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Assessing Masked Semantic Priming: Cursor Trajectory versus Response Time Measures

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Abstract

Measuring response times has been a staple for evaluating masked semantic priming. Its efficacy, however, has been challenged on several grounds — reported effect sizes of these studies are relatively small, and priming effects pertaining to response time measures are difficult to be replicated. Here, we report a complementary method — recording trajectories of a computer cursor. Participants judged whether two digits were the same or different, preceded by a briefly presented masked prime. Each prime had either positive or negative connotations, and the priming effects were evaluated either by response times or cursor trajectories associated with the area under the curve. Results indicate that the effect size of the congruency effect measured by cursor trajectories (i.e. area under the curve) was far greater than that measured by response times, suggesting that the cursor trajectory measure is more sensitive to masked semantic priming than the response time measure.

Keywords: masked semantic priming; congruency effect; cursor trajectories; response time

Introduction

Masked semantic priming has played a pivotal role in deepening our understanding of conscious and unconscious processing. In a typical masked semantic priming study, participants judge whether two numbers are the same or different (e.g., "3 / 3" or "3 / 5"), preceded by two masked priming letters (e.g., "A / a" or "A / g"). Trials where primes and targets semantically conflict are called incongruent trials (e.g., "A / g" prime and "3 / 3" target), otherwise they are congruent trials (e.g., "A / a" prime and "3 / 3" target). It is found that response times in incongruent trials are longer than those in congruent trials, which is called "congruency effect" (Van Opstal, Gevers, Osman, & Verguts, 2010).

Congruency effects can occur at a semantic level in near absence of awareness. For example, masked letters, words or pictures can be categorized subliminally (Dehaene et al., 1998, Dell'Acqua & Grainger, 1999; Weibel, Giersch, Dehaene, & Huron, 2013). In addition, complicated judgments can be unconsciously applied to masked stimuli (Kiesel, Kund, Pohl, Berner, & Hoffmann, 2009). A further study suggests that semantic context information can be processed without much awareness (Van Opstal, Calderon, Gevers, & Verguts, 2011).

However, the credibility of masked semantic priming has been questioned on several grounds. First, effect sizes reported in these studies are relatively small; a meta-analysis study summarizing masked semantic priming effects suggests that those priming effects are often difficult to be replicated (Van den Bussche, Van den Noortgate, & Reynvoet, 2009). Second, it is argued that congruency effects could be underestimated due to participants' conscious control of response times, known as the Gratton Effect (Gratton, Coles, & Donchin, 1992). Specifically, when a trial is incongruent, participants respond faster to a subsequent incongruent trial, resulting in reduced congruency effects (Desender & Bussche, 2012). Kinoshita, Forster, and Mozer (2008) showed that participants became aware of the incongruent trials, and adjusted their response times to mitigate the response delay. These effects originate from participants' self-control, also known as "trial-by-trial" modulation (Egner, 2007). Such modulation reduces response times for incongruent trials and produces smaller congruency effects.

One important factor that contributes to these shortcomings is the way that semantic priming is assessed. Most behavioral data collected to evaluate masked semantic priming is based on response times, which provides only one data point for each trial. Response times are not very informative with regard to the dynamic cognitive processes that unfold within a short period, which is yet fundamental for the occurrence of subliminal priming. To probe those dynamic processes, a measurement procedure sensitive to fine-tuned data points that correspond to decision-making processes is needed. In addition, the Gratton Effect is attributed to participants' adaptation to semantic conflicts experienced in incongruent trials; such adaptation leads participants to build up a stable response time pattern during experiments. Thus, to alleviate the interference of the Gratton Effect, a measurement procedure that is sensitive to dynamic decision processes should be developed.

Here we introduce a complementary tool to measure semantic priming—assessing trajectories of a computer cursor (Dale, Kehoe, & Spivey, 2007; Song & Nakayama, 2009; Spivey & Dale, 2006; Xiao & Yamauchi, 2014; Yamauchi, 2013; Yamauchi, Kohn, & Yu, 2007). The merit of the cursor motion method is that it records dynamic temporal-spatial information about participants' responses, in addition to response time data (Freeman & Ambady, 2010). For each trial, participants use a computer mouse to respond, while running times and positions of the cursor on the screen are recorded every 20ms to generate a cursor motion trajectory. By analyzing the temporal-spatial

features of cursor motion trajectories, further insights can be gained to understand semantic priming.

There are a few studies that have applied the cursor motion method to study priming. For example, Friedman and Finkbeiner (2010) find that repetition priming and semantic priming can be distinguished by different cursor trajectory patterns. Furthermore, Xiao and Yamauchi (2014) show that congruency effects can be reliably measured by attractions toward unintended choices of cursor trajectories, and incongruent trials elicit larger attractions than congruent trials do. Though cursor motion methods seem powerful, no studies have compared the cursor motion measures directly to response time measures in a masked priming framework.

To compare the two measures, two independent experiments respectively applying the cursor motion measure and response time measure are conducted in the current study. A different group of participants were recruited for each experiment, and the methodology was developed by Xiao and Yamauchi (2014).

Method

Both experiments consisted of two phases: a number judgment task followed by an awareness test. In the number judgment task, participants judged whether two numbers were the same or different, preceded by a briefly presented picture. The trials in the awareness test were identical to those in the number judgment task except that participants were explicitly instructed to identify the primes and choose the correct prime from two options. With this design, we know whether primes are visible to participants.

With the number judgment task, we investigate whether the semantic gist of masked pictures (i.e. primes) can influence participants' "same / different" judgment of numbers. A psychophysics study showed that the "same" or "different" judgments of stimuli are respectively mapped to "yes" or "no" responses (Schoups, Vogels, & Orban, 1995). It is also well known that positive (e.g. "yes") responses elicit shorter response times than negative (e.g. "no") responses (Sternberg, 1966). A similar trend was found for "same / different" judgment: "same" responses took shorter response times than "different" responses (Ratcliff, 1985). Based on Proctor's Unified Theory (1981), such response time differences indicate that "same" and positive judgments employ an analogous processing mechanism, as distinct from processes underlying "different" or negative judgments. Following this rationale, we assume that priming pictures with positive connotations (e.g., a smiley face) are congruent with "same" responses (e.g., "3 \ 3") while primes with negative connotations (e.g., an upset face) are congruent with "different" responses (e.g., "3 \ 5"). Thus, we predict that positive primes facilitate "same" while impede "different" response; in contrast, negative primes facilitate "different" while impede "same" responses (Xiao & Yamauchi, 2014).

Participants

In total, 64 undergraduates from Texas A&M University participated in our experiments for course credits. Among them, 28 participants were assigned to a cursor motion experiment, while 36 to a response time experiment.

Materials

Prime stimuli were three pairs of symbolic pictures. Each pair consisted of one picture with positive connotations and the other with negative connotations (Table 1). Four number pairs were used as target stimuli; two of the pairs demand "same" responses (i.e., "3 \ 3" or "5 \ 5"), and the other two pairs demand "different" responses (i.e., "3 \ 5" or "5 \ 3").
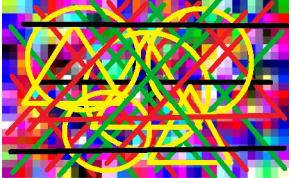
	Prime type		Mask
	Positive	Negative	
Pair 1			
Pair 2			
Pair 3			

Figure 1: Pictures used as primes and masks.

Measuring Cursor Motion

For the cursor motion experiment, the area under the curve (AUC) of a cursor trajectory in each trial is calculated as the geometric area circumscribed by a straight line from the onset position to an ending position, and by the actual trajectory that exceeds the straight line toward the unintended option (Figure 2). The AUC is measured by the number of pixels. A smaller AUC indicates that the trial is easier to respond to, while a larger AUC indicates more semantic conflicts experienced between the prime and target (Freeman et al., 2008). The position of the cursor is recorded as one data point every 20ms (Figure 3), and all data points are normalized into 100 steps for each trial using a linear interpolation method.
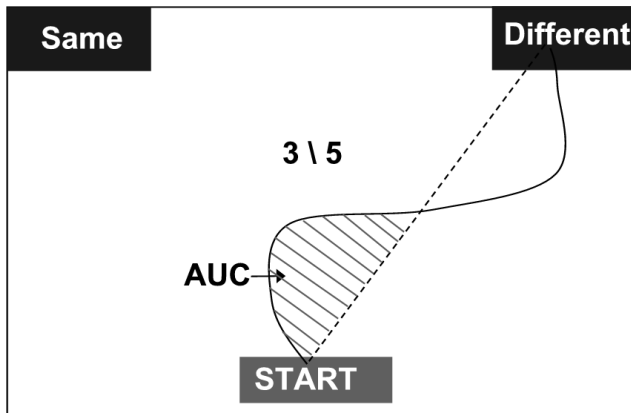
Figure 2: Illustration of the area under the curve (AUC). In this example, participants judge whether the digits 3 and 5 are the same or different. The curve represents a hypothetical trajectory of a cursor moving from the center of the "START" button to the ending position (where the "Different" button is clicked). The dashed straight line represents the shorted path from the onset to ending position. The AUC is defined by the area circumscribed by the shortest path, and by the actual trajectory curve exceeding the shortest path toward the unintended button.
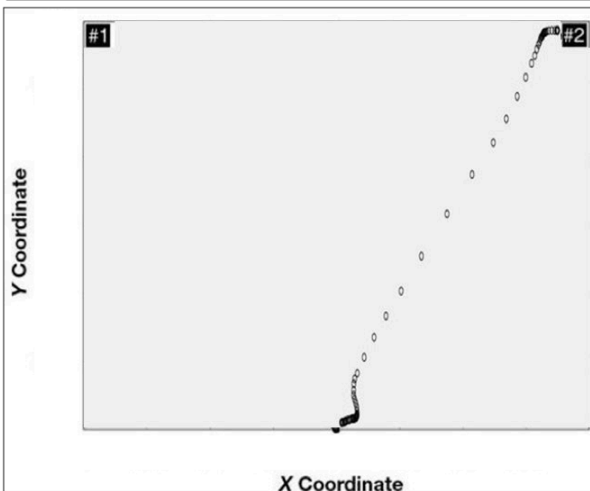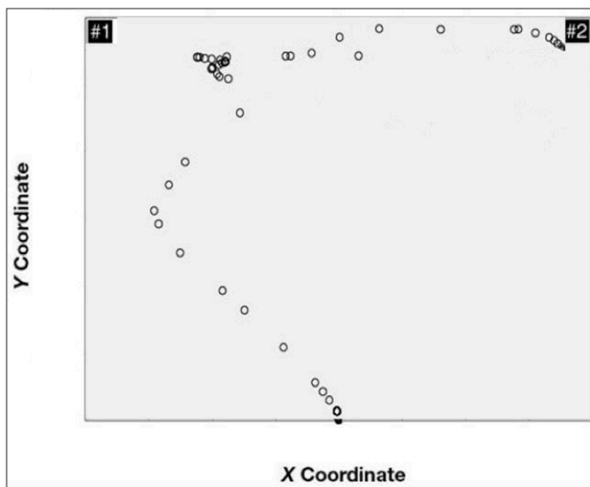

Figure 3: Two examples of cursor trajectories for an incongruent trial and a congruent trial. The first figure shows a trajectory with a large attraction (AUC) towards the unintended button, while the second figure shows a trajectory with a small AUC.

Procedure

In each trial, a fixation cross was presented at the center of the screen for 300ms. Then, a pre-mask was presented for 100ms, followed by a priming picture presented for 20ms, and a post-mask for 100ms. Finally, the target was presented until participants responded. Participants were instructed to judge whether the two numbers were the same or different, while ignoring any pictures flashed prior to the numbers. There were 240 trials for each participant: 120 trials were congruent (60 PP and 60 NN trials) and 120 trials were incongruent (60 NP and 60 PN trials). These trials were further divided into two categories with either the "same" ("3 \ 3" or "5 \ 5" targets) or "different" ("3 \ 5" or "5 \ 3" targets) response trials (See Table 1).

Table 1: Number of trials in each condition

Trial Types		Prime	Target	Number
Congruent	PP	Positive	3\3	30
		Positive	5\5	30
	NN	Negative	3\5	30
		Negative	5\3	30
Incongruent	NP	Negative	3\3	30
		Negative	5\5	30
	PN	Positive	3\5	30
		Positive	5\3	30

For the cursor motion experiment, participants were instructed to use the mouse to click the "Same" or "Different" button on the top of the screen quickly and accurately (Figure 4a). Whether "Same" button was on the left or right was counterbalanced between participants. For the response time experiment, participants were instructed to press the "F" button on a keyboard to choose "Same" and the "J" button to choose "Different" (Figure 5a).

After the number judgment task, participants took part in an awareness test. There were 96 trials in the awareness test; they were identical to those in the number judgment task. However, participants were informed about the prime and asked to identify it. For the cursor motion experiment, participants clicked one of the two optional pictures that matched the prime (Figure 4b). For the response time experiment, participants pressed either "F" to choose the left picture or "J" to choose the right picture (Figure 5b). The d' measure obtained from the awareness test was calculated to examine whether participants' capacity to identify the primes predicts their priming magnitudes. Specifically, selecting the option that was presented as a prime was

regarded as 'hit' and incorrectly selecting the same option that was not actually presented was regarded as 'false alarm'.
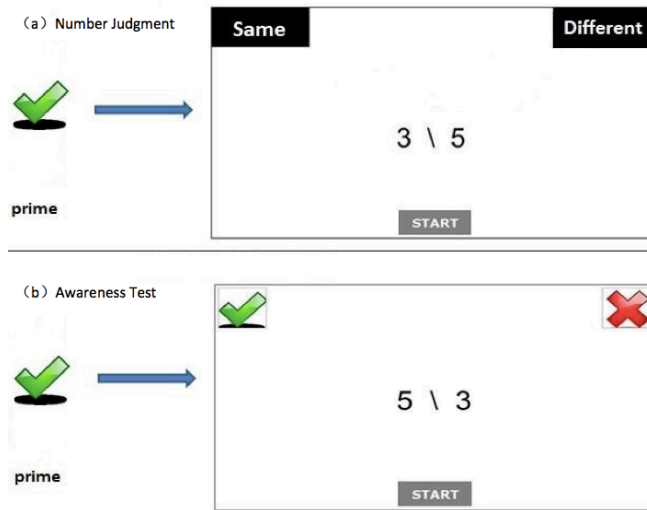

Figure 4: illustrations of the number judgment task and awareness task in the cursor motion experiment. In the number judgment task (a), participants judged whether two digits were the same or different, preceded by a briefly presented masked prime (e.g., a check). In the awareness test, participants were asked to identify the priming picture and click the correct picture of the two options.
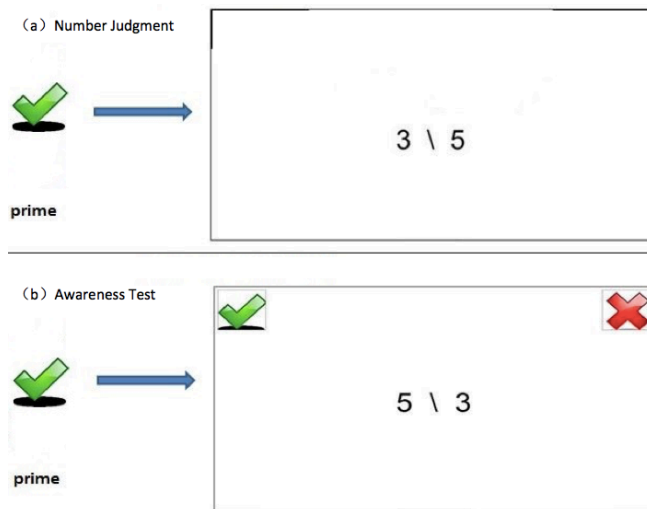

Figure 5: The response time experiment. In the number judgment task (a), participants pressed either "F" button to choose "Same" or "J" to choose "Different". In the awareness test (b), participants pressed either "F" to choose the left picture or "J" to choose the right.

Design

For both groups, the experiment is 2 (prime type: positive, negative) $\times$ 2 (target type: same, different) within-subjects design. The dependent variable is the response time for the response time measure group, and the area under the curve (AUC) for the cursor motion measure group. In the analysis, we collapsed prime type and target type as one factor of congruency (congruent, incongruent), and employed paired t-tests to investigate the congruency effect (i.e. whether the dependent variable for congruent trials is less than that for incongruent trials). To compare congruency effects obtained in the cursor trajectory measure and the response time measure, we applied a meta-analytic method and evaluated the relative magnitudes of the p values and effect sizes obtained in the two experiments (Rosenthal, 1991).

Results

Trials with a response time longer than 3000ms were dropped. Paired t-tests were performed to assess congruency effects. For the cursor motion experiment, the AUC was smaller for congruent trials (M = 3628.43, SD = 3875.79) than for incongruent trials (M = 4746.17, SD = 4135.95), $t(27)$ = 5.13, $p < 0.001$, d = 1.97, 95% CI$_d$ [1.31, 2.64] (Rosenthal & Rosnow, 1991; Fritz, Morris, & Richler, 2012). Similarly, for the response time experiment, the response time (RT) was also shorter for congruent trials (M = 733.32, SD = 156.28) than for incongruent trials (M = 759.50, SD = 168.60). However, this difference was only marginally significant; $t(35)$ = 1.92, p = 0.06, d = 0.65, 95% CI$_d$ [0.16, 1.14].

To further explore whether priming occurred at a subliminal level, we calculated d' for the awareness test to measure the extent to which participants could identify the masked primes (Greenwald, Draine, & Abrams, 1996). To assess whether the priming effects depended on visibility of primes, we performed a linear regression analysis on the d' with the priming magnitude as the predicted variable, which was calculated by subtracting the mean AUC of congruent trials from that of incongruent trials for each subject (Greenwald et al., 1996; Van Opstal, Gevers, Osman, & Verguts, 2010).

For AUC data, there was no correlation between the priming magnitude and d' (Figure 6), $b*$ = 0.29, $t(26)$ = 1.55, p = 0.14, suggesting that the congruency effect was not influenced by prime visibility. Meanwhile, there was a significant intercept at zero d'; b = 758.16, $t(26)$ = 2.40, p = 0.02, indicating that the congruency effect was still significant for participants who could hardly identify the primes.
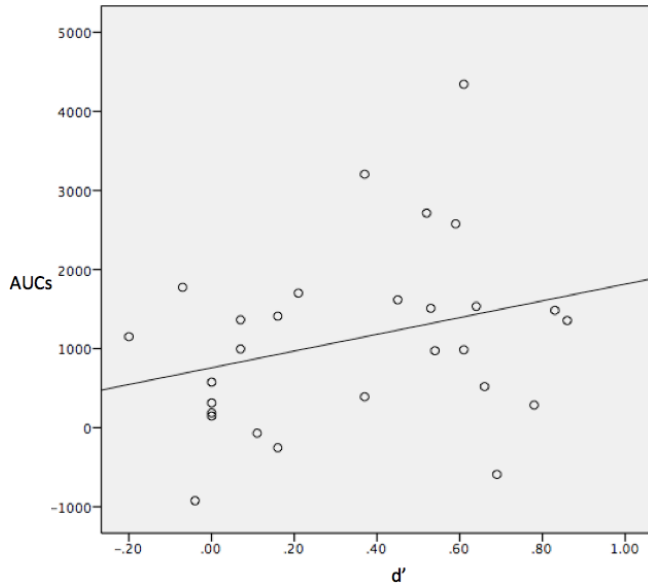
Figure 6: Regression on *d'* with priming magnitude as the predicted variable measured by AUCs. The X-axis is the *d'* and the Y-axis is the priming magnitude, which was calculated by subtracting the AUCs in congruent trials from those in incongruent trials.

The same awareness analysis was performed for RT data. A linear regression on the *d'* with priming magnitude as the predicted variable revealed no correlation between the priming magnitude and *d'* (Figure 7), $b^* = -0.057$, $t(34) = -0.33$, $p = 0.74$; the congruency effect was not influenced by prime visibility. And the intercept was not significant at zero *d'*; $b = 30.60$, $t(34) = 1.59$, $p = 0.12$.
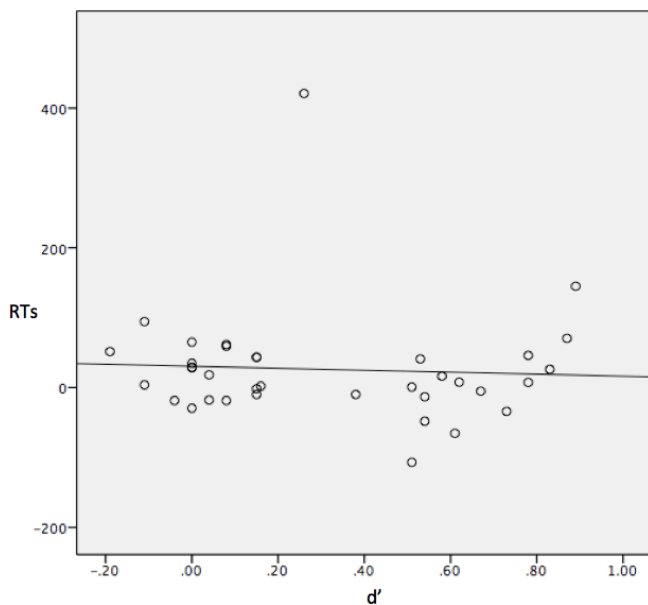

Figure 7: Regression on *d'* with priming magnitude as the predicted variable measured by RTs.

To verify whether the AUC data revealed larger effect size than the RT data, we compared the p values and effect sizes with a meta-analytic method. For the p-value comparison, Z is determined by a formula $(Z_1 — Z_2)/\sqrt{(2)}$ (Rosenthal, 1991). The p-value associated with a Z of 2.56 was 0.005 one-tailed; the difference between the p-values was significant, and the AUC data revealed a smaller p-value than the RT data. For comparison of effect sizes, Z is determined by a formula $(Z_{r1} — Z_{r2})/\sqrt{(1/(N_1-3)+1/(N_2-3))}$ (Alexander, Scozzaro, & Borodkin, 1989; Snedecor & Cochran, 1989). The p-value associated with a Z of 2.09 was 0.018 one-tailed; the difference between the effect sizes was significant, and the AUCs revealed larger effect size than the RTs.

Discussion

Both the response time measure and cursor motion measure show congruency effects where congruent trials yield shorter RTs, as well as smaller AUCs, than incongruent trials. Consistent with the previous findings (Xiao & Yamauchi, 2014), the gist of masked pictures can be processed in near absence of awareness. In addition, the priming effect size measured by AUCs is significantly larger than that of RTs. Two reasons can account for this difference.

First, response times record only the duration from the onset of a target stimulus until a response is made, but no information is recorded for what is happening during this duration. Such information is indispensable, however, to understand the subtle processes of semantic priming. In contrast, a measure integrating temporal-spatial information can reveal real-time features of behavioral data, therefore has better accuracy than measures recording only temporal information.

Second, response time data often suffers from the influence of the Gratton Effect. Participants can more or less estimate their response times and try to control it, which usually results in reduced congruency effects due to participants' adaptation to semantic conflicts experienced in incongruent trials. Cursor motion data is beneficial because it includes spatial information in addition to temporal data. Though temporal data alone may underestimate congruency effects, semantic priming is still revealed by dynamic temporal-spatial data. Admittedly, the current study is far from a conclusion that the AUC data is less vulnerable to the Gratton Effect than the RT data. Further studies are needed to examine the robustness of cursor motion measures against the Gratton Effect.

Though effect sizes are different between response times and AUCs, both show analogous congruency effects, meaning that the two measures are actually accessing the same priming processes. Furthermore, since the effect size measured by AUCs is far larger than that of RTs, though RTs only show marginally significant results, the cursor motion measure appears to be more sensitive to subtle semantic priming. Thus we suggest that the cursor motion

method can be a complementary tool for masked semantic priming research.

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