback condition. This suggests that the decision stage is crucial to serial dependence, so it may not act directly on perception.

*Keywords:* continuity field, visual perception, serial dependence, visual feedback

## **Serial Dependence Compared on Responses Given With and Without Visual Feedback**

### **1. Introduction**

The physical world contains a huge variability caused by the high modifications in the scene conditions, lighting, etc. Additionally, our eye and head movements cause the retinal image of the world – on which visual perception is ultimately based – to change positions all the time. Nevertheless, while the input of the visual system comes from such a highly variable environment, the outputs of visual processes are smooth and stable. For instance, the color we perceive does not change according to every conditional change in the environment's light. Likewise, perceived location is not altered by every movement of the eye and head. Instead, our visual system is capable of producing stable visual outputs despite the noise caused by irrelevant fluctuations in the current input (Fischer & Whitney, 2014).

The continuity field, a spatio-temporal integration window, is one of the fundamental psychological mechanisms thought to contribute to this perceptual stability. This mechanism provides visual stability by integrating sensory evidence over time to determine the immediate perceptual content. Such integration has recently been quantified via the behavioral phenomenon called serial dependence (SD): when observers are asked to report a property of visual stimulus (e.g., the orientation, position, motion), their responses systematically err towards the property of the previous stimulus (Cicchini, Mikellidou, & Burr, 2017; Fischer & Whitney, 2014). While the perceptual responses still rely primarily on the stimulus itself, the response errors are not random but attracted systematically toward the previously seen stimulus. Therefore, the immediate content of perception is affected by the integration of the current input and previous stimulus history (Fischer & Whitney, 2014; Collins, 2019). This behavioral phenomenon of serial dependence is observed in a wide range of cognitive processes and is supported by several studies. For example, it occurs on orientation (Fischer & Whitney, 2014; Liberman, Zhang, & Whitney, 2016), on numerosity (Corbett, Fischer, & Whitney, 2011), even on attractiveness (Xia, Y., Leib, A. Y. & Whitney, D., 2016).

What makes serial dependence critical for perception is that it takes advantage of the temporal redundancy of natural scenes that refers to the tendency of objects to be constant over time. Furthermore, it smooths over irrelevant variations in the input by integrating the information throughout serial moments to achieve perceptual efficiency (Burr & Cicchini, 2014). Thus, serial dependence may be a general processing mechanism that averages the features of successive stimuli to increase the signal-to-noise ratio. The current study will test the extent of the generalizability of this phenomenon. If serial dependence is really a general processing phenomenon, it should not depend on the response type.

A “response type” refers to the modality with which a participant reports a visual feature. In most studies on serial dependence, participants report what they perceived by reproducing or matching the feature with a response cue. In many experiments on orientation, for example, participants match the

orientation of a just-seen Gabor patch but rotating a line that is visible on the screen so that it has the same orientation as the test Gabor patch.

### **1.1. The behavioral characteristics of serial dependence**

Serial dependence has tuning characteristics. Recent studies show that the effect of the recent past on the perception of the present moment is spatially tuned (Fischer & Whitney, 2014; St John-Saaltink, Kok, Lau, & de Lange, 2016; Collins, 2019). That means the serial effect was observed more strongly when two stimuli appeared in nearby locations, and the amplitude of serial dependence decreased with the increasing spatial distance between successive stimuli. Serial dependence is also temporally tuned; its amplitude decreases with the increasing time between trials or increasing intervening trials (Fischer & Whitney, 2014). Furthermore, serial dependence is feature-tuned. That means its effect on perceptual processes is strongest when the features of two successive stimuli are more similar (Burr & Cicchini, 2014). For example, for the orientation discrimination task, the amplitude of serial dependence peaks when the orientation differences between present and current stimuli are between 10-30 degrees (Fischer & Whitney, 2014). Finally, the strength of serial dependence depends on attention, with the highest strength at the attended locations (Fischer & Whitney, 2014). If we need to formulate all these tuning characteristics, serial dependence operates between successively attended stimuli that are near in space, time, and feature- space.

### **1.2. Relationship between serial dependence and other visual history effects**

The dependence of perception of stimulus history is revealed by several other known effects. However, serial dependence is different from all of these. Before moving on to the aim of the current study, the critical discrimination between serial dependence, a positive aftereffect, and similar phenomena needs to be clarified.

#### **1.2.1. Adaptation and negative aftereffects**

In addition to stability, another critical goal of visual perception is to detect differences and changes in the environment. This function of maximizing sensitivity to change is ensured by adaptation which is widely considered an important mechanism that optimizes visual processing (Chopin & Mamassian, 2012). However, contrary to serial dependence, adaptation biases the perception away from the previous stimuli (Fritsche, Mostert, & de Lange, 2017). The balance between these two opposite phenomena that have separate goals on visual perception may depend on the type of change. For example, if the change is not about the object itself or the environment but an internal noise or a transient event, then the serial dependence would be the optimal mechanism and would need to dominate the negative aftereffect to establish stable vision by smoothing out internal noises. Fischer and Whitney (2014) make the separation between serial dependence and negative aftereffects that follow adaptation. Unlike negative aftereffects, serial dependence is modulated by attention and spatial proximity and does

not require a long duration to affect the vision. Thus, in the current study, because we aimed to test serial dependence independently from any negative aftereffects, the stimulus was presented for a short duration and was followed immediately by a mask.

### **1.2.2. Hysteresis**

Another critical distinction needs to be established between perceptual hysteresis and serial dependence. Perceptual hysteresis refers to the enduring influence of the past perception despite the alteration in the perceived pattern (Hock, Scott & Schöner, 1993). Studies on both of these phenomena showed that while hysteresis is observed in ambiguous stimuli (Williams, Phillips & Sekuler, 1986), serial dependence occurs for unambiguous stimuli (Fischer & Whitney, 2014). Thus, the stimulus chosen for the present study was a Gabor patch that was unambiguous in terms of its orientation.

### **1.2.3. Explicit memory**

Additionally, a series of control studies demonstrated that serial dependence is independent of explicit memory by showing that the positive bias toward prior stimulus emerged even in the absence of explicit memorization of the previous stimuli (Fornaciai & Park, 2018).

### **1.2.4. Priming effects**

Lastly, priming effects enhance the accuracy and the speed of perception when stimuli are repeated. Serial dependence can be differentiated from priming by the differential effects on discriminability. Visual discriminability is improved by priming (Noles, Scholl & Mitroff, 2005), whereas serial dependence reduces discriminability (Lieberman, Fischer & Whitney, 2014).

## **1.3. Serial dependence: early sensory or late decision?**

There is an ongoing debate in the literature about whether serial dependence occurs at an early sensory level of perception or the later decision level. Fritsche et al. (2017) measured serial dependence with a reproduction task and argued that it occurs at the post perceptual decision stage rather than the sensory stage. Indeed, they found a positive bias between responses but a repulsive bias between stimuli.

Cicchini et al. (2017) repeated the experimental design that Fritsche et al. used in their original study, but they use a wider range of stimulus differences. They reported that post perceptual decision processes are positively biased toward recent history, whereas sensory representations are biased away from recent history. In further support for a perceptual level of serial dependence, Fischer & Whitney (2014) showed that the effect was observed even in the absence of participants' behavioral responses. Additionally, BOLD activity in V1 is biased toward recently presented stimuli even when observers are not required to respond (StJohn-Saaltink et al., 2016). Finally, using the oddball task to differentiate perception and decision processes, Collins (2020) reported that serial dependence occurs at a relatively early level of perception.

All of these studies provide a good amount of literature that suggests that perception is the result of

an integration between current and past stimuli. Such spatio-temporal integration helps eliminate the current visual scene's temporal redundancy and optimizes perception (Cicchini, Mikellidou, & Burr, 2018). Although serial dependence has recently been studied extensively, which perceptual components carry over from one trial to the next remains a key question. In a classic perceptual experiment, processes are highly correlated from sensation to perception and finally response. Serial dependence probably reflects the combination of all of these processing stages. But if serial dependence is a general perceptual processing mechanism, it should be independent of the stimulus type, sensory modality, or response type. Serial dependence was already generalized across different stimulus formats (Fornaciai & Park, 2019) and different sensory modalities (Arrighi et al., 2014), but it still has not been generalized across different response types. That was the goal of the current study.

#### 1.4. The goal of the current study and general hypotheses

If serial dependence is a general processing mechanism, it should be comparable when responses are given by matching a visual response cue to when responses are given by adjusting a manual response device, in the absence of visual feedback. To the best of my knowledge, all studies on serial dependence have tested the responses given by relying on visual feedback, such as adjusting a visual bar to match the orientation of a previously seen Gabor. To test the generalizability of the phenomenon across different response types in an orientation judgment task, the present study introduces responses given solely by manual adjustments and not on visual feedback. Observers were presented with a randomly oriented Gabor. Then they were asked to report the perceived orientation of this Gabor by manually adjusting a lever with their right hand. The lever and their hand were unseen (Figure 1.a). In the visual feedback condition, lever adjustments were mirrored on the screen by a small dot. In the no-visual feedback condition, there was no such feedback (Figure 2.a).

I hypothesize that serial dependence will be comparable when the response is given with or without the visual feedback.

View from above:

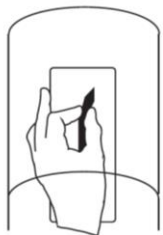


Figure 1.a

Side view:

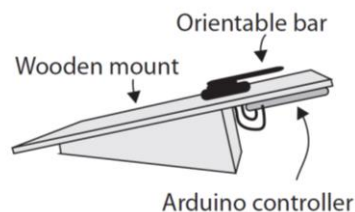


Figure 1.b

## 2. Method

### 2.1. Subjects

The national ethics board (Comité de Protection des Personnes) approved all experimental protocols. Based on the effect size and standard deviation estimates in the literature (Fischer & Whitney, 2014; Collins, 2019; Fritsche et al., 2017), I estimated that 3-7 subjects were needed to get .99 power, i.e., a 1% probability of rejecting the null hypothesis that there is no serial dependence when there actually is one. Since the literature did not give information about the effect size for the serial dependence in the no-visual feedback condition, taking into account the possibility of smaller effect size for this condition, I decided to duplicate the maximum subject number I found by the power analysis. I thought this duplication gives me still a reasonable number of subjects to collect data. Therefore, I decided to use 14 volunteer subjects naïve to the purpose of the study. All participants were healthy human adults with normal or corrected to normal vision and no neurological or visual deficits. Before the experiment started, written informed consent according to the Declaration of Helsinki was obtained from all participants.

14 subjects ran a single session (see Procedure below), and 6 of them were able to run a second session. The main analysis was conducted on the data of all 14 subjects. The analysis and results restricted to the six subjects who had complete data set are given in Annex-1.

### 2.2. Stimuli

A red fixation point (diameter of 0.5 dva) was located at the center of the medium gray, 40x30 dva screen (Figure 2). Stimuli are Gabor patches that were always presented 3 dva below the fixation. Gabor patches all have the same size (the standard deviation of the Gaussian envelope is 2 dva) and have a spatial frequency of 1.3 cycles per degree. They are tilted between  $-80^\circ$  (counter-clockwise rotation) and  $80^\circ$  (clockwise rotation). On each trial, the fixation dot and one randomly selected Gabor patch were presented. In the visual feedback condition, the Gabor patch was followed by a black response dot (diameter of 0.5 dva). The mask stimuli with the same dimensions and locations were generated by Matlab's Create Procedural Noise function, and it implements Perlin noise which is approximately Gaussian. The purpose of the mask was to prevent the data from being contaminated by negative aftereffects and also to abolish the emergence of motion perception between successive orientations.

### 2.3. Instruments

**Eye movement recording and apparatus.** To check fixation, an Eyelink 1k (SR Research, Mississauga, Ontario, Canada) at 1000 Hz sampling rate was used. At the beginning of each condition (visual feedback condition and no-visual feedback condition), the Eyelink was calibrated with the standard 5-point Eyelink procedure. At the beginning of each trial, fixation was checked, and a new calibration occurred if the position deviated more than 1.5 dva from the reference value. Also, after every 80 trials,

calibration was automatically renewed. In the analysis, SR Research's proprietary algorithms were used to smooth the eye movement samples. Then, for each sample, the instantaneous velocity and acceleration were measured and compared with the threshold ( $30^\circ/\text{sec}$  and  $80^\circ/\text{sec}$ ). Saccade onset was defined as two consecutive above-threshold samples. The first sample with a 20-ms period of below threshold was defined as the saccade offset.

## 2.4. Procedure

There were two conditions in the experiment: visual feedback and no-visual feedback conditions. The task was the orientation judgment task. In both conditions, the distance between the subject eye and the computer screen was the same (57 cm), and this distance was stabilized by the chin rest.

In the no-visual feedback condition (Figure 2.a), subjects were first asked to fixate on the black fixation point at the screen center. Fixation was checked by Eyelink for 250 ms. If fixation was not held (within a 1.5 dva tolerance window around the fixation point), a warning appeared, and the trial was canceled and replayed before the subject saw the target. When correct fixation was achieved for 350 ms., the trial begins. A Gabor patch with random orientation was presented for 500 ms while the subject was maintaining fixation. The distance between the middle of the Gabor patch and the fixation dot was 3 degrees. If fixation was not maintained, a warning appeared, and the trial was re-run. The Gabor patch was followed immediately by the mask presented in the same location of the Gabor patch for 500 ms. The subject was no longer required to fixate at this stage. The subject was required to report the perceived orientation of the Gabor patch that was seen just before by rotating the lever (between  $-90^\circ$  and  $90^\circ$ ) in the clockwise or counter-clockwise direction. Once the subjects were satisfied with their response, they validated the response by pressing on the space bar. There was no time pressure for the response stage. The time interval between pressing on the space bar and the next trial was 0. Once they pressed on the space bar, the fixation dot appeared at the center, and the subject had to fixate the dot again. The next trial began when the fixation is maintained for the required time. So, the interval between trials depended on how long it takes the subject to fixate the center again. Between each trial, the lever was reset to a random orientation to prevent the subjects' response in the previous trial from becoming a manual cue. The response lever was hidden from view with a closed response box, preventing the subject from visually inspecting the response (Figure 1).

The visual feedback condition (Figure 2.b) followed the same procedure as the no-visual feedback condition, except that when the mask appeared, a black response dot appeared simultaneously 2 dva above the fixation point. The distance between the mask and the fixation point was always 2 degrees. After 500 ms, the mask was turned off, and the response dot stayed until the response is given. The invisible fixation point and the response dot formed an invisible line, and this line could be oriented between  $-90^\circ$  and  $90^\circ$  (see Figure 2.b). Like in the no-visual feedback condition, the subject was required

to match the orientation of the Gabor that was seen just before by rotating the lever. However, now the subject had visual feedback about the orientation of the lever while giving the response. Once the subjects were satisfied with their response, they validated the response by pressing the space button. Then the new trial began. Between each trial, the orientation of the lever reset to a randomly chosen angle between  $-90^\circ$  and  $90^\circ$  to prevent a confound between attraction to the previous response and attraction to the initial position of the lever.

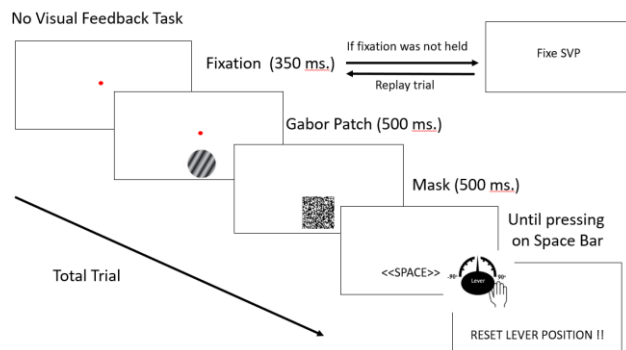


Figure 2.a

Visual Feedback Condition

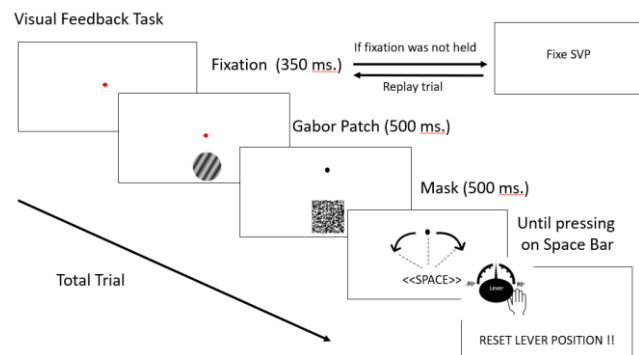


Figure 2.b

No Visual Feedback Condition

Each condition included 320 trials (each orientation from  $-80$  to  $80$  tested two times in each condition). All participants performed each condition in counterbalanced order, so the experiment uses a within-subject design. Each run lasted approximately 2 hours, with 640 trials in total divided into eight blocks (320 trials per condition divided into four blocks). After each block, subjects had a small break (a few minutes), and between conditions, subjects had a relatively long break (up to a few hours).

After gathering data in one experimental session from each of the 14 subjects, 6 subjects were re-tested in a second session to increase the overall number of trials available for analysis. Data from the two sessions were combined for the analysis. Therefore, the main analysis was conducted on a data set of 14 subjects (8 subjects with a single session and 6 subjects with two sessions). The analysis and results restricted 6 subjects with two sessions can be found in Annex-1.

## 2.5.Design

The independent variable in the study was response type which was manipulated within-subject and had two levels: (1) responses given with visual feedback and (2) responses given without visual feedback. The dependent variable was the amplitude of serial dependence, calculated individually.

## 2.6.Operational Hypothesis

In general, based on the literature that suggests that serial dependence is a general perceptual processing mechanism, we expected to see comparable serial dependence in visual feedback and no-visual feedback conditions. Furthermore, I expected to replicate the feature-tuning in serial dependence: greater error in the direction of the previous Gabor when the orientation difference between the previous

Gabor and the current Gabor was between  $\pm 0$ -30 degrees, with a gradual decrease in error moving away from this relative orientation range.

## 2.7. Data Analysis

The experiment data was analyzed by using Matlab with the CircStat toolbox to calculate relative orientation and error by circular statistics (Berens, 2009) and R Studio to fit the serial dependence graphs with the derivative of Gaussian (DoG). First, for each subject, the raw orientation response was plotted as a function of the Gabor orientation to check that the subject was able to perform the task properly. Then, for each condition, the relative orientation was quantified by the circular distance between the current and the previous Gabor patch orientation. Positive values mean that the previous Gabor patch was more clockwise than the current one. Negative values mean that the previous Gabor patch was more counter-clockwise than the current one. The error was calculated by the circular distance between the real orientation of the current Gabor and the response. Positive values mean that the reported orientation is more clockwise than the real orientation. For each subject's data, the relative orientation was first sorted, and the error sorted according to relative orientation. Error and relative orientation were then smoothed using windows of 32 trials to calculate the running average in each condition (with and without visual feedback). The smoothed error was plotted as a function of smoothed relative orientation.

The error distribution pooled over 14 subjects' data for each condition obtained by getting the grand average of error and relative orientations of all subjects. However, the main part of the analysis was conducted only on the individual data and not on the pooled data.

After obtaining these error distributions, I realized that since the Gabor patches' orientation is selected uniformly between  $-80$  and  $+80$ , some subjects seem to have a prior/bias that the distribution is bounded. That means in the data of observers who use the information about the distribution to respond, if the Gabor at trial  $N$  is  $-80^\circ$ , then the average orientation in the  $[N-1, N-32]$  window is necessarily positive with respect to trial  $N$ . On the contrary, if the Gabor at trial  $N$  is  $80^\circ$ , then the average orientation in the  $[N-1, N-32]$  window is necessarily negative with respect to trial  $N$ . If trial  $N$  is  $0^\circ$ , on average, there should be no bias (that is, the distribution of the average of the  $[N-1, N-32]$  window should be centered on 0). Therefore, responses of these Bayesian observers seem to repel away from the boundary and create a form of regression. To avoid the impact of this statistical knowledge on the data (which is not of interest to the current study), the Fast Fourier Transform (FFT) conducted for the data of all subjects to find the linear component in the graph and take it out. By this detrending, the statistical knowledge which is not of interest to the current study excluded from the serial dependence. So the combined influence of these two psychological effects was prevented on the data of the individual subject. After this Fast Fourier Transform (FFT), the rest of the analysis was conducted with these detrended versions of data.

To calculate the amplitude of serial dependence (the extent to which the error depended on the orientation of the previous Gabor), the error distribution of each individual data was fitted with the derivative of Gaussian (DoG). The DoG is given by  $y = h + (x+b)awce - (w(x+b))^2$ , where  $x$  is the relative orientation between successive test patches, "a" the amplitude of the curve,  $w$  its width,  $h$  its height,  $b$  the intercept and  $c$  the constant  $\sqrt{2} / e - 0.5$ . The amplitude ( $a$ ) for each subject's data was extracted from the individual fits for each condition.

To assess significant differences between conditions, I initially planned to look at the overlap between the 95% confidence intervals and perform a t-test. However, the DoG fit was not possible for many subjects in the no visual feedback conditions, making it nonsensical to conduct inferential statistics based on a limited number of data points (see Results section). Therefore, we decided to conduct a t-test on the data obtained by another calculation method. We decided to conduct a t-test by getting the difference between the averaged relative orientation between  $0^\circ$  and  $-22.5^\circ$  and between  $0^\circ$  and  $22.5^\circ$ . We selected  $-22.5^\circ$  and  $22.5^\circ$  as reference points based on where the relative orientation graphs obtained from the visual feedback condition peaked in average (See Results). So, for each subject, we first had 2 data points (see in Figure 4.a and Figure 5.a): one for the averaged error of the relative orientation between  $-22.5^\circ$  and  $0^\circ$ , and one for the averaged error of the relative orientation between  $0^\circ$  and  $22.5^\circ$ . The difference between these 2 data points was taken and ended up with 1 data point for each condition. The t-test was run on these extracted data points. If the subject's data differ in terms of the serial dependence between conditions, the conditions should differ in terms of this extracted data point.

### 3. Results

As can be seen in Figure 3, all 14 participants performed the task properly: there is a very good correspondence between the Gabor orientation (real tilt) and the response in both conditions. Although there are a few outliers, we did not exclude any data from the analysis.

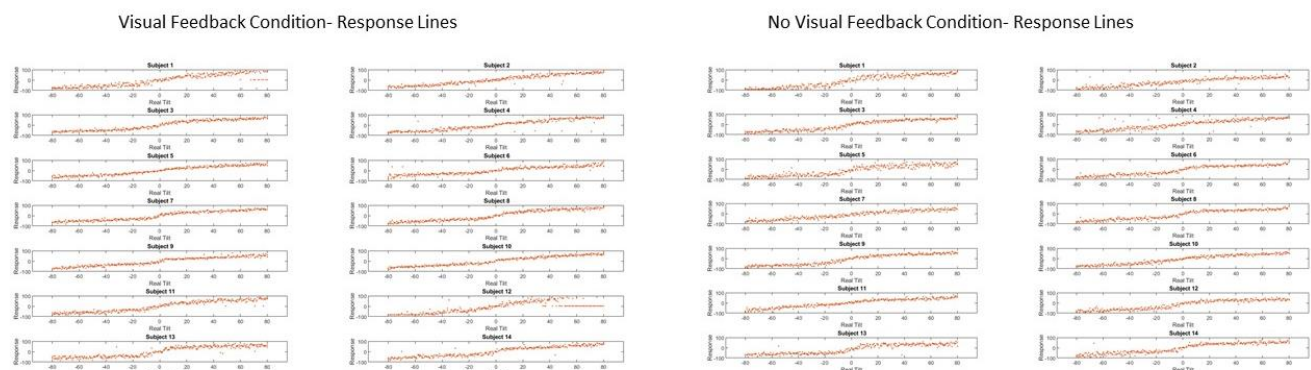


Figure 3. a

Figure 3. b

Figure 3- Response Lines

a. Response lines for individual data - Visual Feedback Condition. Relationship between the Gabor orientation (real tilt) and the response. All 14 participants performed the task properly

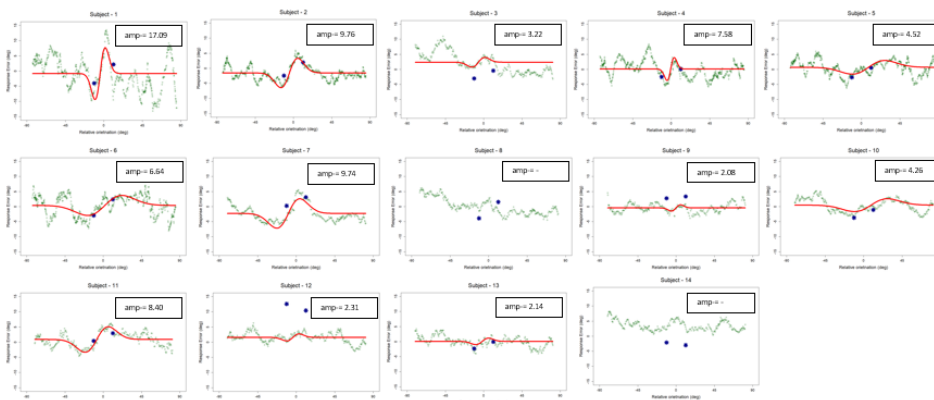
**b. a. Response lines for individual data – No Visual Feedback Condition.** Relationship between the Gabor orientation (real tilt) and the response. All 14 participants performed the task properly

Serial dependence was measured by the relationship between the relative orientation (circular distance between the current and previous Gabor patch orientations) and the response error (circular distance between correct orientation and the reported orientation). The amplitude obtained by the fit of the first derivative of Gaussian (DoG) of this error distribution in each condition quantified the serial dependence.

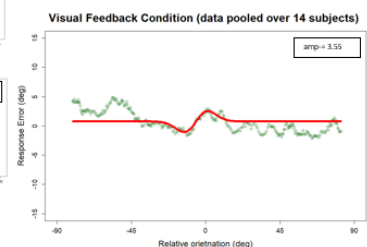
**3.1. Visual Feedback Condition**

The individual fits represented in Figure 4.a shows us that despite the little bit of noise presented in the running averages of the subjects' orientation judgment error, except for two subjects (subject-8 and subject-14), all the other subjects' reported orientation systematically attracted by the previously seen orientation. This attraction followed a derivative of Gaussian (DoG)-shaped curve with an amplitude of  $\pm 6.48$  (SD=4.41) in positive and negative directions.

Figure 4-b represents error as a function of relative orientation and the DoG fit for the visual feedback condition on data pooled over 14 subjects. The amplitude of this pooled data (amp= 3.55) was obtained by calculating the distance between the maximum and the minimum points of the fit of DoG. The main analysis, however, was not conducted on this pooled data but on the individual data obtained from each subject.



**Figure 4. a**



**Figure 5.b**

**Figure 4 (Visual Feedback Condition)**

**a. Individual data. Error as a function of relative orientation between previous and current trials for each of the 14 subjects in visual feedback condition.** The green line represents the running averages of error across windows of 32 trials. Red lines show the derivative of Gaussian (DoG) fit that data. The amplitude of the Serial Dependence varied across subjects. Blue dots represent the averaged error of the relative orientation between -22,5° and 0° (left dot), and the averaged error of the relative orientation between 0° and 22.5° (right dot).

**b. Grand average. Error distribution on responses given with visual feedback** The data pooled over 14 subjects. The green line represents the running averages of error across windows of 32 trials. The red line shows the derivative of Gaussian (DoG) fit the error distribution of the pooled data.

Therefore, it was concluded that when observers were asked to report the orientation of a visual stimulus with relying on visual feedback, a systematic error towards the orientation of the previous stimulus occurred. This data thus replicates the serial dependence effect reported in the literature.

### 3.2.No-Visual Feedback Condition

In the no-visual feedback condition, individual data (except for three subjects) did not follow a DoG shape and did not give an amplitude for quantifying any serial dependence effect (Figure 5.a). Despite the amplitude obtained from the data of subject-6, subject-11, and subject-13, there were not enough data points to compare with visual feedback conditions.

Data pooled over 14 subjects also did not follow a DoG pattern, and this noisy data could not be fit with the model (Fig 5.b). Therefore, the pooled data did not give a reasonable DoG fit and amplitude that quantified a serial dependence effect.

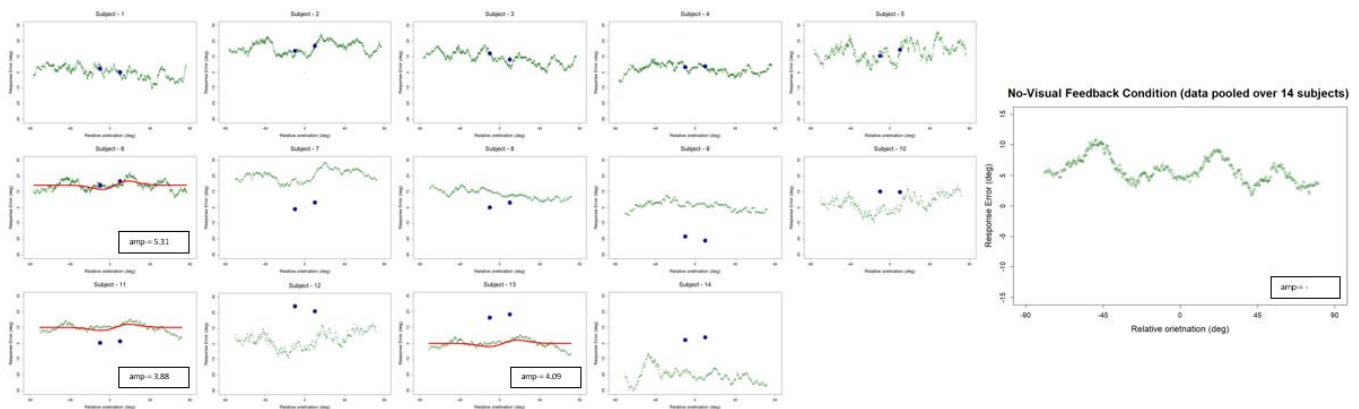


Figure 5. a

Figure 5.b

Figure-5 (No Visual Feedback Condition)

**a. Individual data. Error as a function of relative orientation between previous and current trials for each of the 14 subjects in no visual feedback condition.** The green line represents the running averages of error across windows of 32 trials. Red lines show the derivative of Gaussian (DoG) fits (for the three subjects whose data could be fit). Blue dots represent the averaged error of the relative orientation between  $-22.5^\circ$  and  $0^\circ$  (left dot), and the averaged error of the relative orientation between  $0^\circ$  and  $22.5^\circ$  (right dot).

**b. Grand averages. Error distribution on responses given without visual feedback** The analyzed data pooled over 14 subjects. The green line represents the running averages of error across windows of 32 trials. No DoG fit of the expected function was obtained in this condition.

Therefore, it was concluded that when observers were asked to report the orientation of a visual stimulus without relying on visual feedback, a systematic error towards the orientation of the previous stimulus was not found with this particular data.

### 3.3.Serial dependence compared on responses given with and without visual feedback

Since the DoG fit was not possible on the no visual feedback condition data, an estimate of serial dependence could not be obtained for 11/14 subjects. Therefore, it was nonsensical to conduct any inferential statistics based on these very limited data points obtained from the no-visual feedback condition. Because of this limited number of quantified data, a t-test on the Derivative of Gaussian cannot be conducted. Therefore, descriptively speaking, there is no serial dependence effect obtained in the no visual feedback condition, but it is not possible to test this based on the Derivative of Gaussian.

Nevertheless, to compare conditions quantitatively and drive the hall conclusion, we decided to conduct a t-test on the data obtained by another way of calculation (see Methods / Data analysis).

For the visual feedback condition, a negative error for negative relative orientations between 0 and -22.5 deg and a positive error for the positive relative orientations between 0 and 22.5 deg were predicted. Therefore, the difference between error for negative relative orientations and error for positive relative orientations was predicted to be high.

In the no visual feedback condition, the difference between error for positive and negative relative orientations was predicted to be small and variable between subjects (with a mean centered near zero).

The results of the t-test on the extracted data points indicated that there was indeed a significant difference between visual feedback condition ( $M= 2.68$ ,  $SD=2.33$ ) and no-visual feedback condition ( $M= 0.72$ ,  $SD=2.77$ ),  $t(13)= 2.52$ ,  $p= .02$ . (Figure 6).

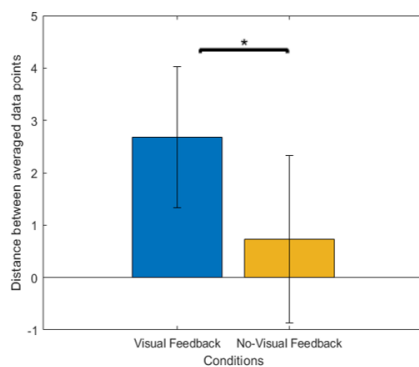


Figure 6

Based on the data collected for this current study, the overall result showed that serial dependence on the responses given with and without visual feedback is significantly different.

#### 4. Discussion

The present experiment shows that the systematic error toward the previous stimuli depends on the type of response. Unlike sensory modality (Arrighi et al., 2014) and stimulus type (Fornaciai & Park, 2019), serial dependence cannot be generalized across different response types. These results do not reveal that there was no serial dependence when the responses were given in the absence of visual feedback, just that the current set-up was not able to show such an effect. Results of the present study are just able to prove that serial dependence differs depending on response type: with and without visual feedback.

What could be the mechanism underlying the difference found between the serial dependence with and without visual feedback?

One possible mechanism could be subjective confidence. It was recently reported that SD biases between successive trials were boosted by the confidence of the estimation response given in the previous trial (Samaha et al., 2019). In the context of the current study, we could speculate that there was a difference in the confidence in responses in the visual feedback versus no visual feedback

conditions (more confidence in the case of feedback than in its absence). Of course, we did not gather an explicit confidence measure after each response, thus making it impossible to test the effect of confidence on the present results. Still, the newly introduced no visual feedback condition in the present study can serve as a benchmark for testing the effect of confidence on serial dependence independently of the quality of evidence.

Another possible explanation for the present results could be the opposite effects of stimulus history on perception versus decision, as pointed out by recent studies (Zhang & Alais, 2020; Fritsche et al., 2017). In this perspective, the undetectable serial dependence in the no visual feedback condition may be the result of different weights on perceptual versus decisional processes as a function of the type of response. Note, however, that we did not find a repulsive effect (as shown by Fritsche et al., 2017) in the no visual feedback condition, and the gating of a particular process by the type of response seems somewhat unparcimonious. Nevertheless, different balances between biases coming from perceptual choice and motor response that induce the difference in the overall serial effect between conditions.

This explanation brings us to the debate of whether serial dependence occurs at an early sensory level of perception or a later decision level. We reasoned that if SD acts on perception, then it should occur independently of response type. Therefore, the current study is consistent with findings supporting the idea that serial dependence occurs at the level of decision and response choice rather than perception (Fritsche et al., 2017). However, the current results conflict with reports of SD in the absence of an explicit task reported (Fornaciai & Park, 2018; Fischer & Whitney, 2014). Therefore, it might be of interest to conduct the same experimental paradigm in the present study by using the absence of an explicit task as a control.

What the present study adds to the serial dependence literature is the no visual feedback condition, which makes it possible to test the effect of response type on serial dependence. Although different response methods for the visual task were already used in the serial dependence literature (Suárez-Pinilla et al., 2018; Cicchini et al., 2018), they all include visual feedback. Furthermore, the aim of the response type manipulations in these studies was not to test serial dependence as a general processing mechanism but to deal with the possibility that their results were influenced by the decision level processes or to explicitly test a model for response optimization. Therefore, testing the effect of the response method on serial dependence is also a new research question introduced by the present study.

The present study raises several outstanding questions that might be interesting to ask to investigate serial dependence in further research: How does response type influence serial dependence in a 2AFC task, which does not require any adjustment? Does confidence influence serial dependence independently of the quality of the evidence? Does the different amplitude of serial dependence between different response types reported in this study exist in higher-level features (such as face, identity,

attractiveness)?

In sum, the present study shows that the particular way the observer produces a response influences serial dependence. The amplitude of SD was larger when subjects were given visual feedback about their ongoing manual response, relative to the condition without such feedback. This suggests that the decision or response determination stage is crucial to serial dependence, which therefore, may not act directly on perception.

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**Annex-1: Analysis on the restricted dataset**

**Serial dependence compared on responses given with and without visual feedback**

The same analysis conducted on the data restricted to the 6 subjects who had the complete data set. The data pooled over 6 subjects for Visual Feedback Condition and for No Visual Feedback Condition represented in Figure 6-a and Figure 6-b, respectively. However, the t-test analysis was conducted on the individual data points extracted from each subjects' error distribution as I did previously in 14 subjects' data.

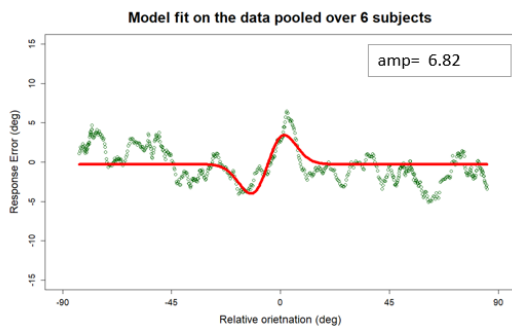


Figure 7.a

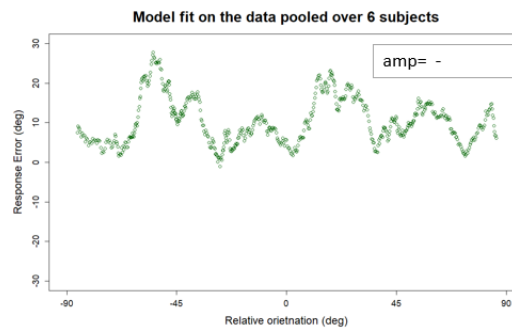


Figure 7.b

The results of the t-test on the extracted data points from the 6 subjects' data indicate that there is a significant difference between visual feedback condition (M= 2, SD=2.43) and no-visual feedback condition (M= -0.04, SD=2.41),  $t(5) = 2.88$ ,  $p = .03$ . (Figure-7).

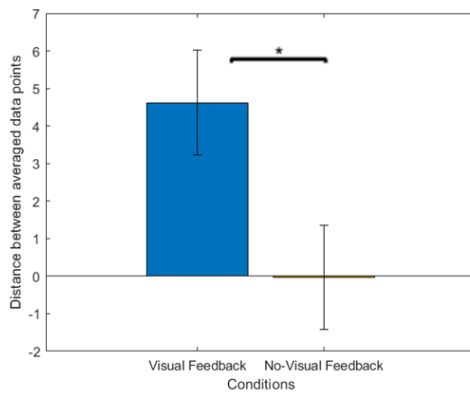


Figure 8