Modulation of congruence effects with masked primes in the parity decision task

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As at August 8, 2006

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Keywords: masked priming, prime validity effect, list composition effect, parity decision

Abstract

In the parity (odd-even) decision task, a congruence effect is observed in which the response to the target is faster when the prime and target are congruent (i.e., same parity) than when they are incongruent (i.e., different parity). Bodner and Dypvik (2005) found that the congruence effect is magnified in the block containing a high proportion of congruent trials relative to a block containing a low proportion of such trials, even though the prime is masked. In this paper, we investigated the mechanism underlying this prime-validity effect. The main findings are that: 1) a reliable prime-validity effect was obtained more readily by increasing the latency difference between the congruent and incongruent trials (Experiments 1, 2 and 3), and 2) the modulation of congruence effect is dependent not on the proportion of valid primes in a block, but on the proportion of easy trials vs. hard trials (Experiments 4 and 5). Based on these data, we suggest that the modulation of the congruence effect by block proportion is better explained in terms of adaptation of response initiation processes to the difficulty of preceding trials rather than the recruitment of memory episode for masked primes as suggested by Bodner Dypvik (2005).

Modulation of congruence effects with masked primes in the parity decision task

In the masked priming procedure, a prime is presented very briefly and both forward- and backward-masked, followed by a target. Despite the fact the prime is not consciously perceived, primes that are related to the target in various ways (e.g., identity/repetition – *table-TABLE*, or semantic – *chair-TABLE*) facilitate responses to the target relative to unrelated primes. Because the prime is not available for conscious report, masked priming effects are generally thought to reflect unconscious, automatic processes.

However, Bodner and colleagues (Bodner & Dypvik, 2004; Bodner & Masson, 2001, 2003, 2004) have amassed a body of data that poses a major challenge to the assumption that masked priming effects are automatic and are therefore not subject to strategic modification. The basis of their challenge is the phenomenon that masked priming effects are magnified in a block containing a high proportion of trials with *valid* (e.g., repetition) primes relative to a block containing a high proportion of trials with *invalid* (e.g., unrelated) primes. This effect is referred to as a *prime-validity effect*, and it has been found across several tasks, including lexical decision (Bodner & Masson, 2001, 2003), naming (Bodner & Masson, 2004), and both number magnitude judgment and number parity judgment (Bodner & Dypvik, 2005). The prime-validity effect in the parity judgment task forms the focus of the present study.

In the parity task, the odd/even response to a visible target is faster when the masked prime shares parity with the target (e.g., *1-3* or *2-8*) than when it has the opposite parity (e.g., *2-3* or *1-8*) (e.g., Reyvoet, Caessens, & Brysbaert, 2002, Fabre & Lemaire, 2006). Bodner and Dypvik (2005) showed that this congruence effect is magnified in a block containing a high proportion (.8) of congruent trials relative to a block containing a low proportion (.2) of congruent trials. By referring to this effect as a prime-validity effect, Bodner and Dypvik (2005) suggest that it has the same basis as the effect observed with supraliminal primes (e.g., Neely, 1991). The basic tenet of their *memory recruitment account* (see also Bodner & Masson, 2001, 2003, 2004) is that processing operations applied to the prime form a new memory representation that serves as an instance of episodic learning or skill acquisition of which the subject is unaware. To explain the observed effect of block type, the account assumes that a memory episode is more likely to be recruited in a block where prime validity is high rather than low.

As we have argued previously (Kinoshita, Forster & Mozer, submitted), we find the memory recruitment account unsatisfactory, for several reasons. The main reason is that its key assumption - that a masked prime that is unavailable to consciousness establishes an episodic record - seems diametrically opposed to the generally accepted view that conscious awareness is a prerequisite for establishing an episodic record. This view forms the basis for a diverse range of concepts including the object file (Kahneman & Treisman, 1984), token individuation account of the repetition blindness phenomenon (Kanwisher, 1987; see also Mozer, 1989) and Moscovitch's (1995) model of consciousness and memory. What is common to all of these perspectives is that although conscious awareness is not necessary to activate a pre-stored representation, it is necessary to establish an episodic token of an event. These perspectives seem to be inconsistent with the proposal that a memory episode is established for masked primes. Other than to explain the phenomenon at hand, the proposal does not seem to be theoretically well-motivated. Moreover, the memory recruitment account does not specify the mechanism via which the size of masked priming effect is modulated, other than to point to the empirical similarities with the proportion effects produced by supraliminal primes. (For a comprehensive review of semantic priming effects, see Neely, 1991.) The fact that the prime-validity effect reported with masked primes empirically resembles the effect reported with supraliminal primes does not necessarily imply that the same mechanism is involved. In fact, the mechanisms that have been proposed to explain the proportion effects observed with supraliminal primes such as the expectancy strategy (e.g., Neely, 1977) and the retrospective semantic matching strategy (e.g., De Groot, 1984; Neely, 1991) assume conscious identification of the prime as a prerequisite, making them inadequate candidates for explaining the effect observed with masked primes.

To distinguish the supraliminal and subliminal effects, we prefer not to use the term prime-validity effect for the subliminal case, instead opting for *proportion effect*. This term is more neutral with regards the assumed mechanism, and it does not presuppose that list-wide prime validity – the usefulness of masked primes – is the key factor underlying the effect. Indeed, in our previous study of masked priming using a naming task (Kinoshita, Forster & Mozer, submitted), we reported that, inconsistent with the memory recruitment account, the proportion effect was not dependent on list-wide prime validity: Increasing the proportion of repetition trials (e.g., *wedge-WEDGE*) per se did not increase the size of the priming effect. In this paper, we seek to validate an alternative explanation for the proportion effect observed with the parity decision task.

The ASE account. Mozer, Kinoshita, and Davis (2004) proposed a model to account for sequence effects in simple naming and choice tasks. Specifically, the model, termed the Adaptation to the Statistics of the Environment (ASE) model, explains the finding that the same item is responded to faster when followed by a series of mostly easy items than when followed by a series of mostly hard items (e.g., Lupker, Brown & Colombo, 1997; Lupker, Kinoshita, Coltheart, & Taylor, 2003; Rastle, Kinoshita, Lupker, & Coltheart, 2003). We previously suggested that ASE might serve as an alternative to the memory-recruitment account (Kinoshita, Forster & Mozer, submitted), if the proportion effect is viewed as a sequence effect in which the high and low congruence-proportion conditions are viewed as sequences in which most of the recent items are easy (congruent trials) or hard (incongruent trials), respectively. Here, we elaborate by presenting an example of ASE performing the parity task with congruent or incongruent primes, in the context of a block of trials with either a high or low proportion of congruent primes.

Much like a random walk or accumulator model, ASE accumulates evidence in favor of each of the two response alternatives ("odd" or "even"). The model translates this evidence into a time-varying probability distribution over responses. Figures 1A and 1B show this probability distribution as a function of processing cycles (on the x axis) for congruent and incongruent primes, respectively. The line with open circles represents the correct response, whose probability grows over time. The congruency of the prime determines the initial bias of the response: spillover activation from the prime boosts the probability of the correct response to the target when prime and target are congruent, but boosts the probability of the incorrect response when prime and target are incongruent. The time-varying distributions shown in Figures 1A and 1B are used by ASE to select a response at any point in time. Thus, if a response were to be initiated at simulation time 400, the probability of a correct response would be around 90% for a congruent trial, but only about 75% for an incongruent trial.

ASE includes a response-initiation mechanism, assumed to be general across tasks, that determines the point in time following stimulus onset at which to initiate a response. The decision about when to initiate a response depends on the trade off between speed and accuracy: ASE must determine whether to risk a higher likelihood of error by responding quickly or be less efficient by responding slowly. The trade off is handled by computing a response *cost*, which increases with both RT (i.e., the penalty involved with waiting) and expected error rate (i.e., the penalty of possibly making an incorrect response). A response is initiated at the point in time when a minimum in total cost is attained.

One challenge the model faces is to estimate its expected error rate as processing within a trial unfolds. Presumably the error rate decreases over time as evidence builds up concerning the appropriate response given the stimulus. By assuming that its current response distribution (Figures 1A and 1B) reflects the distribution of correct responses, ASE can compute an error estimate by taking the expectation of an incorrect response under the current response distribution. Effectively, this result is similar to assuming that the most probable response at any point in time is correct, and the expected error rate is the probability of the alternative response. The solid curves in Figures 1C and 1D show the model's estimate of its error as a function of processing time for congruent- and incongruent-prime trials, respectively. The error estimate drops more slowly for in incongruent-prime trial because the probability of the correct response (Figure 1B) rises slowly. Note the nonmonotonicity in Figure 1D: initially the model believes that the primed response is likely to be correct, but as evidence for the correct (nonprimed) response builds up, its confidence in its response diminishes, and the expected error rate rises. After cycle 200, evidence for the nonprimed response builds to the point where it becomes the most likely response, and the model's error estimate then decreases monotonically over time.

As is standard in RT models, evidence concerning the response grows over time, so generally there is a greater probability of making an error if the response is emitted early (i.e., a speed-accuracy tradeoff is expected). Also common to RT models, the reduction in error with additional processing time diminishes as the level of evidence builds toward an asymptote.

The error curve can be viewed as a penalty associated with an error at any point in time, decreasing to zero if the model waits long enough. Figures 1C and 1D also show a dashed line that represents the penalty for waiting to any point in time to respond; the longer the wait, the greater the penalty. As explained in Mozer, Kinoshita, and Davis (2004) and Kinoshita and Mozer (2006), the overall response cost - which combines a cost for errors and a cost for waiting - is minimized by finding the point of intersection of the error penalty and the time penalty - the solid curve and dashed lines in Figures 1C and 1D. The optimal point of time to response – the point that minimizes the cost – is shown by the vertical line and asterisk in the Figures 1A-1F.

A key assumption of ASE is that the error estimates obtained during the ongoing processing of any particular stimulus (Figures 1C,D) are unreliable, either because the model's assumption – necessary to estimate the error – that the current response distribution reflects the correct response distribution is incorrect, or because the information available to response systems to estimate the error is noisy. To overcome the unreliability of the error estimate, a sensible strategy in a stationary environment is to average the error estimate being computed for the current stimulus with the error estimates from recent trials. By "stationary environment", we mean an environment where item difficulty – and hence the shape of the error curve – does not vary much from one trial to the next. By "average", we mean that the error curve used to estimate the cost is a combination of the current error curve and a *historical trace,* which itself is an (exponentially weighted) average of the error curves from recent trials.

Figure 1E shows this averaging process for a block with 80% congruent trials. The graph zooms in on the region of time around which responses are produced (compare the range of x values in Figure 1C and Figure 1E). The thin and thick solid lines are error curves for congruent and incongruent trials, respectively; these curves are identical to those in Figures 1C and 1D. The dotted line is the historical trace, representing 80% congruent trials and 20% incongruent trials, and is therefore closer to the curve for a congruent trial than for an incongruent trial. The averaging of historical trace and the current trial (congruent and incongruent) is depicted by the (thin and thick) dash-dotted curves; as in Figures 1C,D, the vertical lines indicate the time of response initiation for congruent and incongruent trials. Figure 1F shows the analogous information as in Figure 1E, except for a block of 20% congruent and 80% incongruent trials.

The historical error curve is shifted to the left in the 80% congruent block relative to the 20% congruent block (Figure 1E vs. 1F). Consequently, when the error curve reflecting the accumulation of evidence about the current stimulus is averaged with the historical trace, the curve for the current trial is shifted to the left in the 80% block relative to the 20% block. This shift causes responses to be faster in the 80% block than in the 20% block, regardless of item type. Comparing Figures 1E and 1F, however, one notices not only a main effect of block type, but also a proportion effect: the effect of the prime – the difference in RT between congruent and incongruent trials – is larger in the 80% congruent block than in the 20% congruent block: 94 time steps versus 63 time steps. The proportion effect occurs because of an asymmetry in the error curves for congruent- and incongruent-prime trials: In the interval of time when responses can occur, the error curve for the congruent trial is near asymptote, and therefore has a shallower slope than the error curve for the incongruent trial. This asymmetry is apparent when examining the thick and thin solid lines in Figure 1E or 1F. As a result of the asymmetry, the averaging of error curves tends to cause the curves to hug the steeper-sloped curve (for the incongruent trial) more than the shallower-sloped curve (for the congruent trial), resulting in the asymmetry of the priming effect in the 80% vs. 20% congruent blocks.

In the above analysis, one key property is required to obtain the proportion effect: The evidence for the correct response in an incongruent trial must build more slowly than evidence for the correct response in a congruent trial. As long as this occurs, the model necessarily obtains a proportion effect.

ASE has five parameters that can be adjusted for the parity-experiment simulation.[1.] If the proportion effect is a strong prediction of ASE, then ASE should yield the proportion effect regardless of parameter choices. One way to show that ASE is not only consistent with the proportion effect but is *inconsistent* with other outcomes is to verify that all parameter settings yield a proportion effect. We performed a simulation in which we ran 2000 replications of the model, each with *random* parameter settings, chosen over a broad plausible range. For each simulation, we measured the *magnitude of the proportion effect*, quantified as the ratio of the priming facilitation in the 80%-congruent condition to the priming facilitation in the 20%-congruent condition. If increasing the proportion of congruent primes in a block increases priming facilitation, this ratio should be greater than 1.0. In 2000 replications, 1991 (99.55%) showed a ratio greater than 1.0. The remaining 9 replications were priming effects of negligible magnitude. (When the magnitudes get very small, ratios can vary wildly.) This result indicates that the model is not only compatible with a proportion effect, but strongly predicts the effect.

The model makes a further prediction, illustrated by the scatterplot shown in Figure 2. The scatterplot contains one X for each replication, which is characterized by two variables: the magnitude of the proportion effect (y axis), and the magnitude of the priming manipulation (x axis). The latter variable is related to the difference in RT between congruent and incongruent targets. The scatterplot clearly shows that nearly all proportion effects have a ratio greater than 1.0. The scatterplot also shows a correlation between the magnitude of the priming effect and the magnitude of the proportion effect: As the prime has a greater influence on responses to the target, the proportion effect spans a greater range of values, and the mean proportion effect (across different instantiations of the model) grows. This relationship is not necessary, because the proportion effect is expressed as a ratio, and it's completely consistent for the priming effect to grow without influencing the proportion effect. We return to the importance of this relationship after presenting experimental results.

A critical claim of ASE is that the proportion effect occurs not because of masked primes per se, but because masked primes influence the *difficulty* of a trial; by "difficulty", we simply mean the rate at which evidence concerning the correct response builds. By ASE's account, the proportion effect does not critically depend on the manipulation of prime validity within a block of trials, but rather on the proportion of easy and hard trials within a block, by *whatever* means the difficulty manipulation is achieved.

The aim of the present series of experiments is to test a prediction of the ASE model that the proportion effect does not depend on prime validity (usefulness of primes in a block), but only on item difficulty, using the parity decision task. The assumption of greater item difficulty (slower rate of evidence accumulation) for the incongruent trials in this task follows from the evidence that these trials engender response conflict. This evidence includes the demonstration by Dehaene and colleagues (Dehaene, Naccahe, Le Clec, Koechlin, Mueller, Dehaene-Lambertz, van der Moortele, & Le Bihan, 1998) that masked primes in number judgment tasks are processed down to the level of motor response (as indexed by lateralized readiness potentials, an event-related potential (ERP) measure, and by fMRI), as well as the finding by Damian (2001) that the congruence effect observed with masked primes in semantic categorization tasks is critically dependent on the primes having been responded to previously as supraliminal targets (and hence having stimulus-response mappings established).

The outline of the present study is as follows. The aim of the first two experiments was to establish the proportion effect in the parity decision task, with Experiment 1 using digit stimuli (e.g., *3*) and Experiment 2 using number word stimuli (e.g., *three*). Contrary to expectation, neither experiment produced a reliable proportion effect. We then considered the reason for this failure to obtain a reliable proportion effect within the framework of the ASE model, and came to the view that it was due to the small magnitude of the effect of difficulty of task environment. Experiment 3 demonstrated a proportion effect by making the latency difference between the congruent and incongruent trials larger thus supporting the prediction of the ASE account. Experiments 4 and 5 then pitted the prediction of the ASE account against the memory recruitment account. We will describe Experiment 1 (using digit stimuli) and Experiment 2 (using number word stimuli) together, as they were identical in design and yielded similar results, and postpone the discussion until after Experiment 2.

Experiment 1 (Digit stimuli)

Method

Participants. Twenty-four volunteer Macquarie University students participated in Experiment 1 for course credit.

Design. The experiment constituted a 2 (*Prime type*: congruent vs. incongruent) x 2 (*Block type*: high vs. low proportion of congruent primes) x 2 (*Block order*: high- vs. low-proportion block first) factorial design, with the first two factors manipulated within subjects. Block order was counterbalanced between subjects, with half of participants doing the high-proportion block first and the other half, the low-proportion block first. There were 120 trials in each block. In the high-proportion block, 96 trials were congruent and 24 trials were incongruent (.8/.2); in the low-proportion block, 24 trials were congruent and 96 trials were incongruent (.2/.8). The dependent variables were response latency and error rate.

Materials. The stimulus materials used in this experiment were digits 1 through to 9, excluding 5 (so that there were equal numbers of even digits and odd digits). In the congruent trials, an odd-number target was paired with an odd-number prime (e.g., *7-1*; *9-3*), and an even number target was paired with an even-number prime (e.g., *2-4, 8-6*), but never the target number itself (i.e., the prime and target were always different numbers). Thus, each target was paired with three congruent primes (e.g., *3-1, 7-1, 9-1*). In the incongruent trials, an odd-number target was paired with an even-number prime (e.g., *8-1, 6-3*) and an even number target was paired with an odd number prime (e.g., *1-4, 5-6*). Each target was paired with three incongruent primes (e.g., *2-1, 4-1,6-1*). This generated 24 unique congruent prime-target pairs (12 odd number targets and 12 even number targets) and 24 unique incongruent prime target pairs (also 12 odd number targets and 12 even number targets).

The high-proportion block contained the 24 congruent pairs repeated 4 times (96 trials) and 24 incongruent pairs used once (24 trials). The low-proportion block contained 24 congruent pairs used once (24 trials) and the 24 incongruent pairs repeated four times (96 trials).

Prior to each test block, participants were given 20 practice and warm-up items that were representative of the block type. These items were not included in the analysis.

Apparatus and Procedure. Participants were tested individually, seated approximately 40 cm in front of a Dell 19" Flat Trinitron monitor. Each participant completed two blocks of trials, the high-proportion block and the low-proportion block. The order of blocks was counterbalanced across participants so that half of the participants started with the high-proportion block, and the other half started with the low-proportion block. Within each block, a different random order of trials was generated for each participant.

Participants were instructed at the outset of the experiment that they would be presented with a series of single digits, and their task was to decide for each item whether it was an even or odd number, as fast and accurately as possible. They were instructed to press a button marked “+” for “even” and a key marked “-“ for “odd” on a response keypad. No mention was made of the prime.

Stimulus presentation and data collection were controlled by the DMDX display system developed by K.I. Forster and J.C. Forster at the University of Arizona [Forster, 2003 #700]. Stimulus display was synchronized to the screen refresh rate (13.3 ms).

Each trial started with the presentation of a forward mask consisting of three hash marks (###), presented in Courier 10 point font, in the center of the screen for 500 ms. The forward mask was followed by the prime presented for 53 ms, which was then replaced by the target. The target remained on the screen for a maximum of 2000 msec, or until the participant's response. Following a blank screen for 300 ms, the next trial started. Participants were given no feedback on either latencies or error rates during the experiment.

Results

For this and subsequent analyses, the preliminary treatment of trials was as follows. Any trial on which a participant made an error was excluded from latency analysis. To reduce the effects of extremely long and short latencies, a cutoff was set for each participant at 3 S.D. units from each participant's mean latency and latencies shorter or longer than the cutoff was replaced with the cutoff value. In Experiment 1, this affected 1.58% of trials. Latencies and error rates were analyzed using a three-way analysis of variance (ANOVA) with *Prime type* (congruent vs. incongruent), *Block type* (high- vs low proportion of congruent trials) and *Block order* (high-proportion block first vs. low-proportion block first) as factors. The first two factors were within-subject factors; *Block order* was a between-group factor. Effects were considered to be significant at the .05 level. Mean response latencies and error rates are presented in Table 1.

Insert Table 1 about here

In the analysis of latencies, the main effect of *Prime type* was significant, $F(1,22) = 35.78$, $MSe = 437.59$: Congruent trials were 26 ms faster than incongruent trials. None of the other main or interaction effects was significant (all $F(1,22) < 1.54$, $p > .23$), although *Block order* approached significance, $F(1,22) = 3.09$, $MSe = 14479.51$, $p = .09$.

Critically, the *Prime type* x *Block type* interaction (the proportion effect) was non-significant, F(1,22) < 1.0; nor did it interact with *Block order*, F(1,22) < 1.0.

In the analysis of error rate, the only significant effect was *Prime type*, F(1,22) = 5.98, MSe = 13.92. Congruent trials were 1.86% more accurate than incongruent trials. None of the other main or interaction effects were significant, F(1,22) < 2.48, p > .13 in all cases.

Analysis of first block. One methodological difference between the present study and Bodner and Dypvik (2005) is that they manipulated *Block type* between groups, whereas we used a within-subject manipulation. Therefore we carried out a similar analysis by comparing just the first blocks, using a two-way ANOVA with *Block type* (high- vs low-proportion), which is now a between-group factor, and *Prime type* as factors. For latency, the interaction between *Prime type* and *Block type* was non-significant, F(1,22) < 1.0. However, the size of *Prime type* effect was 28 ms in the high-proportion block, a significant effect, F(1,11) = 11.25, MSe = 415.50, and 18 ms in the low-proportion block, which was only marginally significant, F(1,11) = 4.21, MSe = 479.58, p = .065. For error rate, the interaction between *Prime type* and *Block type* was non-significant, F(1,22) < 1.0. The size of *Prime type* effect in the high-proportion block was 1.8%, a non-significant effect, F(1,11) < 1.0. For the low-proportion block, the effect was 2.0%, and was significant, F(1,11) = 7.19.

Experiment 2 (Number word stimuli)

Experiment 2 was identical to Experiment 2, except that instead of digits, number words (e.g., *ONE, EIGHT*) were used as stimuli (both as primes and targets).

Method

Participants. Twenty-eight volunteer students from University of Arizona participated in Experiments 2 for course credit.

Design. The experiment was identical in design to Experiment 1.

Materials. The stimulus materials used in this experiment were number words ONE through to NINE, excluding FIVE (so that there were equal numbers of even and odd numbers). The composition of stimuli was identical to that of Experiment1 except that instead of digits, number words were used. The primes were presented in lowercase letters (e.g., *one, two*) and the target were presented in uppercase letters (e.g., *ONE, TWO*).

Apparatus and Procedure. Task instruction, timing parameters and apparatus were identical to Experiment 1.

Results

Preliminary data treatment was identical to Experiment 1. In Experiment 2, the data trimming procedure affected 1.2% of trials. As in Experiment 1, latencies and error rates were analyzed using a three-way ANOVA with *Prime type* (congruent vs. incongruent), *Block type* (high- vs. low proportion of congruent trials) and *Block order* (high-proportion block first vs. low-proportion block first) as factors. Mean response latencies and error rates are presented in Table 2.

Insert Table 2 about here

In the analysis of latencies, the main effect of *Prime type* was significant, F(1,26) = 59.08, MSe = 316.44: Congruent trials were 29 ms faster than incongruent trials. None of the other main or interaction effects was significant (all F(1,26) < 2.03, p > .16), although the interaction between *Block order* and *Block type* approached significance, F(1,26) = 3.49, MSe = 1701.91, p = .07. Critically, the *Prime type* x *Block type* interaction (the proportion effect) was non-significant, F(1,26) = 2.03, MSe = 308.38, p = .17; nor did it interact with *Block order*, F(1,26) = 1.03, MSe = 308.38.

In the analysis of error rates, the only significant effect was *Prime type*, F(1,26) = 30.82, MSe = 12.53. Congruent trials were 3.7% more accurate than incongruent trials. None of the other main or interaction effects were significant, F(1,22) < 3.14, p > .09 in all cases.

Analysis of first block. As in Experiment 1, we analyzed the data for just the first block using a two-way ANOVA with *Block type* (high- vs low-proportion) as a between-groups factor and *Prime type*. For latency, the interaction between *Block type* and *Prime type* was non-significant, F(1,26) < 1.0. However, the size of *Prime type* effect was numerically larger in the high-proportion block (26 ms), a significant effect, F(1,13) = 30.68, MSe = 150.05, than the 19 ms effect in the low-proportion block, which was also significant, F(1, 13) = 12.79, MSe = 203.57. For error rate, the *Block type* by *Prime type* interaction was non-significant, F(1,26) < 1.0. The 3.6% *Prime type* effect in the high-proportion block was significant, F(1,13) = 9.71, MSe = 9.20, as was the 3.0% effect in the low-proportion block, F(1,13) = 8.45, MSe = 7.67.

Combined analysis of Experiment 1 and 2. In an effort to increase power, we combined data from Experiments 1 and 2 and analyzed them using a four-way ANOVA with *Prime type* (congruent vs. incongruent), *Block type* (high- vs. low proportion of congruent trials), *Block order* (high-proportion block first vs. low-proportion block first) and *Stimulus type* (digits vs. words) as factors. In the analysis of latency, the main effect of *Prime type* was significant, $F(1,48) = 91.72$, $MSe = 371.97$. The main effect of *Stimulus type* was significant, $F(1,48) = 4.57$, $MSe = 13860.80$, and interacted with *Block order*, $F(1,48) = 4.85$, $MSe = 13860.80$. This indicated that responses to word stimuli were slower than to digit stimuli (by 35 ms) and that this difference was greater for the groups who did the high proportion block first. *Block type* and *Block order* also interacted, $F(1,48) = 4.76$, $MSe = 1699.12$, indicating that whereas the high proportion block was slower than low proportion block in the group who did the high proportion block first, this was reversed in the groups who did the low proportion block first. This most likely reflects a practice effect, indicating whichever block was the first was slower. None of the other main or interaction effects reached significance, $F(1,48) < 1.61$, $p > .21$ in all cases. Critically, the *Block type* by *Prime type* interaction (the proportion effect) was still non-significant, $F(1,48) = 1.61$, $MSe = 312.72$, $p = .21$.

Combined analysis of Experiment 1 and 2 (first block only). Our final effort involved the analysis of the first block only, using a three-way ANOVA with *Block type* (high- vs. low-proportion), now a between-groups factor, *Prime type* (Congruent vs. Incongruent) and *Stimulus type* (Digits vs. Words). *Prime type* was significant $F(1,48) = 44.63$, $MSe = 14442.83$, as was *Stimulus type*, $F(1,48) = 4.22$, $MSe = 8404.93$, and the interaction between *Stimulus type* and *Block type* approached significance, $F(1,48) = 3.18$, $MSe = 8404.93$, $p = .08$. No other main or interaction effects were significant, $F(1,48) < 1.36$, $p > .25$ in all cases. Critically, the interaction between *Prime type* and

Block type (the proportion effect) was non-significant, F(1,48) = 1.36, MSe = 14442.83, p = .25. Simple effects analysis showed that the 27 ms *Prime type* effect in the High-proportion block was significant, F(1,26) = 35.42, MSe = 261.511, as was the 19 ms effect in the Low-proportion block, F(1,25) = 14.57, MSe = 316.99.

Discussion

In Experiments 1 and 2, using within-subject manipulation of proportion of congruent vs. incongruent trials, we failed to find a reliable proportion ("prime validity") effect in the parity decision task whether the stimuli were digits (Experiment 1) or number words (Experiment 2). Congruent trials were responded to faster than incongruent trials whether the block contained a high proportion (.8) or low proportion (.2) of congruent trials. Combining the two experiments did not make the interaction statistically significant. Analysis of the first block only (comparing the size of congruence effect between groups) did not change the conclusion either. To summarize, although there was a trend in the same direction as the proportion effect reported by Bodner and Dypvik (2005), our effect was not statistically reliable however we analyzed the data. We point out that in the combined analysis we had more subjects (N = 52) than Bodner and Dypvik's Experiment 2 (N = 40), which was identical in design to our experiments, hence sample size is unlikely to be the issue. Also, the congruence effect itself was highly significant in our experiments and its size was no smaller than in Bodner and Dypvik's experiments: Averaged over the high- and low-proportion blocks (first block only in our experiments), the congruence effect was 23 ms for both digit stimuli and number word stimuli, while Bodner and Dypvik reported the effect size of 13 ms for number word stimuli and 17 ms for digit stimuli. Thus, our failure to obtain a statistically significant proportion effect was not due to an unreliable congruence effect.

We will return later to a discussion of the discrepancy between our results and Bodner and Dypvik (2005). For now, our goal is to obtain a proportion effect in the parity decision task, based on which we could design further experiments to test the ASE account. This then was the aim of the next experiment.

Experiment 3 (Digit and number word stimuli)

As described earlier, the ASE model views the proportion effect as reflecting an interaction between difficulty of the current trial (congruent or incongruent) and the mean difficulty of recent trials (the 20% or 80% congruent conditions): In an easy task environment (the 80% congruent condition), the influence of the mean item difficulty causes difficult (incongruent) trials to speed up; in a hard task environment (the 20% congruent condition), the influence of the mean item difficulty causes easy (congruent) trials to slow down. However, the magnitude of speed up is greater than the magnitude of slow down, leading to the interaction.

In Experiment 1 and 2, although there was a trend in the expected direction, the interaction was not reliable. One possible reason for this is that the effect of the difficulty of task environment was not sufficiently large. Recall that Figure 2 shows 2,000 replications of the model, each with random parameter settings. It can be seen from Figure 2 that as the magnitude of priming effect is increased (going across from left to right along the x-axis), the scatter of data points (each representing a replication) has a positive slope, indicating that a positive proportion effect is more likely to be observed. That is, the ASE model predicts that a proportion effect is more likely to be found by increasing the magnitude of priming. The aim of Experiment 3 was to test this possibility. To this end, we deliberately confounded stimulus type and prime type, based on the observation that digit stimuli are responded to faster than number word stimuli in number judgment tasks (recall that there was a main effect of stimulus type in the combined analysis of Experiment 1 vs. 2; see also Bodner & Dypvik, 2005; Damian, 2004; Dehaene, et al., 1998; Koechlin, Naccache, Block, & Dehaene, 1999). That is, all congruent trials used digit stimuli (e.g., *1-3, 2-8*) and all incongruent trials used number word stimuli (e.g., *one-EIGHT, two-THREE)*. These items were presented in two blocks: One containing a high proportion of congruent trials (.8 congruent trials involving digit stimuli and .2 incongruent trials involving word stimuli) and the other containing a low proportion of congruent trials (.2 congruent trials involving digit stimuli and .8 incongruent trials involving word stimuli). Based on the ASE model, we expected a proportion effect to emerge in this case, with the congruence effect being larger in the block containing a high proportion of congruent (easy) trials.

Method

Participants. Twenty volunteer students from University of Arizona participated in Experiments 3 for course credit.

Design. The experiment was identical in design to previous experiments, and constituted a 2 (*Prime type*: congruent vs. incongruent) x 2 (*Block type*: High vs. Low proportion of congruent primes) factorial design, with both factors manipulated within subjects. *Prime type* was deliberately confounded with target type such that all congruent items were digits (e.g., *1-3, 8-2*) and all incongruent items were number words (e.g., *eight-ONE, three-TWO*).

Materials. As in Experiments 1 and 2, the stimulus materials used in this experiment were digits and number words 1 through to 9 (ONE through to NINE), excluding 5 (FIVE). Except for the fact that all congruent items were digits and all incongruent items were number words, the construction of materials was identical to the previous experiments.

Apparatus and Procedure. Task instructions, timing parameters and apparatus were identical to Experiment 1.

Results

Preliminary data treatment was identical to Experiment 1. In Experiment 3, the data trimming procedure affected 1.8% of trials. As in Experiment 1, latencies and error rates were analyzed using a three-way ANOVA with *Prime type* (congruent vs. incongruent), *Block type* (high- vs low proportion of congruent trials) and *Block order* (high-proportion block first vs. low-proportion block first) as factors. Mean response latencies and error rates are presented in Table 3.

Insert Table 3 about here

In the analysis of latencies, the main effect of *Prime type* was significant, $F(1,18) = 366.19$, $MSe = 328.67$: Congruent trials (digit stimuli) were 78 ms faster than incongruent trials (number word stimuli). *Prime type* interacted with *Block order*, $F(1,18) = 16.52$, $MSe = 328.67$: Prime type effect was greater in the high proportion first group (94 ms) than the low-proportion first group (61 ms). Critically, *Prime type* interacted with *Block type*, $F(1,18) = 12.91$, $MSe = 814.05$, indicating a strong proportion effect, with the congruence effect being greater in the high proportion block (100 ms) than in the low-proportion block (55 ms). There were no other main or interaction effects, all F(1,18) < 1.0.

In the analysis of error rate, the main effect of *Prime type* was significant, F(1,18) = 4.62, MSe = 24.69: Congruent trials (3.1%) were more accurate than incongruent trials (5.4%). There were no other main or interaction effects, all F(1,18) < 2.46, p > .13.

Discussion

The results of Experiment 3 showed that with a greater effect of item difficulty (produced by deliberately confounding prime type with stimulus type), a reliable proportion effect was readily obtained. This result was expected from the property of the ASE model described earlier, and it suggests that the failure to observe a reliable proportion effect in Experiments 1 and 2 is likely to have been due to a small effect of item difficulty (as indexed by the smaller RT difference between the easy – congruent - and hard – incongruent - trials) which in turn produced a small effect of difficulty of task environment.

Having found a reliable proportion effect, we are now in a position to pit the ASE account against the memory-recruitment account. According to the ASE model, the proportion effect reflects an interaction between item difficulty and difficulty of task environment. Further, what makes the environment easy is irrelevant: As long as the easy items are as easy as the congruent trials, the proportion effect should still be observed even if the easy items do not involve valid primes. In contrast, according to the memory recruitment account, the proportion effect reflects *prime validity*: The congruence effect is magnified in a block containing a high proportion of congruent trials because the prime is more useful (more valid) in the high-proportion block. These two accounts can be tested by varying the proportion of easy items while at the same time holding the proportion of congruent trials (valid items) constant. Specifically, the ASE account predicts that in a block containing a high proportion of filler items that do not contain valid primes but that are as easy as the congruent trials, the congruence effect should be larger than in the block containing a high proportion of hard items. The next experiment was conducted as a preliminary step before testing this prediction, with the aim of finding suitable filler items that are comparable in difficulty to the congruent trials.

Experiment 4

In previous studies using masked primes in number judgment tasks (e.g., Koechlin, Naccache, Block, & Dehaene, 1999; Naccache & Dehaene, 2001), congruence effects have been reported to be inhibition-dominant. That is, these previous studies used magnitude judgments ("Is the number bigger than 5?"), and found that relative to trials containing a neutral prime (number 5 in Koechlin et al., 1999, Experiment 2A; $ sign in Naccache & Dehaene, 2001), incongruent trials were slower but congruent trials were not faster. The aim of Experiment 4 was to test whether this inhibition-dominant pattern is also observed with parity-judgment: If the neutral primes are as easy as congruent trials, then the neutral primes can be used as suitable fillers in the high proportion block to test between the ASE account and the memory recruitment account. To this end, we included a neutral prime condition containing a single # sign (e.g., # - *3*). Stimuli in this experiment were all digits, and there were an equal number of congruent trials (e.g., *1-3*), incongruent trials (e.g., *8-3*) and neutral trials (e.g., # - *3*).

Method

Participants. Twenty-four volunteer students from Macquarie University participated in Experiments 4 for course credit.

Design. The experiment involved just one factor, namely, *Prime type*, with three levels: congruent vs. neutral vs. incongruent, manipulated within subjects. Only digits were used as stimuli.

Materials. The stimulus materials used in this experiment were digits 1 through to 9, excluding 5. The construction of congruent and incongruent trials was identical to Experiment 1. The neutral prime was "#", and it was paired with each digit three times. Thus, there were a total of 72 trials, consisting of 24 congruent trials, 24 incongruent trials and 24 neutral trials, with an equal number of even and odd digits in each condition. The critical test trials were preceded by 24 practice and warmup trials constructed in the same way as the test trials. They were not included in the analysis.

Apparatus and Procedure. Task instruction, timing parameters and apparatus were identical to Experiment 1.

Results and Discussion

Preliminary data treatment was identical to Experiment 1. The data trimming procedure affected 1.8% of trials. Latencies and error rates were analyzed using a one-way ANOVA with *Prime type* (congruent vs. neutral vs. incongruent) as a within-subject factor. Mean response latencies and error rates are presented in Table 4.

Insert Table 4 about here

In the analysis of latencies, planned contrasts tested showed that the 9 ms difference between the congruent trials and neutral trials was non-significant, $F(1,23) < 1.0$, $MSe = 1120.80$, but that the 30 ms difference between the incongruent trials and neutral trials was significant, $F(1,23) = 9.82$, $MSe = 1120.80$.

In the analysis of error rates, neither the 0.9% difference between the congruent trials and neutral trials, nor the 1.2% difference between the incongruent trials and neutral trials was significant, $F(1,23) = .68$; $F(1,23) = 1.37$, $MSe = 13.19$, respectively.

These results confirm the pattern reported previously (Koechlin et al., 1999; Naccache & Dehaene, 2001), namely that in a number judgments involving masked primes there is little difference in latencies between the congruent and neutral trials but there is a large difference between the neutral and incongruent trials.

Experiment 5 (Digit and number word stimuli with neutral primes)

The critical finding of Experiment 4 is that in the parity decision task, neutral trials (involving # as the prime) were as easy as the congruent trials. Experiment 5 made use of this finding to contrast the predictions of the ASE account and the memory recruitment account. Experiment 5 was identical to Experiment 3 (with all congruent trials containing digit stimuli and all incongruent trials containing number word stimuli), except that the high-proportion block contained .2 congruent trials, .2 incongruent trials and .6 neutral trials. The low-proportion block was identical to Experiment 3 and contained .2 congruent trials and .8 incongruent trials. According to the ASE account, the proportion effect reflects an interaction between item difficulty and the difficulty of task environment. From this perspective, the high-proportion block in Experiment 5 would be equivalent to the high-proportion block in Experiment 3, containing .8 easy items and .2 hard items. Thus the ASE account predicts the same pattern of data for Experiment 5 as for Experiment 3, i.e., an increase in the size of congruence effect in the "high-proportion" block. In contrast, the memory recruitment account views the proportion effect in terms of prime validity: Subjects make greater use of the prime when the list-wide context makes it more useful. From this perspective, the high-proportion block in Experiment 5 is no more valid because the proportion of congruent trials is the same as the low-proportion block (.2) and hence there is no reason to expect the size of congruence effect to be modulated by block type.

Method

Participants. Twenty volunteer students from Macquarie University participated in Experiments 5 for course credit.

Design. The experiment was similar in design to Experiment 3, and constituted a 2 (*Prime type*: congruent vs. incongruent) x 2 (*Block type*: high vs. low proportion of easy items) factorial design, with both factors manipulated within subjects. However, the critical difference between this experiment and Experiment 3 is that the high-proportion block contained .6 (72 trials) neutral trials, .2 (24 trials) of congruent items and .2 (24 trials) of incongruent items. As in Experiment 3, *Prime type* was deliberately confounded with stimulus type such that all congruent trials involved digits (e.g., *1-3, 8-2*) and all incongruent trials involved number words (e.g., *eight-ONE, three-TWO*).

Materials. The stimulus materials used in this experiment were digits and number words identical to Experiment 3. All congruent trials involved digit primes and digit targets (e.g., *1-3, 2-8*) and all incongruent involved number word primes and targets (e.g., *one-EIGHT, two-THREE*). Neutral trials involved a single # sign as primes and digit targets (e.g., # - *3*, # - *8*). The construction of stimuli were identical to that of Experiment 3, except that the high-proportion block contained 72 (.6) neutral prime trials, 24 (.2) congruent trials and 24 (.2) incongruent trials. The composition of low-proportion block was identical to that of Experiment 3 (.2 congruent trials and .8 incongruent trials).

Apparatus and Procedure. Task instruction, timing parameters and apparatus were identical to Experiment 1.

Results and Discussion

Preliminary data treatment was identical to Experiment 1. In Experiment 5, the data trimming procedure affected 1.5% of trials. As in previous experiments, latencies and error rates were analyzed using a three-way ANOVA with *Prime type* (congruent vs. incongruent), *Block type* (high- vs low proportion of congruent trials) and *Block order* (high-proportion block first vs. low-proportion block first) as factors. It should be noted however that the congruent condition in the high-proportion block in this experiment was based on 24, rather 96 trials as in previous experiments. Mean response latencies and error rates are presented in Table 5.

Insert Table 5 about here

In the analysis of latencies, the main effect of *Prime type* was significant, $F(1,18) = 74.05$, $MSe = 1173.78$: Congruent trials were 66 ms faster than incongruent trials. *Block order* was also significant, $F(1,18) = 5.12$, $MSe = 15513.53$, indicating that the group who did the low-proportion block first was 63 ms faster. *Block order* also interacted with *Prime type*, $F(1,18) = 5.57$, $MSe = 1173.78$. This indicated that the *Prime type* effect was greater in the group who did the high-proportion block first. Importantly, *Prime type* and *Block type* interacted, $F(1,18) = 7.71$, $MSe = 1497.79$, indicating that the *Prime type* effect was greater in the high-proportion block (90 ms) than the low-proportion block (42 ms). There were no other main or interaction effects, all $F(1,18) < 2.47$, $p > .13$.

In the analysis of error rates, the main effect of *Prime type* was significant, $F(1,18) = 4.01$, $MSe = 10.25$. No other main or interaction effects were significant, all $F(1,18) < 2.56$, $p > .13$.

The results were clear-cut: Consistent with the prediction of the ASE account and inconsistent with the prediction of the memory recruitment account, the congruence effect was magnified in a block containing a high proportion of easy items, even though the proportion of valid primes was the same (.2) in the two blocks.

General Discussion

The experiments reported here used the parity (odd-even) decision task and investigated the mechanism underlying the modulation of congruence effect (faster response to numbers preceded by parity-congruent primes) as a function of the proportion of congruent trials in a block, reported recently by Bodner and Dypvik (2005). We were specifically interested in testing the ASE (Adaptation to the Statistics of the Environment) account, which views the proportion effect in terms of an interaction between item difficulty and the difficulty of task environment. To summarize the findings, Experiment 1 used digit stimuli and Experiment 2 used number word stimuli, and unexpectedly showed that although there was a trend in the expected direction, the proportion effect was not reliable. Analysis of the ASE model suggested that the absence of a reliable proportion effect may have been due to the effect of the difficulty of task environment (which is in turn based on item difficulty) not being sufficiently large. Experiment 3 therefore sought to increase the magnitude of the effect of item difficulty by deliberately confounding stimulus type and prime type: All congruent trials involved digit stimuli and all incongruent trials involved number word stimuli. This experiment readily produced a reliable proportion effect. Experiment 5 showed that this proportion effect is obtained without varying list-wide prime validity but by increasing the proportion of easy items (neutral trials), with the results of Experiment 4 confirming that the neutral trials were as easy as the congruent trials. The results of these experiments are consistent with the ASE account but not with the memory recruitment account. This conclusion is in line with a recent study (Kinoshita, Forster & Mozer, submitted) which showed that the size of masked repetition priming effect in the naming task is modulated by the proportion of items varying in difficulty, but not by list-wide prime validity.

Two bases of proportion effect? As noted earlier, Experiments 1 and 2 did not produce a reliable proportion effect. This stands in contrast to the results reported by Bodner and Dypvik (2005). In examining possible reasons for the discrepancy, we note that Bodner and Dypvik used many more trials per block (360 trials per block compared to the 120 trials per block in our study) as well as a between-group manipulation of block type. It should be recalled that proportion effects were readily demonstrated with 120 trials per block, and using a within-subject manipulation of block type in Experiments 3 and 5, so they are unlikely to be the necessary conditions for finding a proportion effect. Rather, we suggest that the two conditions used by Bodner and Dypvik may have contributed additionally towards finding proportion effects, via a separate, criterion adjustment mechanism, as suggested below.

One point worth noting concerns a discrepancy between ASE and the human data with regard to the main effect of task environment – whether a block of trials contains a high or a low proportion of easy items. In both Experiments 3 and 5, the main effect of block type is not significant: In Experiment 3, $F(1,18) = 0.29$, $p = .87$; In Experiment 5, $F(1,18) = .21$, $p = .66$. Similarly, in Bodner and Dypvik's (2005) study, the main effect of block type was not significant except in their Experiment 1.[2] The simulation of ASE in Figure 1, in contrast, shows a main effect of task environment: The block containing a high proportion of easy items produces faster response latencies overall than the block containing a high proportion of hard items. The discrepancy between data and simulation is made clearer in Figure 3: the left panel shows the RT data from Experiment 3, and the center panel shows the ASE simulation RTs. One observes the main effect of block type in the simulation but not in the human data.

In the ASE simulation (Figure 1), we made one highly constraining assumption: that participants adopt the same point on the speed-accuracy trade off in both high-proportion-easy and high-proportion-hard blocks. In the RT-modeling literature, the trade off between speed and accuracy is often characterized by a *response criterion* – the amount of evidence that must accumulate before a response is initiated. Lowering the criterion obtains faster but less accurate responses. There is no a priori reason why participants should adopt the same response criterion in the high-proportion-easy and high-proportion-hard blocks. Indeed, in the more difficult block of trials, participants may adjust their response criterion to reduce errors, thereby operating with a more stringent response criterion for high-proportion-hard than high-proportion-easy blocks. When we relax assumptions of ASE, and allow ASE to choose different response criteria for the different blocks, ASE obtains a lovely quantitative fit to the data, as shown in the right panel of Figure 3. One possibility that may explain why Bodner and Dypvik (2005) were able to obtain a proportion effect with more trials per block than we have used in Experiments 1 and 2 is that a shift in response criteria may occur slowly, over a large number of trials, and hence would be more likely to be observed when a block contains a large number of trials.

Findings consistent with this possibility have been reported recently by Brown and Steyvers (2005), in a study using a lexical decision task investigating the dynamics of the effects of stimulus environment (operationalized as the difficulty of nonword foils where difficult nonwords were highly wordlike, e.g., *subvirt, lifrary*, and the easy nonwords were not, e.g., *cnotsun, haswend*). Brown and Steyvers reported that shifts in response criterion, as indexed by a change in hit and false alarm rates, lagged many trials behind the change in the stimulus environment. This conclusion stands in contrast to the mechanisms of ASE, in two respects. One is that the ASE assumes the effect of stimulus environment to be local and immediate (cf. Mozer et al., 2004, for the model's simulation of Trial N-1 effects reported by Taylor & Lupker, 2001). The second is that within the ASE model, the main mechanism responsible for the effect of stimulus environment is not the shift in response criterion: As mentioned above, the default assumption is that the slope of the RT cost function (the point at which it intersects the error curves determines the response criterion) remains stable throughout a block of trials. It is relevant to note that Brown and Steyvers (2005) used a "signal-to-respond" procedure, in which a series of rhythmic tones are presented throughout the trials and participants are trained to respond within 330 ms to 700 ms after stimulus onset. This contrasts with the "respond-when-ready" RT tasks for which the ASE model was developed. Within the ASE model, balancing the cost of responding too early and making an error and the cost of responding unnecessarily too slowly plays a central role in deciding when to initiate a response. With the signal-to-respond procedure, however, the cost associated with the latter is fixed by the experimenter-determined signal, and also the range of latency of previous trials would be much more limited than in the respond-when-ready RT tasks. Thus, the slow-acting criterion adjustment process reported by Brown and Steyvers (2005) is likely to be based on a different mechanism of list composition effects from that described by the ASE model. The speculative suggestion here is that the proportion effect observed by Bodner and Dypvik (2005) in their Experiment 2 and 3 (but perhaps not their Experiment 1, see Footnote 2) involving many more trials per block than our experiments reported here may have involved an additional, slow-acting mechanism of this sort.

It is relevant in this regard to note that in other studies, Bodner and Masson (2001, 2003) reported finding proportion effects with masked (repetition) primes using lexical decision. At present, we are unsure if the ASE mechanism described here alone could account for these effects. This is because Bodner and Masson used unrelated letter strings of the same lexical class as the target (i.e., unrelated word for a word target and unrelated nonword for a nonword target), and hence the hard items (control trials) would not have engendered response conflict. It is unclear in this case if the rate of evidence accumulation would differ substantially between the control trials and the repetition trials (although this would depend on the model of lexical decision assumed). Because these experiments also involved a large number of trials (400 trials), it is possible that the slow-acting criterion adjustment mechanism also contributed to the finding of the proportion effect.[3.] We should also note that in the series of lexical decision experiments using masked repetition primes, Bodner and Masson (2001) reported that the proportion effects were absent in some cases, and the ASE model provides a ready explanation for the null result. Specifically, Bodner and Masson (2001, Experiments 3, 5A) reported that proportion effects were absent when using only high-frequency words as word targets. This would be readily explained by the ASE model, based on the fact that repetition priming effects were smaller for high-frequency words than low-frequency words (see Masson & Bodner, 2003, for statistical analysis of the interaction between repetition priming and word frequency in these experiments). These possibilities will need to be tested empirically in the future.

In conclusion, the present series of experiments showed that the size of congruence effects in the parity decision task can be readily modulated as a function of proportion of congruent trials in a block provided that the congruent trials and incongruent trials differ substantially in difficulty. The results also showed that the modulation is a function of the proportion of easy vs. hard items, not prime validity. These findings provide clear support for the ASE account of proportion effects obtained with masked primes.

References

Bodner, G. E., & Dypvik, A. T. (2005). Masked priming of number judgments depends on prime validity and task. *Memory & Cognition*, *33*, 29-47.

Bodner, G. E., & Masson, M.E.J. (2001). Prime validity affects masked repetition priming: Evidence for an episodic resource account of priming. *Journal of Memory and Language, 45*, 616-647.

Bodner, G.E., & Masson, M.E.J. (2003). Beyond spreading activation: An influence of relatedness proportion on masked semantic priming. *Psychonomic Bulletin & Review, 10*, 645-652.

Bodner, G. E., & Masson, M. E. J. (2004). Beyond binary judgments: Prime validity modulates masked repetition priming in the naming task. *Memory & Cognition, 32*, 1-11.

Brown, S., & Steyvers, M. (2005). The dynamics of experimentally induced criterion shifts. *Journal of Experimental Psychology: Learning, Memory and Cognition, 31*, 587-599.

Damian, M. (2001). Congruity effects evoked by subliminally presented primes: Automaticity rather than semantic processing. *Journal of Experimental Psychology: Human Perception and Performance, 27*, 154-165.

Damian, M. (2004). Asymmetries in the processing of Arabic digits and number words. *Memory & Cognition, 32*, 164-171.

De Groot, A.M.E. (1984). Primed lexical decision: Combined effects of the proportion of related prime-target pairs and the stimulus-onset asynchrony of prime and target. *Quarterly Journal of Experimental Psychology, 36A*, 253-280.

Dehaene, S., Naccache, L., Le Clec, H.G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., van de Moortele, P.F., & Le Bihan, D. (1998). Imaging unconscious semantic priming. *Nature, 395*, 597-600.

Fabre, L., & Lemaire, P. (2005). Age-related differences in automatic stimulus-response associations: Insights from young and older adults' parity judgments. *Psychonomic Bulletin & Review, 12*, 1100-1105.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory and Cognition, 10*, 680-698.

Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers, 35*, 116-124.

Forster, K. I., Mohan, K., & Hector, J. (2003). The mechanics of masked priming. In S. Kinoshita & S. J. Lupker (Eds.), *Masked priming: The state of the art* (pp. 3-38). New York: Psychology Press.

Kahneman, D., & Treisman, A. (1984). Changing views of attention and automaticity. In R. Parasuraman, & D.R. Davies (Eds.), *Varieties of attention*. New York: Academic Press, 29-61.

Kanwisher, N. G. (1987). Repetition blindness: Type recognition without token individuation. *Cognition. 27, 117-143*.

Kinoshita, S., Forster, K.I., & Mozer, M.C. (2006). Modulation of masked repetition priming effect in the word naming task. Manuscript submitted for publication.

Kinoshita, S., & Mozer, M.C. (2006). How lexical decision is affected by recent experience: Symmetric vs. asymmetric frequency-blocking effects. *Memory & Cognition*, *34*, 726-742.

Koechlin, E., Naccache, L., Block, E., & Dehaene, S. (1999). Primed numbers: Exploring the modularity of numerical representations with masked and unmasked semantic priming. *Journal of Experimental Psychology: Human Perception and Performance, 25*, 1882-1905.

Kolers, P. A., & Roediger, H. L. (1984). Procedures of mind. *Journal of Verbal Learning and Verbal Behavior, 23*, 425-449.

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

Lupker, S. J., Brown, P., & Colombo, L. (1997). Strategic control in a naming task: Changing routes or changing deadlines? *Journal of Experimental Psychology: Learning, Memory and Cognition, 23*, 570-590.

Lupker, S. J., Kinoshita, S., Coltheart, M., & Taylor, T. (2003). Mixing costs and mixing benefits in naming words, pictures, and sums. *Journal of Memory and Language, 49*, 556-575.

Masson, M.E.J., & Bodner, G.E. (2003). A retrospective view of masked priming: Toward a unified account of masked and long-term repetition priming. In S. Kinoshita & S.J. Lupker (Eds.), *Masked priming: The state of the art*. New York: Psychology Press, pp.57-94.

Moscovitch, M. (1995). Models of consciousness and memory. In M. Gazzanigga (Ed.), *The cognitive neurosciences*. Cambridge, MA: MIT Press, 1341-1356.

Mozer, M.C. (1989). Types and tokens in visual letter perception. *Journal of Experimental Psychology: Human Perception and Performance, 15*, 287-303.

Mozer, M. C., Kinoshita, S., & Davis, C. (2003, November 6-9). *Control and adaptation of the speed-accuracy tradeoff: A mathematical theory.* Paper presented at the 44th Annual Meeting of the Psychonomic Society, Vancouver, Canada.

Mozer, M. C., Kinoshita, S., & Davis, C. (2004). Control of response initiation: Mechanisms of adaptation to recent experience. *Proceedings of the Twenty Sixth Annual Conference of the Cognitive Science Society* (pp. 981-986). Hillsdale, NJ: Erlbaum Associates.

Naccache, L., & Dehaene, S. (2001). Unconscious semantic priming extends to novel unseen stimuli. *Cognition, 80*, 223-237.

Neely, J.H. (1977). Semantic priming and retrieval from lexical memory: Roles of inhibitionless spreading activation and limited-capacity attention. *Journal of Experimental Psychology: General, 106,* 226-254.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G.W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition*. Hillsdale, N.J.: Erlbaum. pp. 264-336.

Rastle, K., Kinoshita, S., Lupker, S. J., & Coltheart, M. (2003). Cross-task strategic effects. *Memory & Cognition, 31*, 867-876.

Reynvoet, B., Caessens, B., & Brysbaert, M. (2002). Automatic stimulus-response associations may be semantically mediated. *Psychonomic Bulletin & Review, 9*, 107-112.

Taylor, T. E., & Lupker, S. J. (2001). Sequential effects in naming: A time-criterion account. *Journal of Experimental Psychology: Learning, Memory and Cognition, 27*, 117-138

Table 1.

Mean Response Latencies (RT, in ms) and Percent Errors (%E) in Experiment 1 with digit stimuli

	Prime type					
	Congruent		Incongruent		Congruence effect	
Proportion of congruent trials	RT	%E	RT	%E	RT	%E
Averaged over block order						
High	514	3.9	541	5.4	**27**	**1.5**
Low	512	3.1	536	5.4	**24**	**2.3**
High proportion block first group						
High	497	4.4	525	6.3	**28**	**1.9**
Low	483	4.5	513	7.0	30	2.5
Low proportion block first group						
High	530	3.4	557	4.5	27	1.1
Low	542	1.8	560	3.7	**18**	**1.9**

Items in bold indicate the relevant comparisons tested in the experiment

Table 2.

Mean Response Latencies (RT, in ms) and Percent Errors (%E) in Experiment 2 with number word stimuli

	Prime type					
	Congruent		Incongruent		Congruence effect	
Proportion of congruent trials	RT	%E	RT	%E	RT	%E
Averaged over block order						
High	543	3.5	574	8.0	**31**	**4.5**
Low	553	3.3	574	6.2	**21**	**2.9**
High proportion block first group						
High	567	3.0	593	6.6	**26**	**3.6**
Low	559	1.8	582	4.6	23	2.8
Low proportion block first group						
High	519	4.1	554	9.5	35	5.4
Low	547	4.8	566	7.8	**19**	**3.0**

Items in bold indicate the relevant comparisons tested in the experiment

Table 3.

Mean Response Latencies (RT, in ms) and Percent Errors (%E) in Experiment 3 with digit and number word stimuli

	Prime type					
	Congruent (Digits)		Incongruent (Number words)		Congruence effect	
Proportion of congruent trials	RT	%E	RT	%E	RT	%E
Averaged over block order						
High	539	3.8	639	5.8	**100**	**2.0**
Low	560	2.3	615	5.0	**55**	**2.7**
High proportion block first group						
High	537	3.3	657	4.2	120	0.9
Low	557	2.9	624	4.5	67	1.6
Low proportion block first group						
High	541	4.3	621	7.5	80	3.2
Low	563	1.7	605	5.6	42	3.9

Items in bold indicate the relevant comparisons tested in the experiment

Table 4.

Mean Response Latencies (RT, in ms) and Percent Errors (%E) in Experiment 4 with digit stimuli

Prime type					
Congruent		Neutral		Incongruent	
RT	%E	RT	%E	RT	%E
536	5.7	545	6.6	575	7.8

Table 5.

Mean Response Latencies (RT, in ms) and Percent Errors (%E) in Experiment 5 with digit and number word stimuli

	Prime type							
	Congruent (Digits)		Incongruent (Number words)		Congruence effect		Neutral (Digits)	
Proportion of easy trials	RT	%E	RT	%E	RT	%E	RT	%E
Averaged over block order								
High	531	3.5	621	4.6	**90**	**1.1**	525	3.5
Low	561	2.9	603	4.7	**42**	**1.8**		
High proportion first group								
High	562	5.0	675	5.0	113	0.0	556	4.5
Low	576	4.6	631	5.3	55	0.7		
Low proportion first group								
High	501	2.1	568	4.2	69	2.1	495	2.5
Low	547	1.3	576	4.2	29	2.9		

Items in bold indicate the relevant comparisons tested in the experiment

Author notes

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Thanks are due to Tania Malouf and Shaun Greenfield for research assistance. This study was supported by the Australian Research Council (DP0556805) and USA National Science Foundation (project no. 0518319).

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Footnotes

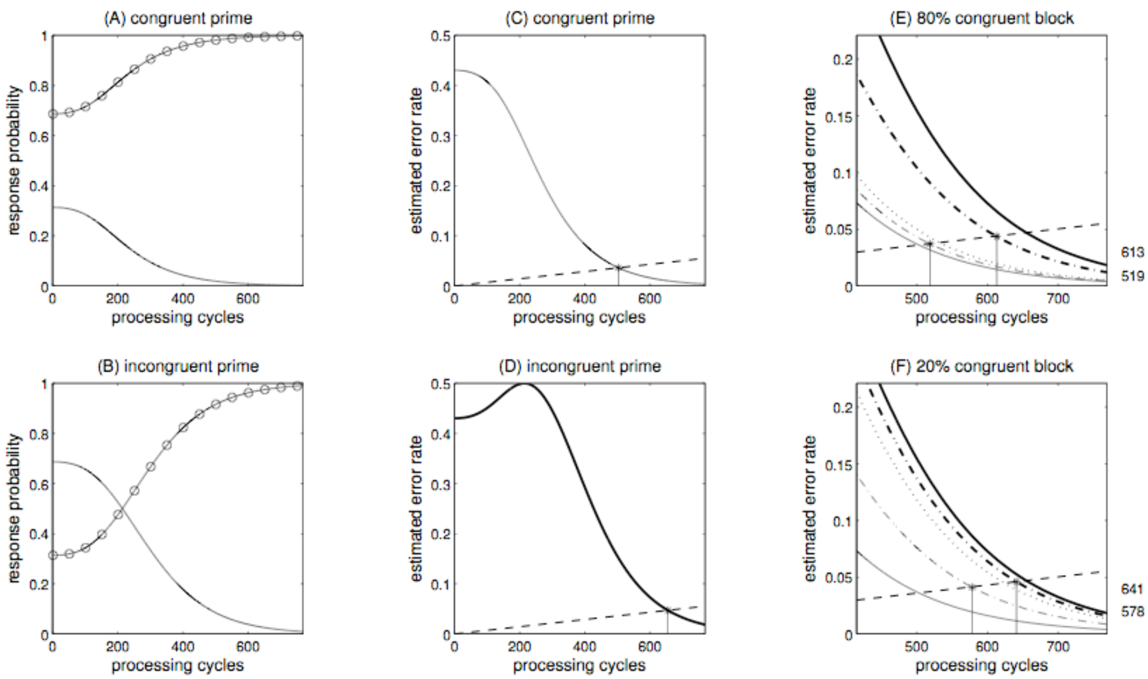
1. The parameters specify: (1) the relative cost of speed versus accuracy, (2) the mean association strength in a perceptual pathway mapping visual representations to object-identity representations, (3) the mean association strength in a response pathway mapping object-identity representations to a response, (4) the degree to which the current error curve should be based on the historical trace; and (5) the residual activation from the prime that remains to influence processing of the target.
2. In Bodner and Dypvik's (2005) Experiment 1, unlike the other experiments, the high-proportion block contained .6 of repetition prime trials (e.g., *three-THREE*), .2 of congruent trials and .2 of incongruent trials. Because the repetition prime trials were even faster than the congruent trials, the high-proportion block would have represented a substantially easier task environment than the low-proportion block, and indeed, the main effect of block type was significant in this experiment.
3. We should note that by a slow-acting criterion adjustment mechanism, we do not mean that the subjects require many trials to *set the initial criterion level*, but rather, that once set, it is not changed on a trial-by-trial basis. Thus, the notion of a slow-acting criterion-adjustment process is not inconsistent with the fact that Bodner and Masson (2001) reported using a lexical decision task and a between-subject manipulation of block type that the prime validity effect was apparent from the first 40 trials and did not change in size across sub-blocks containing 100 trials each.

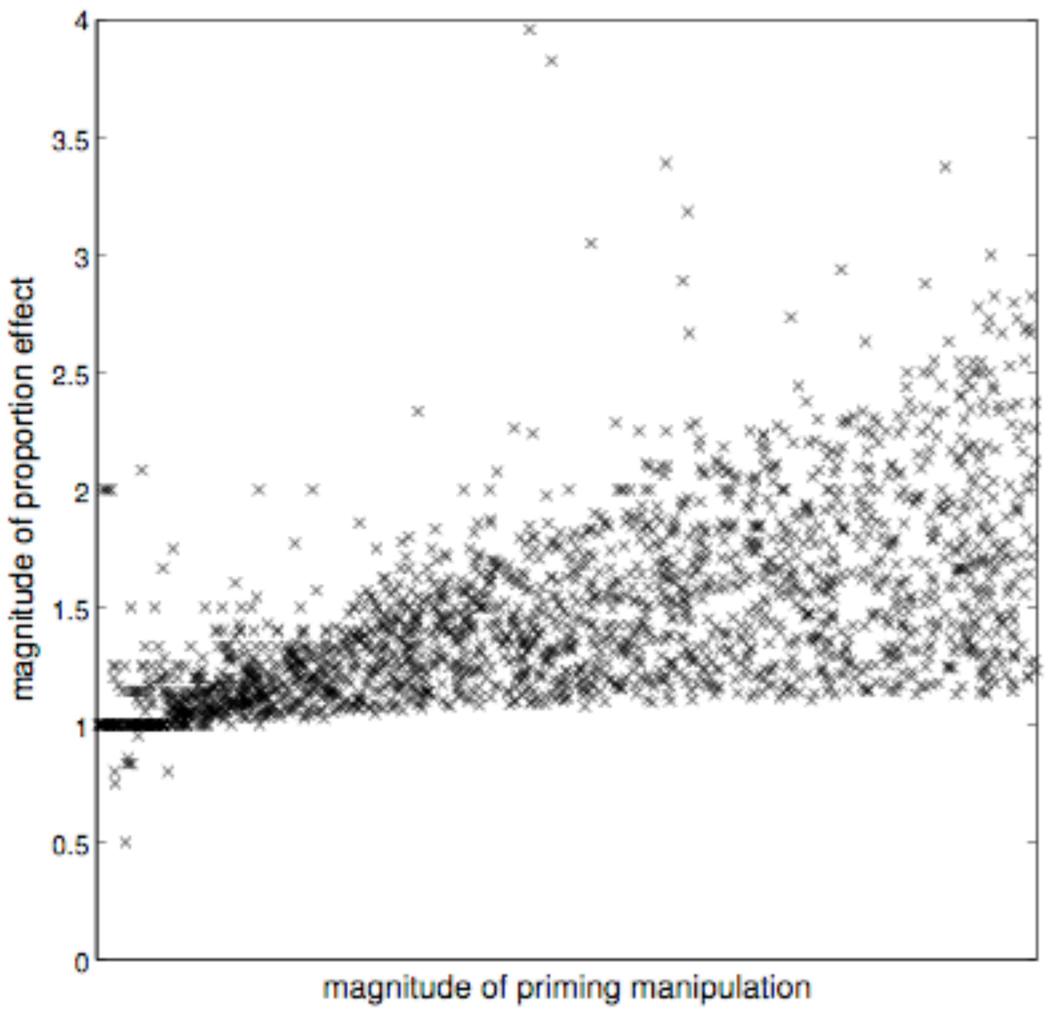
Figure captions

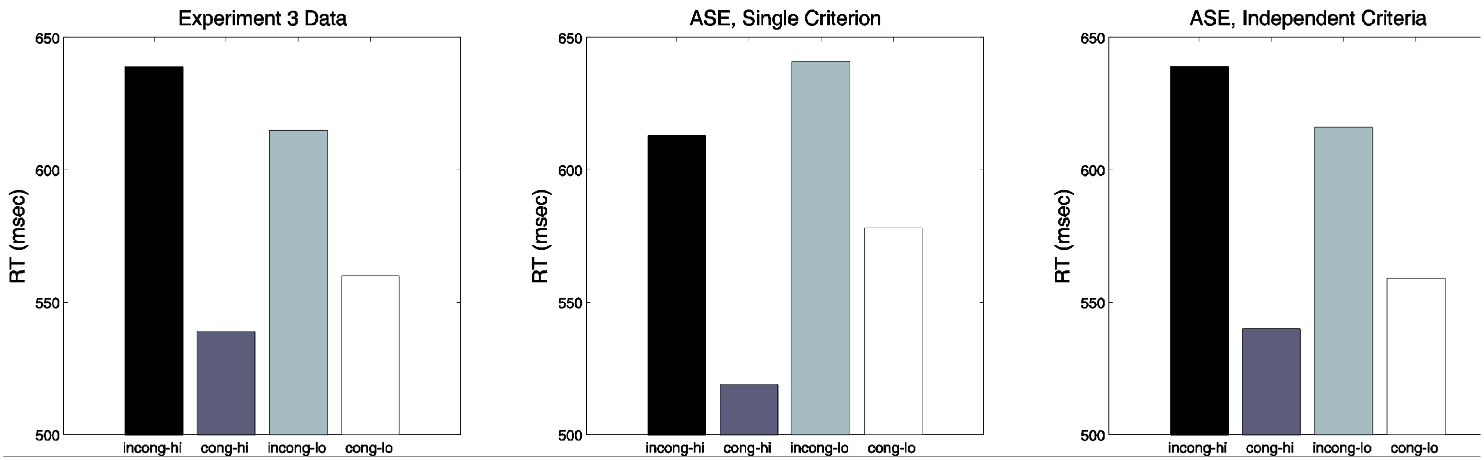
Figure 1. The ASE account of prime validity effect. (see text for explanation)

Figure 2. 2,000 replications of the ASE model with random parameter settings

Figure 3. (left panel) RT data from Experiment 3, where “incong” and “cong” refer to an incongruent or congruent trial, respectively, and “hi” and “lo” refer to the proportion of easy trials in a block (80% for high and 20% for low); (center panel) simulation result from ASE in which the same response criterion is used in the two block types; (right panel) simulation result from ASE in which the two block types are allowed to have different response criteria.


(A) congruent prime
response probability
processing cycles
(B) incongruent prime
response probability
processing cycles
(C) congruent prime
estimated error rate
processing cycles
(D) incongruent prime
estimated error rate
processing cycles
(E) 80% congruent block
estimated error rate
processing cycles
613
519
(F) 20% congruent block
estimated error rate
processing cycles
641
578


magnitude of proportion effect
magnitude of priming manipulation
0
0.5
1
1.5
2
2.5
3
3.5
4


Experiment 3 Data
RT (msec)
650
600
550
500
incong-hi
cong-hi
incong-lo
cong-lo
ASE, Single Criterion
RT (msec)
650
600
550
500
incong-hi
cong-hi
incong-lo
cong-lo
ASE, Independent Criteria
RT (msec)
650
600
550
500
incong-hi
cong-hi
incong-lo
cong-lo