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Adding temporally localized noise can enhance the contribution of target knowledge on contrast detection

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External noise paradigms are widely used to characterize sensitivity by comparing the effect of a variable on contrast threshold when it is limited by internal versus external noise. A basic assumption of external noise paradigms is that the processing properties are the same in low and high noise. However, recent studies (e.g., Allard & Cavanagh, 2011; Allard & Faubert, 2014b) suggest that this assumption could be violated when using spatiotemporally localized noise (i.e., appearing simultaneously and at the same location as the target) but not when using spatiotemporally extended noise (i.e., continuously displayed, full-screen, dynamic noise). These previous findings may have been specific to the crowding and 0D noise paradigms that were used, so the purpose of the current study is to test if this violation of noise-invariant processing also occurs in a standard contrast detection task in white noise. The rationale of the current study is that local external noise triggers the use of recognition rather than detection and that a recognition process should be more affected by uncertainty about the shape of the target than one involving detection. To investigate the contribution of target knowledge on contrast detection, the effect of orientation uncertainty was evaluated for a contrast detection task in the absence of noise and in the presence of spatiotemporally localized or extended noise. A larger orientation uncertainty effect was observed with temporally localized noise than with temporally extended noise or with no external noise, indicating a change in the nature of the processing for temporally localized noise. We conclude that the use of temporally localized noise in external noise paradigms risks triggering a shift in process, invalidating the noise-invariant processing required for the paradigm. If, instead, temporally extended external noise is used to match the properties of internal noise, no such processing change occurs.

Introduction

External noise paradigms (Lu & Dosher, 2008; Pelli, 1981; Pelli & Farell, 1999) are widely used to characterize sensitivity by comparing the effect of a variable on contrast thresholds when it is limited by internal versus external noise. An underlying assumption of such an external noise paradigm is that the processing properties are the same in the presence and absence of external noise. This noise-invariant processing assumption (Allard & Cavanagh, 2011) is generally taken for granted because the visual system has some intrinsic noise, so adding external noise is expected to increase the total amount of noise without triggering a shift in processing properties. However, Allard and colleagues (Allard & Cavanagh, 2011; Allard & Faubert, 2013; Allard & Faubert, 2014a, 2014b; Allard, Renaud, Molinatti, & Faubert, 2013) recently found evidence that this assumption can be violated for a contrast detection task when the noise is spatiotemporally localized to the target (i.e., appears simultaneously and at the same location as the target) but not when it is spatiotemporally extended (i.e., continuously displayed, full-screen, dynamic noise). Although these studies suggest that localized noise can

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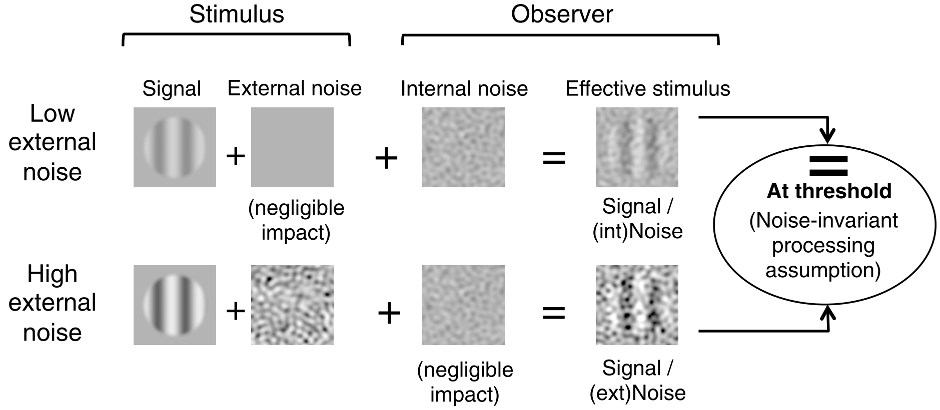

Figure 1. Noise-invariant processing assumption. The top row represents a signal presented in low external noise, in which case the external noise is dominated by internal noise and therefore has a negligible impact. The detection of this signal would therefore depend on the internal noise of the observer and on his signal-to-(internal)noise ratio at threshold. The bottom row represents a signal in high external noise, in which case the internal noise is dominated by external noise and therefore has a negligible impact. The detection of this signal would depend only on the signal-to-(external)noise ratio, which can be experimentally measured as the signal and external noise contrasts are known (Pelli, 1981; Pelli & Farell, 1999). The relative impact of the internal noise (i.e., equivalent input noise) can be estimated by assuming that the signal-to-(internal)noise ratio at threshold is the same as the evaluated signal-to-(external)noise ratio at threshold, which is expected if the same processing strategy operates in low and high external noise (noise-invariant processing assumption).

trigger a change in processing properties, most recent studies using external noise paradigms based on the noise-invariant processing assumption continue to use spatially and/or temporally localized noise (e.g., Baldwin, Baker, & Hess, 2016; Bejjanki et al., 2014; Chen et al., 2014; Hou, Lu, & Huang, 2014; Wyart, Nobre, & Summerfield, 2012). A potential violation of the noise-invariant processing assumption is probably ignored because the evidence for a shift in processing properties is indirect (e.g., aging, Allard et al., 2013), is for a specific noise type (e.g., 0D noise, Allard & Faubert, 2013, 2014b), is for a specific task (e.g., motion discrimination, Allard & Faubert, 2014a), or relies on a peripheral phenomenon that is not fully understood (e.g., crowding, Allard & Cavanagh, 2011). The target of the current study was to directly test if adding noise that is spatiotemporally localized could trigger a shift in processing properties for a standard contrast detection task in central vision.

The most widely used variant of the external noise paradigm is the linear amplifier model (LAM; Pelli, 1981, 1990; Pelli & Farell, 1999), which is used to factor contrast sensitivity into equivalent input noise and calculation efficiency. Because the impact of internal noise[1] becomes negligible in high external noise, contrast threshold in high noise depends only on calculation efficiency (calculated from the measured signal-to-[external]noise ratio at threshold; Figure 1, bottom). The equivalent input noise can be estimated by assuming that the low-noise calculation efficiency (i.e., the signal-to-[internal]noise ratio at threshold; Figure 1, top) is the same as the estimated high-noise calculation efficiency. This noise-invariant calculation efficiency assumption can be justified only if the processing properties are the same in low and high noise. Otherwise, there is no reason to assume that the signal-to-noise ratios at threshold are the same in low and high noise. Thus, the equivalent input noise can be estimated only if the processing properties are the same in low and high noise, and a violation of the noise-invariant processing assumption therefore compromises the applicability of the external noise paradigm.

Although there are many variants of the observer model (e.g., perceptual template model [PTM]; Lu & Dosher, 2008), they all implicitly assume that the processing properties are the same in low and high noise. Indeed, a key interest of adding external noise is to characterize the processing properties of a stimulus in the absence of noise (e.g., estimate equivalent input noise). Consequently, these models implicitly assume that the processing properties are the same in low and high noise (i.e., the noise-invariant processing assumption).

Although it has been suggested that adding localized noise may trigger a shift in processing strategy (Allard & Cavanagh, 2011; Allard et al., 2013; Allard & Faubert, 2013; Allard & Faubert, 2014a, 2014b), the nature of the strategy operating in localized noise is still elusive. One study suggested that a detection processing strategy may shift to a recognition strategy in localized noise (Allard & Cavanagh, 2011). In this study, crowding was found to affect contrast threshold in localized noise but not in the absence of noise or in extended noise. Given that crowding affects recognition but not detection (Levi, 2008; Pelli, Palomares, & Majaj, 2004), these results suggest that a recognition strategy was used in localized noise and a detection strategy was used in the absence of noise and in extended noise. However, crowding is not fully understood, and its underlying causes are still widely debated (Dakin, Bex, Cass, & Watt, 2009; Freeman & Pelli, 2007; Greenwood, Bex, & Dakin, 2009; Levi, 2008; Pelli et al., 2004). This weakens the interpretation based on a crowding effect. The current study therefore used a paradigm that does not rely on a controversial phenomenon such as crowding. If the processing that operates in localized noise relies on recognizing the shape of the target, then uncertainty about the shape of the target should impair the ability to recognize it. In other words, uncertainty about the shape of the target will degrade its recognition. Thus, if the processing operating in localized noise relies more on target knowledge than does the processing in the absence of noise and in extended noise, then uncertainty about the shape of the target should impair performance more in localized noise than in the absence of noise or in extended noise. Note that uncertainty can weakly affect contrast detection in the absence of noise by filtering out noise within irrelevant channels (Davis, Kramer, & Graham, 1983; Davis & Graham, 1981; Pelli, 1985). Nonetheless, the rationale of the current study was that uncertainty about the shape of the target should have a greater effect on recognition-based processing than on detection-based processing. To measure the effect of shape uncertainty on contrast threshold, the current study investigated contrast detection thresholds when the orientation of the target was known versus unknown to the observer. Orientation uncertainty effects were evaluated in the absence of noise and in different noise conditions (spatial and temporal windows, each either localized or extended).

Methods

Observers

Eleven observers, aged 23 to 39 years (mean age = 28.73 years, *SD* = 5.68) with normal or corrected-to-normal vision participated in this study. This study was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki), and informed consent was obtained.

Apparatus

All stimuli were generated by a homemade program and presented on a VIEWPixx/EEG LCD monitor with a refresh rate of 120 Hz and a resolution of 1,920 × 1,080 pixels. Stimuli were presented at the center of a gray square of 8.4° × 8.4° of visual angle (dva) and mean luminance of 50 cd/m^2. The screen being rectangular, the luminance of the unused pixels was minimized. Stimuli were viewed binocularly at a distance of 2 m. The monitor was the only source of light in the room. The output intensity of each color gun was linearized psychophysically using a homemade program. The noisy-bit method (Allard & Faubert, 2008) implemented independently to each color gun, made the eight-bit display perceptually equivalent to an analog display having a continuous luminance resolution.

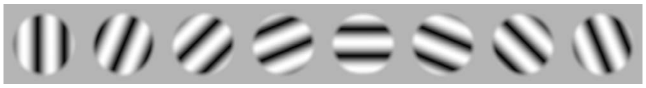

Figure 2. The eight possible orientations of the signal. From left to right: 0°, 22.5°, 45°, 67.5°, 90°, 112.5°, 135°, and 157.5°. Signals are represented here at 100% contrast.

Stimuli/procedure

A two-interval forced-choice procedure was used with an interstimulus interval of 500 ms. The signal was presented in only one of the two 33-ms intervals, and each interval was indicated by a synchronized 33-ms sound. The detection task consisted in determining if the stimulus was presented simultaneously with the first or second sound by pressing one of two keys. Auditory feedback was given to the observer.

Stimuli were sinusoidal gratings at two cycles per degree, having one of eight possible orientations (0°, 22.5°, 45°, 67.5°, 90°, 112.5°, 135°, and 157.5°; Figure 2). The spatial window of the stimulus had a diameter of 1 dva, and its temporal window was 33 ms. A black circle with a 4-dva diameter and centered on the target was continuously presented to maximally reduce spatial uncertainty (Figure 3).

The noise was sampled from a Gaussian distribution and filtered in the Fourier domain to remove all spatial frequencies above eight cycles per degree. The rms contrast of the noise was fixed at 20%, and the noise was resampled at 30 Hz. The spatial window of the noise was either localized (same spatial window as the target) or extended (covered the entire displayed area), and the temporal window was also either localized (same temporal window as the target, i.e., 33 ms) or extended (continuously displayed during and between trials). The four noises plus no-noise conditions are shown in Figure 3.

For each noise condition, eight staircases were performed in which the observer knew the orientation of the target and eight in which he did not know the orientation of the target. The subject alternated between unknown and known orientation conditions

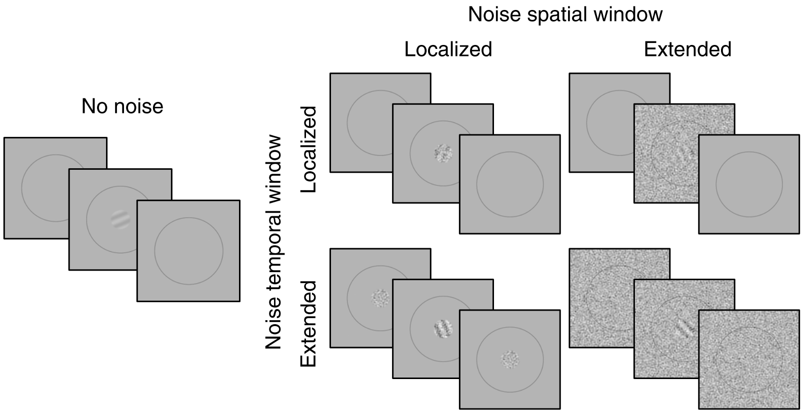

Figure 3. The five noise conditions. On the left, the no-noise condition. On the right, the four different noise conditions. The noise was either spatially localized (noise and signal have the same spatial window, left column) or spatially extended (covered the entire displayed area, right column) and either temporally localized (one 33-ms noise frame, top row) or temporally extended (continuously displayed during and between trials, bottom row).

until the 16 staircases for the given noise condition were performed. In the unknown orientation condition, the orientation of the signal was pseudo-randomized at each trial. In the known orientation condition, the orientation was fixed for each staircase (pseudo-randomly selected so that one staircase was performed for each of the eight orientations) and was known to the observer. There were a total of 80 conditions: (8 × unknown orientation condition + 8 × known orientation condition) × 5 noise conditions. The subjects carried out five testing sessions (i.e., one noise condition per session), which lasted about 30 min each and were spread out over five days of testing (not necessarily consecutive).

Contrast detection threshold was measured using a 3-down, 1-up staircase procedure (Levitt, 1971) with a step size of 1.25 factor and was interrupted after 12 inversions. The threshold for each staircase was estimated as the geometric mean of the last 10 inversions. For each noise condition, the contrast threshold in the unknown orientation condition was estimated as the geometric mean of the eight threshold estimations (i.e., eight staircases with pseudo-randomized orientation), and the contrast threshold in the known orientation condition was the geometric mean of the eight threshold estimates for the eight known orientations.

Results

Contrast thresholds for the known orientation and the unknown orientation conditions are shown in Figure 4. Contrast thresholds were substantially higher in noise conditions than in the absence of noise (see in Figure 4 the different range of the y-axis). This considerable effect of the noise on the contrast threshold confirms that the impact of the internal noise was negligible in the four high-noise conditions (Pelli & Farell, 1999).

The orientation uncertainty effect was defined as the contrast threshold ratio between the unknown orientation and known orientation conditions (Figure 5). An orientation uncertainty effect greater than 1 represents an advantage of knowing the orientation of the target, whereas an orientation uncertainty effect of 1 (similar contrast thresholds in the two conditions) represents no advantage of knowing the orientation.

One of the aims of the current study was to determine if the processing in spatiotemporally localized and extended noise (second and fifth columns in Figure 5, respectively) was the same as the processing in the absence of noise (left column in Figure 5). Paired t tests showed that the orientation uncertainty effect was significantly greater in spatiotemporally localized noise than in no noise, $t(10) = 3.0$, $p < 0.05$, and in spatiotemporally extended noise, $t(10) = 3.7$, $p < 0.01$. The no-noise and the spatiotemporally extended noise conditions did not significantly differ, $t(10) = 1.1$, $p = 0.3$. Knowing the orientation of the stimulus was therefore more useful in the presence of spatiotemporally localized noise than in the other two conditions, demonstrating an additional contribution of target knowledge in spatiotemporally localized noise.

The difference in orientation uncertainty effects between the spatiotemporally localized noise and the spatiotemporally extended noise could be due to the temporal or spatial window of the noise. The orientation uncertainty effect at intermediate noise conditions (i.e., spatially extended and temporally localized noise and spatially localized and temporally extended noise, third and fourth columns in Figure 5, respectively) can be used to test which dimension of the noise was

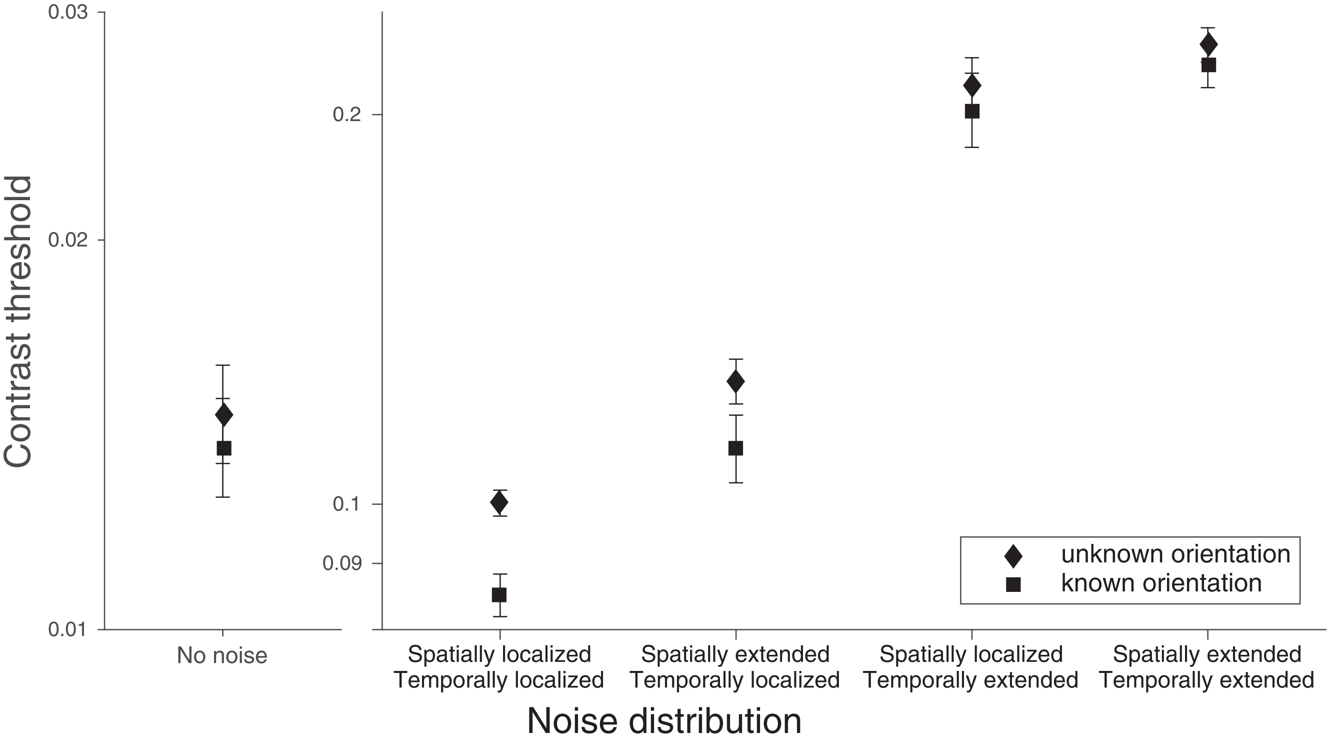

Figure 4. Contrast thresholds for the known and unknown orientation conditions. Mean contrast thresholds for the unknown orientation condition (diamonds) and the known orientation condition (squares) for the no-noise condition and the four different noise distributions. The error bars represent the standard error of the mean. The two *y*-axes cover different ranges but have the same logarithmic scale.

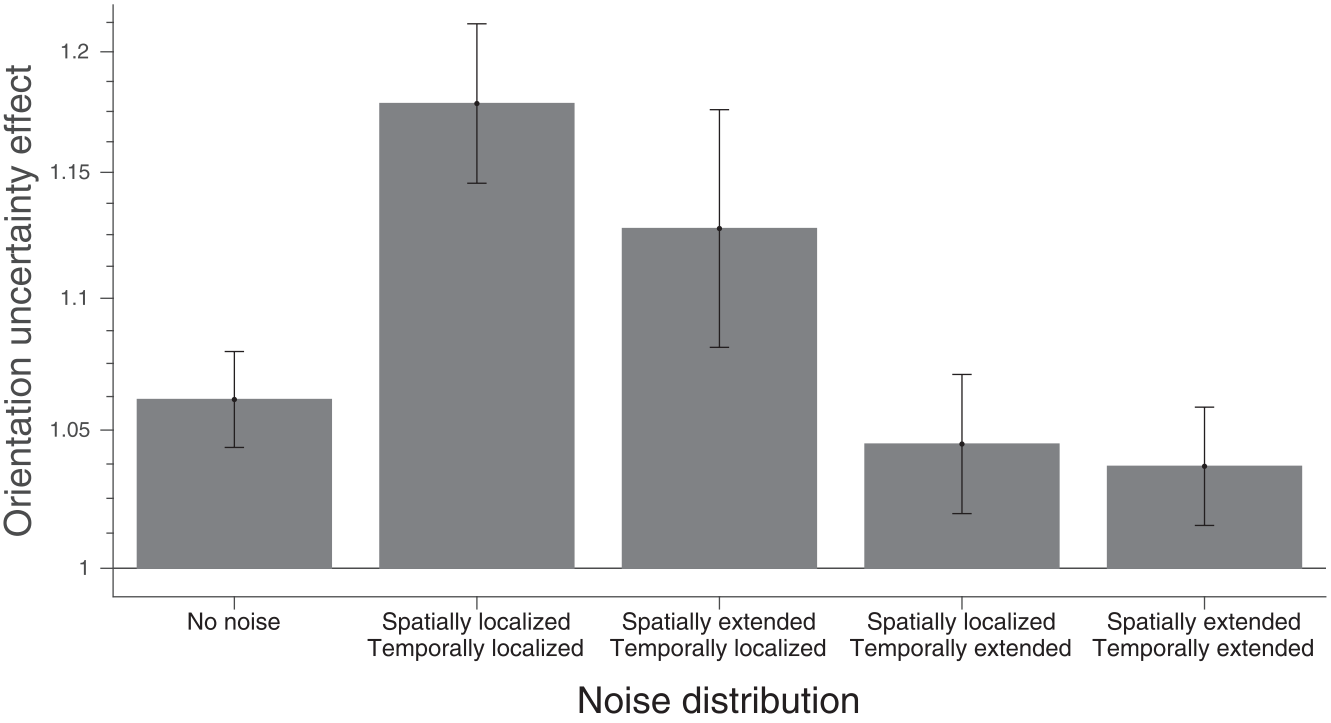

Figure 5. Orientation uncertainty effects for the different noise conditions. For each noise condition, an orientation uncertainty effect corresponds to the contrast threshold ratios of the unknown-known orientation conditions (calculated from the data shown in Figure 4). A ratio greater than 1 indicates that the contrast threshold was greater in the unknown orientation than known orientation conditions. The error bars represent the standard error of the mean.

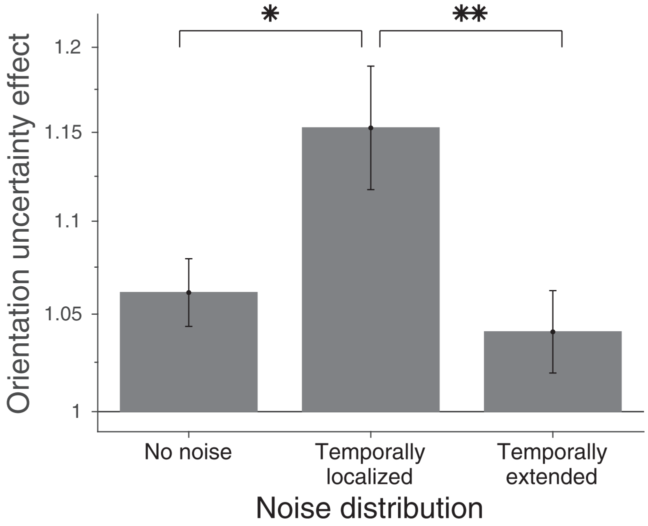

Figure 6. Orientation uncertainty effects for the noise conditions regrouped according to their temporal window. Ratio of the unknown-known orientation conditions of the subject's mean for the no-noise condition, the temporally localized condition (geometric mean of the spatiotemporally localized noise and the spatially extended and temporally localized noise in Figure 5), and the temporally extended condition (geometric mean of the spatiotemporally extended noise and the spatially localized and temporally extended noise in Figure 5). The error bars represent the standard error of the mean.

responsible for the greater orientation uncertainty effect in spatiotemporally localized noise. A two-way analysis of variance (ANOVA; two spatial windows × two temporal windows) showed a simple main effect of the temporal window, $F(1, 10) = 19.37$, $p < 0.01$, but not of the spatial window, $F(1, 10) = 1.49$, $p = 0.25$. This suggests that the higher orientation uncertainty effect in the spatiotemporally localized noise was due to the fact that the noise was temporally localized, not that it was spatially localized.

Because the ANOVA showed that the spatial window of the noise had no significant impact on the orientation uncertainty effect, the effect of the temporal window can be examined with additional statistical power by grouping the orientation uncertainty effects that varied only according to the spatial window of the noise (i.e., geometric mean of the orientation uncertainty effects in spatially localized and extended noise for each temporally localized and extended noise), as shown in Figure 6. Paired t tests showed that the orientation uncertainty effect in the temporally localized noise was significantly higher than in the no-noise condition, $t(10) = 2.5$, $p < 0.05$, and highly significantly higher than in the temporally extended noise condition, $t(10) = 4.4$, $p < 0.01$. Furthermore, the orientation uncertainty effects in the no-noise condition and in the temporally extended noise condition did not significantly differ, $t(10) = 0.91$, $p = 0.38$. The greater orientation uncertainty effect in temporally localized noise shows that knowledge about the shape of the target was more relevant to the processing in temporally localized noise than in temporally extended noise or in the absence of noise, which reveals an additional contribution of target knowledge in temporally localized noise.

Discussion

The results of the current study showed that knowing the orientation of the target was more advantageous in temporally localized noise than in the absence of noise or in temporally extended noise. These results revealed additional contribution of target knowledge for detection in temporally localized noise.

External noise paradigms are often used to characterize sensitivity by comparing the effect of a variable on contrast thresholds in low and high noise, that is, threshold limited by internal and external noise, respectively. Given that the contribution of target knowledge depended on the temporal window of the noise, implementing the external noise paradigm using temporally localized or temporally extended noise would lead to different outcomes and interpretations. For instance, consider the two main variants of the external noise paradigm: the LAM (Pelli, 1981; Pelli & Farell, 1999) and the perceptual template model (PTM; Lu & Dosher, 1999, 2008). The LAM has a factor affecting threshold in both low and high noise (namely, calculation efficiency) and another factor affecting threshold only in low noise (namely, equivalent input noise). Based on the greater uncertainty effect in temporally localized noise than in the absence of noise, the LAM would suggest that knowing the orientation improved calculation efficiency (equivalent to orientation uncertainty effect in temporally localized noise of Figure 6) and surprisingly increased equivalent input noise (lower equivalent input noise when orientation is unknown, first column in Figure 7). On the other hand, based on the similar and small uncertainty effects in the absence of noise and in temporally extended noise, the LAM would suggest instead that knowing the orientation did not affect equivalent input noise (right column in Figure 7) and slightly improved calculation efficiency (right column in Figure 6). Thus, applying the LAM to data collected with different temporal noise windows leads to dramatically different interpretations.

Contrary to the LAM, the PTM has a parameter affecting threshold only in high noise: an early perceptual template filtering out irrelevant information operating before the main internal noise (namely, external noise exclusion). Thus, the PTM could explain

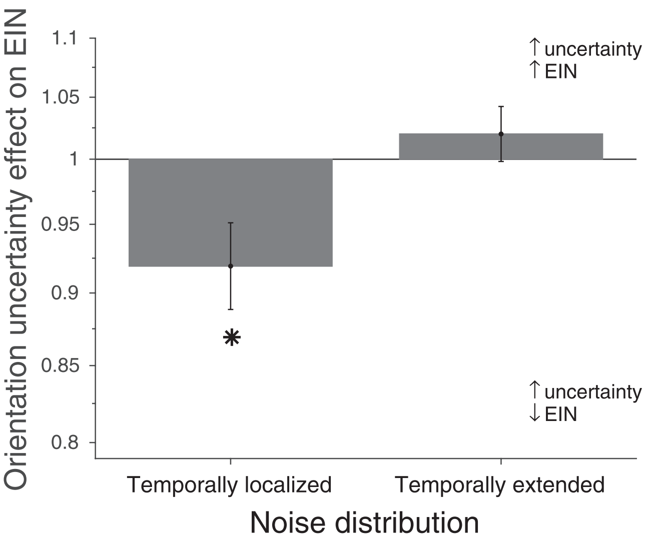

Figure 7. Orientation uncertainty effect on equivalent input noise (EIN). The EIN ratio of the unknown-known orientation conditions of the subject's mean for the temporally localized condition and the temporally extended condition. A ratio greater than 1 represents more EIN in the unknown orientation condition, whereas a ratio less than 1 represents less EIN in the unknown orientation condition. The error bars represent the standard error of the mean.

the greater uncertainty effect in temporally localized noise than in the absence of noise due to a better filter tuning along the known orientation, excluding external noise at irrelevant orientations. However, the much smaller uncertainty effect observed in temporally extended noise (Figure 6) would rather suggest that knowing the orientation did not considerably filter out external noise at irrelevant orientations. As a result, applying the PTM also leads to drastically different interpretations depending on the temporal window of the noise. More generally, given that the contribution of target knowledge depends on the temporal window of the noise, applying any variant of the external noise paradigm (e.g., LAM, PTM) would result in different interpretations depending on whether the noise is temporally localized or extended.

The rationale of the external noise paradigm is to better characterize processing by evaluating performance limited by internal and external noise (i.e., in the absence of noise and in high noise, respectively). If different processing properties are observed in temporally localized and extended noises, then the external noise paradigm should be implemented with temporally extended noise to match the properties of internal noise. Indeed, internal noise does not turn on and off with the signal presentation and is therefore temporally extended, so the interpretation from any variant of the external noise paradigm based on temporally localized noise would be invalid. For instance, the LAM assumes that the processing properties that affect contrast threshold in high noise (i.e., calculation efficiency) equally affect contrast threshold in the absence of noise. Thus, because internal noise is temporally extended, the greater contribution of target knowledge observed specifically in temporally localized noise could not be interpreted as occurring in the absence of noise. In other words, applying the LAM using temporally localized noise would overestimate the contribution of target knowledge on the calculation efficiency effective in the absence of noise.

Within the PTM framework, an effect only in high noise suggests a variation in early template tuning occurring *before* the internal noise. Indeed, filtering out noise *after* the limiting internal noise should equally affect contrast threshold in low and high noise, whereas filtering out noise *before* the limiting internal noise should affect contrast threshold only in high noise. However, given that the greater contribution of target knowledge was specific to temporally localized noise and internal noise is temporally extended, a process specific to temporally localized noise occurring *after* the internal noise would equally account for the data: It would affect performance only in temporally localized noise and not in temporally extended noise or in the absence of noise. Thus, applying the PTM using temporally localized noise would unjustifiably suggest that target knowledge affects *early* template tuning. In sum, if an effect depends on some property of the noise that differs between internal and external noise, then it compromises the interpretation of any external noise paradigms implicitly assuming that the processing properties are noise invariant. Therefore, to avoid triggering a potential shift in processing properties and thereby compromise the application of the external noise paradigm, external noise should be temporally extended to match the properties of internal noise.

Why was there a larger contribution of target knowledge in temporally localized noise compared with temporally extended noise and absence of noise? The rationale of the current study was based on a previous study (Allard & Cavanagh, 2011) suggesting that adding localized noise causes a shift from a detection to a recognition strategy. This study found that crowding affected the contrast detection threshold in localized noise, but not in the absence of noise or in extended noise. Given that crowding affects recognition but not detection (Levi, 2008; Pelli et al., 2004), these results suggest that a recognition strategy operates in localized noise and that a detection strategy operates in the absence of noise and in extended noise. Given that a recognition strategy relies more on target knowledge than does a detection strategy, such a shift in processing strategy can explain the greater contribution of target knowledge in temporally localized noise that is observed in the current study.

This interpretation is consistent with other studies that found a processing strategy shift in localized noise (Allard et al., 2013; Allard & Faubert, 2014a, 2014b). For instance, Allard and Faubert (2014a) found that the most sensitive detectors for a moving stimulus were direction selective (e.g., direction-selective complex cells) in the absence of noise and in temporally extended noise but not in temporally localized noise, as the most sensitive detectors in that case were labeled for orientation but not direction (e.g., simple cells). The stimulus in the current study was not moving but was briefly presented (33 ms), which makes it probable that the most sensitive detectors were transient based in the absence of noise and in temporally extended noise. Thus, the involvement of different channels depending on the temporal window of the noise could be part of the reason why the effect of target knowledge depended on the nature of the external noise in the current study.

There is, nevertheless, an alternative explanation that we must consider. A notable property of temporally localized noise is that it reduces temporal uncertainty, and the possibility of an interaction between temporal and orientation uncertainty could explain different orientation uncertainty effects in temporally localized and extended noise. In particular, adding uncertainty along one dimension may have a negligible effect when there is a high uncertainty along another dimension. In this case, reducing orientation uncertainty may have no effect when temporal uncertainty is high (absence of noise and in temporally extended noise) but may have an effect when temporal uncertainty is low (temporally localized noise). Consequently, it is theoretically possible that the greater contribution of target knowledge in temporally localized noise could be triggered by a temporal uncertainty reduction.

However, the different processing properties in temporally localized noise compared with temporally extended and absence of noise observed in some previous studies cannot be explained by temporal uncertainty. Indeed, there is no reason for a temporal uncertainty reduction to trigger a crowding effect in a detection task (Allard & Cavanagh, 2011) or cause a shift in processing channel (Allard & Faubert, 2014a). Furthermore, there was little temporal uncertainty to reduce in these studies. Indeed, the temporal window of the signal was longer than in the current study (i.e., ≥200 ms compared with 33 ms), and in the crowding study (Allard & Cavanagh, 2011), flankers were presented near the target with the same temporal window as the target. Given that a shift in processing strategy has been observed for a detection task in temporally localized noise and that, in the current study, temporal uncertainty was minimized with an auditory cue, we consider more likely that the greater contribution of target knowledge in temporally localized noise was due to a shift in processing strategy, rather than an interaction between orientation and temporal uncertainty.

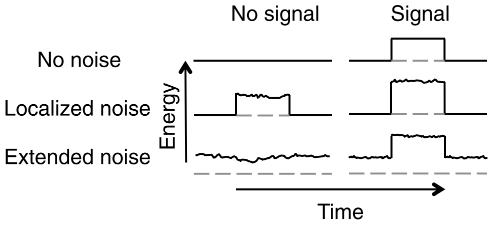

Figure 8. Energy levels in the different noise conditions. Energy level when the signal is present (right column) or absent (left column) as a function of a given dimension (e.g., time) for three conditions: no noise (first line), localized noise (second line), and extended noise (third line).

Most important, whether the greater contribution of target knowledge was due to a shift in processing strategy or a reduction in temporal uncertainty does not alter the main implication of the current study. Specifically, the data show that processing properties are noise dependent, and this compromises the interpretation of the external noise paradigms that use temporally localized noise.

Previous studies have suggested that processing strategy shifts in localized noise may be caused by the match between the energy variation of the noise and that of the signal (Allard & Cavanagh, 2011; Allard et al., 2013; Allard & Faubert, 2014a, 2014b). For the briefly presented signals used in the current study, signal detection in the absence of noise and in temporally extended noise is likely to be transient based. If the same transient-based strategy operated also in temporally localized noise, then similar effects of orientation uncertainty would be expected in all noise conditions. The substantial temporal energy variation caused by temporally localized noise (Figure 8, second row) could have impaired the ability to detect the simultaneous signal transients. Noise turning on and off with the target would impair the ability to detect transients caused by the signal, which would increase the relative effectiveness of other strategies (e.g., recognition, or a different processing channel that is not transient based). On the other hand, the energy fluctuation of temporally extended noise is not synchronous with the signal energy (Figure 8, third row), leaving the detection of transients the optimal strategy.

Conclusion

In conclusion, the contribution of target knowledge was greater in temporally localized noise than in

temporally extended noise and in the absence of noise. This implies different processing properties between temporally localized external noise and internal noise (which is temporally extended), which violates the noise-invariant processing assumption of external noise paradigms. Therefore, to avoid triggering a potential shift in processing properties and thereby compromise the application of the external noise paradigm, temporally extended noise should be used to match the properties of internal noise.

Keywords: noise paradigm, equivalent input noise, noise-invariant processing assumption, orientation uncertainty, contrast detection

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Footnote

[1] In this article, the term *internal noise* refers to additive internal noise. Multiplicative noise was not relevant for the purpose of this article.

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