Attentional modulation of short- and long-lead-interval modification of the acoustic startle eyeblink response: comparing auditory and visual prestimuli

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Abstract

Studies in our laboratory have shown that modification of startle by lead stimuli with short- and long-lead-intervals is modulated by stimulus significance. The significant stimulus in a tone duration judgement task generates enhanced short-lead-interval startle inhibition as well as pronounced long-lead-interval startle facilitation. The present study was designed to compare tones with simple visual stimuli as lead stimuli in a counterbalanced within-subjects design (Experiment I) or between-subjects design (Experiment II). The results show that auditory compared to visual lead stimuli generate more short-lead-interval inhibition but comparable amounts of long-lead-interval startle facilitation, which was significantly enhanced on to-be-attended trials independent of sensory modality. The attentional manipulation did not yield short-lead-interval effects in Experiment I, but previously reported attention effects were replicated in Experiment II. The results suggest early modality effects on startle modification, reflected by the differing levels of inhibition. Late effects of both modality and attention, however, seem to reflect a sensory modality independent process in startle modification.

Keywords: Startle eyeblink reflex; Attention; Sensory modality; Auditory; Visual

1. Introduction

The purpose of the present study was to test the sensory modality specificity of the attentional modulation of short-lead-interval inhibition and long-lead-interval facilitation of acoustic startle. Whereas previous studies that reported effects of attentional variations have exclusively used auditory lead stimuli (e.g., Filion et al., 1993, 1994) or visual stimuli (DelPezzo and Hoffman, 1980; Vanman et al., 1996), the present study tested both auditory and visual lead stimuli to extend the scope of these findings and to enhance our under-
standing of the effects of visual stimuli as lead stimuli in startle modification.

Short-lead-interval inhibition and long-lead-interval facilitation of startle were discovered as basic phenomena in animals by Hoffman and Fleshler (1963) and were reexamined in humans by Graham (1975, 1980). In general, startle modification research in humans is based on the reliable observation that the amplitude of the eyelink component of the startle reflex can be modified by presentation of a non-startling stimulus prior to the presentation of a startle eliciting stimulus (see Graham, 1980; Hoffman and Ison, 1980; Filion et al., 1998 for reviews). The phenomenon of lead stimulus modification of startle varies with a variety of experimental variables, e.g. the duration of the lead interval, which is defined as the time between the onset of the lead stimulus and the onset of the startle eliciting stimulus, and the sensory modalities of lead and startle eliciting stimuli (see Dawson et al., in press, chapter 1 for a review of startle modification paradigms). In most experimental paradigms, short-lead-intervals up to approximately 500 ms coincide with inhibition of the startle reflex. Effects obtained in studies that use extended lead intervals are bidirectional. Depending on the affective content of the lead stimuli (see Lang et al., 1990, for a review) or the direction of attention startle can either be inhibited or facilitated. Whereas affective effects in startle modification have been shown to be extraordinarily robust and reliable, sensory modality effects have been investigated less extensively. According to Putnam (1990), long-lead-interval startle facilitation is observed when sensory modalities match, whereas inhibition occurs when the modalities of the lead and the startle eliciting stimulus mismatch (e.g., Anthony et al., 1978; Anthony and Putnam, 1980; Putnam and Meiss, 1980, 1981; Silverstein et al., 1981). Modality effects are explained by sensory pathway enhancement. According to this view, the lead stimulus directs attention to its modality of presentation, thus enhances input in the same modality and inhibits input from other modalities (e.g. Silverstein et al., 1981; Putnam, 1990).

A series of five independent studies from our laboratory (Dawson et al., 1993; Filion et al., 1993, 1994; Schell et al., 1995; Jennings et al., 1996) have shown that both short-lead-interval inhibition and long-lead-interval facilitation of startle can be modulated by attentional variations. Attention was operationalized by a task that involves temporal and auditory discrimination in these studies. High (1200 Hz) and low (800 Hz) pitch 70 dB(A) tones were presented as lead stimuli for the purpose of startle modification for either 5 or 7 s. The participant's task was to count the number of 7-s presentations of the tones of one pitch, which was the ‘to-be-attended’ condition, which required a temporal discrimination. In addition, the participant was instructed to ignore the tones of the other pitch, which constituted the ‘to-be-ignored’ condition. Acoustic startle was elicited 120 or 2000 ms after onset of the continuous tones. The consistent pattern of results obtained in these five studies showed enhanced inhibition of the startle eyelink response to to-be-attended tones compared to to-be-ignored tones with a lead interval of 120 ms. Furthermore, long-lead-interval facilitation as well was enhanced by to-be-attended lead stimuli using lead intervals over 2000 ms.

A study by Vanman et al. (1996) used visual lead stimuli (pictures from the International Affective Picture System, Lang et al., 1988) instead of tones as the temporal discrimination task and startle modification lead stimuli. Two results deviating from the pattern described above were obtained. First, using these complex visual lead stimuli, no short-lead-interval attentional modulation of startle was observed. Second, a significant long-lead-interval effect of attention was obtained. It was found that to-be-attended pictures as lead stimuli enhanced long-lead-interval facilitation of startle compared to to-be-ignored picture lead stimuli. This effect was opposed to the direction predicted by the sensory enhancement hypothesis. The sensory enhancement hypothesis would have predicted that the crossmodal design of the study (i.e. visual lead stimuli, auditory startle eliciting stimuli) would have resulted in less long-lead-interval startle facilitation and that this decrease of facilitation should be pronounced on to-be-attended trials due to an emphasized attentional focus on the visual lead stimulus. In-
stead, the effect obtained was enhanced long-
lead-interval startle facilitation to to-be-attended
lead stimuli, which has previously been inter-
preted as indicating a controlled sustained atten-
tion process (e.g., Filion et al., 1993).

However, the complex pictorial affectively
salient stimuli used by Vanman et al. constitute
lead stimuli that not only differ with respect to
sensory modality from neutral pure tones that
have been used in previous studies, but also differ
in complexity, affective quality and immanent in-
terestingness. Therefore, the present study tested
modulatory effects of affectively neutral and less
complex non-pictorial visual lead stimuli on star-
tle. Those effects were compared to effects of
auditory lead stimuli in two experiments that
compared both types of lead stimuli on a within-
subjects (Experiment I) or between-subjects (Ex-
periment II) basis, which was an explorative com-
parison of designs. The design of the present
experiments, by using both long and short-lead-
intervals, thus also allowed a test of modality
effects on short-lead-interval inhibition of startle
and its attentional modulation.

2. Experiment I

2.1. Methods

2.1.1. Participants

Forty-three students from Psychology classes at
the University of Southern California served as
volunteer participants. Thirty-five students were
female and eight students male. The ethnicity of
the participants was as follows: Twenty-one white,
non-Latino; 11 Asian American; three African
American; seven Latino; and one participant of
other ethnicity. All participants were eligible to
win a monetary bonus of up to US$5 per experi-
mental session depending on their task perform-
ance. All participants received course credit for
their participation.

A total of 30 participants was included in the
statistical analyses. Eleven participants out of the
total of 43 that were tested were excluded for
displaying small or no blink activity on most of
the trials. To determine excessive non-respond-
ing, the following criteria were applied. A re-
sponse was defined as any increase in EMG activ-
ity equal to or exceeding 3 μV within the re-
sponse scoring time window post-startle stimulus
offset. A participant was excluded for the purpose
during the ITIs within each block of 24 trials.
Two further participants were excluded from the
statistical analyses for displaying outlying blink
amplitudes on more than two trials as defined by
exceeding the population means by more than 3
S.D. or its closest neighbor by 2 S.D. This left a
total of 30 participants with usable data.

2.2. Design

The study used a 2 × 2 × 4 × 2 within subjects
design. The first factor consisted of the attentio-
nal instruction lead stimulus to-be-attended vs.
lead stimulus to-be-ignored. The second factor
consisted of the lead stimulus modality auditory
vs. visual. The third factor consisted of four lead
intervals (60, 120, 240 and 4500 ms), and the
fourth factor was two repeated measures for each
of the 16 attend × lead interval × modality condi-
tions. The orders of lead intervals, the modality
of lead stimulus presentation, as well as the order of
attend/ignore instruction trials were counter-
balanced across subjects. A minimum of two par-
ticipants were tested under each of the 16 coun-
terbalanced within subjects conditions.

2.3. Experimental stimuli

The startle stimulus consisted of a 102 dB(A)
white noise that was 50 ms in duration. The white
noise was generated by a Grason-Stadler 901B
noise generator and was gated at a near instanta-
neous rise time. The stimulus was presented bina-
urally through Telephonic TDH49 headphones.

To-be-attended and to-be-ignored slides were
presented by a Kodak Ektaapro model slide pro-
jector. The slides consisted of black and white
zebra patterns in two different spatial orienta-
tions (see Fig. 1). The slides were presented on a
blank, white wall in the center of the participant’s
visual field, 32 inches in front of the participant.
The dimensions of the projected patterns were 9.25 \times 19.5\text{ inches}. Pure 800- and 1200-Hz tones were presented binaurally through headphones at a SPL of 70 dB(A) as the auditory to-be-attended and to-be-ignored lead stimuli.

2.4. Recording and scoring of the blink response

Eyeblink responses were recorded using a GRASS model 7 polygraph. The startle eyeblink was measured as electromyographic activity (EMG) from two miniature electrodes (4 mm in diameter) placed above the orbicularis inferior muscle of the left eye. One electrode was centred below the pupil and the other placed approximately 1 cm laterally on the lower eyelid. EMG was recorded both raw and integrated. The EMG signal was fed into a GRASS 7P3 wide-band integrator preamplifier and a 7DA driver amplifer. The signals were then digitized and eyeblinks were recorded at full wave rectification and integrated at a time constant of 20 ms, with a sampling rate of 2000 Hz from 200 ms before onset to 300 ms post onset of the startle eliciting stimulus. Startle eyeblink amplitudes were scored off-line from raw EMG, using an automated scoring program by Vanman et al. (1996). In this algorithm the amplitude of each response is scored in microvolts as the difference between the mean rectified EMG activity in the 200 ms preceding the onset of the startle stimulus and the mean rectified EMG activity in the 10 ms preceding and following the peak EMG activity following the startle stimulus. The peak of the response is defined as the highest microvolt average taken across three consecutive EMG samples (across a 1.5 consecutive ms time period). The response scoring window is from 21 to 120 ms post startle stimulus offset.

2.5. Procedure

Following attachment of the electrodes, the participant was instructed to relax for 5 m. At the conclusion of this rest period, the experimenter presented three examples of the startle stimulus in order to calibrate the EMG recording equipment. Participants were then presented with audiotaped instructions which informed the subject that the task required them to count the number of slides and tones displayed for a ‘longer than usual’ time, explicitly 7 vs. 5 s. Participants were also instructed to only estimate the duration of lead stimuli of one category per modality, e.g. ‘count the longer than standard high tones and vertical zebra pattern’ and ‘do not count the longer than standard low tones and horizontal zebra pattern’. The participant was then informed that he/she could win a bonus of up to US$5 per session if the counts of ‘longer than standard’ slides and tones during the experiment were correct and that US$1 would be subtracted for each missed count down to a point where no monetary bonus would be awarded. The monetary bonus was awarded in order to increase the salience of the task. After these instructions, the participant was presented with examples of the patterns and the two different tones displayed for the standard
duration of 5 s and the longer than standard duration of 7 s.

The order of the modality and attend instruction trials was mixed, but fixed within 2 × 2 counterbalanced orders. The task phase consisted of two blocks of 24 trials. Block 2 was a repetition of Block 1. Within a block, half of the trials were visual and half of the trials were auditory. Half of the auditory as well as half of the visual trials were to-be-attended. In eight trials within a block of 24 trials no startle probe was presented. The order of these ‘clear’ trials was fixed. The purpose of the clear trials was to reduce the predictability of the startle eliciting noise burst. On the remaining 16 trials, each of the four lead interval conditions 60, 120, 240 and 4500 ms was distributed to the four modality × attention conditions. The timing of the lead intervals was defined as the time from the onset of the high or low pitch tones to the onset of the startle eliciting stimulus. The order of lead intervals was counterbalanced across subjects. The duration of the intertrial intervals varied between 13 s and 46 s, with an average of 28 s. During 14 inter-trial intervals (ITI) within each block, startle stimuli were presented at fixed positions varying between 10 s and 35 s. The response to the first ITI startle probe in block 1 was not included in the data analysis, since previous research has shown that the response to the first startle probe is unusually large in most participants. Responses to the ITI probes served as a baseline measure for startle modification indexes. In order to calculate percentual change from baseline scores, the responses to the ITI probes within one block were averaged. Half of the slides in each category were displayed for either 5 s and the other half for 7 s. The order of 5 or 7 s slides was fixed. After termination of the task trials, the participant received feedback about her or his task performance, was debriefed, and received the appropriate amount of money.

2.6. Results

All statistical analyses were performed by using SPSS 4.0 (1990) software for the Macintosh computer. Probabilities for tests for within subject factors with more than 2 d.f. in the repeated measures analyses of variance (ANOVA; performed by the SPSS MANOVA module) were adjusted with Greenhouse-Geisser corrections. Epsilon values are reported if indicated.

Fig. 2 displays the percent-change-scores from baseline startle measures for auditory and visual

![Fig. 2. Means and S.E. of means for all experimental conditions in Experiment I. The asterisk indicates a significant difference from zero, the asterisk above the flipped bracket indicates a significant difference between ‘attend’ and ‘do not attend’ conditions. Please note that only those between conditions differences that refer to the variation of attention within the same modality are indicated here.](image)
attend’ and ‘ignore’ conditions. The short-lead-interval conditions (60, 120, and 240 ms) resulted in startle inhibition which was significantly different from zero under all auditory lead stimulus conditions and most visual lead stimulus conditions, except for the two ‘ignore’ conditions at the 120- and 240-ms lead intervals. Startle facilitation with the 4500-ms lead interval was significantly different from zero with both ‘attend’ visual and auditory lead stimuli, but not with ‘ignore’ lead stimuli.

The repeated measures ANOVA with two levels of ‘attend’ (attend, ignore), two levels of ‘modality’ (auditory, visual), three levels of lead interval (60, 120, and 240 ms) and two levels of trial blocks for the analysis of the short-lead-interval conditions showed that within short-lead-interval conditions only the factor ‘modality’ yielded a significant effect ($F_{1,29} = 32.09, P < 0.001$), whereas there was no significant difference between the three different lead intervals nor between the ‘attend’ and ‘ignore’ conditions. There was also a significant attention by modality interaction ($F_{1,29} = 5.03, P < 0.05$), indicating that with auditory lead stimuli, the ignore condition yielded more inhibition than the attend condition at the 120- and 240-ms lead intervals, whereas this was opposed with visual lead stimuli.

In contrast, the factor ‘attention’ generated a highly significant main effect in the separate analysis of the long-lead-interval conditions (2400-ms lead interval; $F_{1,29} = 16.43, P < 0.001$), whereas the factor modality failed to reach statistical significance. In this analysis, none of the two-way or the higher order interactions reached statistical significance. As can be seen in Fig. 2, the auditory prepulse consistently produced greater prepulse inhibition than the visual prepulse at short-lead-intervals and at the long lead interval an effect of attention was observed independent of modality.

Multiple pairwise ‘attend’ vs. ‘ignore’ condition comparisons by T-test for dependent samples revealed no significant attention differences at any short-lead-interval for either modality. For the long-lead-interval conditions, multiple pairwise comparisons revealed significant differences between ‘attend’ and ‘ignore’ conditions for both auditory and visual lead stimuli, with greater facilitation occurring during attended stimuli ($T(29) = 2.43, P < 0.05$; $T(29) = 3.96, P < 0.001$, respectively). There was no significant difference between ‘attended’ visual and auditory lead stimuli.

The task difficulty was comparable for auditory and visual lead stimuli. The mean error rates were 3.46 for the slide count and 3.35 for the tone count ($T < 1$, n.s.).

3. Experiment II

In Experiment II, the same apparatus, recording and scoring methods and stimuli were used as in Experiment I.

3.1. Participants

Thirty-two voluntary participants were tested. All participants were recruited from the subject pool of the University of Southern California and received course credit for their participation in Experiment II. The sample consisted of 22 female and 10 male participants. Seventeen participants were white, non-Hispanics; six African American; five Asian American; one Native American; and one of other ethnicity.

3.2. Design

The study used a $2 \times 4 \times 4 \times 2$ mixed design. The first within subjects factor consisted of the attentional instruction (lead stimulus to-be-attended vs. lead stimulus to-be-ignored). The second within subjects factor consisted of four lead intervals (60, 120, 240 and 4500 ms), and the third within subjects factor were four repeated measures for each attend × lead interval condition. The fourth factor tested the lead stimulus modality (auditory vs. visual) as a between-subjects factor.

The order of lead intervals (four orders) and of attend/ignore instruction trials (two orders) was counterbalanced across participants. A minimum of two participants was tested under each of the
counterbalanced two by four orders within each modality condition.

3.3. Procedure

The procedure of Experiment II was essentially the same as that used in Experiment I with the exception that four instead of two repeated measures for each within subjects experimental condition were obtained. Furthermore, since modality was treated as a between-subjects factor in Experiment II, the following changes to the procedure outlined in the description of Experiment I became necessary.

The participants were randomly assigned to one of the two modality conditions. The instructions then informed the participants that the task required them to count the number of tones (or slides) displayed for ‘longer than usual’, explicitly 7 vs. 5 s, i.e. ‘count the longer than standard high (or low) tones’ or ‘count the longer than standard vertical (or horizontal) zebra pattern’. The type of ‘attend’ and ‘ignore’ stimulus (high vs. low tone or vertical vs. horizontal pattern) was counterbalanced between participants within each modality condition; thus one out of the two participants assigned to each of the 16 different trial orders attended to the high tone, whereas the other attended to the low tone, or the vertical or horizontal pattern respectively in the visual condition.

The task phase consisted of four blocks of 12 trials, thus totalling 48 trials as in Experiment I. As in Experiment I, half of the trials were to-be-attended. On four trials within a block of 12 trials no startle probe was presented. The order of these ‘clear’ trials was fixed. On the remaining eight trials, each of the four lead interval conditions 60, 120, 240 and 4500 ms was presented once under each of the two attention conditions. The order of lead intervals was counterbalanced across subjects. The duration of the intertrial intervals varied between 13 s and 46 s, as in Experiment I, with an average of 28 s. During eight ITIs in block I, and during seven ITIs in blocks II, III, and IV, startle stimuli were presented at fixed positions varying between 10 s and 35 s. The response to the first ITI startle probe in Block I was not included in the data analysis. The responses to the ITI probes served as a baseline measure for startle modification indexes. For purposes of the task, half of each of the lead stimuli within each modality condition were displayed for either 5 or 7 s. The order of 5 or 7 s slides was fixed. After termination of the task trials, the participant again received feedback about her or his task performance, was debriefed, and was given the amount of money earned according to his or her task performance.

3.4. Results

A total of 31 participants was included in the statistical analyses of Experiment II. One participant out of the total of 32 that were tested was excluded for displaying small or no blink activity on most of the trials.

Fig. 3 displays the percent-change-scores from baseline startle measures for auditory and visual ‘attend’ and ‘ignore’ conditions. The short-lead-interval conditions 60, 120, and 240 ms resulted in startle inhibition which, as in Experiment I, was significantly different from zero under all auditory lead stimulus conditions. However, in contrast to Experiment I, inhibition was not significant under visual conditions with the sole exception of the ‘ignore’ 120 ms lead interval condition.

The repeated measures ANOVA for the short-lead-interval conditions with four levels of trial block, two levels of ‘attend’ (attend, do-not-attend), three levels of lead interval (60, 120, and 240 ms) and two levels of ‘modality’ (auditory, visual) as a between subjects factor, showed that within short-lead-interval conditions the factor ‘modality’ was marginally significant ($F_{1,29} = 3.7, \ P < 0.07$), which reflects the greater inhibition produced by the auditory prepulse seen in Fig. 3. The overall effect of attention was as well marginally significant ($F_{1,29} = 3.87, \ P < 0.06$), which reflects the big ‘attend’ vs. ‘ignore’ difference within the auditory 120-ms lead interval condition, that as well can be seen in Fig. 3. The overall effect of the lead interval duration as well as the effect of trial block were not significant.

In the separate analysis of the long-lead-interval conditions, a marginal effect of modality was
observed ($F_{1,20} = 3.19, P < 0.09$), which reflects the generally greater facilitation of startle in the two auditory conditions that is shown in Fig. 3. However, as in Experiment I, attention yielded a highly significant main effect ($F_{1,29} = 29.07, P < 0.001$).

Multiple pairwise ‘attend’ vs. ‘ignore’ conditions comparisons by T-test for dependent samples within the two modality conditions revealed a significant difference for the auditory 120-ms lead interval conditions, with enhanced short-lead-interval inhibition during the to-be-attended trials ($T(14) = -2.23, P < 0.05$), thus replicating the effect of attention that has been found in previous research from our laboratory. There were no further significant ‘attend’ vs. ‘ignore’ differences in either of the two modality conditions, i.e. at the 60-ms and 240-ms lead intervals for the auditory lead stimuli, or at any lead interval for the visual lead stimuli.

The long-lead-interval results replicated those of Experiment I. Startle facilitation with the 4500-ms lead interval was significantly different from zero with both to-be-attended visual and auditory lead stimuli, but not with to-be-ignored lead stimuli. And again, pairwise comparisons of attend vs. ignore conditions revealed significant differences between the two conditions for both auditory and visual lead stimuli, with greater facilitation occurring during attended stimuli ($T(14) = 2.49, P < 0.05$; and $T(15) = 3.18, P < 0.01$, respectively).

The task difficulty was again comparable for auditory and visual lead stimuli. The mean error rates were 4.23 for the slide count and 3.5 for the tone count ($T = 1$, n.s.).

4. Discussion

With short-lead-intervals, startle inhibition varied with the sensory modality of the lead stimuli more than with the attention-varying instruction. The auditory lead stimuli produced more inhibition of auditory startle than the visual lead stimuli used here, which is in line with a report by Graham (1980). Nevertheless, the visual lead stimuli produced significant startle inhibition under most experimental conditions in Experiment I, although this was not the case in Experiment II.
In contrast, with long-lead-intervals, the sensory modality of the lead stimulus had no effect in Experiment I and only a marginal effect in Experiment II. But whereas the attention varying instruction had little effects with short-lead-intervals, it had marked effects on the long-lead-interval conditions. In both experiments, significant startle facilitation with a long-lead-interval was observed with the lead stimuli that were task-significant, i.e. the to-be-attended lead stimuli.

A marked difference between the results of the two present experiments is the absence or presence of an effect of attention to auditory stimuli at the 120-ms lead interval that has consistently been shown in previous studies from our laboratory. With the complete within-subjects design of Experiment I, we failed to replicate the attention modulation effect, whereas it was obtained in the auditory lead stimuli group in Experiment II that exactly replicated previously used designs. On the other hand, both experiments failed to show a short-lead-effect of attention with visual lead stimulus conditions, consistent with previous studies which failed to do so with affective (Vanman et al., 1996) or neutral pictures (Böhmelt et al., 1995). It was suggested (see Böhmelt, 1995) that the absence of visual short-lead-interval effects of attention has been due to the complexity of pictorial stimuli which led even the pictures that were ‘to-be-ignored’ to actually be attended because of their inherent interestingness. The current results obtained with the simple visual stimuli used here cannot be explained in this way.

Instead, we suggest that a short-lead-interval effect of attention needs stimulus presentation saliency as is realized with 70-dB tones applied via headphones against a very low background noise. This hypothesis needs further testing, i.e. by tachistoscopic presentation of pictures in a completely darkened room. Consistent with the saliency hypothesis is the observation that we have found less overall visual short-lead-interval inhibition in the present study with our simple visual stimuli than we have found in earlier studies with complex pictorial stimuli. More salient, complex and interesting stimuli seem to generate more short-lead-interval inhibition than comparably less salient, complex and interesting lead stimuli. This is consistent with findings of Bradley et al. (1993), who studied startle modification during affectively valenced (positive and negative) and neutral stimuli at a lead interval of 300 ms (their shortest lead interval). Startle inhibition was greater during the more attention catching positive and negative pictures than during neutral pictures.

One of the most interesting findings of our study is that we were able to replicate an auditory short-lead-interval effect of attention in the between subjects design of Experiment II, but not in the within subjects design of Experiment I. This effect of attention has been shown to be a robust effect in studies that exclusively used auditory lead stimuli (Dawson et al., 1993; Filion et al., 1993, 1994; Schell et al., 1995; Jennings et al., 1996; Hazlett et al., 1998). Thus, the question is why this effect was not replicable in the within subjects design of Experiment I. It can be suggested that the use of two types (visual and auditory) of ‘attend’–‘ignore’ stimuli for the discrimination task in Experiment I added complexity and difficulty to the task. In particular, the low predictability of the nature of each upcoming stimulus with regard to modality may have prevented a short-lead-interval effect of attention due to an increased demand for stimulus identification and analysis.

We have tested this hypothesis in a pilot study with $n = 11$ participants. The design of Experiment I was replicated identically with the exception that the nature of upcoming lead stimuli was signalled. We displayed slides that read ‘slide’ or ‘tone’ to indicate the type of stimulus to follow. Under these conditions, maximum inhibition to auditory stimuli occurred to attended tones at the 120-ms lead interval, followed by the inhibition observed to the ignored auditory stimulus at 120 ms. Thus, we generally found maximum inhibition at the 120-ms lead interval with auditory lead stimuli and a difference between ‘attend’ and ‘ignore’ stimuli in the predicted direction. Due to the small number of participants and relatively large standard deviations in this pilot study, this difference between ‘attend’ and ‘ignore’ stimuli was not significant. However, the result still suggests that increased predictability was associated
with increased inhibition to the ‘attend’ auditory lead stimulus, relative to the auditory ‘ignore’ stimulus. Therefore, it seems likely that the increased task difficulty and decreased predictability of the within subjects design diminished the effect of the attentional instruction in Experiment I.

The long-lead-interval results were very similar over Experiments I and II. Furthermore, the long-lead-interval effects with both auditory and visual lead stimuli were in line with results from previous studies that used auditory (e.g., Filion et al., 1993, 1994) or visual lead stimuli (Böhmelt et al., 1995; Vanman et al., 1996), which underscores the reliability of long-lead-interval effects. The results show that significant facilitation was only obtained during the significant ‘attended’ lead stimuli, independent of modality. Furthermore, in both modality conditions the difference between the ‘attend’ and ‘ignore’ lead stimulus conditions was significant, independent of the use of a within- or between subjects design. The effect of long-lead-interval facilitation by sustained attention to a significant stimulus represents a robust phenomenon in startle modification, which can be independent of startle stimulus-lead stimulus modality mismatch. Similar results were also obtained by Lipp et al. (1997), who presented subjects with visual (slides depicting an ellipse or a circle) or auditory (pure 70-dB tones in two pitches) lead stimuli, and auditory startle stimuli, at long-lead-intervals (3500 and 4500 ms). Half of the participants were instructed to perform a discrimination task with the tones, while the other half performed the task with the slides, as was the case in the present Experiment II. Both groups displayed significant auditory startle facilitation during to-be-attended lead stimuli.

The long-lead-interval findings of both our group and of Lipp et al. are contrary to a sensory specific long-lead-interval startle modification hypothesis as postulated by Silverstein et al. (1981) and elaborated by Putnam (1990). According to this view, long-lead-interval startle facilitation is interpreted as a sensory pathway enhancement process which occurs when the modalities of the lead stimulus and the startle stimulus match. Inhibition or diminution should occur if the modalities mismatch. Thus, the visual lead stimulus, which constituted a condition of modality mismatch to the auditory startle stimulus, should have resulted in startle inhibition or at least a pronounced diminution of long-lead-interval startle facilitation, according to this hypothesis in both present experiments, in the study by Lipp et al. (1997), and in the previous studies by Böhmelt et al. (1995) and Vanman et al. (1996). Instead, the effect obtained in these studies reflects a process of generalized sustained attention rather than a sensory modality specific process. A comparison of these studies indicates that the effect is not related to the characteristics of the lead stimuli, since these differed between studies (pure tones, complex affective pictures, neutral pictures, or comparably simple geometric figures). In spite of the differences between the lead stimuli used, the common finding is enhanced startle facilitation to the to-be-attended lead stimulus. Therefore, crossmodal as well as unimodal long-lead-interval startle facilitation rather provides evidence for an explanation within the framework of generalized orienting (i.e. Graham, 1980, 1992) and/or information processing (see Hackley, in press, for a review of information processing approaches to startle modification research).

Taken together, the results of the present two experiments show that prepulse inhibition by visual lead stimuli appears to be, on average, less pronounced and less reliable than inhibition by auditory lead stimuli. The present Experiment II showed once more an effect of selective attention with a lead interval as short as 120 ms. The lead stimuli in the present experiments were matched according to information content and shared the same task difficulty. Their intensity was in the moderate range. Therefore, the current results suggest that the attention effect is modality specific with short-lead-intervals, but modality independent with long-lead-intervals.

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