Development of a computerized assessment for visual masking

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ABSTRACT Visual masking provides a highly informative means of assessing the earliest stages of visual processing. This procedure is frequently used in psychopathology research, most commonly in the study of schizophrenia. Deficits in visual masking tasks appear to reflect vulnerability factors in schizophrenia, as opposed to the symptoms of the illness. Visual masking procedures are typically conducted on a tachistoscope, which limits standardization across sites, as well as the number of variables that can be examined in a testing session. Although visual masking can be administered on a computer, most methods used so far have had poor temporal resolution and yielded a limited range of variables. We describe the development of a computerized visual masking battery. This battery includes a staircase procedure to establish an individual's threshold for target detection, and a relatively dense sampling of masking intervals. It includes both forward and backward masking trials for three different masking conditions that have been used previously in experimental psychopathology (target location, target identification with high-energy mask, and target identification with low-energy mask).

Key words: visual masking, backward masking, visual processing, schizophrenia, bipolar disorder, neurocognition

Visual masking procedures assess the earliest components of visual processing. In visual masking, the visibility of a briefly presented *target* is reduced by a *mask* presented very shortly before or after the target (Breitmeyer, 1984; Breitmeyer, 1992; Breitmeyer and Ganz, 1976). When the mask follows the target, the effect is called *backward* masking. *Forward* masking occurs when the mask precedes the target.

Visual masking procedures are frequently used to assess early visual processing deficits in psychiatric disorders, particularly backward masking anomalies in schizophrenia. Schizophrenic patients consistently show backward masking performance deficits (they require a longer interval between target and mask to identify the target) compared with non-clinical subjects (Braff et al., 1991; Cadenhead et al., 1998; Green and Walker, 1986; Rund, 1993; Saccuzzo and Braff, 1981; Saccuzzo et al., 1996; Schwartz et al., 1983; Slaghuis and Bakker, 1995). Although most

visual masking studies in psychopathology research have involved schizophrenia, symptomatic bipolar patients show masking deficits comparable to those in schizophrenia (Green et al., 1994a; Green et al. 1994b).

These deficits appear to reflect vulnerability to schizophrenia, as opposed to the symptoms of the illness, because remitted patients and unaffected siblings show deficits as well (Green et al., 1997; Green et al., 1999; Miller et al. 1979). Furthermore, deficits are sometimes found among non-psychotic individuals who are considered 'psychosis-prone' because of schizotypal symptoms or scores on psychometric tests (Braff, 1981; Cadenhead et al., 1996; Merritt and Balogh, 1989). Visual masking deficits in schizophrenia are related to negative symptoms, poor prognosis, and thought disorder, but not positive psychotic symptoms (Braff et al., 1989; Braff and Saccuzzo, 1982; Butler et al., 1996; Cadenhead et al., 1997; Green and Walker,

1986; Knight, 1992; Knight et al., 1985; Perry and Braff, 1994; Slaghuis and Bakker, 1995; Slaghuis and Curran, 1999; Weiner et al., 1990).

Visual masking depends on the interactions of two types of visual pathways: transient and sustained (Breitmeyer, 1984; Breitmeyer and Ganz, 1976). These pathways form the basis of complex visual processing such as object recognition and spatial relationships among objects (Van Essen et al., 1992). A recent model extends the hypothesized interactions of sustained and transient channels to include underlying gamma range oscillations (30 Hz to 70 Hz) in the sustained channels (Purushothaman et al., 2000). Abnormalities in the establishment or maintenance of gamma range oscillations could help to explain visual masking and other perceptual deficits in schizophrenia (Green and Nuechterlein, 1999; Green et al., 1999; Kwon et al., 1999).

Advantages of a computerized system

Although visual masking procedures have been highly informative for psychopathology, their applications have been hampered by difficulties in assessment. Most of these studies in psychopathology have used tachistoscopes. While tachistoscopes provide excellent temporal control, computerized procedures offer substantial advantages including:

- ease in replicating stimuli and administration parameters at different sites;
- better ability to develop stimuli that closely surround, but not overlap, the target stimuli (meta-contrast);
- ease in modifying stimuli;
- faster data collection and data reduction;
- ability to enter responses directly into a database; and
- ability to generate a wider range of stimulus types including a broader range of intensities.

Moreover, the major manufacturer of tachistoscopes (Gerbrands) went out of business. Until recently, the slow refresh rates of computer monitors made them undesirable for masking procedures, but this problem is now resolved. In this report, we describe our development of computerized versions of several visual masking tasks similar to those used previously in studies of schizophrenia and bipolar disorder (Green et al., 1997; Green et al., 1994a; Green et al., 1994b).

Equipment

The task was administered on a standard Dell Pentium computer with a 17" Sony Multiscan 200PS monitor driven at 150 Hz with a graphics card from Number Nine Technologies. At this rate, each screen sweep was 6.67 ms, which is acceptable for refined masking procedures. Stimuli were dark on a light background so that speed of offset for any stimulus was dependent on the rise time of the phosphor, which is essentially instantaneous. For masking procedures, speed of stimulus offset is critical because a slow offset constitutes persistence in presentation that would confound and possibly obscure persistence of the neural response.

Critical stimulus intensity (CSI)

Masking can be conducted with threshold, or supra-threshold, target stimuli. A thresholding procedure tries to equate subjects on initial (unmasked) target identification, whereas a supra-threshold target is one target setting that all participants can identify in the absence of a mask. Use of a supra-threshold target in schizophrenia masking research makes it difficult to interpret patient-control differences; group differences with such a task could be true masking deficits or subtle differences in initial (unmasked) target detection. Hence it is advantageous to set the target to an individual's threshold.

One common way to set target threshold is to increase the duration of a target gradually until the participant obtains a certain number of consecutive correct responses. However, because target duration is always increased when an error is made, momentary lapses in attention (which may be more common in patient groups) would yield a threshold value that is artificially high (Badcock et al., 1988). Thus, it is helpful to use a staircase procedure in which values are moved both up and down.

Manipulating target duration, however, creates another problem. Intervals between target and mask are typically measured by stimulus onset asynchronies (SOAs) (the interval from *onset* of the first stimulus) or interstimulus intervals (ISIs, the interval from the *offset* of the first stimulus). There is no consensus in the literature as to which of these parameters is best to use (Breitmeyer and Ogmen, 2000). If target duration differs across subjects, then ISIs and SOAs cannot both be held constant across subjects. Thus, we developed a procedure that keeps the target duration constant and manipulates grey scale values to determine each

subject's critical stimulus intensity (CSI) for a target. The constant target duration allows SOAs and ISIs that are standardized across subjects.

To determine the CSI, the duration of the target was set at two screen sweeps (13 ms). Grey scale values were selected in a linear range of the grey scale. Using an up-down-transformed-response method, contrast of the target was gradually increased or decreased by adjusting the grey scale value based on subject's performance (Wetherill and Levitt, 1965). The value was decreased for every four consecutive correct responses and increased for every incorrect response. A 'reversal' occurred when the grey scale values went from decreasing to increasing, or vice versa. The grey scale value that is the average of six 'reversals' yields performance of about 84% accuracy. This contrast level was the subject's CSI and was used for all subsequent stimuli. Subjects who could not identify the target at the darkest grey-scale value were considered untestable.

Interspersed unmasked trials

Although the CSI procedure yields a grey-scale value at which all subjects are performing at 84% accuracy, there could be fatigue or practice effects within a session, which could differ between groups. To monitor this possibility, 12 unmasked trials were randomly interspersed within each of the masking conditions.

Stimuli and procedures

A fixation symbol (a small cross) was presented for a duration of 300 ms, starting 400 ms prior to each target onset. The target was a square with a gap on one side (see Figure 1). The gap could appear at the top, the bottom, or on the left side. Targets could appear at any one of four corners of a notional square centred at fixation (upper left, upper right, lower left, lower right).

All subjects were screened for visual acuity prior to testing to ensure that they had corrected acuity of at least 20/30. Subjects were seated one meter from the screen. For identification tasks, subjects indicated the direction that the gap was facing by saying 'up', 'down' or 'side' and then an experimenter entered the response on a keyboard. We chose to have subjects verbalize instead of manually enter their responses to minimize any possible mistakes or confusion that could contribute to patient/control differences. A target with a gap on the right side was not included to avoid creating a right versus left decision, and to minimize resemblance to actual letters (such as 'C' or 'G').

For the location task, subjects indicated the target position by stating the corresponding number of the quadrant. The quadrants were numbered clockwise with numbers displayed on the rim of the monitor, so participants did not need to memorize them. Targets were always shown for two screen sweeps (13 ms). The mask was a composite square made up of four smaller squares. One of these composite squares appeared at each of the four possible target locations and overlapped the area occupied by the target (Figure 1). Each target location was 1.03 degrees of visual angle from fixation and each target subtended 0.27 degrees of visual angle. Background luminance measured with a hand-held meter with diffuser against the screen was lux = 89.

Figure 1. Example of target and mask. The target was a square with a gap at the top, bottom, or left that could appear at any one of four locations. The mask consisted of boxes that covered all possible target locations.

Backward and forward masking conditions

Target location with high-energy mask

In this condition, subjects did not need to identify the target; instead they indicated where the target appeared. This task is thought to rely more on transient visual channels and less on sustained ones. It should generate a monotonic masking function in which performance gradually increases as intervals move away from an SOA of 0. Masking in this condition involves both integration (sustained channels summing together and transient channels summing together) and interruption (transient channel activity inhibiting sustained channel activity) masking mechanisms. The *energy* of the mask was twice that of the target (four screen sweeps for the mask; two for the target). 'Energy' in this context refers to light intensity times the duration of a stimulus.

Target identification with high-energy mask

Subjects identified a target while the mask energy was greater than that of the target. This condition typically generates a monotonic masking function. The energy of the mask was twice that of the target (four screen sweeps for the mask; two for the target).

Target identification with low-energy mask

Subjects identified a target when the mask energy was less than that of the target. A low-energy mask typically generates a non-monotonic masking function in the backward masking component: an initial decrease in performance followed by an increase (a U-shaped function). This type of procedure involves masking primarily by interruption. The mask energy was half the energy of the target (one screen sweep for the mask; two for the target).

For all three masking conditions, 12 trials were presented for each SOA (three targets times four locations). For the location condition, the SOAs ran from -80 to $+80$ ms in 13.3 ms increments (two screen sweeps) and included interspersed unmasked trials. Negative SOAs indicate forward masking; positive SOAs, backward masking. We used a slightly broader placement of SOAs for the identification conditions because the slope of these functions tends to be shallower. The two identification conditions (with high- and low-energy masks) have the same SOAs as the location condition from -80 to $+80$, and in addition, have forward and backward masking intervals at -120 ms and $+120$ ms, respectively.

Figure 2 shows the results from a group of 48 normal controls for each of the three masking conditions. The participants were recruited from flyers placed around the UCLA campus and the VA Greater Los Angeles Healthcare System. All of the participants gave written informed consent after the procedures were explained. Consenting procedures and forms were approved by the appropriate human subject committees at the VA and

UCLA. Average age was 36.7 years and average educational level was 13.3 years. Seven of the normal controls (15%) could not complete the CSI procedure, so data are presented for 41 subjects (19 males).

The shapes of the masking functions across conditions fit the expected pattern. The location and high-energy identification conditions are monotonic with near chance performance at 0 SOA and maximal performance at the longest intervals. The low-energy condition is U-shaped in the backward masking component (right side) with lowest performance at an SOA of 27 ms. Performance for the interspersed unmasked trials was relatively high (97.6, 83.5, and 81.9, for target location, high-energy masking, and low-energy masking, respectively), indicating that fatigue was not a major factor during the course of testing.

Performance on perceptual tests often decreases with age and we found significant associations (all p values <0.05) for two of the masking conditions: target location ($r = -0.41$ and -0.48) and target identification with a high-energy mask (-0.34 , -0.38 , for forward and backward masking, respectively). Correlations with age for low-energy mask condition were in the same direction (-13 , -29) and were non-significant.

Reliability

Reliability coefficients (alpha) were determined for each masking condition separately for forward and backward masking trials (see Table 1). For these calculations, the forward and backward masking trials were summed, and trials at SOA = 0 were not used. The values indicate excellent reliability across conditions, with roughly equivalent reliability for forward and backward masking.

Modifications to the existing program

Based on these findings we have recently upgraded the software to address some limitations of these visual masking procedures and to increase ease of distribution. Some of the participants (7/48 or 15%) could not

Table 1. Coefficient alpha values for visual masking conditions

Visual masking condition	Forward masking	Backward masking
Target location	0.877	0.876
Target identification with a high-energy mask	0.752	0.802
Target identification with a low-energy mask	0.850	0.852

Figure 2. Performance on three masking conditions. Performance is shown on the x axis (higher is better) and SOAs are listed on the y axis. The negative numbers on the left show forward masking, positive numbers of the right show backward masking. Chance performance is 25% for the location condition and 33% for the other two conditions.

achieve a reliable threshold during the CSI procedure. In other words, they did not see the target sufficiently well, even with the grey scale at its darkest setting. Age seemed to be a factor: subjects who could not reliably

detect the target tended to be older than those who could. The newer version has a longer target duration for the CSI (25 ms) to address this issue. In addition, the previous program was limited because it relied on a

particular graphics card (from Number Nine Technologies) and it ran in DOS. The upgraded programme runs on multiple graphics cards that are generally available, and it runs in a Windows environment.

Summary

Visual masking procedures provide a highly informative way to assess early visual processing and they have been frequently used in experimental psychopathology. Research with visual masking procedures in psychopathology have been limited by difficulties with standardization across sites because most of the work has been conducted with tachistoscopes. We presented a description of a computerized visual masking battery that includes:

- a staircase CSI procedure to establish an individual's threshold;
- three different masking conditions;
- relatively dense sampling of the SOAs (most at 13 ms intervals);
- interspersed unmasked trials; and
- both forward and backward masking trials.

In addition, the computerized programme graphs the data for individual subjects and groups (for ongoing validity checks), and stores and reduces the data for subsequent analyses.

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