The effect of stimulus modality and task difficulty on attentional modulation of blink startle

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Task difficulty and attentional blink modulation

Abstract

The effects of the sensory modality of the lead stimulus and of task difficulty on attentional modulation of the electrical and acoustic blink reflex were examined. Participants performed a discrimination and counting task with either two acoustic, two visual or two tactile lead stimuli. In Experiment 1, facilitation of the electrically elicited blink was greater during task-relevant than during task-irrelevant lead stimuli. Increasing task difficulty enhanced magnitude facilitation for acoustic lead stimuli. In Experiment 2, acoustic blink facilitation was greater during task-relevant lead stimuli, but was unaffected by task difficulty. Experiment 3 showed that a further increase in task difficulty did not affect acoustic blink facilitation during visual lead stimuli. The observation that blink reflexes are facilitated by attention in the present task domain is consistent across a range of stimulus modality and task difficulty conditions.

Descriptors: Attention, startle reflex, blink reflex, stimulus modality

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People have the capacity to focus attention on select stimuli in the environment, often at the expense of other, concurrent stimulation. In recent years, our understanding of the psychophysiological aspects of selective attention has been advanced by the study of blink reflex modulation. The blink reflex is elicited by a moderately intense and abrupt stimulus such as a loud noise, flash of light, or by electrical stimulation of the trigeminal nerve. The blink reflex can be modulated if a lead stimulus is presented prior to the blink-eliciting stimulus (Graham, 1975). If the lead stimulus precedes the blink-eliciting stimulus by a short lead interval, such as 120 ms, the blink reflex may be inhibited (Graham, 1975). Moreover, the amount of inhibition can increase if the participant is instructed to attend to the lead stimulus (Filion, Dawson, & Schell, 1993). If the lead stimulus precedes the blink-eliciting stimulus by a longer lead interval, such as 2000 ms, the blink reflex may be facilitated or inhibited depending on the task conditions. The present research was conducted to explore the conditions under which long lead interval blink facilitation is observed.

Long lead interval blink facilitation has been consistently observed during the so-called discrimination and counting task. In this task, participants are presented with two lead stimuli in the same sensory modality. Participants are asked to count the number of longer than usual presentations of one lead stimulus (task-relevant) and to ignore the other lead stimulus (task-irrelevant). The longer than usual lead stimulus has been 7 s in duration, compared to the usual duration of 5 s. In the research reported to date, the stimulus modality of the lead stimulus has been varied and an acoustic blink-eliciting stimulus has been used. It has been reported that blink magnitude is larger and blink latency is shorter during task-relevant lead stimuli than during task-irrelevant lead stimuli when the lead stimuli are presented in the acoustic and visual

modalities (Böhmelt, Schell, & Dawson, 1999; Fillion, Dawson, & Schell, 1993; Lipp, Siddle, & Dall, 1997, 1998; Lipp, Neumann, Pretorius, & McHugh, 2003). No difference between task-relevant and task-irrelevant lead stimuli has been found when tactile lead stimuli are used (Lipp et al., 1998). This null finding may reflect that the tactile lead stimulus used in previous research has consisted of a discontinuous vibration pulsed at a frequency of 50 Hz. The discontinuous nature of the stimulus may result in short lead interval inhibition and this inhibition may obscure attentional blink facilitation (Lipp et al., 2003).

Lipp et al. (1998, 2003) have interpreted the previous research to suggest that the blink facilitation observed during the discrimination and counting task reflects modality nonspecific attentional processing. This interpretation is in contrast to earlier views about the relationship between stimulus modality and attentional blink modulation. Previous research showed that acoustic blink reflexes were facilitated when participants attended to acoustic lead stimuli (Bohlin & Graham, 1977; Hackley & Graham, 1983; Putnam, 1990), but were inhibited when participants attended to visual lead stimuli (Putnam, 1990; Silverstein, Graham, & Bohlin, 1981). It was suggested that blink facilitation may occur when the modality of the blink-eliciting stimulus and the lead stimulus match and blink inhibition may occur when the modalities mismatch (Putnam, 1990). However, the observation of modality nonspecific blink modulation in the discrimination and counting task (Böhmelt et al., 1999; Lipp et al., 1997, 1998, 2003) suggests that certain task domains will lead to attentional blink facilitation regardless of the modality of the blink-eliciting stimulus and the lead stimulus.

A significant limitation of the previous research that has employed the discrimination and counting task has been that all studies have used an acoustic blink-eliciting stimulus (Böhmelt et al., 1999; Fillion et al., 1993; Lipp et al., 1997, 1998, 2003). As noted by Graham (1992),

unambiguous interpretations concerning the relationship between stimulus modality and attention on blink modulation require that both the modality of the lead stimulus and the blink-eliciting stimulus are varied. The conclusion that blink modulation reflects modality nonspecific attentional processes during the discrimination and counting task would be strengthened by a demonstration of modality nonspecific effects with a non-acoustic blink-eliciting stimulus. The present research aimed to provide such a demonstration by using electrical stimulation of the trigeminal nerve to elicit the blink reflex. Electrical stimulation of the trigeminal nerve produces three components in recordings of the orbicularis oculi (Esteban, 1999). The R1 component has a short latency of 8-12 ms and is obtained from the orbicularis oculi that is ipsilateral to the side of stimulation. The R2 and R3 components have a longer blink latency of 25-40 ms and 75-90 ms respectively and are both bilateral responses. Only the R2 response component was examined in the present study as it occurs at latencies similar to the acoustic blink reflex and like the acoustic blink reflex it is associated with bilateral contraction of the orbicularis oculi.

The present experiments also examined the effect of task difficulty on attentional blink modulation during the discrimination and counting task. Lipp et al. (2000a, Experiment 3) reported an experiment in which participants completed a reaction time task under one of two difficulty levels. It was found that an increase in the difficulty of the task produced a facilitation of acoustic blink magnitude when blinks were elicited during acoustic and visual lead stimuli. There was no effect of task difficulty on acoustic blink latency. Lipp and Hardwick (2003, Experiment 2) also reported that acoustic blink magnitude, but not latency, was facilitated by an increase in the difficulty of a reaction time task during visual lead stimuli. Lipp and colleagues (2000a; Lipp & Hardwick, 2003) concluded that an increase in the difficulty of the task would lead to a facilitation of blink magnitude. However, it cannot be concluded whether this

magnitude facilitation is specific to the attentional requirements during a lead stimulus as the reaction time task employed in the studies used only one type of lead stimulus. An increase in the difficulty of a task may result in an increased facilitation of blink magnitude that is more unspecific in nature. To determine whether an increase in task difficulty will affect blink magnitude only during lead stimuli that signal a task would require a comparison with a lead stimulus that does not signal a task. Such a comparison is available with the discrimination and counting task. Task difficulty would be expected to increase blink magnitude facilitation during task-relevant lead stimuli, but not during task-irrelevant lead stimuli if task difficulty effects are specific to the task signaled by the lead stimulus. If task difficulty has a more general effect on blink modulation, blink magnitude should be facilitated during task-relevant and task-irrelevant stimuli in a similar manner.

The present research used the discrimination and counting task under three conditions of lead stimulus modality and two conditions of task difficulty. In Experiment 1, we used the same sustained lead stimuli as used in previous research (Lipp et al., 1998, 2003), but elicited the blink reflex via electrical stimulation of the trigeminal nerve. In the Standard task difficulty condition, the longer than usual and usual lead stimulus duration was the same as that employed in previous experiments (7 s vs. 5 s). In the High task difficulty condition, the longer than usual lead stimulus was 5.5 s, compared to the usual 5 s. It was hypothesized that modality nonspecific attentional blink modulation would be observed. Blink reflex magnitude was expected to be larger and blink latency was expected to be shorter during task-relevant lead stimuli than during task-irrelevant lead stimuli when acoustic and visual lead stimuli are used. No difference was expected for tactile lead stimuli (Lipp et al., 1998, 2003). Task difficulty was hypothesized to modulate blink magnitude and not blink latency. Blink magnitude was expected to be larger in

the High task difficulty task condition than in the Standard task difficulty for task-relevant lead stimuli, but not for task-irrelevant lead stimuli. Skin conductance responses were also recorded as an independent measure of the attentional demands during the lead stimuli. Skin conductance responses have been found to be larger during task-relevant lead stimuli than during task-irrelevant lead stimuli (Dawson, Filion, & Schell, 1989; Filion et al., 1993; Lipp et al., 1997, 1998). The larger response during task-relevant lead stimuli reflects increased attentional demands because it is associated with greater deceleration of heart rate and a lengthening of secondary task reaction time to probes presented 600 ms following the onset of the lead stimulus (Dawson et al., 1989).

EXPERIMENT 1

Method

Participants

Sixty-one male and 112 female students from the University of Queensland participated after providing informed consent. The participants were obtained from a research participation scheme and they received course credit for their participation. The data from 2 females were excluded due to equipment problems, the data from 8 males and 15 females due to nonresponsiveness to the blink-eliciting stimulus, and the data from 2 males and 4 females due to extreme values in the blink data. The proportion of participants excluded from each group due to nonresponsiveness or outlier exclusion did not differ significantly, both $\chi^2 < 3.74$, $p > .05$. The final sample had a mean age of 19.72 years ($SD = 5.04$). Participants were randomly allocated to one of the six groups, such that each group had a similar distribution of males and females. The groups did not differ significantly in sex distribution or age, both $ps > .05$.

Apparatus

The blink reflex was measured by recording the electromyographic (EMG) activity of the orbicularis oculi muscle with a pair of 4 mm diameter Ag/AgCl domed electrodes filled with a standard electrolyte (Surgicon E10). The two electrodes were placed over the orbicularis oculi: one was placed under the pupil of the left eye, and the second was placed 1 cm laterally. A ground electrode was strapped to the inside of the left forearm. The raw EMG signal was amplified with a Coulbourn Instruments S75-01 Bioamplifier using a high-pass cutoff of 90 Hz and low-pass cutoff of 1000 Hz and a gain setting of 6000. The EMG signal was digitized and sampled online using a sampling rate of 1000 Hz in a time window of 100 ms prior to onset and 400 ms after offset of the blink-eliciting stimulus. The blink reflex was elicited by presenting an electric pulse with a Grass SD9 stimulator coupled in series with a Grass constant current unit. The 0.1 ms electrical pulse was applied to the right supraorbital branch of the trigeminal nerve via two 4 mm diameter Ag/AgCl domed electrodes filled with a standard electrolyte (Surgicon E10). Electric pulse intensity was set at 40 V with the current adjusted to an individual level for each participant until it reliably elicited a blink response.

Skin conductance was measured with a pair of 5 mm Ag/AgCl domed electrodes filled with a 0.05 M NaCl electrolyte and attached to the distal phalanges of the index and second fingers of the nonpreferred hand. A constant 0.5 V current was applied across the electrodes with the resulting skin conductance responses amplified with a Coulbourn Instruments S75-01 Bioamplifier and recorded on-line using a sampling rate of 10 Hz. Respiration was measured with a chest strain gauge (Phipps & Bird) to identify skin conductance responses associated with respiratory artifacts. The stimulus sequence, stimulus presentations, and intertrial intervals were controlled by a Dell OptiPlex 466/Le computer that also sampled the physiological signals.

The nature of the task-relevant and task-irrelevant lead stimuli varied among the groups. In the Acoustic modality groups, 800 Hz and a 1200 Hz pure tones presented at an intensity of 70 dB(A) and a 30 ms rise time were used. All auditory stimuli were generated by a custom-built tone generator and presented via stereophonic headphones (Sennheisser HD25-1). A Crompton Lighting 60 W green reflector spot globe and a Tungsram 60 W yellow discolux reflector spot globe were used in the Visual modality groups. When the spot globes were switched on, the back of a screen (15 x 20 cm) set into the wall of the experimental room was illuminated. This was perceived by the participant as the screen taking on a diffuse color of the corresponding color of the globe. The screen was located 140 cm from the participant at eye level. The illuminance of the lights, as measured from the participant's chair at eye level, was 6.9 Lux. In the Tactile modality groups, the vibration unit of a Mowat sensor was taped to the second phalanx of the middle finger of each hand of the participant. The location of the Mowat sensor did not interfere with the measurement of skin conductance responses from the same hand. The vibration unit was driven by a custom-built power supply at a frequency of 50 Hz. Prior to the present study, pilot work was conducted to match the three stimulus presentation methods (acoustic, visual, and tactile) on perceived intensity.

A post-experimental questionnaire assessed the subjective difficulty of the task and of the discrimination between the usual and longer-than-usual stimuli. For the former, participants answered the question "Taking into account the entire experiment, how difficult was it to perform the counting task" on a 7-point linear scale ranging from 1 "very easy" to 7 "very difficult". The same scale was used to answer the question "How difficult was it to tell the longer than usual presentations from the usual five second presentations". The participants reported how many presentations of the task-relevant lead stimulus were counted as longer-than-

usual prior to answering these questions, but were not told of the correct answer until the entire questionnaire was completed.

Procedure

Participants were seated in a chair opposite the projection screen and the experiment was monitored from an adjoining room. The participant room was darkened (ambient illuminance of 6.6 Lux as measured from the participant's chair) and had a mean temperature and humidity of 27 °C and 68% respectively. Following electrode placement, participants received one or more presentations of the blink-eliciting stimulus to check the blink recordings. The participants next received the instructions for the task. The modality of the lead stimuli and the difficulty of the discrimination between the usual duration and the longer-than-usual lead stimuli were manipulated between groups. Two groups were trained with tones (Acoustic), two groups were trained with lights (Visual), and two groups were trained with vibration stimuli (Tactile). For one of each modality group, the usual duration was 5 s and the longer-than-usual duration was 7 s (Standard task difficulty). In the remaining groups, the usual duration was 5 s and the longer-than-usual duration was 5.5 s (High task difficulty). The design thus resulted in six groups for the combinations of lead stimulus modality and task difficulty. Participants were informed that following a 3-min rest period, they would be presented with two types of tones/lights/vibrations and that each presentation would last for 5 s. Participants were told that following the initial presentations, the stimuli would usually be presented for a duration of 5 s, but that some presentations would be longer. They were instructed to count the number of longer-than-usual presentations of one tone/light/vibration (task-relevant) and to ignore all the presentations of the other tone/light/vibration (task-irrelevant). The participants were further informed that they would receive AUS\$5 if they reported the correct number and that AUS\$1 would be deducted

from the total for each count that was off the correct number. The participants were also told that they might receive presentations of the blink-eliciting stimulus at various times during the task, but that these should be ignored.

Following the instructions, the 3-min rest period began during which participants sat quietly with their eyes open. After the rest period, the two lead stimuli were presented in a familiarization phase and separated by an intertrial interval of 20 s. The nature of the first stimulus presented (task-relevant or task-irrelevant) was counterbalanced between participants. The experimenter checked to see if the participant could correctly identify the stimulus that was to-be-counted after both trials were presented. All participants reported that they could do so.

The experiment proper began next and consisted of 16 presentations of each type of tone/light/vibration arranged into two even blocks of trials. Within each trial block, 2 task-relevant and task-irrelevant lead stimuli were presented for the longer-than-usual duration, whereas the remaining were presented for the usual 5 s duration. The order of presentation was randomized with the restriction that the same lead stimulus was not presented more than two times in succession. The blink-eliciting stimulus was presented during half the lead stimuli and half the intertrial intervals. Blink-eliciting stimuli presented during the lead stimuli were presented at intervals of 3.5 and 4.5 s following lead stimulus onset and were randomly distributed such that each block contained two presentations at each lead interval for each lead stimulus type. In sum, the blink-eliciting stimulus was presented during 8 task-relevant and 8 task-irrelevant lead stimuli, 4 at each lead interval, and during 16 of the intertrial intervals. The intertrial interval varied at random between 20, 25, and 30 s. Blink-eliciting stimuli presented during the intertrial intervals were not presented within 12 s prior to or following a lead stimulus. Allocation of blink-eliciting stimuli during the intertrial intervals was randomized with the

restriction that a maximum of one blink-eliciting stimulus occurred during an interval and that half the presentations occurred in each block. Three different random sequences of stimulus arrangements were developed. These were distributed across participants such that the nature of the lead interval and order of lead stimulus presentations (task-relevant or task-irrelevant) was counterbalanced. After completion of the experiment, the participant completed the post-experimental questionnaire, was debriefed, and given a reward for task performance if warranted.

Scoring, Response Definition, and Statistical Analysis

A 3 x 2 (Modality x Difficulty) factorial chi square analysis was used to examine the frequencies of participants who correctly solved the task (i.e., reported an answer of “four”). Task performance was also examined by calculating error scores. Participants who reported four longer than usual task-relevant stimuli were given an error score of zero, participants who gave an answer of 3 or 5 were given an error score of one and so on. Inspection of the error scores showed highly skewed distributions. The data were thus subjected to a square root transformation to normalize the distributions prior to analysis in a 3 x 2 (Modality x Difficulty) analysis of variance (ANOVA). The rated difficulty in discriminating longer-than-usual stimuli from the usual duration and the rated difficulty of the task were analyzed with separate 3 x 2 (Modality x Difficulty) ANOVAs.

Nonspecific skin conductance responses were counted as the number of responses that exceeded .05 μ S during the 3-min rest period. To examine baseline levels of responsivity, the nonspecific skin conductance responses were subjected to a 3 x 2 (Modality x Difficulty) ANOVA. The magnitude of skin conductance responses that began within 1–4 s after onset of the lead stimuli that did not contain a blink-eliciting stimulus were scored as the stimulus elicited

responses. The respiration record was inspected for respiration-induced artifacts in skin conductance. Responses that coincided with sighs, deep breaths, or sneezing were scored as missing. Response magnitude was subjected to a square root transformation prior to the statistical analyses to reduce the skewness of the distribution (Venables & Christie, 1980). The resulting values were subjected to a 3 x 2 x 2 (Modality x Difficulty x Relevance) ANOVA to determine the effects of lead stimulus relevance on responding in each condition.

Digitized EMG activity was rectified off-line and filtered and integrated with a Butterworth low-pass filter using a time constant of 80 ms. The integrated signal was used to measure response magnitude in A/D units and latency in ms¹. Response magnitude was measured as the difference between the maximum of the integrated response curve within 200 ms after the onset of the blink-eliciting stimulus and the value of the integrated curve at response onset. Response onset was defined as the point at which 10% of the maximum slope was reached. Response latency was measured as the time between blink-eliciting stimulus onset and response onset. On trials in which no response was detectable, magnitude was scored as zero and latency was scored as missing. Trials were discarded from the data set if the baseline EMG was not stable within 100 ms before the blink-eliciting stimulus or the onset of the response was not within 20 to 70 ms after the onset of the blink-eliciting stimulus. The complete data set from a participant was discarded if the number of discarded trials or zero responses at any lead interval in each trial block was greater than half of all trials or if the number of discarded trials or zero responses in a trial block was greater than one third of all trials.

The presence of between-group differences in baseline levels of responding to the blink-eliciting stimulus were tested by averaging blink magnitudes and latencies elicited during the intertrial intervals and subjecting them to separate 3 x 2 (Modality x Difficulty) ANOVAs. Blink

magnitude and latency were averaged across all trials. Analyses conducted for this experiment and subsequent experiments indicated that blink modulation did not differ between the 3.5 and 4.5 s lead intervals for both the blink magnitude and latency measures, all $F_s < 1.35$. As a result, the data were averaged across lead intervals, separately for each lead stimulus type. Blink magnitude and latency elicited during the lead stimuli were converted to change scores to reduce the impact of individual differences in baseline reactivity to the blink-eliciting stimulus. Blink magnitude was converted to percentage change scores using the formula, (lead stimulus – intertrial interval)/intertrial interval * 100. Blink latency change score calculation used the formula, (lead stimulus – intertrial intervals). A 3 x 2 x 2 (Modality x Difficulty x Relevance) ANOVA was also used to examine the effects of stimulus relevance on blink magnitude and latency modulation in each condition. For all ANOVAs, post hoc comparisons were conducted with t tests that used critical values derived from Sidak's tables to protect against the accumulation of α -error (Rohlf & Sokal, 1981). The level of significance was set at .05 for all analyses.

Results

Fewer participants in the High task difficulty condition (20.8%) than in the Standard task difficulty condition (59.7%) solved the task correctly, $\chi^2(1) = 22.85$, $p < .001$. There were also more errors made in the High task difficulty condition (raw error score: $M = 1.70$, $SD = 1.42$; transformed error score: $M = 1.11$, $SD = .68$) than in the Standard task difficulty condition (raw error score: $M = .65$, $SD = 1.32$; transformed error score: $M = .45$, $SD = .67$), $F(1,140) = 29.04$, $MSE = .46$, $p < .001$. Participants rated the difficulty of the discrimination of longer-than-usual stimuli, $F(1,140) = 69.55$, $MSE = 1.78$, $p < .001$, as higher in the High difficulty condition ($M = 5.21$, $SD = 1.17$) than in the Standard difficulty condition ($M = 3.36$, $SD = 1.42$). The overall

task was also rated as more difficult by participants in the High difficulty condition ($\underline{M}$ = 4.48, $\underline{SD}$ = 1.48) than by participants in the Standard task difficulty condition ($\underline{M}$ = 3.46, $\underline{SD}$ = 1.16), $F(1,140) = 19.24$, $\underline{MSE} = 1.90$, $p < .001$. Stimulus modality had no significant effect on task performance or subjective ratings, all $F_s < 1$.

The number of nonspecific skin conductance responses did not differ significantly between the conditions, all $F_s < 1.17$. Mean skin conductance responses were larger during task-relevant lead stimuli ($\underline{M}$ = .17 μ S, $\underline{SD}$ = .12) than during task-irrelevant lead stimuli ($\underline{M}$ = .10 μ S, $\underline{SD}$ = .14), $F(1, 142) = 82.65$, $\underline{MSE} = .003$, $p < .001$. Responses also differed between the modality conditions, $F(2, 137) = 4.31$, $\underline{MSE} = .02$, $p < .05$, however, subsequent pairwise comparisons between the means (Acoustic: $\underline{M}$ = .17 μ S, $\underline{SD}$ = .11; Visual: $\underline{M}$ = .12 μ S, $\underline{SD}$ = .10; Tactile: $\underline{M}$ = .10 μ S, $\underline{SD}$ = .08) did not yield any significant differences when α -protected t -values were used, all $t_s < 1.99$, $p > .05$. Although responses showed a tendency to be larger in the High difficulty condition than in the Standard difficulty condition, this effect failed to reach the preset level of significance, $F = 3.47$, $p = .065$.

Groups did not differ significantly in the magnitude of blinks elicited during the intertrial intervals (Acoustic/Standard: $\underline{M}$ = 1252.25, $\underline{SD}$ = 790.82; Acoustic/High: $\underline{M}$ = 1139.51, $\underline{SD}$ = 727.80; Visual/Standard: $\underline{M}$ = 1158.73, $\underline{SD}$ = 711.03; Visual/High: $\underline{M}$ = 1823.93, $\underline{SD}$ = 982.10; Tactile/Standard: $\underline{M}$ = 1404.63, $\underline{SD}$ = 639.24; Tactile/High: $\underline{M}$ = 1595.68, $\underline{SD}$ = 887.89; all measures in A/D units), all $F_s < 3.28$, $p > .05$. The latency of blinks elicited during the intertrial intervals also did not significantly differ between groups (Acoustic/Standard: $\underline{M}$ = 50.02, $\underline{SD}$ = 4.81; Acoustic/High: $\underline{M}$ = 49.08, $\underline{SD}$ = 4.14; Visual/Standard: $\underline{M}$ = 49.14, $\underline{SD}$ = 3.96; Visual/High: $\underline{M}$ = 47.05, $\underline{SD}$ = 3.76; Tactile/Standard: $\underline{M}$ = 48.61, $\underline{SD}$ = 4.04; Tactile/High: $\underline{M}$ = 48.07, $\underline{SD}$ = 3.43; all measures in ms), all $F_s < 3.10$, $p > .05$.

Blink reflex magnitude modulation for each group is shown in Figure 1. Blink magnitude was larger during task-relevant lead stimuli than during task-irrelevant lead stimuli, $F(1, 140) = 13.51$, $MSE = 625$, $p < .001$. There was also an interaction between lead stimulus modality and task difficulty, $F(2, 139) = 3.63$, $MSE = 1449$, $p < .05$. All other main effects and interactions were not significant, all $F_s < 1.21$. The interaction between lead stimulus modality and task difficulty was examined by post hoc analyses that compared Standard and High task difficulty conditions, separately for each lead stimulus modality. The comparisons showed that blink magnitude was larger in the High task difficulty condition than in the Standard task difficulty condition when acoustic lead stimuli were used, $t(139) = 2.70$, $p < .05$. The comparisons for visual and tactile lead stimuli were not significant, both $t_s < 1$, $p > .05$.

Insert Figure 1 about here

Blink latency yielded a consistent pattern of results across groups in that latency was shorter during task-relevant lead stimuli ($M = -2.08$ ms, $SD = 2.38$) than during task-irrelevant lead stimuli ($M = -.65$ ms, $SD = 2.34$), $F(1, 140) = 48.79$, $MSE = 3.01$, $p < .001$. Blink latency was not significantly affected by task difficulty or lead stimulus modality, all $F_s < 2.26$, $p > .05$.

Discussion

The main findings of Experiment 1 were as follows. Task performance, subjective ratings, and skin conductance responses confirmed that task demands were greater in the High task difficulty condition than in the Standard task difficulty condition and that the attentional demands were greater during task-relevant lead stimuli than during task-irrelevant lead stimuli. Across all groups, blink magnitude was larger and blink latency was shorter during task-relevant

lead stimuli than during task-irrelevant lead stimuli. In contrast to previous research that has used the discrimination and counting task (Lipp et al., 1998) the increased blink facilitation during task-relevant lead stimuli was also found with tactile lead stimuli. Importantly, the increased blink facilitation was found using the same tactile lead stimulus as has been used previously, suggesting that a discontinuous vibration can support attentional blink modulation. Task difficulty influenced blink magnitude modulation, but not latency modulation. Blink magnitude was larger in the High task difficulty condition than in the low task difficulty condition when acoustic lead stimuli were used. This effect of task difficulty was present for both task-relevant and task-irrelevant lead stimuli. No effect of task difficulty was found for the visual and tactile lead stimulus conditions.

The present experiment in which the blink reflex was elicited by electrical stimulation of the trigeminal nerve extends the findings from previous studies that have examined the acoustically elicited blink reflex in the discrimination and counting task (Böhmelt et al., 1999; Lipp et al., 1997, 1998, 2003). The task demands used in the Standard task difficulty groups directly replicated that used previously. In these groups, blink reflex magnitude was larger and latency was shorter during task-relevant lead stimuli than during task-irrelevant lead stimuli for all lead stimulus modality conditions. Tests of the modality specific and nonspecific interpretation of attentional blink modulation require that both the modality of the lead stimulus and blink-eliciting stimulus be varied (Graham, 1992). The present experiment did not include an electrically elicited lead stimulus, although subsequent research could extend the range of lead stimuli to include this condition. Both the modality specific and nonspecific interpretations would predict that the electrically-elicited blink will be facilitated by attentional demands during this lead stimulus. The crucial distinction between the modality specific and nonspecific

interpretations, however, is the pattern of results that are observed during modality mismatch conditions because the interpretations result in different predictions. The present experiment used a blink-eliciting stimulus modality that did not match any of the lead stimuli and yielded findings that were consistent with the modality nonspecific blink facilitation observed in previous research with the acoustic blink-eliciting stimulus (Böhmelt et al., 1999; Lipp et al., 1997, 1998, 2003). This consistent pattern of results across different combinations of lead stimulus and blink-eliciting stimulus modalities supports the conclusion that attentional blink modulation reflects modality nonspecific processes in the discrimination and counting task. It remains to be seen, however, what pattern of results will be observed when visual and tactile blink-eliciting stimuli are used in the present task domain.

The present experiment varied the difficulty of the discrimination and counting task. Participants in the High task difficulty condition were required to discriminate 5.5 s long presentations from the usual 5 s usual presentations. Blink magnitude was larger during task-relevant and task-irrelevant lead stimuli in the High task difficulty condition than in the Standard task difficulty condition only when acoustic lead stimuli were used. Previous researchers who used a reaction time task and only one lead stimulus have reported that blink magnitude is larger when the task demands are increased (Lipp et al., 2000a; Lipp & Hardwick, 2003). The finding in which task difficulty effects were present for both task-relevant and task-irrelevant lead stimuli suggests that the effects of task difficulty are not specific to lead stimuli that signal a task. An increase in task difficulty seems to produce a more general effect on blink magnitude modulation. However, an unexpected finding was that the task difficulty effects were not found with visual and tactile lead stimuli. Lipp et al. (2000a) and Lipp & Hardwick (2003) found increased blink magnitude for acoustic and visual lead stimuli as the reaction time task was made

more difficult. Either the different task or the different blink-eliciting stimulus used in the present experiment may have contributed to the contradictory findings. Due to the relevance of task difficulty as a factor that may influence long lead interval blink modulation, a second experiment was conducted. In Experiment 2, the discrimination and counting task was employed under the two task difficulty conditions used in Experiment 1. However, the blink reflex was elicited by an acoustic stimulus, as used in the previous studies in which task difficulty effects have been observed (Lipp et al., 2000a; Lipp & Hardwick, 2003).

EXPERIMENT 2

Method

Participants

Sixty-two male and 103 female students from the University of Queensland who did not participate in Experiment 1 provided informed consent prior to taking part in the experiment. The participants received course credit for their participation or AUS\$10.00. The data from 9 male and 9 female participants were excluded due to excessive missing blink reflex data, mainly due to complete habituation of the blink reflex. A further 3 female participants were excluded due to extreme values in the blink reflex data. The final sample had a mean age of 20.2 years ($SD = 3.2$). Upon arrival at the laboratory, participants were randomly allocated to one of the six groups until each group contained 24 participants with complete data sets. The groups did not differ in sex distribution or age, both $ps > .05$.

Apparatus and Procedure and Statistical Analysis

The apparatus, procedure, and statistical analysis were similar to that used for Experiment 1. The apparatus differed, however, for the processing of the EMG and skin conductance signal and for the elicitation of the blink reflex. The blink-eliciting stimulus was a 105 dB(A) burst of

white noise presented with a duration of 50 ms and an instantaneous rise time. The white noise was generated by a custom-built tone generator and presented via stereophonic headphones (Sennheisser HD25-1). The raw EMG signal was processed using a Grass 7P3C AC preamplifier set with a 0.5 amplitude high-pass cutoff of 10 Hz and a low-pass cutoff of 3000 Hz. The raw EMG was displayed on a Grass 7D polygraph (calibration: 100 μ V/cm pen deflection) using a paper speed of 2.5 mm/s and digitized and sampled online using a sampling rate of 1000 Hz with an IBM-compatible (486) computer. The sample window began 100 ms prior to the blink-eliciting stimulus onset and ended 400 ms after blink-eliciting stimulus onset. The skin conductance responses were amplified using a Grass 7P1G preamplifier and displayed on the polygraph (calibration 0.05 μ V/mm pen deflection). Respiration was measured with a chest strain gauge (Phipps & Bird) and displayed on the polygraph to identify skin conductance responses associated with respiratory artifacts. Skin conductance responses were scored on paper using the same scoring criteria as used in Experiment 1.

Results

Performance on the counting task declined as the task difficulty was increased. Fewer participants in the High task difficulty condition (12.5%) than in the Standard task difficulty condition (54.2%) solved the task correctly, $\chi^2(1) = 28.12$, $p < .001$. The mean error scores were also greater in the High task difficulty condition (raw error score: $\underline{M} = 2.47$, $\underline{SD} = 1.95$; transformed error score: $\underline{M} = 1.40$, $\underline{SD} = .71$) than in the Standard task difficulty condition (raw error score: $\underline{M} = 1.03$, $\underline{SD} = 1.79$; transformed error scores $\underline{M} = .64$, $\underline{SD} = .79$), $F(1,142) = 36.76$, $\underline{MSE} = .56$, $p < .001$. In addition, the High task difficulty condition ($\underline{M} = 5.34$, $\underline{SD} = .89$) was given a higher rating than the Standard task difficulty condition ($\underline{M} = 3.76$, $\underline{SD} = 1.47$) for the difficulty of detecting longer-than-usual stimuli, $F(1,142) = 60.11$, $\underline{MSE} = 1.48$, $p < .001$.

Likewise, the High task difficulty condition ($\underline{M} = 4.53$, $\underline{SD} = 1.41$) was rated higher than the Standard task difficulty condition ($\underline{M} = 3.57$, $\underline{SD} = 1.56$) for the difficulty of the overall task, $F(1,135) = 14.64$, $\underline{MSE} = 2.26$, $p < .001$. Lead stimulus modality did not significantly affect task performance or subjective ratings, all $F_s < 1.53$.

The frequency of nonspecific skin conductance responses differed between the modality conditions, $F(2,141) = 3.81$, $\underline{MSE} = 132$, $p < .05$, due to a higher number in the visual modality condition than in the tactile modality condition, $t(141) = 2.46$, $p < .05$. Skin conductance responses were larger during task-relevant lead stimuli ($\underline{M} = .25 \mu\text{S}$, $\underline{SD} = .20$) than during task-irrelevant lead stimuli ($\underline{M} = .13 \mu\text{S}$, $\underline{SD} = .12$) in all groups, $F(1, 142) = 111.73$, $\underline{MSE} = .02$, $p < .001$. Responses did not significantly differ between the task difficulty conditions for any lead stimulus modality, all $F_s < 1.85$, $p > .05$.

Blink magnitude during the intertrial intervals did not significantly differ between the modality or task difficulty conditions (Acoustic/Standard: $\underline{M} = 142.25$, $\underline{SD} = 111.62$; Acoustic/High: $\underline{M} = 99.32$, $\underline{SD} = 74.66$; Visual/Standard: $\underline{M} = 158.24$, $\underline{SD} = 135.24$; Visual/High: $\underline{M} = 182.40$, $\underline{SD} = 135.51$; Tactile/Standard: $\underline{M} = 151.43$, $\underline{SD} = 107.83$; Tactile/High: $\underline{M} = 125.07$, $\underline{SD} = 102.71$; all measures in μV), all $F_s < 2.36$, $p > .05$. There were also no significant group differences in blink latency (Acoustic/Standard: $\underline{M} = 41.44$, $\underline{SD} = 4.38$; Acoustic/High: $\underline{M} = 41.77$, $\underline{SD} = 5.36$; Visual/Standard: $\underline{M} = 41.12$, $\underline{SD} = 5.34$; Visual/High: $\underline{M} = 41.12$, $\underline{SD} = 5.34$; Tactile/Standard: $\underline{M} = 41.39$, $\underline{SD} = 5.71$; Tactile/High: $\underline{M} = 43.58$, $\underline{SD} = 5.93$; all measures in ms), all $F_s < 1.63$, $p > .05$.

Blink magnitude modulation in each experimental group is shown in Figure 2. Similar to Experiment 1, blink magnitude was larger during task-relevant lead stimuli than during task-irrelevant lead stimuli, $F(1, 142) = 20.89$, $\underline{MSE} = 1370$, $p < .001$. In addition, blink magnitude

differed between the lead stimulus modalities, $F(2, 141) = 27.86$, $MSE = 4297$, $p < .001$.

However, the effect of stimulus relevance did not interact with the between group variables, all $F_s < 1.97$. Post hoc comparisons were conducted to examine the difference between the lead stimulus modality conditions. Pairwise comparisons show that blink magnitude was larger during acoustic lead stimuli than during visual and tactile lead stimuli, both $t(141) > 6.29$, $p < .001$. The visual and tactile lead stimuli did not significantly differ, $t < 1$.

 Insert Figure 2 about here

Blink latency shortening was significantly greater during task-relevant lead stimuli ($M = -3.64$ ms, $SD = 3.15$) than during task-irrelevant lead stimuli ($M = -1.85$ ms, $SD = 3.59$), $F(1, 142) = 35.44$, $MSE = 6.54$, $p < .001$. Similar to the blink magnitude modulation, blink latency shortening tended to be greater during acoustic lead stimuli ($M = -3.40$ ms, $SD = 3.52$) than during visual ($M = -2.13$ ms, $SD = 1.90$) and tactile ($M = -2.70$ ms, $SD = 2.84$) lead stimuli. However, the main effect for Modality failed to reach the preset level of significance, $F(2, 141) = 2.38$, $MSE = 16.36$, $p = .1$. No other main effects or interactions were significant, all $F_s < 1$.

Discussion

Consistent with the findings of Experiment 1, task performance and subjective ratings confirmed that reducing the duration of longer-than-usual lead stimuli increased the difficulty of the discrimination and counting task. Contrary to expectations, however, task difficulty did not affect acoustic blink magnitude in any lead stimulus modality condition. Replicating previous studies (Lipp et al., 1997, 1998, 2003) blink magnitude was larger during acoustic lead stimuli than during visual and tactile lead stimuli. This difference between the lead stimulus modalities

reflects the effects of continuous stimulus input on modulating the blink reflex and not the engagement of modality specific attentional processes (Lipp et al., 2003). The effects of attention on blink magnitude and latency modulation, as indicated by the comparison between task-relevant and task-irrelevant lead stimuli, showed that attention to the lead stimulus facilitated acoustic blink reflexes. In contrast to previous experiments (Lipp et al., 1998), but replicating the findings of Experiment 1, the increased blink facilitation during task-relevant lead stimuli was also present when the lead stimuli were tactile.

The present results do not support the hypothesis that an increase in the difficulty of a task will produce a facilitation of blink reflexes. This conclusion is in contrast to earlier reports in which acoustic blink reflexes were examined during a reaction time task (Lipp et al., 2000a; Lipp & Hardwick, 2003). Indeed, visual inspection of Figure 2 suggests that there was a tendency for acoustic blink magnitude to be attenuated, rather than facilitated, by an increase in the difficulty of the task when visual and tactile lead stimuli were used. The size of this effect was not sufficiently great to result in any statistically significant effects for task difficulty. The tendency for an attenuation of blink magnitude is surprising because it is opposite to that reported by Lipp and colleagues who used an acoustic blink eliciting stimulus and a visual lead stimulus in a reaction time task (Lipp et al., 2000a; Lipp & Hardwick, 2003) and opposite to that found in Experiment 1 in which the electrical blink reflex and an acoustic lead stimulus was used in the discrimination and counting task. It is, however, to be expected from a modality specific viewpoint of attentional blink modulation. This viewpoint would suggest that an increase in the difficulty of the task would enhance blink attenuation during a modality mismatch condition. It might be argued from a modality nonspecific interpretation that a further increase in the difficulty of the task is needed to result in a significant attenuation of the acoustic blink reflex

during visual lead stimuli. A further experiment was thus conducted to examine this possibility. Experiment 3 used two groups in which each group was presented with visual lead stimuli. The Standard task difficulty group replicated that used in Experiment 2, by requiring participants to differentiate 7 s presentations from the usual 5 s presentations. In the Very High task difficulty group, the detection of longer-than-usual presentations was made more difficult to that operationalized in Experiment 2 by using longer-than-usual presentations of 5.2 s.

EXPERIMENT 3

Method

Participants

Twenty-seven male and 30 female undergraduate psychology students participated after providing informed consent. The data from six males and three females were excluded due to excessive missing blink reflex data. Participants were allocated randomly to one of two groups upon arrival at the laboratory until each group had 24 participants with complete data sets. The final sample had a mean age of 19.5 years ($SD = 4.5$) and the groups did not differ in sex distribution or age, all $ps > .05$.

Apparatus and Procedure

The experiment was conducted in the same room as Experiment 2 and used similar apparatus and procedures. The yellow and green light spot globes used as the lead stimuli were matched so that the globes were equal in intensity (illuminance measured from the participant's chair at eye level was 7.6 Lux). The experimental procedure differed from Experiment 2 in that only two groups of participants were used. Each group was presented with the lights as the lead stimuli. In the Standard task difficulty group, the longer than usual lead stimuli were presented for 7 s and the usual duration was 5 s, the same duration used in the Standard condition of

Experiment 1 and 2. In the Very High task difficulty group, however, the longer than usual lead stimuli were presented for 5.2 s and the usual duration was 5 s. All other aspects of instructions, stimulus presentation, trial sequences, and counterbalancing were the same as that reported in Experiment 1. Scoring and statistical analyses followed that used in Experiment 1, although the factor Modality was not used in the analyses.

Results

Task performance and subjective ratings confirmed that the task was more difficult in the Very High task difficulty condition than in the Standard task difficulty condition. Twelve participants (50%) in the Standard task difficulty group solved the task correctly, whereas only two participants (8.3%) in the Very High task difficulty group were correct, $\chi^2(1) = 10.14$, $p < .01$. Error scores were also lower in the Standard task difficulty group (raw error: $\underline{M} = .67$, $\underline{SD} = .76$; transformed error: $\underline{M} = .57$, $\underline{SD} = .59$) than in the Very High task difficulty group (raw error: $\underline{M} = 2.50$, $\underline{SD} = 2.14$; transformed error: $\underline{M} = 1.42$, $\underline{SD} = .70$), $t(46) = 4.53$, $p < .001$. The discrimination between longer-than-usual and Standard duration lead stimuli was rated as easier in the Standard task difficulty group ($\underline{M} = 3.75$, $\underline{SD} = 1.39$) than in the Very High task difficulty group ($\underline{M} = 5.46$, $\underline{SD} = 1.06$), $t(46) = 4.78$, $p < .001$. The overall task was rated as less difficult in the Standard task difficulty group ($\underline{M} = 3.54$, $\underline{SD} = 1.25$) than in the High task difficulty group ($\underline{M} = 4.58$, $\underline{SD} = 1.44$), $t(46) = 2.67$, $p < .05$. The number of spontaneous skin conductance responses did not differ significantly between groups, $t(46) < 1$. The mean skin conductance response was significantly larger during task-relevant lead stimuli ($\underline{M} = .21 \mu\text{S}$, $\underline{SD} = .19$) than during task-irrelevant lead stimuli ($\underline{M} = .08 \mu\text{S}$, $\underline{SD} = .14$) in both groups, $F(1, 142) = 27.32$, $\underline{MSE} = 1.37$, $p < .001$. Task difficulty had no significant effect, all $\underline{Fs} < 1.43$.

Insert Figure 3 about here

Blink magnitude and latency to intertrial interval blink-eliciting stimuli did not significantly differ between the Standard task difficulty group (Magnitude: $\underline{M} = 126.80 \mu\text{V}$, $\underline{SD} = 106.46$; Latency: $\underline{M} = 42.35 \text{ ms}$, $\underline{SD} = 6.22$) and the Very High task difficulty group (Magnitude: $\underline{M} = 114.57 \mu\text{V}$, $\underline{SD} = 93.19$; Latency: $\underline{M} = 42.34 \text{ ms}$, $\underline{SD} = 6.01$), all $\underline{F}_s < 1$. Figure 3 shows the mean blink magnitude (left panel) and blink latency (right panel) change in each task difficulty group. Blink magnitude was significantly larger during task-relevant lead stimuli than during task-irrelevant lead stimuli, $\underline{F}(1, 46) = 14.35$, $\underline{MSE} = 1730$, $p < .001$. Task difficulty had no effect, all $\underline{F}_s < 2.29$, $p > .05$. Blink latency was significantly shorter during task-relevant lead stimuli than during task-irrelevant lead stimuli in both task difficulty conditions, $\underline{F}(1, 46) = 14.39$, $\underline{MSE} = 10.45$, $p < .001$. No other effects were significant, all $\underline{F}_s < 1$.

Discussion

The present experiment did not support the hypothesis that a further increase in the task demands would lead to a significant attenuation of blink magnitude relative to the standard task difficulty. There was no significant difference in overall blink magnitude between the two task difficulty conditions. The task performance data indicated that only 2 out of the 24 participants in the Very High task difficulty group correctly solved the task and the subjective ratings of task difficulty were high. It would seem that the procedure of discriminating 5.2 s presentations from the usual 5 s presentations has reached the maximum difficulty possible with the discrimination and counting task. A further decrease in the duration of longer than usual stimuli (e.g., 5.1 s) would be unlikely to yield substantially different findings. Taking the findings of Experiment 2

and Experiment 3 together, a consistent pattern has emerged in which acoustic blink reflexes are not modulated by an increase in the difficulty of the discrimination and counting task.

One interpretation for the present failure to find task difficulty effects is that whether such effects are found will depend on the way in which “task difficulty” is manipulated. The demands of the task can be increased by making the cognitive aspects of a task more difficult or by increasing the perceptual load. Manipulations of task difficulty may affect only the cognitive demands of the task, only the perceptual load, or both simultaneously. Lavie (2001) argued that task performance may be affected differently depending on whether the cognitive demands or the perceptual load of a task was varied. The present experiment increased the difficulty of detecting a longer than usual presentation, but kept the perceptual features of the lead stimulus constant. As such, the cognitive demand was increased, but the perceptual load remained constant across task difficulty conditions. Manipulations that increase perceptual load may be those that require more perceptual operations for a stimulus or involve the presentation of more stimuli. It may be that increases in perceptual load may be more likely to modulate blink reflexes. Future research may benefit from investigating whether an increase in perceptual load will modulate the blink reflex during the discrimination and counting task.

General Discussion

The present study investigated the effects of stimulus modality and task difficulty on attentional blink modulation. A consistent pattern emerged for the effects of attention on blink modulation. Blink latency was shorter and blink magnitude was larger during task-relevant lead stimuli than during task-irrelevant lead stimuli across a wide range of lead stimulus modality and blink-eliciting stimulus modality conditions. This included conditions in which the modalities matched and the modalities mismatched. Task difficulty produced a small and inconsistent

effect on blink modulation. The magnitude of the electrically elicited blink reflex was larger when the difficulty of the task was increased for acoustic lead stimuli. Task difficulty did not influence blink modulation during visual or tactile lead stimuli when blinks were elicited by electrical stimulation of the trigeminal nerve or by an acoustic stimulus.

In the present experiment, attentional demands were manipulated by requiring participants to attend to one stimulus and to ignore another. Across all experiments, with various combinations of lead stimulus and blink-eliciting stimulus modalities, a consistent pattern emerged in which the blink reflex was facilitated by attention to the lead stimulus. In addition, attentional blink facilitation was consistently observed under a wide range of task difficulty levels. These findings extend those reported in previous studies that used the discrimination and counting task and a blink-eliciting stimulus from the acoustic modality (Böhmelt et al., 1999; Lipp et al., 1997, 1998). The findings provide a strong argument that attentional modulation of the blink reflex during the discrimination and counting task reflects modality nonspecific processes and is consistent with recent reports of modality nonspecific effects from other experimental paradigms (Bohlin, Graham, Silverstein, & Hackley, 1981; Lipp et al., 2000a, 2000b). These findings are in contrast to the reports of modality specific effects (e.g., Anthony & Graham, 1985; Neumann, 2002; Putnam, 1990; Silverstein et al., 1981; Simons & Zelson, 1985). The development of a model of the cognitive neurobiological processes that underlie attentional modulation of the blink reflex will be assisted by studies that can determine the conditions under which modality specific and nonspecific effects are found.

A novel finding in the present experiment was that attentional blink modulation was observed when tactile lead stimuli were used. Lipp et al. (1998) reported that acoustic blink magnitude and latency did not differ between task-relevant and task-irrelevant tactile lead

stimuli. In contrast, Experiment 1 and 2 showed that the electrical and acoustic blink reflex is larger in magnitude and shorter in latency during task-relevant tactile lead stimuli. We have previously suggested that the failure to find attentional blink modulation during tactile lead stimuli was due to the nature of the stimulus that has been used (Lipp et al., 2003). The tactile stimulus has been operationalized as a discontinuous vibration pulsed at a frequency of 50 Hz. The discontinuous nature of the lead stimulus may result in both short lead interval inhibition and long lead interval facilitation when employed in the discrimination and counting task. Consistent with this interpretation, no attentional blink modulation has been found when the vibration has been sustained throughout the lead interval. In contrast, attentional blink modulation has been observed when the vibration was a discrete presentation (Lipp et al., 2003). In this study, we used the same sustained discontinuous tactile lead stimulus as used in previous research (Lipp et al., 1998, 2003). The present findings suggest that attentional blink modulation can be observed during sustained discontinuous vibration stimuli. The previous failures to find this effect suggest that such an observation may be difficult to reliably obtain. Attentional blink modulation during tactile lead stimuli may be more consistently observed if a continuous stimulus, such as a stream of air to the skin, is employed (Lipp et al., 2003).

Lipp et al. (1998) reported that blink magnitude was larger during acoustic lead stimuli than during visual and tactile lead stimuli when an acoustic blink-eliciting stimulus was used. The findings of Experiment 2 replicated this effect. Lipp et al. (2000a, 2003) suggested that the increased acoustic blink magnitude during acoustic lead stimuli reflects a process that results from the matching of the modality of the lead stimulus and the blink-eliciting stimulus, but is independent of selective attention to the lead stimulus. The present results in which the increased facilitation during acoustic lead stimuli was observed during task-irrelevant lead

stimuli is consistent with this interpretation. As suggested by Lipp et al. (2003), blink magnitude may be larger during a modality match condition because of a greater overlap in the subcortical neural circuitry that is involved in the sensory processing of the lead stimuli and the blink-eliciting stimulus. The greater overlap will cause a larger priming of the startle reflex circuit and result in larger blink magnitude. Another explanation could be that the increased blink magnitude during acoustic lead stimuli is due to a unique feature in processing of acoustic stimuli that is not shared in the processing of visual or tactile stimuli. The findings of Experiment 1 in which blink magnitude facilitation during acoustic lead stimuli was markedly smaller than in Experiment 2 and the observation that no blink magnitude facilitation was found during acoustic task-irrelevant lead stimuli in the Standard task difficulty condition in Experiment 1 seems to argue against this interpretation.

Stimulus modality, task difficulty, and attentional demands all influenced blink magnitude modulation, whereas only the attentional demands influenced blink latency modulation. It appears that stimulus modality differentially influences the onset of the reflex and the size of the elicited reflex. The failure of stimulus modality to modulate blink latency also implies that blink reflex latency may provide a “pure” measure of attentional demands in situations that may use stimuli from different stimulus modalities or in different levels of task difficulty. If blink reflex latency is sensitive only to the attentional demands of a task, this measure may prove useful for researchers who wish to avoid possible contaminating influences of the lead stimulus characteristics when measuring the blink reflex.

References

- Anthony, B. J., & Graham, F. K. (1985). Blink reflex modulation by selective attention: Evidence for the modulation of “automatic” processing. Biological Psychology, 20, 43-59.
- Böhmelt, A. H., Schell, A. M., & Dawson, M. E. (1999). Attentional modulation of short- and long-lead-interval modification of the acoustic eyeblink reflex response: comparing auditory and visual prestimuli. International Journal of Psychophysiology, 32, 239-250.
- Bohlin, G., & Graham, F. K. (1977). Cardiac deceleration and reflex blink facilitation. Psychophysiology, 14, 423-430.
- Bohlin, G., Graham, F. K., Silverstein, L. D., & Hackley, S. A. (1981). Cardiac orienting and startle blink modulation in novel and signal situations. Psychophysiology, 18, 603-611.
- Dawson, M. E., Filion, D. L., & Schell, A. M. (1989). Is elicitation of the autonomic orienting response associated with the allocation of processing resources? Psychophysiology, 26, 560-572.
- Esteban, A. (1999). A neurophysiological approach to brainstem reflexes. Blink reflex. Neurophysiologie Clinique, 29, 7-38.
- Filion, D. L., Dawson, M. E., Schell, A. M. (1993). Modification of the acoustic startle reflex eyeblink: A tool for investigating early and late attentional processes. Biological Psychology, 35, 185-200.
- Graham, F. K. (1975). The more or less startling effects of weak prestimulation. Psychophysiology, 12, 238-248.
- Graham, F. K. (1992). Attention: The heartbeat, the blink, and the brain. In B. A. Campbell, H. Hayne, & R. Richardson (Eds.), Attention and information processing in infants and

- adults: Perspectives from human and animal research (pp. 3-29). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Hackley, S. A., & Graham, F. K. (1983). Early selective attention effects on cutaneous and acoustic blink reflexes. Physiological Psychology, *11*, 235-242.
- Lavie, N. (2001). Capacity limits in selective attention: Behavioral evidence and implications for neural activity. In J. Braun, C. Koch, & J. L. Davis (Eds.), Visual attention and cortical circuits (pp. 49-68). Cambridge, MA: The MIT Press.
- Lipp, O. V., & Hardwick, S. A. (2003). Attentional blink modulation in a reaction time task: performance feedback, warning stimulus modality, and task difficulty. Biological Psychology, *62*, 115-132.
- Lipp, O. V., Neumann, D. L., Pretorius, N. R., & McHugh, M. J. (2003). Attentional blink modulation during sustained and after discrete lead stimuli presented in three sensory modalities. Psychophysiology, *40*, 285-290.
- Lipp, O. V., Siddle, D. A. T., & Dall, P. J. (1997). The effect of emotional and attentional processes on blink startle modulation and on electrodermal responses. Psychophysiology, *34*, 340-347.
- Lipp, O. V., Siddle, D. A. T., & Dall, P. J. (1998). Effects of stimulus modality and task condition on blink startle modulation and on electrodermal responses, Psychophysiology, *35*, 452-461.
- Lipp, O. V., Siddle, D. A. T., & Dall, P. J. (2000a). The effect of warning stimulus modality on blink startle modulation in reaction time tasks. Psychophysiology, *37*, 55-64.
- Lipp, O. V., Siddle, D. A. T., & Dall, P. J. (2000b). The effects of change in lead stimulus modality on the modulation of acoustic blink startle. Psychophysiology, *37*, 715-723.

- Neumann, D. L. (2002). Effects of varying levels of mental workload on startle eyeblink modulation. Ergonomics, 45, 583-602.
- Putnam, L. E. (1990). Great expectations: Anticipatory responses of the heart and brain. In R. Johnson, J. W. Rohrbaugh, R. Parasuraman, & R. Johnson, Jr. (Eds.), Event-related brain potentials: Basic issues and applications (pp. 178-209). New York: Oxford University Press.
- Rohlf, F. J., & Sokal, R. (1981). Statistical tables. San Francisco: Freeman.
- Silverstein, L. D., Graham, F. K., & Bohlin, G. (1981). Selective attention effects on the reflex blink. Psychophysiology, 18, 240-247.
- Simons, R. F., & Zelson, M. F. (1985). Engaging visual stimuli and reflex blink modification. Psychophysiology, 22, 44-49.
- Venables, P. H., & Christie, M. J. (1980). Electrodermal activity. In I. Martin & P. H. Venables (Eds.), Techniques in Psychophysiology (pp. 3-67). New York, NY: John Wiley & Sons.

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Footnote

¹Blink magnitude values in μV are available from the authors.

Figure Captions

Figure 1. Mean electrically elicited blink magnitude percent change during task-relevant and task-irrelevant lead stimuli as a function of lead stimulus modality for the Standard (left panel) and High (right panel) task difficulty conditions in Experiment 1. (vertical bars represent standard error of the mean).

Figure 2. Mean acoustic blink magnitude percent change during task-relevant and task-irrelevant lead stimuli as a function of lead stimulus modality for the Standard (left panel) and High (right panel) task difficulty conditions in Experiment 2. (vertical bars represent standard error of the mean).

Figure 3. Mean acoustic blink magnitude percent change (left panel) and blink latency change (right panel) during task-relevant and task-irrelevant visual lead stimuli as a function of task difficulty in Experiment 3. (vertical bars depict standard error of the mean).