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BRIEF REPORT

Impact of stimulus signal-to-noise ratio on prepulse inhibition of acoustic startle

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Abstract

Prepulse inhibition (PPI) of the human acoustic startle response is reduced in the presence of background noise of a sufficient intensity, possibly due to a reduction in signal-to-noise ratio (prepulse intensity relative to background noise). We examined this hypothesis by varying prepulse intensity and background noise intensity in order to hold three different signal-to-noise ratios constant (5, 15, and 25 dB(A) above background noise intensity). The results showed that signal-to-noise ratio proved to be a more important factor than absolute stimulus intensity in determining the degree of PPI of startle eyeblink response magnitude. Therefore, the effectiveness of a prepulse is determined by prepulse salience, not intensity, and this effectiveness is equivalent across a range of physical intensities.

Descriptors: Startle, Eyeblink, Prepulse, PPI, Stimulus intensity, Signal-to-noise ratio

The startle response is a defensive reflex that occurs in reaction to a sufficiently sudden and intense stimulus. In humans, the startle response is most often quantified with electromyography (EMG) of an eyeblink response to an acoustic stimulus (Blumenthal et al., 2005; Yeomans, Li, Scott, & Frankland, 2002). Prepulse inhibition (PPI) of the human acoustic startle response occurs when a stimulus, or prepulse, is presented 15–500 ms before a startle-eliciting stimulus (Blumenthal, 1999; Graham, 1975). PPI may function to protect the processing of the prepulse from interruption by the startle-eliciting stimulus (Graham, 1975).

More intense prepulses generally result in greater PPI (Blumenthal, 1995; Graham & Murray, 1977), and higher background noise intensities result in less PPI (Blumenthal, Noto, Fox, & Franklin, 2006; Flaten, Nordmark, & Elden, 2005; Hsieh, Swerdlow, & Braff, 2006). Background noise is noise that is constant throughout a testing session, and studies have used background noise levels as low as 28 dB(A) (ambient), although the majority of PPI studies use background noise levels between 60 and 75 dB(A) (Blumenthal et al., 2006). The primary reason for a decrease in PPI as background noise increases or prepulse intensity decreases may be due to a decreased signal-to-noise ratio between prepulse intensity and background noise intensity. Presumably, a decreased signal-to-noise ratio interferes with the processing of the prepulse, and, therefore, activation of the inhibitory mechanism is reduced. This is caused by an increase in the peripheral masking of the prepulse by the background noise.

Previous studies have investigated the effect of signal-to-noise ratio by varying either background noise intensity or prepulse intensity. However, the three parameters of background noise intensity, prepulse intensity, and signal-to-noise ratio have only two degrees of freedom, such that changing any two parameters determines the third. Although previous literature has attributed effects of background noise intensity to a change in signal-to-noise ratio, it is possible that the same signal-to-noise ratio may have varying effects at different points on the physical intensity spectrum. To address this possibility in the present study, we held signal-to-noise ratio constant across a range of prepulse and background noise intensities. We used background noise intensities of 50, 60, and 70 dB(A) as the between-groups variable and prepulse intensities that were 5, 15, and 25 dB(A) above each background intensity as the within-participants variable. If PPI is determined by signal-to-noise ratio, then varying prepulse intensity and background noise level together to achieve a range of signal-to-noise ratios should result in variations in PPI. If PPI is determined by stimulus intensity, then variations in prepulse intensity or background noise while holding signal-to-noise ratio constant should affect PPI, independent of signal-to-noise ratio.

The findings of this study will allow a more complete understanding of the impact of stimulus parameters on PPI, which will facilitate comparisons across startle modification studies that use different stimulus values. This should increase our ability to make sense of data obtained in a variety of research settings and from various participant populations.

Methods

Participants

Participants ($N = 55$, 40 men, 15 women, 18–22 years of age) were selected from a group of students earning credit for a

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research participation option. Two other participants were excluded due to equipment problems, and none of the remaining participants had self-reported hearing problems or psychiatric disorders or were using stimulant medication. All procedures were approved by the Institutional Review Board of Wake Forest University.

Stimuli

Startle stimuli were 95 and 105 dB(A) broadband noise (20 Hz–20 KHz), with a 50-ms duration and a rise/fall time of <1 ms. Background noise was 50, 60, and 70 dB(A) broadband noise. Prepulses were broadband noises 5, 15, and 25 dB(A) above each background noise intensity, resulting in prepulse intensities of 55, 65, and 75 dB(A) for the 50-dB(A) background noise intensity condition, 65, 75, and 85 dB(A) for the 60-dB(A) background noise intensity condition, and 75, 85, and 95 dB(A) for the 70-dB(A) background noise condition. Each prepulse had a duration of 40 ms and a rise/fall time of <1 ms.[1] Participants were tested in three groups according to background noise conditions of 50 dB(A) ($N = 18$; 6 women, 12 men), 60 dB(A) ($N = 18$; 3 women, 15 men), and 70 dB(A) ($N = 19$; 6 women, 13 men). All stimuli were generated by Coulbourn S-series noise generators, gated through Coulbourn rise/fall gates, amplified by Coulbourn audio mixer amplifiers, and presented to the participants through Telephonics TDH-39 headphones. Stimulus intensities were calibrated with steady-state signals presented through the headphones and measured with a Quest sound level meter with a fitted earpiece.

Response Measures

Eyeblink EMG responses were measured from the orbicularis oculi by In Vivo Metric surface recording electrodes (Ag/AgCl, 11 mm outer diameter, 4 mm inner diameter contact surface) placed below the left eye. EMG activity of this muscle was amplified with a Biopac EMG amplifier and sampled (1000 Hz) by a Biopac MP150 workstation, filtered online with a passband of 28–500 Hz, rectified, and then smoothed (five-sample boxcar filter).

Procedure

Participants were seated in a sound-attenuated room where they read and signed an informed consent form and filled out a brief medical history questionnaire. After cleaning the skin with a cotton swab dipped in rubbing alcohol, surface recording electrodes filled with Synapse conducting paste were placed on the skin overlaying the orbicularis oculi, one directly below the pupil (but below the lower eyelid) and the other approximately 15 mm (center to center) lateral to and slightly higher than the first. The ground electrode was placed on the skin overlaying the left temple. Headphones were then comfortably placed on the participant.

Six test trials of 95 dB(A) stimuli were then presented (these trials were not included in the data analysis), immediately followed by the onset of background noise, which remained on throughout the session, at 50, 60, or 70 dB(A), depending on group. Five minutes after background noise onset, 64 startle trials were presented in eight blocks of eight trials each, with each block including four trials of 95-dB(A) and four trials of 105-dB(A) startle stimuli, both presented alone or preceded at a 120-ms lead interval (onset to onset) by a prepulse that was 5, 15, or 25 dB(A) above the background noise level, in random order. Intertrial intervals ranged from 15 to 25 s.

Data Analysis

The dependent variable in this study was eyeblink EMG response magnitude, the difference between peak and onset voltage of the smoothed EMG signal, within a window of 20–150 ms after stimulus onset, for all trials on which a response could have been detected. These data were averaged within each stimulus condition (not including the 3.7% of trials contaminated by artifact), with trials on which no response was seen assigned a magnitude of zero. PPI of response magnitude was calculated as the proportion of the difference from control ((prepulse condition − control condition)/control condition), as recommended by Blumenthal, Elden, and Flaten (2004). Within each stimulus condition, the 95% confidence interval of deviation from control condition reactivity (startle stimulus alone) was calculated, and PPI was said to be present if the particular cell in the design matrix did not include zero. ANOVA were conducted on startle response magnitude recorded on control (no prepulse) trials, with background noise intensity (50, 60, and 70 dB(A)) serving as the between-participants variable and startle stimulus intensity (95 and 105 dB(A)) serving as the within-participants variable. ANOVA were also conducted on the PPI of startle response magnitude, with background noise intensities (50, 60, and 70 dB(A)) as the between-participants variable and startle stimulus intensity (95 and 105 dB(A)) and signal-to-noise ratio (5, 15, and 25 dB(A) above background noise intensities) as the within-participants variables. Greenhouse–Geisser degrees of freedom were used to evaluate significance, but uncorrected degrees of freedom are reported.

Results

The 105-dB(A) startle stimulus elicited responses that were larger than those to the 95-dB(A) eliciting stimulus (means = 233.40 and 101.50 μV, respectively, $F[1,52] = 64.65$, $p < .001$). No significant effects of background noise intensity were found on control startle reactivity.

For PPI of startle response magnitude, there was a main effect of signal-to-noise ratio, $F(2,104) = 45.36$, $p < .001$, $\varepsilon = .850$, and this effect was quadratic, $F(1,52) = 10.88$, $p < .01$ (see Figure 1), with average PPI of 54.50%, 74.30%, and 81.10% for signal-to-noise ratios of +5, +15, and +25, respectively. Background noise had no effect on PPI, either as a main effect or in any interaction, all Fs < 2.26, all ps $> .09$.

Discussion

For responses to startle stimuli on control trials, reactivity was greater to the 105-dB(A) startle stimulus, but there were no effects of background noise intensity. This agrees with the findings of Blumenthal et al. (2006), who found that control startle reactivity increased as background noise intensity increased from 30 to 50 dB(A), but further increase to 70 dB(A) had no further effect. For PPI of startle responses, increased signal-to-noise

[1]The majority of studies in which startle and PPI are used to investigate clinical samples do not control the rise time of the prepulse, such that this rise time is less than 1 ms, as in the present study. Although a fast-rising prepulse can increase the probability of eyeblinks being elicited by the prepulse, the degree of PPI is generally not affected by rise time differences below 10 ms (Reilly & Hammond, 2001).

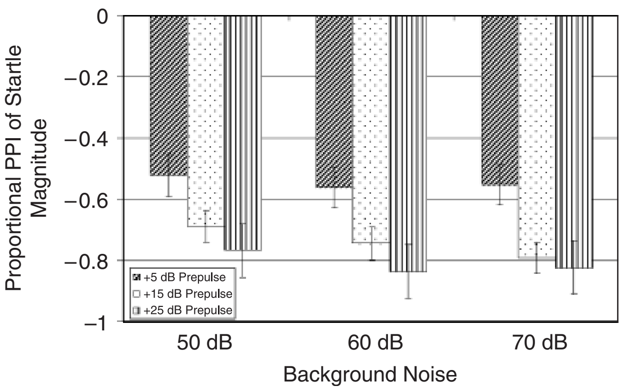

Figure 1. Prepulse inhibition of startle eyeblink magnitude (bars = *SEM*).

ratio led to greater inhibition of startle magnitude, although this inhibition was unaffected by background noise intensity.

The advantage of stimuli with a high signal-to-noise ratio compared to those with a low signal-to-noise ratio may be due to a number of factors. The simplest explanation involves the occurrence of sensory masking in the auditory periphery, with this masking being more pronounced at low signal-to-noise ratios (Durant & Lovrinic, 1984). Many previous studies have found an effect of stimulus intensity on startle response magnitude inhibition, but those studies have usually confounded stimulus intensity and signal-to-noise ratio, by varying stimulus intensity while holding background noise intensity constant. By separately manipulating these parameters in the present study, we find that signal-to-noise ratio, not stimulus intensity itself, is the crucial parameter in determining PPI.

It is important to note that this study and the previous studies that have varied prepulse and background noise intensities have generally been interested in the physical intensities of these stimuli, not in the psychophysical effectiveness of the stimuli. That is, signal-to-noise ratio as used here is based on the physics of sound, measured in decibels of sound pressure level. Therefore, a given decibel difference yields the same signal-to-noise ratio no matter what the baseline "noise" level (background noise intensity, in these studies). If one instead measures the psychophysical impact of a stimulus, by requiring the participant to assign magnitude estimations of loudness to each stimulus, the linearity of signal-to-noise ratios across background noise levels might not hold (Gescheider, 1997). However, in this and previous studies (Blumenthal et al., 2006; Flaten et al., 2005; Hsieh et al., 2005), the physiological impact of the stimulus combinations is measured, without the inclusion of a psychophysical judgment, under the assumption that the degree of PPI is determined by the physical parameters of the stimuli involved, acting on the underlying neurological substrates. Although prepulses have been shown to affect psychophysical judgments (Swerdlow, Geyer, Blumenthal, & Hartman, 1999), psychophysical data were not collected in the present study.

The present study suggests that it is not stimulus intensity per se that determines PPI; it is prepulse salience, which varies with signal-to-noise ratio. Equally intense prepulses presented over different background noise intensities differ in signal-to-noise ratio and, therefore, differ in salience. The present study shows that the effectiveness of a prepulse is determined by salience, not intensity, and that this effectiveness is equivalent across a range of physical intensities. One logical next step in this line of research involves testing these signal-to-noise ratio findings in the context of directed attention, to determine whether an attentional effect would enhance the strength of the "signal" or decrease the impact of the "noise." Another extension of this work would involve conducting similar studies with clinical patients, because background noise and reduced signal-to-noise ratio may interfere with PPI to a greater extent in schizophrenia patients than in clinical control participants (Blumenthal et al., 2006; Wynn et al., 2004).

The stimulus intensities used in the present study span the range of prepulse and background noise intensities usually found in studies of acoustic startle modification. The finding that PPI is more sensitive to signal-to-noise ratio than to either prepulse intensity or background noise intensity may facilitate comparisons across studies using different stimulus parameters. That is, variations in stimulus intensities across studies may not jeopardize our ability to compare the outcomes of those studies, to the extent that signal-to-noise ratio is the same across these experiments. However, variations in signal-to-noise ratio may hinder comparisons even when prepulse intensity is the same across studies, if background noise intensity is not also considered. The present study suggests that comparability across studies must take signal-to-noise ratio into consideration.

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