SUBLIMINAL PRIMING AS A TASK-CHARACTERISTIC ARTIFACT

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by
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The Undersigned appointed by the Dean of the Graduate School, have examined the thesis entitled,

SUBLIMINAL PRIMING AS A TASK-CHARACTERISTIC ARTIFACT

Presented by Michael S. Pratte,

A candidate for the degree Master of Arts,

And hereby certify that in their opinion it is worthy of acceptance.

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ABSTRACT

Demonstrations of subliminal priming rely on a dual task design: A target identification task in which the priming effect is measured, and a prime identification task in which visibility of the primes is assessed. The validity of this design relies on the critical assumption that the estimates of prime visibility accurately reflect prime visibility in the target identification task. Here it is suggested that the difference in difficulty between the two tasks results in a violation of this assumption. Specifically, the target identification task is easy while the prime identification task is extremely difficult. It is shown that decreasing the overall difficulty of the prime identification task results in increased prime identifiability. It is also shown that primes which are unable to be identified in a task which accurately estimates prime identifiability do not elicit a priming effect. Hence, we conclude that demonstrations of subliminal priming are an artifact of this violation rather than a real phenomenon.

Introduction

Priming is said to occur when the presentation of a prime stimulus affects the processing of a subsequently presented target stimulus. Many researchers have claimed that priming can occur subliminally; i.e., primes that are presented so quickly that they can not be identified will nevertheless affect processing of a target. To demonstrate this effect, researchers often utilize a dual-task design. In the first task, participants identify the targets. In the second task, participants identify the primes. Subliminal priming occurs if: 1) The identity of primes affects target identification, and 2) Participants are unable to accurately identify the primes.

In one type of subliminal priming, single-digit numbers serve as primes and targets, termed subliminal *number* priming (e.g., Dehaene et al., 1998). In a subliminal number priming experiment, a prime digit is presented for a short duration and followed by a pattern mask to make it difficult to see. Following the mask is a clearly visible target digit (see Figure 1). Participants first perform a target identification task in which they judge whether the target is less-than or greater-than 5. The main manipulation is whether primes and targets fall on the same side of 5 (and thus elicit the same response, termed *congruent* trials) or different sides of 5 (termed *incongruent* trials). Priming is said to occur when responses to targets are faster to congruent trials than incongruent trials. In the prime identification task, participants judge whether the primes are greater or less-than 5. If participants' accuracy in this task does not differ from chance, then any priming effect found in the target identification task is considered subliminal.

Subliminal priming has also been investigated using simple perceptual stimuli. Vorberg et al. (2003), for example, demonstrated subliminal priming using left and

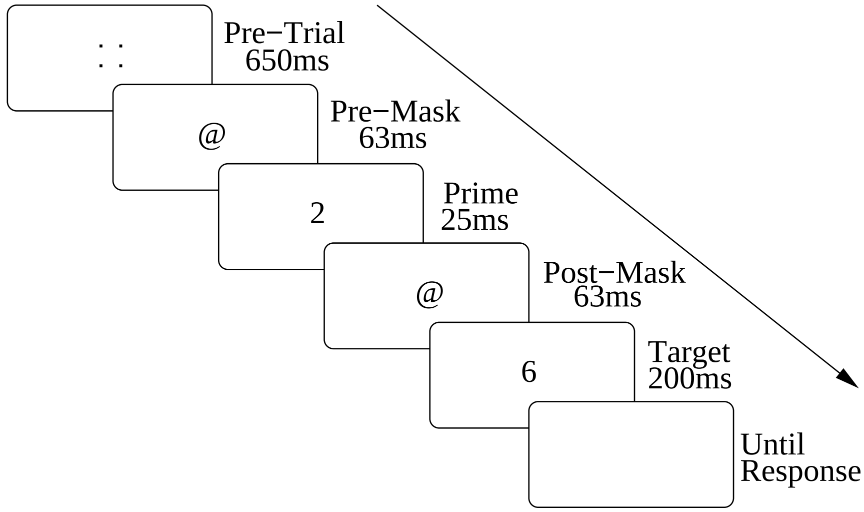

Figure 1. Incongruent trial in a subliminal number priming task.

right pointing arrows as primes and targets. The orientations of target arrows were identified more quickly in congruent trials (i.e., when prime and target arrows share the same orientation) than in incongruent trials. This priming effect occurred even though participants were unable to identify the orientation of the prime arrows with greater than chance accuracy. This effect is termed *perceptual* subliminal priming, as it can result from low-level perceptual analysis of the prime arrows. Demonstrations of *semantic* subliminal priming are even more impressive. In these experiments, prime-target pairs are either semantically related or unrelated words. Although participants are unable to identify the prime words, targets are identified faster when they are semantically related to the prime. (e.g., Draine & Greenwald, 1998). This result suggests that the meaning of a word can be processed and affect subsequent behavior, even though the identity of the word is not consciously available. Whether or not number priming reflects semantic priming is widely debated. However, it certainly involves richer analysis of the primes than simple perceptual processing (see Klauer et al., 2007 for a review).

The methodology used to demonstrate subliminal priming has been critiqued on both psychological (e.g., Merikle & Reingold, 1998, Reingold & Merikle, 1988) and statistical grounds (e.g., Dousher, 1998; Rouder et al., in press). Recent work in cognition that supports the existence of subliminal priming, however, ignores many of these critiques. Instead, subliminal priming is assumed to exist while more subtle questions concerning the nature of the effect are investigated. For example, whether subliminal number and word priming reflects semantic processing of the primes or some other subliminal process has been widely debated over the past decade (Klauer et al., 2007). Other examples include the use of electrophysiological and brain imaging techniques to study the neurological locus of subliminal priming (e.g., Dehaene et al., 1998) and the timecourse of the effect (e.g., Greenwald et al., 1996)

In other areas of psychology, subliminal priming is also assumed to exist, and is used for theory building and testing. For example, emotional processing is commonly assessed with subliminal priming (Arndt et al., 2001; Mather et al., 2004; Naccache et al., 2005; Ohman, 2002; Sato & Aoki, 2006; Whalen et al., 1998). Subliminal priming is also utilized in the clinical literature to explore a variety of pathologies (Aron et al., 2003; Dannlowski et al., 2006; Kamio et al., 2006; Lim & Kim, 2005; Seiss & Praamstra, 2004; Seiss & Praamstra, 2006; Suslow et al., 2003). Given the widespread use of subliminal priming, we believe that the methods used to support its existence merit close inspection.

There have been many demonstrations of subliminal priming that utilize the dual-task design (i.e., a target identification task followed by a prime identification task). This design relies on a critical assumption: participants' abilities to identify the primes are the same in the target and prime identification tasks (Reingold & Merikle, 1988). If participants were able to identify the primes in the target identification task and unable to in the prime identification task, then a priming effect arising from visible primes would appear subliminal. This situation may arise whenever there is a difference between the prime and target identification tasks.

Many types of differences between the prime and target identification tasks can result in a difference in prime identifiability between the tasks. For example, primes could be presented brightly during the target identification task and dimly in the prime identification task. This difference would result in a priming effect from the bright primes which would appear subliminal if participants could not identify the dim primes. Although such a drastic difference is artificial, less obvious differences have been shown to affect prime identifiability in the two tasks. For example, McCauley et al. (1980) did not present target stimuli during the prime identification task. Purcell et al. (1983) later showed that primes are more identifiable when the target is present than when it is absent. As a result, primes were more visible in the target identification task, when the priming effect was measured, than in the prime identification task. Such task differences lead to a priming effect resulting from visible primes, which falsely appears subliminal.

We suggest that a more subtle difference between the prime and target identification tasks may result in a difference in prime identifiability between the tasks. While serving as participants in a subliminal priming experiment, we immediately became aware that a great deal of effort was required to maintain attention and motivation to perform well during the prime identification task. The target identification task, however, did not impose such a demand. In the target identification task, it is not necessary to expend much effort to perform well. Alternatively, in the prime identification task performance will be poor (though not necessarily at chance) regardless of how much effort is expended to perform well in the task. This difference in task difficulty may result in high levels of attention and motivation to perform well during the target identification task, and low attention and motivation during the prime identification task.

If motivation and attention are high during the target identification task and low during the prime identification task, estimates of prime identifiability as measured in the prime identification task may be lower than prime identifiability in the target identification task.[1] This situation will result in a priming effect from visible primes which appears subliminal.

Beyond the difference in task difficulty, another characteristic of the dual-task design may result in low motivation to perform well in the prime identification task. Most experiments begin with the target identification task. After completing this task, participants are asked whether they noticed the prime stimuli. Typically, participants report no awareness of the primes. They are then asked to identify those primes which they have just reported no awareness of. This situation may lead participants to begin the prime identification task with the belief that they are unable to see the primes, and that the experimenter expects them to perform poorly on the prime identification task. These beliefs will result in low motivation to perform well in the prime identification task. As a result, prime identification performance will underestimate participant's true abilities to identify the primes.

We propose a test to determine whether the difficulty of the prime identification task leads to an underestimation of prime identifiability. In this test, some participants perform a typical prime identification task in which all primes are weakly visible. Others perform a task in which the same weakly visible primes are intermixed with visible primes. Including visible primes in the prime identification task will make the overall task less difficult. Presenting visible primes will also violate participants' belief that they are unable to see the primes, and that the experimenter expects poor performance. If our concerns of underestimating prime identifiability

[1] We assume that overall attention and motivation in a task will determine the levels of attention and motivation during each part of that task. The result is that attention will be high during prime presentation in the target identification task, when overall attention is high, and will be low in the prime identification task, when overall attention is low.

are correct, then identification accuracy for weakly visible primes should be higher when they are intermixed with visible primes than when they are presented alone.

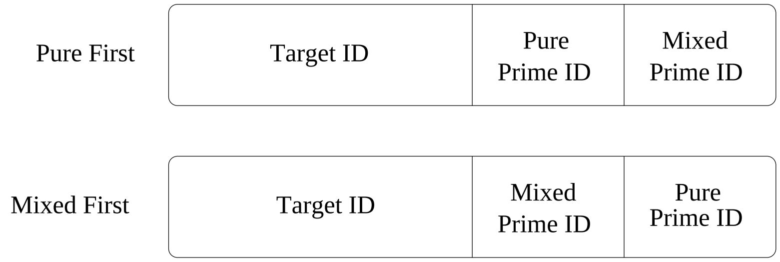

Figure 2. Design of Experiment 1. All participants first performed a target identification task. Half of the participants then performed a pure prime identification task followed by a mixed prime identification task; the remaining participants performed the reverse order.

Experiment 1

In Experiment 1, the effect of presenting visible primes with weakly visible ones was tested. All participants began by performing a target identification task with only weakly visible primes. Some participants then performed a prime identification task in which all primes were weakly visible (termed a *pure* task), followed by a prime identification task in which half of the primes were weakly visible, and half were clearly visible (termed a *mixed* task). The remaining participants began the prime identification session with a mixed task, followed by a pure task (Figure 2). After completing all three tasks, participants were asked to rate how motivated they were to perform well in the target, pure prime, and mixed prime identification tasks. We expect identification accuracy for the weakly visible prime and self-reported motivation to be higher in the mixed tasks than in the pure tasks.

Methods

Participants. Forty-four University of Missouri students participated in Experiment 1 as part of a course requirement.

Apparatus and Stimuli. The digits 2, 3, 4, 6, 7, and 8 served as targets. Prime stimuli consisted of the same digits used as targets and a blank field. Including a blank field allows for estimation of participants' bias for one response over the other in the prime identification task. The experiments were implemented on a Pentium IV PC-compatible computer running MS-DOS. The displays were 17-inch Dell CRTs programmed for a 800 pixel by 600 pixel resolution. The refresh rates of the displays were set at 80 hz to achieve a prime duration of 25ms. Stimuli were displayed in an 18 point Fixedsys font. Stimulus display and data collection were controlled by a custom-written set of C routines.

It is important that the prime stimuli and masks are displayed for the correct duration across all trials to ensure that some trials do not display more or less visible primes than intended. This situation can occur when the system is unable to write a frame to the screen quickly enough, resulting in the the skipping of that frame. Skipping a prime frame will result in its being displayed for half of the intended time, whereas skipping the mask frame after the prime can degrade the effectiveness of the mask. We employed two checks to ensure the integrity of our system. The first was an internal software check which recorded whether any frames were skipped on each trial of the experiment. To perform an independent check of the system, a photoresistor was attached to a monitor. Stimuli similar to those used in an experimental trial were displayed continuously for 10 hours while a separate computer recorded the voltage output of the photoresistor. This analysis revealed that the number of recorded voltage spikes matched the number of frames that were intended to be displayed. This independent check of our system strongly suggests that our hardware and software are able to accurately display stimuli for the duration intended.

Procedure. The structure of trials and the duration of each stimulus is shown in Figure 1. Primes and targets were randomized across all trials and participants.

For each participant, 43% of the trials were congruent, 43% were incongruent, and 14% were neutral (no prime) across the entire experiment. Participants began Experiment 1 by performing 8 blocks (84 rials each) of target identification in which all primes were presented for 25ms. In this task participants were instructed to identify "the number" as greater or less than 5 with both speed and accuracy. Responses were made using the "z" (less than) and "?" (greater than) keys on a standard keyboard. Participants were instructed that they would be presented with the fixation points, an @ symbol, and a clearly visible number which was to be identified. Participants were not informed of the presence of the primes at this time. After the target identification task, participants were fully informed of the prime stimulus, and performed 8 blocks of the prime identification task. Half of the participants began by performing 4 blocks of a *pure* prime-identification task in which all primes were presented for 25ms. Following a short break, they then performed 4 blocks of a *mixed* prime-identification task in which half of the primes were presented for 25ms and half for 100ms. Prime duration was randomized across mixed blocks and participants. The remaining participants began with 4 blocks of a mixed prime-identification task, followed by 4 blocks of a pure prime-identification task (see Figure 2). After completing the second prime-identification task, all participants completed a survey assessing their motivation to perform well on each of the three tasks they had completed (see Appendix).

Results

Priming Effect. One participant's data were not analyzed due to a failure to follow task instructions. Since prime and target stimuli were presented randomly, they were the same digit on about 15% of the trials. Although the effect of perceptually identical prime-target pairs is interesting, it may result from perceptual processes as opposed to semantic analysis of the primes (Dehaene et al., 1998; VanOpstal et al., 2005). As we are interested in number priming as a semantic priming effect, only trials in which the prime and target were different numbers were analyzed.

Another conventional step in analysis involves defining a range of RTs which is believed to capture only the processes of interest. For example, if a participant answered their cellular phone during the task, we would not want to include this time in our analysis of the priming effect. Using a common range of 200 to 1500ms (e.g., Kunde et al., 2003), 1.1% of trials were removed. Analysis of the priming effect is also restricted to trials in which a correct response was given (95%). In the remaining trials, targets preceeded by congruent primes were identified 11ms faster than targets preceded by incongruent primes ($t(42) = 4.88$, $p < .0001$). Although the effect is small (Cohen's d=.14), it is similar to that found in other studies (e.g., Van Opstal et al., 2005; Draine & Greenwald, 1998; Forster, 1998).

While choosing a range of RTs is a commonly accepted practice, our data indicates that the magnitude and variance of the priming effect depends crucially on the choice of bounds. Specifically, the size of the priming effect increases and the variance of the effect decreases as lower upper bounds are chosen. This result is especially troubling as different bounds are used across experiments. Common ranges include 0 to 1200ms (e.g., Kouider & Dupoux, 2004), 250 to 1000ms (e.g., Naccache & Dehaene, 2001), and including only those responses which fall within two standard deviations of each participant's mean (Kemp-Wheeler & Hill, 1988). This situation renders interpretation of mean priming effects obtained from arbitrarily censored data inappropriate.

To circumvent the problem of choosing bounds, we investigated the priming effect across a range of RTs by the method of percentile averaging[2]. This method entails calculating the $10, 20, ..., 90\%$ percentiles for each participant's RT in each

[2] This type of analysis has also been used by Greenwald et al. (2003) and Eimer (1999), although for different purposes.

condition. Each percentile for the congruent condition is then subtracted from each percentile for the incongruent condition, yielding a priming effect for each percentile and participant. The percentiled effects for each participant are displayed in the top-right panel of Figure 3. That almost all participants have a positive priming effect across a range of RTs provides strong evidence of priming. The average of these effects over participants is shown in the upper-left panel of Figure 3. This analysis reveals that the priming effect is greatest for the fastest responses, and gradually decreases as responses become slower. In addition, the variance of the effect increases with RT. As a result, the priming effect will appear larger and more significant as lower upper bounds are chosen.

Prime Identifiability. Four participants failed to complete the second prime identification task. Interestingly, three of these participants began with the pure task and all four remained seated in the room for about 15 minutes, but failed to continue the task. That participants would rather do nothing than complete the prime identification task exemplifies how difficult it is to maintain motivation during the task. These participants' performance on the prime identification tasks will not be analyzed; the results do not change if the tasks they completed are included.

Easily visible (100ms) primes were identified with 85% accuracy when the mixed task was performed first, and 76% accuracy when the mixed task was performed second. Prime identification accuracies for the 25ms primes are presented in the bottom-left panel of Figure 3. These scores were subjected to an ANOVA with block type (pure vs. mixed) as a within-subjects factor, and order (pure first vs. mixed first) as a between-subjects factor. The analysis revealed that identification accuracy in a mixed task is significantly higher than in a pure task ($F(1, 37) = 17.85$, $p < .01$).[3] There was no main effect of order, or an interaction between block type and order.

[3]These results do not change if the ANOVA is performed on the arcsin square root transform of accuracy scores.

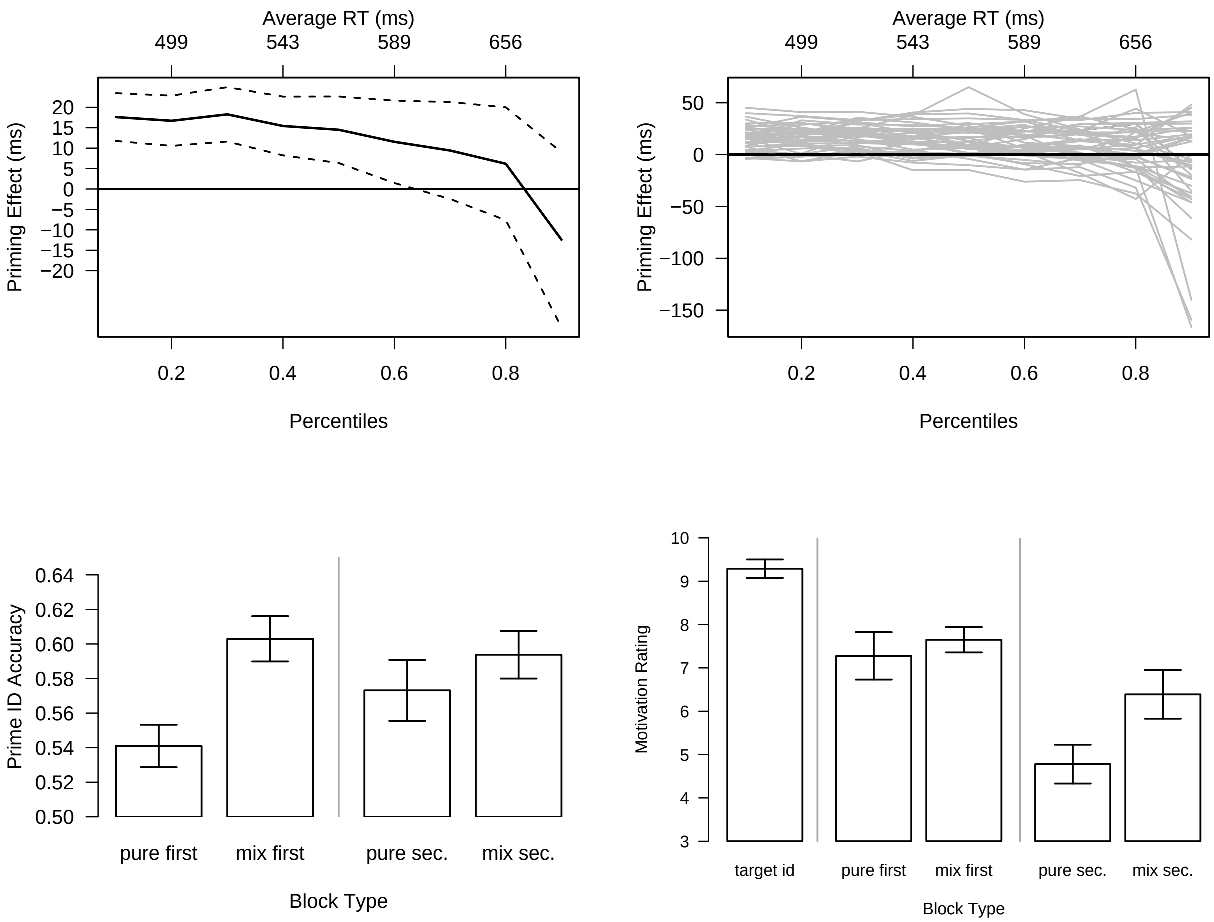

Figure 3. (Top-left) Percentiled priming effects averaged over participants considering RTs between 200 and 3000ms. Including RTs up to 3000ms reveals the magnitude and variance of the priming effect for RTs considered in experiments which use a high upper bound. Dotted lines are the standard errors for each percentile. (Top-right) Percentiled priming effects for each participant considering all RTs between 200 and 3000ms. (Bottom-left) Prime identification accuracies for 25ms primes with SEs. (Bottom-right) Motivation survey scores with SEs.

Although the interaction was not significant, accuracy in the pure task was higher when it was performed after a mixed block, than when it was performed first. This may be due to increased motivation after completing a mixed task. Alternatively, it may be that a mixed task provides participants with perceptual information about the primes, allowing them to perform better in the subsequent pure task. This possibility is addressed in Experiment 2.

If participants are biased to one response over the other, or are able to identify some items better than others, then accuracy may be an inappropriate measure of prime identifiability. To test for bias and differences in item identifiability, the model in Figure 4 was fit to the data from the pure task when performed first. In this model, b_j represents each participant's bias toward one response over the other. The model is made identifiable by utilizing data from trials in which no prime stimulus was presented (the right tree of the model). Parameters d_{ij} represent each participant's identification ability for each item, taking into account each participant's bias. The model was fit to each participants' data using a maximum likelihood procedure (Myung, 2003).

Parameter estimates $\hat{d}_{i\cdot}$ and $\hat{b}_{\cdot}$ for the pure task when performed first are shown in Figure 5. A t-test on the estimates of bias shows that at the group level there is no significant bias toward either response (mean=.51, $t(18) = .06$, $p = .96$). An ANOVA on the estimates of each item's identifiability suggests that all items are equally identifiable ($F(5, 18) = 1.36$, $p = .25$). An ANOVA may be inappropriate for these data, as the estimates for each item deviate substantially from normality, with most participants' scores clustered very close to zero, and a few outliers. As a result, the estimates of item identifiability were subjected to a non-parametric Friedman test, which also suggests that items were equally identifiable ($\chi^2(5) = 3.30$, $p = .65$). These results increase our confidence that mean identification accuracy scores are a

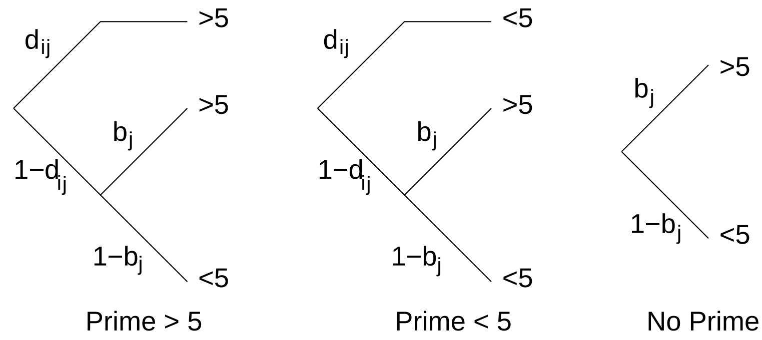

Figure 4. A model of prime identification. The structures in the left and middle panels are fit to trials in which the prime is greater-than and less-than 5, respectively. Parameters d_{ij} are the j^{th} participant's probability of identifying the i^{th} item. Parameters b_j are the j^{th} participant's bias to one response over the other. The bias parameter is arbitrarily set such that a bias to say greater-than-five results in a b_j greater than .5, while a bias to say less-than-five results in a b_j less than .5. The structure in the right panel is fit to trials in which no prime is presented.

good measure of performance, and that our mask was equally effective for all prime stimuli.

Motivation Surveys. Four surveys were not recorded due to experimenter error. The results from the remaining motivation surveys (excluding those for participants who did not complete the experiment) are presented in the bottom-right panel of Figure 3. As predicted, motivation to perform well in the target identification task was higher than in any prime identification task. Scores for the prime identification tasks were subjected to an ANOVA with block type (pure vs. mixed) as a within-subjects factor and order (pure first vs. mixed first) as a between-subjects factor. The results show a significant main effect of block type ($F(1, 36) = 19.20$, $p < .0001$), and a significant interaction between block type and order ($F(1, 36) = 5.04$, $p < .05$). The interaction reflects the fact that there was not a difference in motivation between the pure and mixed blocks when performed first, while there was such a difference when the two block types were performed second. Since motivation surveys were

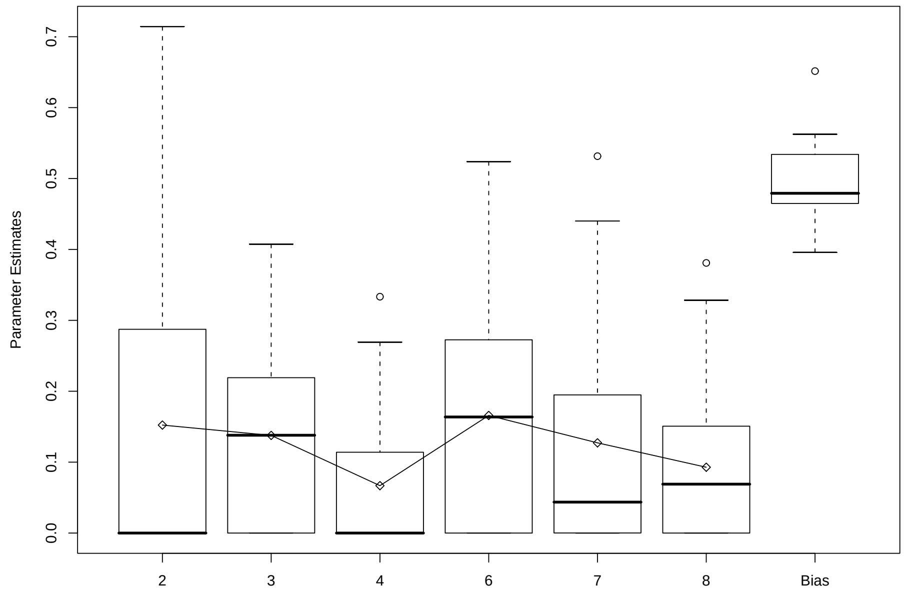

Figure 5. Boxplots of parameter estimates for each item's identifiability ($\hat{d}_{i\cdot}$) and bias ($\hat{b}_{\cdot}$). Lines drawn across estimates of identifiability are the mean identifiability for each item. Values of $d_{i\cdot} = 0$ reflect no ability to identify an item. A value of $b_{\cdot} = .5$ reflects no bias toward one response over the other.

completed at the end of the entire experiment, self-reported levels of motivation are more reliable for the second task than the first. We are therefore confident that these results suggest that motivation to complete a mixed task is higher than motivation to complete a pure task.

Evidence for Subliminal Priming. While the priming effect across all participants is significant, an important question is whether this effect would have been considered subliminal as evidenced by prime identification accuracy in the pure task when performed first (as in a typical experiment). Accuracy for the pure prime identification task, when performed first (54%), differed significantly from chance ($t(18) = 3.17$, $p < .01$). As a result not all of these participants can be considered as performing at chance levels. Various methods have been developed to test for subliminal priming with such data. The most widely used is the regression method developed by Greenwald, Klinger, & Schuh (1995). In this procedure, each participant's priming effect is regressed on a measure of their discrimination ability (dprime). The y intercept represents a theoretical point at which discrimination ability is at chance. Therefore, a significant y-intercept is interpreted as evidence for subliminal priming.

The left panel of Figure 6 depicts the regression method applied to prime identification abilities in the pure task, when performed first, and those participants' priming effects. The y-intercept of 16ms is significantly greater than zero ($t(17) = 4.30, p < .001$). Consequently, these data would have been taken as evidence for subliminal priming if only a pure prime identification task was administered. The right panel of Figure 6 depicts the regression method applied to prime identification abilities in the mixed task, when performed first, and those participants' priming effects. For these data, the y-intercept does not differ from zero ($t(18) = .10$, $p = .93$)[4]. The priming effect for all participants who completed the mixed task first was significant (mean=8ms, $t(20) = 2.92$, $p < .01$). The results of the regression method, however, suggest that when identification accuracy is measured correctly utilizing a mixed task, these primes only elicit a priming effect in participants who have some ability to identify them.

Discussion

In Experiment 1, a typical prime identification task was modified to make it less difficult, and to diminish participants' beliefs that poor performance is expected

[4]For the regression method to be valid, the slope of the regression line should be significantly positive in addition to a positive intercept (Dosher, 1998; Greenwald et al., 1998). While the slope of the regression line for the pure task data did not differ significantly from zero, many researchers have ignored this constraint altogether and continue to utilize a significant intercept as evidence for subliminal priming (e.g., Greenwald et al., 1998). The slope of the regression line for the mixed task data, however, was marginally significant ($t(18) = 2.04$, $p = .056$). That this method is more appropriate when applied to the mixed task data further supports our claim that these primes do not provide evidence of subliminal priming.

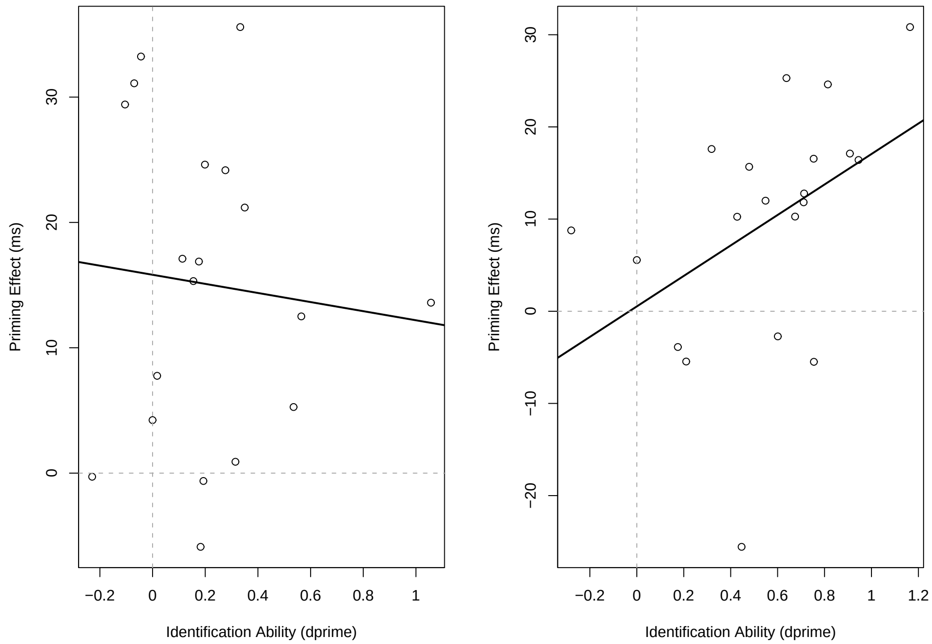

Figure 6. (Left) The regression method applied to prime identification abilities as measured in the pure task (when performed first) and those participants' priming effects. (Right) The regression method applied to prime identification abilities as measured in the mixed task (when performed first) and those participants' priming effects.

in the task. Participants showed higher accuracy for identifying primes in this task than in a typical task. For participants who completed a typical experiment (target identification followed by a pure prime identification task), the regression method provides evidence of subliminal priming. Alternatively, application of this analysis to participants who completed a target identification task followed by a mixed prime identification task suggests that these primes will only effectively prime participants who can identify them.

Experiment 2

Experiment 2 was designed to test for subliminal priming with primes which are unable to be identified in a mixed prime identification task (i.e., a task which more accurately measures prime identification abilities). If these primes are capable of producing a priming effect, we suggest that this would be the first reliable demonstration of subliminal priming.

It is possible that increased identification accuracy in a mixed task over a pure task is due to factors other than motivation. For example, visible primes may provide perceptual information which makes weakly identifiable primes more visible. If this where the case, the mixed prime identification task in Experiment 1 may have actually overestimated prime identifiability in the target identification task, as these perceptual cues were not available in the target identification task. To account for this possibility in Experiment 2, both the target and prime identification tasks were mixed tasks. This design provides a strong test of subliminal priming: Available perceptual information of the primes and motivation are maximally equated across the target and prime identification tasks.

Method

Participants. Twenty-Nine University of Missouri students participated in Experiment 2 as part of a course requirement.

Apparatus and Stimuli. The apparatus and stimuli were identical to those used in Experiment 1 with the exception that the refresh rate of the monitors was set to 110 hz. This rate allowed primes to be presented for 18ms. The pre-trial interval, mask duration, and target duration were 655, 64, and 200ms, respectively.

Procedure. Experiment 2 was identical to Experiment 1 with the following exceptions. All participants began the experiment by performing a mixed target identification task. On half of the trials primes were presented for 100ms, and 18ms for the remaining half. Prime-target relationship and prime duration was randomized across blocks and participants. Following target identification, participants performed 4 blocks of a mixed prime identification task. Prime durations were the same as those used in the target identification task.

Results

One participant was excluded from analysis for failing to follow task instructions. Again, the priming effect is only analyzed for non-repetition trials in which the target was accurately identified (targets were identified with 95% accuracy). Also, targets identified faster than 200ms and slower than 1500ms were excluded (2%). Primes presented for 100ms were accurately identified (76% accuracy) and produced a priming effect in both RT (effect=31ms, $t(27) = 5.02$, $p < .0001$) and accuracy (92 vs. 96%, $t(27) = 2.55$, $p < .05$). At the group level, primes presented for 18ms in the presence of 100ms primes were visible to participants as evidenced by a t-test (mean=52.6%, $t(27) = 3.23$, $p < .01$). These 18ms primes, however, show no evidence of a priming effect (effect=-2ms, $t(27) = -.53$, $p = .60$; the 95% confidence interval on the effect has an upper bound of 4.7 ms). A percentile analysis of the priming effect is presented in Figure 7. This plot clearly shows that there is no priming effect for any percentile. In addition, application of the regression method (Figure 8) reveals neither a significant intercept (effect=-4.7ms, $t(26) = -1.00$, ns) nor slope ($t(26) = 1.05$, ns).

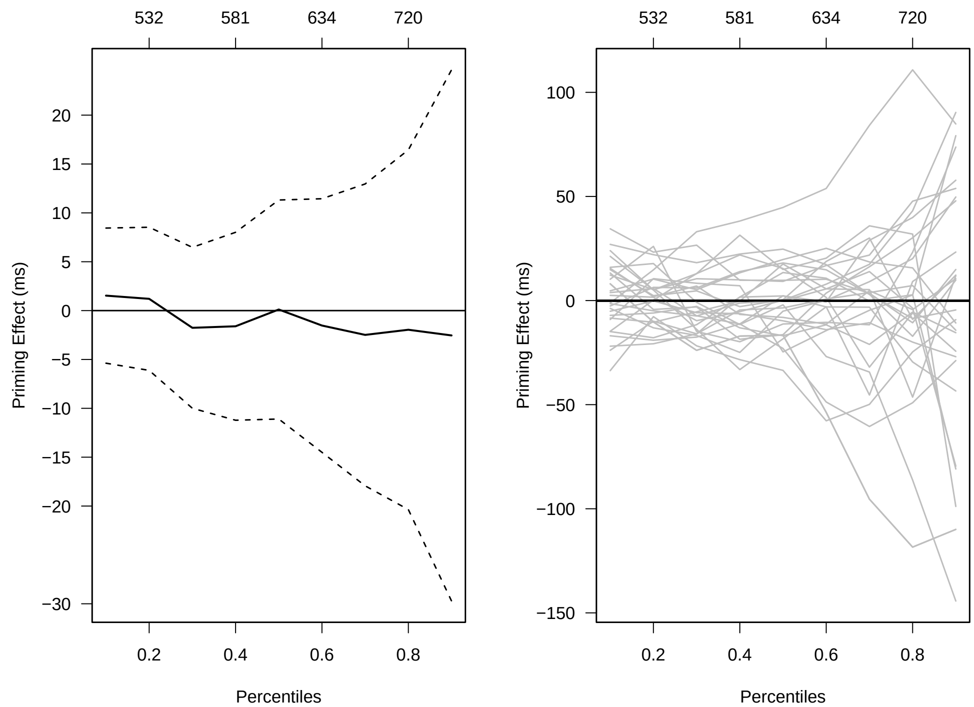

Figure 7. Percentiled priming effects resulting from 18ms primes considering all responses between 200 and 3000ms. (Left) Percentiled effect averaged over participants. (Right) Percentiled effect for each participant.

Discussion

Participants in Experiment 2 had high motivation and perceptual information about the primes in both the prime and target identification tasks. The results show that primes were identified with greater-than-chance performance in the mixed prime identification task, yet these primes failed to elicit a priming effect. The percentile analysis of these effects and the regression method both confirm this null finding. These results suggest that primes presented at a duration such that participants are truly unable (and even partially able) to accurately identify them produce no priming effect.

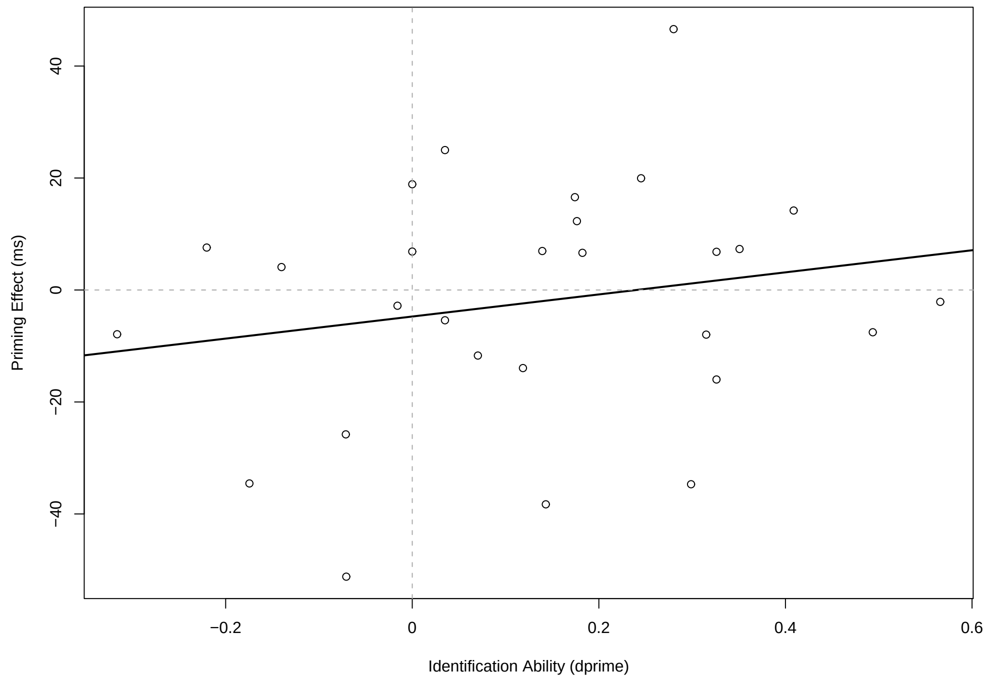

Figure 8. The regression method applied to priming and identifiability of 18ms primes when mixed with 100ms primes in both the prime and target identification tasks.

General Discussion

Experiment 1 revealed that making the overall difficulty of a prime identification task more comparable to that of the target identification task results in an increase in prime identification accuracy. Taking this finding into account in Experiment 2, we showed that primes that are truly unidentifiable (and even partially identifiable) do not elicit any priming effect. In Experiment 2, primes were presented for 18ms, a much shorter duration than is common in other subliminal number priming experiments.[5] Nevertheless, these primes were able to be identified with above chance accuracy when

[5]Common durations include 33ms (Van Opstal et al., 2005) and 43ms (Dehaene et al., 1998; Kunde et al., 2003).

the overall difficulty of the prime identification task was decreased. That our 18ms primes could be identified here suggests that primes presented for the much longer durations used in other experiments could have been very accurately identified in a mixed prime identification task.

The results of our experiments discredit the claim that number primes which are unable to be identified can elicit a priming effect. The identification threshold, however, is not the only definition of "subliminal" that has been proposed. For example, some researchers have classified primes as subliminal if participants simply did not notice them in the target identification task (e.g,. Cheesman & Merikle, 1984). In fact, in Experiment 1 participants generally denied awareness of the primes after completing the target identification task, yet these primes elicited a priming effect. This less stringent definition of subliminal, however, is not widely accepted. One reason is that participants who did not notice the primes in the target identification task still perform above chance on a prime identification task (e.g., Cheesman & Merikle (1984) report that participants were unaware of stimuli that were presented 30 to 50ms longer than the duration that resulted in above-chance accuracy in a forced-choice identification task). Another problem with this definition is that measuring whether the primes were seen relies on self-report, with no principled method for confirming subliminality.

An even stronger definition of "subliminal" than the identification threshold is the detection threshold, i.e., the point at which participants can not discriminate between the presentation of a prime and a blank screen. To achieve this threshold when equating task difficulty between the prime and target identification tasks, primes would have to be presented for a substantially shorter duration than those used in our Experiment 2 (18ms). It is unlikely that primes of such a short duration would yield any priming effect. Snodgrass et al. (2004), however, have suggested that priming at the detection threshold exists, while priming at the identification threshold does not. This theory can be tested by administering mixed target and prime identification tasks with primes that are un*detectable* in the mixed prime detection task.

Our failure to observe a subliminal number priming effect suggests that reports of even more complex subliminal priming effects result from a difference in task difficulty (e.g., semantic priming using word primes). Alternatively, perceptual priming (e.g., left and right-pointing arrows as primes and targets) requires only simple perceptual processing of the primes to yield a priming effect. It is possible that perceptual processing of a stimulus can occur even when that stimulus is unidentifiable. To test this, our mixed prime and target identification tasks can be easily implemented in a perceptual priming task.

Although our experiments suggest that previous claims of subliminal priming reflect a design artifact, this conclusion does not effect all theories utilizing subliminal priming equally. For example, subliminal priming is often used to test the theory that depressed patients have an automatic bias for negative information (e.g, Bradley et al., 1996). While the stimuli used in these studies may not be truly subliminal, it is still possible that weakly-visible stimuli are processed differently than visible stimuli. Specifically, very weakly-visible stimuli may be available to consciousness, while people's reaction to these stimuli can not be consciously controlled (i.e., an automatic response). Alternatively, many researchers have made claims that are irreconcilable with our findings. For example, Dehaene et al. (1998) used a "subliminal" number priming task and brain imaging to make the claim that "cerebral processing, including perception, semantic categorization and task execution, can be performed in the absence of consciousness" (p. 599). Our results suggest that these processes did not occur outside of consciousness, but rather, that the methods used to assess conscious awareness of the primes was flawed. Instead, we suggest that these high-level cerebral processes were simply shown to occur in response to weakly-visible stimuli, a far less interesting claim.

Correct estimation of prime identifiability can be achieved using a mixed task design. This design can be applied to many forms of priming (e.g., perceptual, semantic, emotional, etc.) and other definitions of subliminality. We advocate that researchers use caution when utilizing "subliminal" priming until a demonstration of such priming effects are available which take into account the difference in difficulty between the target and prime identification tasks.

References

Arndt, J., Allen, J., & Greenberg, J. (2001). Traces of terror: Subliminal death primes and facial electromyographic indices of affect. *Motivation and Emotion*, *25*, 253-277.

Aron, A., Schlaghecken, F., Fletcher, P., Bullmore, E., Eimer, M., Barker, R., et al. (2003). Inhibition of subliminally primed responses is mediated by the caudate and thalamus: evidence from functional MRI and Huntington's disease. *Brain*, *126*, 713-723.

Bradley, B., Mogg, K., & Millar, N. (1996). Implicit memory bias in clinical and non-clinical depression. *Behaviour Research and Therapy*, *34*, 865-879.

Cheesman, J., & Merikle, P. M. (1984). Priming with and without awareness. *Perception & Psychophysics*, *36*, 387-395.

Dannlowski, U., Kersting, A., Lalee-Mentzel, J., Donges, U., Arolt, V., & Suslow, T. (2006). Subliminal affective priming in clinical depression and comorbid anxiety: A logitudinal investigation. *Psychiatry Research*, *143*, 63-75.

Dehaene, S., Naccache, L., Le Clech, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., et al. (1998). Imaging unconscious semantic priming. *Nature*, *395*, 597-600.

Dosher, B. (1998). The response-window regression method - Some problematic assumptions: Comment on Draine and Greenwald (1998). *Journal of Experimental Psychology: General*, *127*, 311-317.

Draine, S. C., & Greenwald, A. G. (1998). Replicable unconscious semantic priming. *Journal of Experimental Psychology: General*, *127*, 286-303.

Eimer, M. (1999). Facilitatory and inhibitory effects of masked prime stimuli on motor activation and behavioural performance. *Acta Psychologica*, *101*, 293-313.

Forster, K. (1998). The pros and cons of masked priming. *Journal of Psycholinguistic Research*, *27*, 203-233.

Greenwald, A., Klinger, M., & Schuh, E. (1995). Activation by marginally perceptible ("subliminal") stimuli: Dissociation of unconscious from conscious cognition. *Journal of Experimental Psychology: General*, *124*, 22-42.

Greenwald, A., McGhee, D., & Schwartz, J. (1998). Measuring individual differences in implicit cognition: The Implicit Association Test. *Journal of Personality and Social Psychology*, *74*, 1464-1480.

Greenwald, A. G., Banaji, M. R., & Nosek, B. A. (2003). Understanding and using the implicit association test: I. an improved scoring algorithm. *Journal of Personality and Social Psychology*, *85*, 192-216.

Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996). Three cognitive markers of unconscious semantic activation. *Science*, *273(5282)*, 1699-1702.

Kamio, Y., Wolf, J., & Fein, D. (2006). Automatic processing of emotional faces in high-functioning pervasive developmental disorders: An affective priming study. *Journal of Autism and Developmental Disorders*, *36*, 155-167.

Kemp Wheeler, S., & Hill, A. (1988). Semantic priming without awareness: Some methodological considerations and replications. *Quarterly Journal of Experimental Psychology*, *40*, 671-692.

Klauer, K. C., Eder, A., Greenwald, A., & Abrams, R. (2007). Priming of semantic classifications by novel subliminal prime words. *Consciousness and Cognition*, *16*, 63-83.

Kouider, S., & Dupoux, E. (2004). Partial awareness creates the "Illusion" of subliminal semantic priming. *Psychological Science*, *15*, 75-81.

Kunde, W., Keisel, A., & Hoffman, J. (2003). Conscious control over the content of unconscious cognition. *Cognition*, *88*, 223-242.

Lim, S., & Kim, J. (2005). Cognitive processing of emotional information in depression, panic, and somatoform disorder. *Journal of Abnormal Psychology*, *114*, 50-61.

Mather, M., Canli, T., English, T., Whitfield, S., Wais, P., Ochsner, K., et al. (2004). Amygdala responses to emotionally valenced stimuli in older and youger adults. *Psychological Science*, *15*, 259-263.

McCauley, C., Parmelee, C., Sperber, R., & Carr, T. (1980). Early extraction of meaning from pictures and its relation to conscious identification. *Journal of Experimental Psychology: Human Perception and Performance*, *6*, 265-276.

Merikle, P. M., & Reingold, E. M. (1998). On demonstrating unconscious perception: Comment on Draine and Greenwald (1998). *Journal of Experimental Psychology: General*, *127*, 304-310.

Myung, I. J. (2003). Tutorial on maximum likelihood estimation. *Journal of Mathematical Psychology*, *47*, 90-100.

Naccache, L., & Dehaene, S. (2001). Unconscious semantic priming extends to novel unseen stimuli. *Cognition*, *80*, 215-229.

Naccache, L., Gaillard, R., Adam, C., Hasboun, D., Clemenceau, S., Baulac, M., et al. (2005). A direct intracranial record of emotions evoked by subliminal words. *Proceedings of the National Academy of Science*, *102*, 7713-7717.

Ohman, A. (2002). Automaticity and the amygdala: Nonconscious responses to emotional faces. *Current Directions in Psychological Science*, *11*, 62-66.

Purcell, A., Stewart, A., & Stanovich, K. (1983). Another look at semantic priming without awareness. *Perception & Psychophysics*, *34*, 65-71.

Reingold, E., & Merikle, P. (1988). Using direct and indirect measures to study perception without awareness. *Perception & Psychophysics*, *44*, 563-575.

Rouder, J. N., Morey, R. D., Speckman, P. L., & Pratte, M. S. (in press). Detecting chance: A solution to the null sensitivity problem in subliminal priming. *Psychonomic Bulletin and Review.*

Sato, W., & Aoki, S. (2006). Right hemispheric dominance in processing of unconscious negative emotion. *Brain and Cognition*, *62*, 261-266.

Seiss, E., & Praamstra, P. (2004). The basal ganglia and inhibitory mechanisms in response selection: evidence from subliminal priming of motor responses in Parkinson's disease. *Brain*, *127*, 330-339.

Seiss, E., & Praamstra, P. (2006). Time-course of masked response priming and inhibition in Parkinson's disease. *Neuropsychologia*, *44*, 869-875.

Snodgrass, M., Bernat, E., & Shevrin, H. (2004). Unconscious perception: A model-based approach to method and evidence. *Perception & Psychophysics*, *66*, 846-867.

Suslow, T., Roestel, C., & Arolt, V. (2003). Affective priming in schizophrenia with and without affective negative symptoms. *European Archives of Psychiatry and Clinical Neuroscience*, *253*, 292-300.

Van Opstal, F., Reynvoet, B., & Verguts, T. (2005). How to trigger elaborate processing? A comment on Kunde, Kiesel, and Hoffmann (2003). *Cognition*, *97*, 89-97.

Vorberg, D., Mattler, U., Heinecke, A., Schmidt, T., & Schwarzbach, J. (2003). Different time course for the visual perception and action priming. *Proceedings of the National Academy of Sciences*, *100*, 6275-6280.

Whalen, P., Rauch, S., Etcoff, N., McInerney, S., Lee, M., & Jenike, M. (1998). Masked presentations of emotional facial expressions modulate amygdala activity without explicit knowledge. *The Journal of Neuroscience*, *18*, 411-418.

Appendix

The following motivation survey was given to participants at the end of Experiment 1:

You have just identified numbers as greater than or less than five in three blocks of trials. Blocks were separated by leaving the computer to see the experimenter. In the first block, you identified the second, clearly visible number as greater or less than 5. Below, please rate your motivation to accurately identify these numbers on a scale of 1-10 (1=I didn't care how well I did; 10=I did my best to accurately identify the numbers).

Motivation in First Block: ______ (1-10)

In the second block, you identified the first number as less than or greater than 5. Please rate how motivated you were to perform well in this block:

Motivation in Second Block: ______ (1-10)

After another break, you again identified the first number. Please rate your motivation to perform well in this last block:

Motivation in Third Block: ______ (1-10)