Vision Research 92 (2013) 47–52

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Contrast sensitivity, healthy aging and noise

Rémy Allard [a,b,*], Judith Renaud [b], Sandra Molinatti [a,b], Jocelyn Faubert [a,b]

[a] Visual Psychophysics and Perception Laboratory, Université de Montréal, Canada
[b] School of Optometry, Université de Montréal, Canada

ARTICLE INFO

Article history:
Received 4 July 2013
Received in revised form 3 September 2013
Available online 23 September 2013

Keywords:
Aging
Contrast sensitivity function
Internal noise
Calculation efficiency
External noise paradigms

ABSTRACT

At least three studies have used external noise paradigms to investigate the cause of contrast sensitivity losses due to healthy aging. These studies have used noise that was spatiotemporally localized on the target. Yet, Allard and Cavanagh (2011) have recently shown that the processing strategy can change with localized noise thereby violating the noise-invariant processing assumption and compromising the application of external noise paradigms. The present study reassessed the cause of age-related contrast sensitivity losses using spatiotemporally extended external noise (i.e., full-screen, continuously displayed dynamic noise). Contrast thresholds were measured for young (mean = 24 years) and older adults (mean = 69 years) at 3 spatial frequencies (1, 3 and 9 cpd) and 3 noise conditions (noise-free, local noise and extended noise). At the two highest spatial frequencies, the results were similar with local and extended noise: the sensitivity loss was mainly due to lower calculation efficiency. At the lowest spatial frequency, age-related contrast sensitivity losses were attributed to the internal equivalent noise when using extended noise and, like in previous studies, due to calculation efficiency with local noise. These results show that the interpretation of external noise paradigms can drastically differ depending on the noise type suggesting that external nose paradigms should use external noise that is spatiotemporally extended like internal noise to avoid triggering a processing strategy change. Contrary to previous studies, we conclude that healthy aging does not affect the calculation efficiency of the detection process at low spatial frequencies.

1. Introduction

Healthy aging affects contrast sensitivity, especially at high spatial frequencies (for a recent review, see Owsley, 2011), but the causes of this sensitivity loss are still debated. Aging could impair contrast sensitivity because the elderly have more distortions that impair the visual input (i.e., internal noise) or because they are less efficient at detecting a target embedded in internal noise (i.e., require a greater signal-to-noise ratio to detect the signal). A greater amount of noise could be due to optical factors (e.g., smaller pupil size, Loewenfeld, 1979; lens densification, Pokorny, Smith, & Lutze, 1987) or neural factors (e.g., greater spontaneous neural activity, Schmolesky et al., 2000). The efficiency to detect a target (namely, calculation efficiency) would be affected if aging affects the ability of the detection mechanism to integrate the relevant visual information. For instance, contrast sensitivity could be impaired due to lower integration of relevant information (e.g., lower spatial or temporal summation) or the integration of irrelevant information (e.g., due to spatial, temporal or frequency uncertainty).

External noise paradigms (Pelli, 1981, 1990) can be used to investigate whether age-related contrast sensitivity losses are due to internal noise or calculation efficiency. When the external noise is high, the impact of the internal noise added by the visual system becomes negligible, so contrast detection thresholds in high noise depend only on the calculation efficiency (i.e., signal-to-noise ratio required to detect the signal). The impact of the internal noise can be quantified as the amount of external noise that has the same impact as the internal distortions, namely, the internal equivalent noise. This corresponds to the knee of the contrast threshold curve when plotted as a function of noise contrast on a log–log plot (Fig. 1). Thus, more internal noise would affect contrast thresholds in low but not in high external noise (Fig. 1, left), whereas lower calculation efficiency would affect detection thresholds in both low and high external noise (Fig. 1, right). By evaluating contrast thresholds in low and high external noise, it is therefore possible to determine if an age-related sensitivity loss is due to more internal noise, lower calculation efficiency or both.

We are not the first to investigate whether age-related contrast sensitivity losses are due to higher internal equivalent noises or lower calculation efficiencies. At a low spatial frequency (1 cycle

* Corresponding author at: Visual Psychophysics and Perception Laboratory, Université de Montréal, Canada.
E-mail address: remy.allard@umontreal.ca (R. Allard).

0042-6989
http://dx.doi.org/10.1016/j.visres.2013.09.004

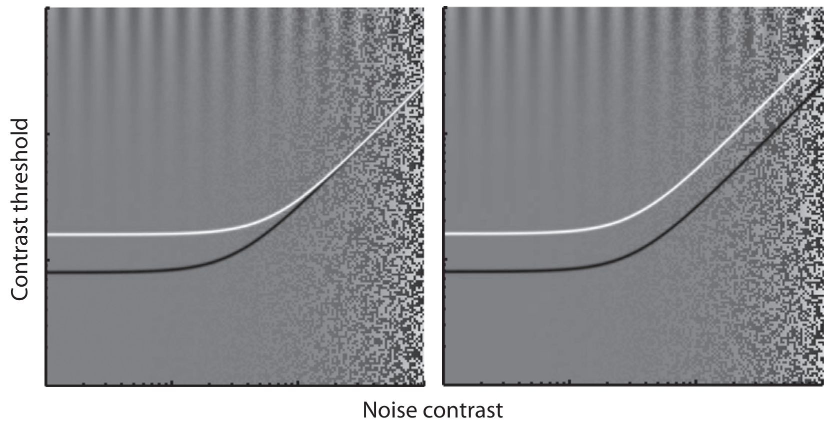

Fig. 1. Hypothetical contrast thresholds as a function of external noise contrast for young (black) and older (white) subjects. When external noise is lower than internal equivalent noise, it is negligible and performance is unaffected by its variation (flat portion of the curve). When external noise is higher than internal equivalent noise, it affects contrast thresholds (rising asymptote). If aging affects internal noise, then it would impair contrast threshold only when it is limited by internal noise (i.e., when external noise is low), but not when external noise dominates (left graph). If aging affects calculation efficiency (i.e., detection mechanisms of elderly requires greater signal-to-noise ratio), then it would impair contrast thresholds whether it is limited by internal or external noise (right graph).

per degree, cpd), many studies (Bennett, Sekuler, & Ozin, 1999; Pardhan, 2004; Speranza, Moraglia, & Schneider, 2001) found that older observers had lower calculation efficiencies but similar internal equivalent noise, suggesting that aging affects the efficiency of the detection mechanism extracting the signal from noise. At high spatial frequencies (6–10 cpd), different studies found different results. Pardhan (2004) found a significant age-related change in internal equivalent noise and no significant change in calculation efficiency, whereas Bennett, Sekuler, and Ozin (1999) and Pardhan et al. (1996) found the opposite pattern of results: a significant change in calculation efficiency and no significant change in internal equivalent noise.

An underlying assumption of external noise paradigms is that the signal is detected by the same mechanism whether thresholds are limited by internal or external noise, that is, in low and high external noise, respectively. If this assumption is valid, it is possible to measure the calculation efficiency of the detection mechanisms by adding external noise, which nulls the impact of internal noise. Previous studies have implicitly made this noise-invariant processing assumption, but Allard and Cavanagh (2011) have recently shown that it can be violated. Under some conditions, adding external noise can change a detection task to a discrimination or recognition task. The mechanisms detecting the signal in low noise (i.e., when internal noise dominates) can be different from the one "detecting" the signal in high noise. This processing strategy shift could be caused by the fact that when external noise dominates internal noise (i.e., high noise), the observer always detects something (i.e., the noise) whether the target is present or not. As a result, the observer would need to discriminate both stimuli (signal + noise vs. noise) by using a discrimination or recognition strategy (e.g., which of the two stimuli is shaped like the target?) rather than a simple detection strategy (e.g., was something presented or not?). Allard and Cavanagh (2011) observed this processing strategy shift when external noise was spatiotemporally localized to the target (i.e., appear simultaneously with the target and at the target location), but not when the external noise was spatiotemporally extended (i.e., continuously present over the entire screen). This can be explained by the fact that, with high local noise, the observer always detects something distinct from the background whether the signal was present or not (Fig. 2, middle column). However, with extended noise the task would consist in determining if a pattern can be distinguished from the noisy background (Fig. 2, right column). This would be highly similar to detecting a target embedded in internal noise (Fig. 2, left column),

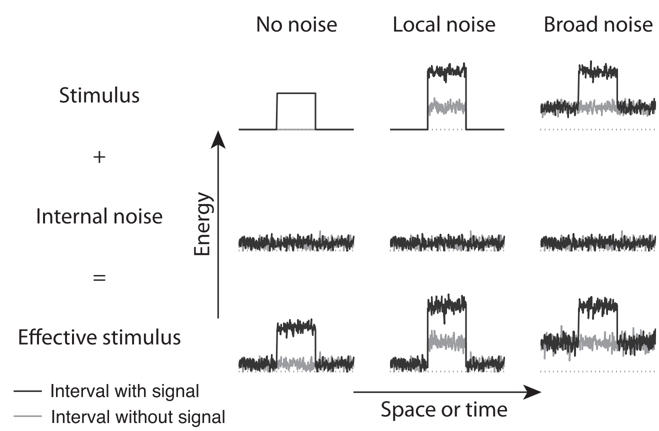

Fig. 2. Energy level when a target is present (black) or absent (gray) as a function of a given dimension (e.g., space or time) for three noise conditions: no noise (left), local noise (middle) and extended noise (right). The top row represents the energy level of the external stimulus, the middle row represents internal noise added by the visual system and the bottom row represents the effective stimulus (i.e., the external stimulus summed with internal noise). The effective stimulus of the no and extended noise conditions have similar profiles, which is different from the one with the local noise that shows an important energy variation even in the absence of a signal. This could explain why different processing strategies underlie detection in local noise. The dotted line represents the zero energy level.

which should be continuously present across time and space. Thus, whether internal or extended external noise dominates, the detection task would consist in determining if a pattern can be distinguished from the noisy background.

The studies that investigated whether age-related contrast sensitivity losses are due to more internal noise or lower calculation efficiencies (Bennett, Sekuler, & Ozin, 1999; Pardhan, 2004; Pardhan et al., 1996; Speranza, Moraglia, & Schneider, 2001) have used local, static external noise. Thus, it is possible that in high external noise conditions they were not evaluating the calculation efficiency of the *detection* mechanism per se (i.e., detecting a signal embedded in a noisy background) as they assumed they were, but were rather measuring the efficiency of a higher-level discrimination or recognition process. The objective of the current study was to reassess whether the age-related contrast sensitivity losses at low, medium and high spatial frequencies are due to higher internal equivalent noise or lower calculation efficiency by using extended dynamic noise to avoid triggering a processing strategy