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Motivated attention: Incentive effects on attentional modification of prepulse inhibition

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Abstract

Prepulse inhibition (PPI) of startle is greater for attended compared to ignored prestimuli, and, consistent with theories of motivated attention, initial evidence suggests that this effect is greater among participants given performance-based incentives. The present study examined a within-subjects incentive manipulation. Participants ($n = 41$) completed two blocks of a tone discrimination task. During the incentive block, participants received trialwise feedback with small monetary incentives for task performance. Startle eyeblink EMG responses to auditory probes were assessed at 60-, 120-, and 180-ms tone-probe stimulus onset asynchronies (SOAs). As predicted, PPI was enhanced during attended compared to ignored prestimuli only at the 120-ms SOA in the incentive condition. There was no evidence of attentional modification in the no-incentive condition. These data suggest that attentional modification of PPI is sensitive to within-subjects manipulations of incentive, providing a useful tool for testing models of motivated attention in psychopathology and psychopharmacology.

Descriptors

Attention; Startle reflex; Prepulse inhibition; Incentive; Motivation

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Our limited attentional capacity frequently necessitates that resources focus on a subset of motivationally salient stimuli. To use a real-world example, students in a classroom attend to material they find inherently interesting to a greater extent than a topic they find less engaging. However, the degree to which they pay attention may also depend on the external consequences of their performance in the course. That is, the allocation of attentional resources is influenced by intrinsic (e.g., the student's interest in the course material) and extrinsic motivational factors (e.g., threat of losing a scholarship for not getting an “A”; see, e.g., Sarter, Gehring, & Kozak, 2006).

In the laboratory, the interaction between motivational and cognitive processes is receiving greater attention. Indeed, many researchers suggest that these processes cannot be studied in isolation from one another, resulting in hybrid constructs such as motivated attention (Lang, Bradley, & Cuthbert, 1997), attentional effort (Sarter et al., 2006), and motivational inhibition (Derryberry & Tucker, 1994; Nigg, 2003). Regardless of the nuances among these constructs, proponents of these theories generally agree that more attention is directed to motivationally salient cues compared to less important ones (Lang et al., 1997). For the purposes of the present work, we refer to this process generally as motivated attention.

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As in real-world examples, motivation in the laboratory has intrinsic and extrinsic components. For example, more difficult tasks have been conceptualized as more intrinsically motivating than those that are less demanding (Tomporowski & Tinsley, 1996). However, the separation between intrinsic and extrinsic motivation may not be clear-cut. Indeed, Sarter et al. (2006) suggest that extrinsic and intrinsic factors interact with one another. Specifically, any enhancement in attentional effort as a result of increased task demand may be dependent on extrinsic factors. In laboratory-based research, monetary incentives are often used to manipulate an individual's extrinsic motivation. These extrinsic incentives may influence behavior and/or cognition by priming the appetitive motivational system (see Bradley, Codispoti, & Lang, 2006; Libera & Chelazzi, 2006). Because money often motivates real-world behavior, performance-based monetary incentives provide a useful laboratory method for studying the impact of motivation on attention.

The interaction between motivational and attentional processes is evident across a variety of paradigms. Indeed, researchers studying psychopathology are becoming increasingly interested in the role of motivated attention. For example, the interaction of motivation and attention may be central in Attention-Deficit/Hyperactivity Disorder (ADHD; e.g., Luman, Oosterlaan, & Sergeant, 2005) and substance abuse (e.g., Franken, Booij, & van den Brink, 2005). To date, much of the research on motivated attention has examined the role of emotionally salient stimuli in picture-viewing paradigms (e.g., Bradley et al., 2006; Schupp et al., 2004), whereas other work has examined basic cognitive processes measuring visual spatial attention via target detection tasks (e.g., Small et al., 2005) and negative-priming tasks (e.g., Libera & Chelazzi, 2006). Additional methods have included behavioral measures, such as reaction time tasks (e.g., Libera & Chelazzi, 2006) and physiological measures such as heart rate and skin conductance (e.g., Bradley et al., 2006), event-related potentials (ERPs; e.g., Schupp et al., 2004), functional magnetic resonance imaging (fMRI; e.g., Small et al., 2005), and prepulse inhibition (PPI) of the startle eyeblink response (e.g., Hawk, Redford, & Baschnagel, 2002).

The present study utilizes PPI of the startle eyeblink response to investigate motivated attention. PPI has been widely used to investigate early cognitive processes (for a review, see Filion, Dawson, & Schell, 1998). PPI is defined as a decrease in the magnitude of the startle response when a weak, nonstartling stimulus is presented 60–500 ms before the onset of the startle probe. At these short-lead stimulus onset asynchronies (SOAs), PPI is thought to reflect partially automatic protection of processing of sensory stimuli (Graham, 1975). More generally, it has been conceptualized as a sensorimotor gating mechanism that serves a critical inhibitory function for sensory, cognitive, and motor output processing (Braff & Geyer, 1990).

Though PPI does not appear to require conscious awareness, it can be modified by directed attention (see Filion et al., 1998). In the typical tone-discrimination paradigm utilized to measure attentional modification of PPI, participants are presented with a series of tones that serve as prepulses (e.g., Dawson, Hazlett, Filion, Nuechterlein, & Schell, 1993; Filion, Dawson, & Schell, 1993; Schell, Dawon, Hazlett, & Filion, 1995). Participants are asked to attend to tones of one pitch and ignore tones of the other pitch, while counting the number of attended tones that are longer than usual (7 s vs. 5 s). At short-lead SOAs, typically 120 ms, PPI is enhanced during attended prepulses relative to ignored prepulses.

Consistent with broader concepts of motivated attention, attentional modification of startle appears to be influenced by both intrinsic and extrinsic motivational factors (e.g., Hawk et al., 2002; Hazlett, Dawson, Schell, & Nuechterlein, 2001). These processes may be particularly important in PPI research, as the tone discrimination paradigm is often described as a mundane task during which participants listen to a series of 48 to 72 tones that each last between 5 and 7 s, with relatively long intervals of silence in between tones. Indeed, attentional modification of PPI has been observed in the absence of any incentive when a more fast-paced, presumably more intrinsically engaging or motivating continuous performance task was employed (e.g., Hazlett et al., 2001).

To examine extrinsic motivation, participants in the study of Hawk et al. (2002) either received a monetary incentive for task performance or were simply asked to try their best. Attentional modification of PPI at the 120-ms SOA was reliably enhanced among the paid compared to the unpaid group. Based on Dawson, Schell, Swerdlow, and Filion's (1997) model of the tone discrimination paradigm, Hawk et al. suggested that the monetary incentive likely enhanced the allocation of attention once the pitch of the tone was identified and signaled the beginning of the duration discrimination. The authors proposed that the monetary incentive served as an extrinsic motivator that enhanced this controlled attentional processing.

The purpose of the present study was to replicate and extend work examining incentive effects on attentional modification of PPI. Building upon the between-subjects incentive manipulation employed by Hawk et al. (2002), the current study examined the effects of a within-subjects monetary incentive. This is an important type of replication for this work. Because it was not possible to completely rule out preexisting differences in startle modulation in the between-subjects design (Hawk et al., 2002), the within-subjects manipulation provides a clearer demonstration of incentive effects. In addition, the extension to a within-subjects paradigm is important for practical reasons. Providing that the manipulations being employed do not result in carryover effects, a within-subjects design is much more efficient. This is particularly important in studies of clinical groups or medication, clear foci of current work on motivated attention (e.g., Franken et al., 2005).

In previous studies of attentional modification, participants did not receive ongoing information concerning task performance. In the present study, participants were asked to respond to each attended stimulus. To enhance the incentive manipulation, trialwise feedback regarding task performance was provided along with the incentive in one of two blocks of tone discrimination trials during one session. As in prior work with the tone discrimination paradigm, no performance feedback was provided during the no-incentive condition, though the response requirement was still present. We hypothesized that attentional modification would be stronger during the incentive block compared to the no-incentive block.

Trialwise responding reduced the burden on working memory in both incentive conditions, as participants did not need to remember the number of targets throughout the task (cf. Filion et al., 1993; Hawk et al., 2002; Schell, Wynn, Dawson, Sinaii, & Niebala, 2000). It also offered an opportunity to more precisely examine the behavioral data. Specifically, we hypothesized that the incentive would increase the number of correct length discriminations for attended tones (hits) and decrease the number of responses to ignored tones (false alarms). Though this was not a speeded task (i.e., participants were not explicitly asked to respond as quickly as possible), previous work suggests that incentives speed response times (e.g., Slusarek, Velling, Bunk, & Eggers, 2001). Therefore, we also tested the prediction that response time would decrease during the incentive condition relative to the no-incentive condition.

Methods

Participants

Forty-one undergraduate students (22 female, mean age = 20.0, *SD* = 2.8) participated in return for research credit in an introductory psychology course. Although the majority of participants were Caucasian (68%), approximately one quarter were Asian (27%), and the remaining 5% were either African-American (2.6%) or Hispanic (2.4%). Nineteen participants (9 female) received the incentive condition first; the remaining 22 participants (13 female) received the no-incentive condition first. There were no statistically reliable gender, ethnicity, or age differences across incentive order groups (χ^2s < 1). Additional participants were excluded due to outlying EMG data (*n* = 9; see data reduction), poor performance on the task (*n* = 1; see data reduction), and use of psychotropic medication (*n* = 2).

Apparatus

VPM 10.3 software (Cook, Atkinson, & Lang, 1987) running on a Pentium-class computer (Gateway, North Sioux City, SD) controlled the presentation of tone prestimuli and startle probes and sampled the eyeblink EMG and electrocardiogram and skin conductance (autonomic data are not reported). Stimulus parameters were based on earlier work (e.g., Filion et al., 1993; Hawk et al., 2002). Startle probes were 50-ms, 100-dB(A) bursts of white noise with near instantaneous rise/fall times, and prestimuli were 70-dB(A), 800- and 1200-Hz tones with 25-ms rise/fall times. Given that the present study was focused on attentional modification of short-lead PPI, tones were shortened from the typical 5 and 7 s to 2 and 2.5 s. The prepulse tones and startle probes were presented via a Soundblaster 64 AWE Gold sound card, amplified with a Denon (Tokyo) AVR-1400 receiver, and played through matched Telephonics TDH49-P headphones.

The eyeblink startle response was measured electromyographically from orbicularis oculi, using TDE-23 Ag/AgCl surface electrodes (Med Associates, East Fairfield, VT) placed about 1 cm below the pupil and outer canthus of each eye. The electromyogram (EMG) was amplified by Grass Instruments bioamplifiers (7P3/7DA; West Warwick, OH) with half-power cutoff frequencies set to 10 and 500 Hz. Amplifier output was fed to the A/D converter of a Scientific Solutions (Solon, OH) Lab Master DMA interface, which sampled the amplified EMG at 1000 Hz from 50 ms before until 300 ms after the onset of each startle probe.

Procedure

Informed consent was obtained at the beginning of the session. All procedures were conducted in an IAC (Bronx, NY) 2.7- × 2.5-m electrically and acoustically isolated chamber. After the electrodes for EMG eyeblink measurement were attached, the experimenter left the subject room and presented two test startle probes. Next, a series of high and low tones (all 2-s duration) were presented over headphones to ensure consistent pitch discrimination. Finally, a series of 2- and 2.5-s tones of the participant's attended pitch were presented to ensure accurate length discrimination. For both the pitch and length discrimination training, participants were required to make four consecutive correct responses. One participant failed to make the length discrimination and was excluded from the study.

The experimenter returned to the subject room to provide instructions for the task, which were adapted from Filion et al. (1993) and Hawk et al. (2002). During one portion of the task, a monetary incentive for performance was provided, and participants were compensated up to $10. In the other portion of the task (no-incentive condition), participants were asked only to try their best. The order in which the incentive was offered was counterbalanced across participants. For example, a participant randomized to attend to high-pitched tones and receive incentive during the first block would hear the following instructions:

Some of the tones are short, about 2 s long and some of the tones will be longer, about 2.5 s long. Your task will be to decide if the HIGH tones are short or long. So, we only want you to pay attention to the HIGH tones. You can ignore the LOW tones.

When you hear a high tone, you'll need to decide if it was short or long. Every time there is a SHORT, HIGH tone, click the LEFT mouse button (demonstrate). Every time there is a LONG, HIGH tone, click the RIGHT mouse button (demonstrate). The mouse is labeled in case you forget.

As I mentioned before, you will be asked to do this twice: once you can earn money and will receive feedback about your performance. During the other part, you will not earn money, but it's important for you to try your best. For your first session, you *can* earn money. A few seconds after each tone goes off, the computer (point) will let you know if you were correct and whether you earned any money. For example, if you hear a HIGH, SHORT tone, and click the LEFT mouse button, you will earn 50 cents. If you click the RIGHT mouse button, you'll only get 5 cents. If you hear a HIGH, LONG tone, and click the RIGHT mouse button, you will earn 50 cents. If you click the LEFT mouse button, you'll only get 5 cents. If you hear a LOW tone, don't click anything; you won't gain or lose any money.

Following tone offset, participants had a 3-s window in which to respond to the tone. During the incentive block, a Princeton (Santa Ana, CA) Arcadia AR2.7AV monitor (69-cm diagonal screen) located 1.5 m in front of the participant presented trialwise feedback via E-Prime (Psychology Software Tools, Pittsburgh, PA). Feedback regarding the amount of money earned on each attended tone trial appeared in a black box in the center of the screen for 2 s after the response window ended. The small ($.05) incentive for responding to an attended pitch but incorrectly judging tone duration was included to reinforce responding to all attended tones, even when uncertain of duration; the larger incentive for correct length discriminations emphasized the importance of accurate performance. Participants did not lose money for failing to respond to an attended tone (i.e., no response cost) and only an empty box appeared in the center of the screen. On ignored tone trials, the empty box appeared in the center of the screen regardless of the participant's response.

During the no-incentive block, participants were told that they would not earn or lose money, but were provided with the instruction: “For the information that we collect from you to be useful, it's crucial that you try your best.” Though no performance feedback was provided, a box with an asterisk in the center was presented on the computer monitor for 2 s to maintain a comparable trial structure.

Participants completed two blocks (incentive and no-incentive) of 40 tones (20 high, 20 low). Within each block and pitch, half of the tones were short (2 s) and half were long (2.5 s). Bilateral startle eyeblink EMG responses to startle probes presented at 60-, 120-, and 180-ms prepulse-probe SOAs were assessed on 75% of trials. Based on previous work (e.g., Hawk, Yartz, Pelham, & Lock, 2003), the typical 240-ms SOA was replaced with a 180-ms SOA to detect possible attentional modification beyond the 120-ms SOA. The remaining trials were either no startle trials (five trials per block) or included a startle probe during the intertrial interval (ITI; five trials per block). The ITI ranged from 23 to 37 s, with an average ITI of 30 s.

Tones were intermixed with constraints such that there were (a) three or fewer consecutive tones of one pitch, (b) three or fewer consecutive alterations of low and high tones (e.g., LHLHLH or LLHHLL), (c) three or fewer consecutive tones of one length, and (d) no two consecutive trials with the same SOA. Ten pseudorandom orders of stimuli were used to counterbalance across participants the sequence of SOAs and tone pitches, as well as the attended pitch.

Data Reduction and Analysis

Startle responses were digitally integrated off-line (rectified, low-pass filtered with a 50-ms time constant, and high-pass filtered with 30 Hz cutoff; van Boxtel, Boelhouwer, & Bos, 1998), and scored using the computer program of Balaban, Losito, Simons, and Graham

(1986; i.e., onset latency window of 21–120 ms, maximum onset to peak duration of 120 ms, and maximum peak latency of 150 ms; minimum response criterion = 0.6 μV). As in previous work (e.g., Hawk et al., 2002, 2003), trials were also excluded on the basis of excessive baseline range if (a) baseline range exceeded 2 μV or (b) baseline range was 1–2 μV and response magnitude was < 5 times the baseline range. Using these criteria, 8.2% of right eye responses and 10.3% of left eye responses were excluded. If baseline range was between 0 and 1 μV and the response magnitude was less than the baseline range, the magnitude was set to 0.

For each SOA (60, 120, 180 ms) × Attend (attended pitch vs. ignored pitch) × Incentive (incentive vs. no-incentive) × Eye cell of the design, eyeblink EMG magnitude subject averages were used to compute percent inhibition, relative to ITI startle magnitude ($[(M_{prepulse\_trials} - M_{ITI\_trials})/(M_{ITI\_trials})] \times -100$, where, given the importance of this baseline, participants with a mean ITI startle magnitude below the minimum response threshold [*n* = 2] were excluded). For each condition, an average was considered an outlier when it exceeded SPSS boxplot criteria for extreme outliers: greater than three times the interquartile range above the 75th percentile (SPSS, 2005). For subjects with no outlying averages, percent modification scores were averaged across right and left eyes. If one or more outliers were evident at only one eye, then data for the other eye were retained for final analyses. If the data for both eyes contained outlying values, then the participant's data were excluded from the final analyses (*n* = 7).

Percent PPI was analyzed by ANOVA. Incentive order (incentive block first vs. no-incentive block first) was a between-subjects factor. Incentive (incentive vs. no-incentive), SOA (60, 120, 180 ms), and attend (attend vs. ignore) were within-subjects factors. To correct for violation of the sphericity assumption in testing effects involving SOA, Huynh–Feldt epsilon adjustments were used (Huynh & Feldt, 1970). Interactions were followed up with simple effects analyses. ITI startle magnitude was examined via ANOVA, with incentive and incentive order in the model.[1]

For the performance data, the number of hits (attended tones with correct length judgments; maximum = 20), hit response time, and false alarms were analyzed by ANOVA, with incentive (incentive v. no-incentive) as a within-subjects factor and incentive order (incentive first v. incentive second) as a between-subjects factor. One participant was excluded from the study due to task performance (hits) that was more than three standard deviations below the mean.

Results

ITI Startle Magnitude

ITI startle magnitude did not reliably vary between the incentive (*M* = 20.6 μV, *SD* = 3) and no-incentive (*M* = 19.4 μV, *SD* = 3.2) conditions, $F < 1$. However, there was a statistically reliable Incentive × Incentive Order interaction, $F(1,39) = 37$, $p < .01$. Inspecting the pattern of means suggested that this crossed interaction simply reflected habituation. That is, regardless of whether participants received incentive or no incentive first, startles responses decreased from the first block (*M* = 23.9 μV, *SD* = 3.4) to the second block (*M* = 16.1 μV, *SD* = 2.6).

Attentional Modification of Startle

Mean percent prepulse inhibition for all SOA × Attend × Incentive conditions are presented in Figure 1. The predicted SOA × Attend × Incentive interaction was statistically reliable, $F(2,78) = 3.5$, $p < .05$, $\varepsilon = .74$. As expected, simple effects tests revealed that reliable enhancement of PPI during attended compared to ignored prestimuli during the incentive

[1]In supplementary analyses, sex was examined as a between-subjects factor. Because no reliable sex differences were found, sex is not further considered or included in the primary analyses. There was a marginal four-way SOA × Incentive × Incentive Order × Sex interaction ($p = .07$). However, this test may not have been sufficiently powered, given that some cells had fewer than 10 participants.

condition was statistically significant only at the 120-ms SOA, $F(1,39) = 7.6$, $p < .01$. Though the means were in the hypothesized direction at the 180-ms SOA, this difference was not statistically significant, $F(1,39) = 2.4$, $p = .13$. The means at the 60-ms SOA were opposite the hypothesized direction, though this difference was not statistically reliable, $p = .22$. There was no evidence of statistically significant attentional modification during the no-incentive condition. Means for attended and ignored stimuli at the 60- and 120-ms SOAs were nearly identical, *F*s < 1 and means at the 180-ms SOA were opposite the hypothesized direction, though not reliably different from one another, $p = .11$.

To further understand the nature of the interaction, supplemental analyses comparing the no-incentive and incentive conditions at the 120-ms SOA suggested that there was a marginal increase in PPI during attended tones, $F(1,39) = 3.2$, $p = .08$, but no change during the ignored tones, $F < 1$.

Percent prepulse inhibition did not vary significantly by incentive order group, $F(1,39) = 3.4$, $p = .08$ nor were any interactions with incentive order statistically significant, *ps* > .15.

Task Performance

Number of hits—Table 1 presents performance data for all Incentive × Incentive Order conditions. Overall, task performance was generally strong. As predicted, the number of hits tended to be higher during the incentive block (16.8) compared to the no-incentive block (15.9), incentive $F(1,39) = 3.5$, $p = .07$. However, a marginal Incentive × Incentive Order interaction, $F(1,39) = 3.0$, $p = .09$, provided a clearer understanding of the performance data. For those who received incentive in the second block, hits improved from the no-incentive to the incentive block, as predicted, $F(1,39) = 7.0$, $p <. 02$. Among those who received the incentive first, performance was strong in the incentive block but did not decline in the no-incentive block, $F < 1$.

Hit response time—Incentive effects on response time to hits varied between incentive orders, Incentive × Incentive order, $F(1,39) = 7.3$, $p = .01$ (see Table 1). Follow-up tests revealed a pattern consistent with the findings for number of hits. Those who received no-incentive first demonstrated reliably faster response times to attended stimuli during the incentive block, $F(1,39) = 9.5$, $p < .01$, whereas those who received incentive first showed no change across conditions, $F < 1$.

False alarms—As can be seen in Table 1, the number of false alarms, responses to to-be-ignored tones, was very low and did not vary reliably with incentive, order, or their interaction, *ps* > .16.

Discussion

The purpose of the current study was to examine motivated attention using prepulse inhibition of acoustic startle. Specifically, we aimed to replicate work demonstrating that incentives enhance attentional modification of PPI (Hawk et al., 2002) and to extend this finding to a within-subjects design. Participants completed a variation of the typical tone discrimination paradigm in two task blocks. Performance-based monetary incentives and trialwise performance feedback were provided in one block; no incentives or feedback were provided in the other block. Below we discuss the findings and implications of our eyeblink and performance data, and we consider study design features such as the provision of trialwise feedback and the absence of response cost.

The present findings provide support for the hypothesis that attentional modification of prepulse inhibition of startle is sensitive to motivational incentives. Indeed, when participants were provided a compound incentive—the opportunity to earn money and feedback regarding performance—prepulse inhibition to attended tones was reliably greater compared to ignored tones at the typical 120-ms SOA. In contrast, when participants were asked to “try their best,” there was no evidence for statistically reliable attentional modification of startle. These data suggest that when the stimuli were made motivationally significant participants allocated more attentional resources. These findings replicated prior work on incentives and PPI using a between-subjects design (e.g., Hawk et al., 2002) and extend this finding to a within-subjects design. This work is more broadly consistent with theories of motivated attention (e.g., Lang et al., 1997), attentional effort (e.g., Sarter et al., 2006), and motivational inhibition (e.g., Derryberry & Tucker, 1994; Nigg, 2003), which suggest that stimuli that are motivationally salient, either because of their survival value or because of explicit pairing with reinforcers or punishers, garner greater cognitive resources.

The nature of those resources is important to consider. Dawson and colleagues (1997) have proposed a model for the processes involved in the tone discrimination paradigm. Once the tone is detected and the pitch determined (Step 1), resources are allocated to attended stimuli and the duration discrimination begins (Step 2). In the third step, attention to the attended stimulus is sustained (Dawson et al., 1997, p. 260). Hawk and colleagues (2002) suggested that the monetary incentive likely enhances the allocation of attention once the pitch of the tone is identified and signals the beginning of the length discrimination (Step 2). In other words, the monetary incentive serves as an extrinsic motivational factor that increases relatively early controlled attentional processing. Findings from the current study further support this hypothesis. That is, attentional modification was observed at 120 ms. Although the means were in the direction of attentional modification at 180 ms, the effect was not statistically reliable. This suggests that once sustained attention is under way, the attentional modification of PPI begins to diminish, perhaps due to the beginning of long-lead prepulse facilitation (Dawson et al., 1997). Nevertheless, SOAs between the typical 120- and 240-ms SOAs may be useful for tracking the time course of attentional modification and may be more sensitive to attentional modification in patient samples in whom the process may be somewhat delayed (e.g., Schell et al., 1995; see also Hawk et al., 2003).

In addition to the issue of the time course of attentional modification, there is ongoing discussion regarding the type of attentional process involved. Specifically, it is unclear whether attentional modification of PPI is due to increased processing of attended prestimuli, decreased processing of ignored prestimuli, or both. Initially, attentional modification was discussed as enhanced protection of important or salient to-be-attended stimuli at 120 ms, relative to other SOAs (e.g., Filion et al., 1993). Similarly, a comparison of task and no-task protocols suggested that differential blink responding was driven primarily by an increase in PPI to attended stimuli (Thorne, Dawson, & Schell, 2005). However, attentional modification has also been found to be due to decreased PPI during ignored prestimuli (e.g., Schell et al., 2000, Experiment 2), and other studies have demonstrated both increased PPI to attended and decreased PPI to ignored prestimuli (Hawk et al., 2002, 2003). Data from the current study appear to support the hypothesis that attentional modification is due to increased processing (i.e., increased PPI) of attended tones (Filion et al., 1993; Thorne et al., 2005). That is, supplemental analysis of PPI at the 120-ms SOA revealed a marginal increase during attended tones in the incentive condition compared to the no-incentive condition, but no difference during the ignored tones.

However, it is not clear why the present study did not replicate the finding of a decrease in processing of ignored stimuli observed in the earlier incentive work (Hawk et al., 2002). Although there are a number of differences between the two paradigms, the presence or absence of response cost for false alarms to ignored stimuli seems particularly germane. To our knowledge, the present study is the first in the PPI literature to use only positive reinforcement. Perhaps the consequence of losing money for responding to an ignored tone results in earlier or more robust reductions in the processing of that stimulus. Manipulation of mixed reinforcement and response cost contingencies may shed light on this issue. Understanding the nature of the specific processes involved in attentional modification is important in its own right and may improve our ability to examine the relative roles of screening out irrelevant stimuli (i.e., decrease processing of ignored tones) or attending to relevant stimuli (i.e., increase processing of attended tones) in schizophrenia, ADHD, and other psychological disorders. Moreover, given the relevance of reinforcement and motivated attention to psychopathology (e.g., ADHD, Luman et al., 2005; Pelham & Hinshaw, 1992; substance abuse, e.g., Franken et al., 2005; Higgins, Budney, & Bickel, 1994), studies manipulating reinforcement schedules or graded incentives should be of interest to both basic and applied researchers.

Reinforcement of task performance was delivered in the form of trialwise feedback in the present study. This type of compound incentive is unusual in the tone discrimination work, in which participants typically report the number of targets at the end of the study (e.g., Filion et al., 1993; Hawk et al., 2002). However, it was useful both for tracking performance and for providing more immediate reinforcement.

One concern we had regarding the feedback was that it could lead to carryover effects. That is, if the feedback promoted learning the task, then incentive effects would be reduced or eliminated among participants who received the incentive first. Importantly, the incentive effect on attentional modification of PPI did not vary between the two incentive orders. However, task performance, in the form of both number of hits and hit response time, was influenced by incentive order. As predicted, participants who received no incentive first identified more hits and responded more quickly on hit trials in the subsequent incentive block (see Table 1). The incentive block performance was comparable to that of the incentive-first group. However, when the incentive-first group went into the no-incentive block (their second block), the number and speed of their hits did not decrease. Together, these data suggest that when incentive was provided in the first block participants learned the task well and that this learning carried over to the second block, despite the absence of the incentive and feedback. In contrast, when no incentive or information was provided during the first block, participants appeared to have more difficulty learning the task. Although the relatively low number of misses and the limited number of trial blocks preclude a tighter examination of any specific learning hypothesis, the present findings are consistent with a learning account. These data are also broadly consistent with evidence that incentives only enhance task performance in the presence of precise information, relative to more ambiguous information (Kotani et al., 2003). Therefore, it seems reasonable to hypothesize that performance-based feedback may partially explain the increase in performance for those in the no-incentive first group.

Across studies, we have observed incentive effects on attentional modification of PPI both with and without feedback. However, only in the present study were any incentive effects observed on task performance (cf. Hawk et al., 2002). Given the use of a compound incentive in the present work, we cannot determine whether feedback uniquely affected attentional modification beyond the monetary incentive. It will be interesting for future work to directly evaluate the relative contributions of feedback and monetary incentives, both of which may have motivational properties.

Trialwise feedback coupled with the requirement that participants respond to each attended tone may have additional implications for attentional modification studies. In the typical tone discrimination paradigm, participants count the number of longer-than-usual attended tones and report this number at the conclusion of the session (e.g., Dawson et al., 1993; Schell et al., 2000). Some postulate that PPI is stronger when participants are required to encode information in working memory for later recall (Neumann, 2007). Because participants in the present study were not required to encode the number of target tones, the demands on working memory may have been reduced. Yet, attentional modification was still evident, at least in the incentive condition. Nevertheless, it is often difficult to fully separate working memory and attention in a single paradigm (e.g., Tannock, 1998), and findings from a recent study of children with ADHD support the prediction that incentives enhance some aspects of working memory (Shiels, Hawk, Lyczek, Tannock, & Pelham, 2007). Given that both early selective attention and working memory, as well as related processes (e.g., response inhibition; Slusarek et al., 2001), are sensitive to incentives, future work would benefit from the inclusion of measures of both selective attention and working memory within the same study to better examine the impact of incentives on these cognitive processes.

Finally, the present study has focused on the effects of extrinsic motivation on attentional modification of PPI. It seems important for future work to give greater consideration to intrinsic motivation as well (e.g., Sarter et al., 2006). Indeed, a limitation of the present study is that we did not assess participant's self-reported interest in, or motivation to successfully complete, the tone discrimination task (though Hawk et al., 2002, did assess these constructs and found no incentive group differences). Relatedly, future studies may benefit from considering individual differences in intrinsic motivation as potential moderators of attention and the effects of extrinsic incentives on attention. For example, extrinsic incentives may have their greatest effects on cognitive processing among individuals with a low “need for cognition” (Cacioppo, Petty, & Kao, 1984) or who are low in personality dimensions such as conscientiousness (e.g., Pailing & Segalowitz, 2004). Additionally, individuals high in dispositional sensitivity to reward (Torrubia, Avila, Molto, & Caseras, 2001) may exhibit stronger incentive effects on attention.

In summary, the present study replicates earlier work demonstrating incentive effects on attentional modification of prepulse inhibition and extends this finding into a within-subjects paradigm in which a number of task parameters (e.g., tone duration, performance feedback) were modified from the typical tone discrimination paradigm. The present work raises interesting further questions regarding the relative roles of the type of extrinsic consequences (e.g., feedback vs. money) and the role of intrinsic motivation. Nonetheless, the current paradigm appears relatively well suited for testing hypotheses regarding motivated attention in psychopathology and psychopharmacology.

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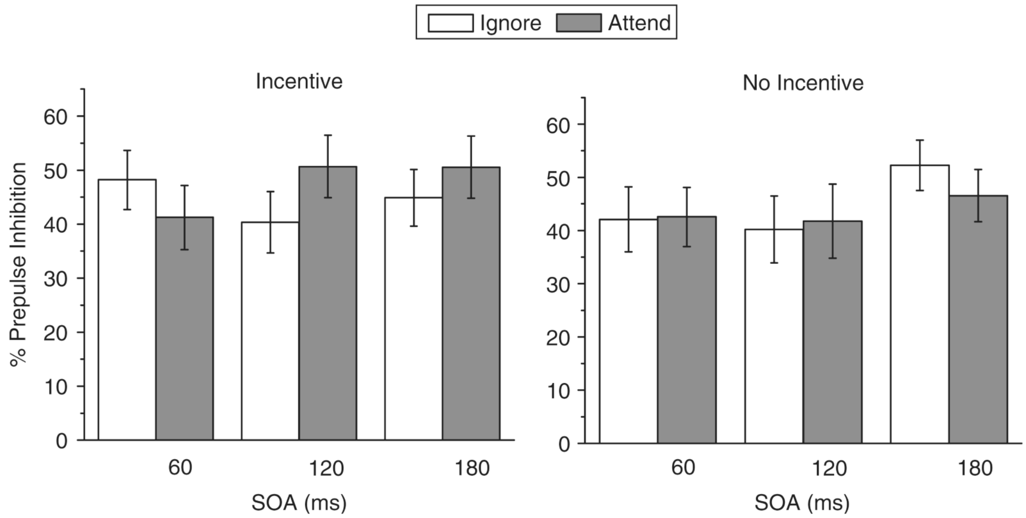

Figure 1.
Mean percent prepulse inhibition for all SOA × Attend × Incentive conditions.

Table 1

Performance Data for All Incentive Order × Incentive Conditions

	Incentive order group			
	Incentive first		No-incentive first	
Measure	**Incentive**	**No incentive**	**Incentive**	**No incentive**
Hits	16.6 (2.4)	16.6 (3.1)	17.0 (2.2)	15.4 (2.4)
Response time	623.8 (225.1)	586.3 (168.2)	615.5 (199.0)	743.1 (242.4)
False alarms	1.4 (4.0)	0.9 (3.2)	0.5 (1.1)	0.7 (1.5)

Note. Values are means (standard deviation).