Effects of perceptual load on startle reflex modification at a long lead interval

GARY L. THORNE, MICHAEL E. DAWSON, AND ANNE M. SCHELL

Abstract

Inhibition of the startle eyeblink response at long lead intervals has been hypothesized to occur when attention is directed away from the modality of the startle stimulus, particularly if attention is directed to a stimulus of high perceptual load. In a test of this hypothesis, participants performed a delayed-matching-to-sample task. On each trial a pattern of dots (the sample) was followed by a second pattern of dots (the target). The task was to say whether the sample and target patterns matched. Perceptual load was manipulated by varying the number of dots in the sample. Auditory startle stimuli were presented 1200 ms after onset of the samples. A linear increase in startle magnitude was found as the number of dots increased. The results are not consistent with the hypothesis that startle inhibition occurs when the lead and startle stimuli are in different modalities under conditions of high perceptual load.

Descriptors: Startle eyeblink, Attention, Attentional modulation, Task demand, Perceptual load, Arousal

A stimulus with an abrupt onset and sufficient intensity, such as a brief loud burst of white noise, elicits a reflexive startle response. In humans this response is most commonly measured by the magnitude of the eyeblink (for reviews of startle elicitation, recording, and quantification, see Berg & Balaban, 1999; Blumenthal et al., 2005). If the startling stimulus is preceded by a nonstartling stimulus, such as a soft tone, the magnitude of the startle response is modified. The nonstartling stimulus is called a lead stimulus or prepulse and the interval between the onset of the lead and startle stimuli is called a lead interval. The effect of the lead stimulus on startle magnitude depends on the lead interval. At short lead intervals (15–400 ms), the magnitude of the startle response is typically decreased compared to the magnitude of the response without the lead stimulus, a phenomenon called prepulse inhibition (for a review of short lead interval startle modification, see Putnam & Vanman, 1999). At long lead intervals (greater than 800 ms), the magnitude of the startle response is typically increased, although the exact effect may depend on the direction of attention (for a review of long lead interval startle modification, see Putnam & Vanman, 1999). Specifically, it has been proposed that long lead interval startle modification is modality specific. Tasks that require attention to the modality of the startle stimulus are hypothesized to increase (facilitate) startle magnitude, whereas tasks that require attention to a modality other than that of the startle stimulus are hypothesized to decrease (inhibit) startle magnitude (Putnam, 1990).

Numerous studies have reported reliable long lead interval startle facilitation when attention is directed toward the modality of the startle stimulus (e.g., Böhmelt, Schell, & Dawson, 1999; Filion, Dawson, & Schell, 1993; Jennings, Schell, Filion, & Dawson, 1996; Lipp & Hardwick, 2003). Other studies have reported reliable long lead interval startle inhibition when attention is directed away from the modality of the startle stimulus (e.g., Anthony, Butler, & Putnam, 1978; Anthony & Graham, 1985; Hazlett, Dawson, Schell, & Nuechterlein, 2001; Lipp & Neumann, 2004; Neumann, 2002; Putnam & Meiss, 1980; Simons & Zelson, 1985; Zelson & Simons, 1986). Both of these findings are consistent with the modality-specific hypothesis. However, contrary to the modality-specific hypothesis, a large number of studies have reported reliable long lead interval startle facilitation even when attention is directed away from the modality of the startle stimulus (e.g., Böhmelt et al., 1999; Lipp & Hardwick, 2003; Lipp, Siddle, & Dall, 1997, 1998, 2000; Neumann, Lipp, & McHugh, 2004; Vanman, Böhmelt, Dawson, & Schell, 1996). These studies used visual lead stimuli with auditory or tactile startle stimuli and found long lead interval facilitation, with greater facilitation generally during attended task-relevant stimuli than during task-irrelevant stimuli. These studies suggest that startle facilitation will be observed with any attended stimulus, regardless of modality match or mismatch.

We gratefully acknowledge the assistance of William C. Williams for providing computer software for off-line scoring of the eyeblink data and Devon Prewitt for help in data collection.

This research was conducted as part of a doctoral dissertation by G. L. Thorne under the direction of M. E. Dawson. It was supported in part by NIMH grants R01 MH46433 and K02 MH01086 to Michael E. Dawson.

Address reprint requests either to: Michael E. Dawson, Department of Psychology, Seeley G. Mudd Building, Room 501, University of Southern California, Los Angeles, CA, 90089-1061, USA; e-mail: mdawson@usc.edu; or Gary L. Thorne, N5307-5 Argonne Lane, Spokane, WA 99212, USA; e-mail: thorne@usc.edu.
with the startle stimulus. The reasons for the inconsistent cross-modality findings are not yet clear.

Lipp and colleagues proposed that modality-specific startle inhibition might occur only when task demand is high enough to require a strategy of strong localized orienting toward the location and modality of an expected stimulus (Lipp & Hardwick, 2003; Lipp et al., 1998). Neumann et al. (2004, experiment 3) tested this hypothesis using a stimulus duration judgment task in which participants counted the number of longer duration lights of one color (attended lead stimuli) while ignoring lights of a different color (ignored lead stimuli). Task demand was manipulated by altering the difference in the durations of the attended lights. In the low demand condition, the longer duration was 7 s and in the high demand condition the longer duration was 5.2 s, both compared to 5 s standard duration. The eyeblink response to auditory startle stimuli at lead intervals of 3.5 and 4.5 s was larger for attended than ignored lead stimuli; however, there was no reliable effect of task demand. Startle response magnitude was facilitated relative to the intertrial interval baseline for both attended and ignored lead stimuli in both task demand conditions, with facilitation apparently being highly significant for the attended stimuli (see Figure 3 of Neumann et al., 2004). Neumann et al. concluded that the results did not support the hypothesis that increased task demand in cross-modality conditions will elicit a decrease in startle response. They noted, however, that their procedure increased task demand by increasing cognitive demand, and hypothesized that it might be necessary to increase task demand by increasing perceptual load (e.g., Lavie, 1995; Lavie & Tsal, 1994) in order to obtain cross-modality startle inhibition.

Perceptual load refers to the complexity of the operations required for stimulus identification by a limited capacity early stage of perceptual processing (Lavie & De Fockert, 2003). Perceptual load is most commonly defined operationally in terms of display set size, the number of independent visual objects that must be perceptually processed in order to perform a task (Lavie & Tsal, 1994). Perceptual load is low when set size is small and perceptual load is high when set size is large. Low perceptual load tasks are hypothesized to use only part of available early perceptual processing capacity; therefore, all stimuli, including task-irrelevant stimuli, are processed, and selection occurs at a later cognitive stage. In contrast, high perceptual load tasks are hypothesized to exceed available early perceptual processing capacity; therefore, selection must occur at an early stage and only task-relevant stimuli are processed. Lavie and colleagues have accumulated a substantial body of research consistent with this hypothesis.

The purpose of the present experiment was to test the Neumann et al. (2004) hypothesis that high task demand, specifically high perceptual load, will elicit cross-modality startle inhibition. We investigated the effect of four levels of perceptual load on long lead interval cross-modality startle modification in a within-subjects design. We used a visual delayed-matching-to-sample task in which subjects reported whether the pattern of dots in a target display matched the pattern of dots in a previous sample display. We manipulated perceptual load by varying set size, the numbers of dots in the displays. On some trials an auditory startle stimulus was presented 1200 ms following onset of the sample displays. If the hypothesis that long lead interval cross-modality startle inhibition requires high perceptual load is correct, we expected to obtain progressively decreasing response to auditory startle stimuli as the number of dots increased, and to observe startle inhibition relative to unmodified baseline at the highest levels of perceptual load.

Method

Participants
Participants were 61 volunteers (48 women and 13 men) from undergraduate psychology classes at the University of Southern California who received course credit for participation. There were no a priori selection criteria. All participants were informed about the experiment and signed consent forms before participating. Research procedures and methods of obtaining informed consent were approved by the University of Southern California Institutional Review Board. The data for 4 participants were excluded from analysis due to technical problems during collection. The data for 3 participants were excluded because their baseline startle responses were too small (median baseline response less than 1 μV) for dependable assessment of startle modification. This left a final sample of 54 participants (46 women and 8 men) with usable data.

Stimuli and Timing
The visual stimuli and the sequence of presentation are illustrated in Figure 1. All stimuli were presented against a dark gray back-
on ground (luminance 5.76 cd/m²) on a computer monitor positioned 1 m in front of the participant.

On each trial, there was a sequence of six stimulus displays. The first display, the cue display, presented a number in light gray (luminance 122.3 cd/m²), indicating the number of dots in the upcoming sample and target. Thus, the cue display allowed participants to anticipate the difficulty of the upcoming trial. The second display, the warning display, consisted of 45 middle-gray dots (luminance 43.65 cd/m²) in a tight circular cluster subtending a visual angle of about 5°. The third display, the sample display, was identical to the warning display except that the dots representing the sample were presented in a lighter gray tone (luminance 122.3 cd/m²). Perceptual load was manipulated by varying the number of lighter gray dots in the sample. There were 3 dots in the low load condition, 6 dots in the medium-low load condition, 9 dots in the medium-high load condition, and 12 dots in the high load condition. The numbers of dots were determined by pilot work to obtain a mean accuracy of about 90% in the low load condition and about 55%, slightly better than chance, in the high load condition.

The fourth display, the delay display, was identical to the warning display. The fifth display, the target display, consisted of a cluster of the same number of dots presented at the same luminance as in the sample. On one-half of the trials, the pattern in the sample was altered by moving one of the dots to a different position. The final display, the response display (not shown in Figure 1), consisted of the dark gray background without any dots. During the response display participants reported whether the pattern of dots in the target display was the same as, or different from, the pattern of dots in the sample display. As shown in Figure 1, warning displays were presented for 500 ms, sample displays were presented for 3000 ms, delay displays were presented for 1000 ms, target displays were presented for 500 ms, and response displays were presented for 2000 ms.

Startle stimuli (50-ms bursts of 105 dBA white noise with a nearly instantaneous rise time) were presented 1200 ms after the onset of the sample display on half of the trials in each condition. Thus, startle response was measured during the interval when participants were processing the pattern of dots needed to perform the task.

Intertrial intervals, during which the cue display for the next trial was presented continuously, were 6 s in duration without, and 12 s in duration with, a baseline startle stimulus. Startle stimuli used to measure baseline (unmodified by task performance) response were presented on randomly chosen trials at the midpoints of the 12-s intertrial intervals.

**Measurement of Dependent Variables**

The startle eyeblink reflex was measured by the magnitude of the electromyographic (EMG) response of the orbicularis oculi muscle, which controls the movement of the eyelid. This response was recorded from two miniature (4 mm) silver-silver chloride (Ag-AgCl) electrodes placed below the lower eyelid of the left eye and one large (8 mm) Ag-AgCl electrode placed behind the left ear for the common connection. Skin preparation and electrode attachment followed standard procedures to obtain an impedance of not more than 10 kΩ, preferably less than 5 kΩ. The EMG signal was amplified, filtered (low-pass 500 Hz, high-pass 10 Hz), digitally sampled at 1000 Hz, and stored on a computer by Contact Precision Instruments equipment and software. The same equipment and software also controlled stimulus presentation and timing.

**Procedure**

There were four phases in this experiment. In the first phase, participants read and signed the consent form and listened to recorded instructions regarding electrode placements and the need to avoid unnecessary movement. In the second phase, the experimenter attached the electrodes for recording EMG and checked impedances. In the third phase, participants listened to additional recorded instructions describing the task, watched a demonstration of the task, and performed a series of 12 practice trials, including 2 startle stimuli. Participants were instructed to compare the pattern of dots in the samples and targets and to say “same” if the patterns were the same and “different” if the patterns were different. In the fourth phase, the experiment proper was conducted, which ran continuously without breaks until completed.

As an incentive for good performance, participants were paid a $5.00 reward if they made no more than 15 wrong judgments or a $3.00 reward if they made no more than 20 wrong judgments on the task. Participants who made more than 20 wrong judgments were not paid. All participants received course credit regardless of performance.

There were six sets of eight trials per set. Within each set, there were two trials at each of the four levels of perceptual load in random order. One trial at each level of perceptual load was probed with a startle stimulus during each set. Two additional startle stimuli were presented randomly between trials in each set. Thus, there were a total of 48 trials and 36 startle stimuli.

**Data Scoring, Reduction, and Analysis**

The recorded EMG data were scored off-line by a computer program that digitally integrated the raw EMG data at a 10-ms time constant and calculated a startle amplitude score for each trial in which blink onset occurred within 21–120 ms of startle stimulus onset and peak magnitude occurred within 150 ms of blink onset. Scores for trials with an unstable prestimulus EMG baseline were replaced with the score for the nearest trial in the same condition. A total of five scores in the entire data set were replaced. Scores of zero were not replaced. The median of the baseline magnitude scores was computed for each participant as a measure of baseline startle response and was used to compute percentage change scores for each trial using the following formula: Percentage change = [(Magnitude during task − Median baseline)/Median baseline] × 100.

Using this formula, positive percentage change scores indicate startle facilitation and negative percentage change scores indicate startle inhibition. The median of the individual percentage change scores was computed for each participant, for each condition. Medians were used for these calculations because they are robust, unaffected by extreme scores (for a discussion of robust statistics, see Wilcox, 2005). The analyses described below were performed using these medians. Means of the median scores were computed by condition across all participants for descriptive purposes, and medians for each condition for each participant were used in the statistical analysis.

Overall statistical analyses were performed using linear, quadratic, and cubic contrasts. Specific comparisons were performed using t tests. An alpha level of .05 was used for all statistical analyses. For each specific comparison, an estimate of effect size (δ, Cohen, 1988) was also computed.

**Results**

Mean baseline startle response was 14.32 μV and maximum baseline startle response was 88.04 μV. Because baseline startle
stimuli were presented during the visual cue displays, and because visual stimuli and their anticipation are known to suppress endogenous activity of the orbicularis oculi muscle (e.g., Bernstein, Taylor, Weinstein, & Riedel, 1985; Goldstein, Bauer, & Stern, 1992; Van Boxtel, Damen, & Brunia, 1996), we compared the mean absolute EMG amplitude for the 500-ms segment prior to the baseline startle stimulus to an identical 500 segments in each task condition. There were no reliable differences between the baseline EMG mean during the ITI and the means prior to the 3-, 6-, 9-, and 12-dot conditions, nor were there reliable differences between the different dot conditions. Thus, any differential startle reactivity under the different experimental conditions cannot be due to differences in ongoing EMG activity at the time of the startle stimulus.

**Accuracy**

The accuracy data revealed the expected decrease in accuracy as the number of dots increased (see Figure 2A). Accuracy was reliably greater than chance in the 3-dot, $t(53) = 27.77$, $p < .001$, $d = 3.78$, 6-dot, $t(53) = 8.47$, $p < .001$, $d = 1.15$, and 9-dot, $t(53) = 5.50$, $p < .001$, $d = .75$, but not the 12-dot, $t(53) = 1.14$, $p > .20$, $d = .15$, conditions. The linear trend was statistically reliable, $F(1,53) = 272.43$, $p < .001$. Accuracy for trials during the first half of the experiment did not differ from accuracy for trials during the second half of the experiment for any condition, all $t$s < 1.5, all $p$s > .10.

**Startle Modification**

The startle modification data revealed an increase in startle magnitude as the number of dots increased (see Figure 2B). Startle magnitude was reliably greater than baseline in the 12-dot, $t(53) = 2.85$, $p < .01$, $d = .39$, 9-dot, $t(53) = 2.74$, $p < .01$, $d = .37$, and the 6-dot, $t(53) = 2.13$, $p < .05$, $d = .29$, but not the 3-dot, $t(53) = 0.73$, $p > .40$, $d = .10$, conditions. The linear trend, $F(1,53) = 9.31$, $p < .005$, but not the quadratic, $F(1,53) = 2.29$, $p > .10$, and cubic, $F(1,53) = .08$, $p > .70$, trends, was statistically reliable.

**Discussion**

The accuracy results are consistent with the conclusion that task demand, manipulated by perceptual load, increased as the number of dots increased. The startle modification results are consistent with the conclusion that, in this procedure, cross-modality startle response at a long 1200-ms lead interval increases as perceptual load increases, rather than decreases as predicted.

The startle modification results are not consistent with the modality-specific hypothesis prediction of startle inhibition for cross-modality procedures (Putnam, 1990). Startle facilitation above baseline was statistically reliable in the 6-, 9-, and 12-dot conditions. There was no evidence of startle inhibition at any level of perceptual load.

The startle modification results are also not consistent with the hypothesis that high perceptual load will elicit long lead interval cross-modality startle inhibition (Neumann et al., 2004). Contrary to this hypothesis, progressive increases in perceptual load elicited progressive increases, instead of decreases, in startle response. There was a slight decrease in mean startle magnitude between the 9-dot and 12-dot conditions, but this was not statistically reliable. It might be argued that this decrease represents the start of a progressive decrease in startle facilitation, which would, with additional increases in perceptual load, lead to startle inhibition; however, this seems unlikely. Accuracy in the 12-dot condition was not reliably above chance, which indicates that the task had become essentially impossible.

We suggest that increasing perceptual load in the present experiment, which would have increased task demand, might have also increased arousal, which in turn might have elicited an increase in startle response above that in the baseline condition. Increased task demand is known to increase nonspecific arousal in a variety of tasks (Kahneman, Tursky, Shapiro, & Crider, 1968; Kramer & Weber, 2000). Graham (1975) suggested that increased arousal facilitates the startle response at long lead intervals. In the present experiment participants were able to anticipate the number of dots, therefore the difficulty, of each upcoming trial from the numbers in cue displays. Thus, the easy conditions (few dots) might have elicited less arousal and a smaller startle response, and the difficult conditions (more dots) might have elicited more arousal and a larger startle response. Therefore, in this discrete trial paradigm, the effects of increasing perceptual load may have been offset by the effects of increased arousal. The task in the 12-dot condition was so difficult that at least some participants might not have tried as hard as they did when the task was less difficult; therefore, arousal might have declined slightly.

Most cross-modality studies, including the present one, have attempted to increase focused attention by increasing task demand; however, increased task demand is also likely to increase arousal, which facilitates the startle response. Thus, task difficulty manipulations may elicit an effect opposite to that intended. This is consistent with the finding that, in the present study, startle response decreased as task demand, due to perceptual load, decreased and was not reliably different from baseline in the
easiest (3-dot) condition, which presumably elicited the lowest level of arousal.

It is unlikely that the results of the present experiment can be attributed to differential memory load across the task conditions. In the present experiment, startle stimuli were presented shortly after sample display onset while the sample displays were still visible; therefore, participants did not have to maintain the patterns of dots in memory without reference to an actual stimulus at the time the startle stimulus was presented.

Vigilance tasks in which participants must maintain constant attention, either because the task is continuous (e.g., Neumann, 2002) or because of a fast pace of discrete trial stimuli (e.g., Hazlett et al., 2001), may be qualitatively different in their effect on startle than tasks with discrete trials with slower pacing. We are aware of five studies that investigated the effect of continuous or fast-paced visual tasks on the startle response to auditory stimuli (Hazlett et al., 2001; Lipp & Neumann, 2004; Neumann, 2002; Rissling, Dawson, Schell, & Nuechterlein, 2005; Zelson & Simons, 1986). All of these studies obtained long lead interval cross-modality startle inhibition. These results are consistent with the suggestion that long lead interval startle modification is modality specific during sustained continuous tasks and fast-paced discrete trial tasks, but not slow-paced discrete trial tasks, which is consistent with the suggestion of Lipp, Neumann, Pretorius, and McHugh (2003) and the results of Lipp and Neumann (2004).

The results of the present experiment are consistent with the hypothesis that, during a discrete trial task, long lead interval startle modification is affected by perceptual load but, contrary to Neumann et al. (2004), the effect is facilitatory rather than inhibitory. Our results are consistent with previous findings that long lead interval startle magnitude is facilitated during discrete trial procedures when the lead and startle stimuli are in different modalities. However, long lead interval cross-modality startle inhibition may increase as perceptual load increases in continuous or fast-paced performance tasks when early selection is more critical for task performance.

REFERENCES


(RECEIVED NOVEMBER 27, 2005; ACCEPTED APRIL 3, 2006)