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The Response-Window Regression Method-Some Problematic Assumptions: Comment on Draine and Greenwald (1998)

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A new response-window regression method for evaluating unconscious semantic priming (S. C. Draine & A.G. Greenwald, 1998) is considered. Four assumptions of the method are discussed: (a) the assumption of standard (ordinary least squares) regression; (b) the assumption of comparable direct and indirect measures; (c) the assumption of linear relationship; and (d) the assumption of forced responding. Situations with strong relationships in the data between indirect- and direct-task measures, coupled with nonstandard regression techniques, provide the strongest evidence from this method. Situations in which the indirect- and direct-task measures show essentially no relationship in the data demand closely reasoned arguments and careful statistical treatment.

Replicable Unconscious Semantic Priming?

Draine and Greenwald (1998), following prior work by Greenwald and colleagues (Greenwald & Draine, 1997; Greenwald, Draine, & Abrams, 1996; Greenwald, Klinger, & Schuh, 1995), have proposed an intriguing new method for demonstrating unconscious semantic priming. The method combines a response-window procedure for maximizing the size of semantic-priming effects with a regression method for evaluating the strength of "unconscious" priming. When done carefully, this methodological approach may provide evidence for unconscious priming. This article highlights certain issues in the application of the regression method and the response-window method and offers several guidelines for strong interpretation. The following assumptions of the method are considered and discussed: (a) the assumption of standard regression; (b) the assumption of comparable direct and indirect measures; (c) the assumption of linear relationship; and (d) the assumption of forced responding.

The Response-Window Regression Method

Greenwald and colleagues (Greenwald et al., 1995, 1996) cleverly proposed a regression method for demonstrating unconscious priming. In the regression analysis, the amount of semantic priming is plotted against a measure of processing of the prime itself. Semantic priming is an indirect measure of the effectiveness of a briefly presented and masked prime. The predictor variable is some measure of direct processing of the prime. •A direct effect is the effect of a task stimulus on the instructed response to that stimulus . . . An indirect effect is an uninstructed effect of the task stimulus on behavior . . ." (Greenwald et al., 1995, p. 23). In

the Draine and Greenwald (1998) experiments, the indirect measure is an index of the influence of the category (a male or female name or a pleasant or unpleasant word) of a briefly presented and masked prime word on the categorization of a test word that follows the prime. The direct measure in several experiments is the accuracy of deciding whether the prime itself is a word or a string of Xs and Gs. In this example, both the index of priming and the index of direct processing are measured in d' units of discriminability. Each data point represents the indirect and direct measures **for a** particular participant in a particular condition defined by prime duration and interval between prime and test. Conditions are analyzed separately. Under the logic of this method, unconscious semantic priming is demonstrated if the intercept for the regression of semantic priming on a direct measure of prime processing is significantly above zero when the direct task accuracy is **at** a (meaningfully defined) zero point.

During the indirect priming phase of the experiment this regression method is combined with a response-window method in which the participant must respond within a time window following shortly after the onset of the test item. This serves to constrain response times within a narrow period within which the responses are still somewhat error prone. The relatively low accuracy level in categorizing the target word allows room for a larger effect of the prime.

The Assumption of Standard Regression

Assumption. Subliminal priming may be measured as a significant intercept when regressing the indirect on the direct measure using standard regression methods.

Suggestion. If the predictor variable (the direct measure) has substantial measurement variability then more suitable elaborated regression methods are required.

In many applications of the standard regression method, the exact value of the intercept parameter is of **little** consequence. In this application, however, the value of the intercept parameter is the key issue. A significantly positive intercept is taken to imply that an indirect priming measure

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is significant when a direct measure of prime processing is at zero. In this section, the effect of measurement error in the predictor variable is considered as a factor in the successful estimation of the intercept.

Figure IA shows a hypothetical "true" underlying relationship between an indirect measure of priming on the y-axis and a direct measure of priming on the x-axis. Specifically, $Y = aX + \text{fl}$, where $a = .3$ and $\text{fl} = 0$. In this example there is no unconscious priming because the indirect measure goes to zero exactly as the direct measure goes to zero. Figure IB illustrates a standard regression example in which there is variability in the predicted measure, in this case the indirect measure of priming. The data in Figure 1B were generated assuming the relationship illustrated in Figure IA, with normal error in y ($Y_i = aX_i + \text{fl} + e_i$, e_i distributed normally). The amount of error was chosen to yield plots with an amount of scatter qualitatively similar to that shown by Draine and Greenwald (1998). In the published data, the variation in direct measures reflects participant-to-participant variation in response to the same stimulus situation. The best fitting equation for regressing indirect priming on direct evaluation in this example is $Y = .273X + .118$. The 95% confidence interval around the estimated intercept is (-0.074, 0.311), which correctly includes zero.

Figure 1C illustrates a problem that may arise when there is noticeable measurement error in estimating x (the direct measure) as well as y (the indirect-priming measure). The y -values of the points in Figure 1C are exactly those in Figure 1B, but the x -values have been perturbed by measurement error. The best fitting standard regression is $Y = .206X + .206$. The 95% confidence interval around the estimated intercept is (0.020, 0.392).¹ As is sometimes the case in this situation, the intercept is significantly greater than zero. This occurs because the error in x "flattens" the best fitting regression line, which in turn increases the value of the intercept estimate when the relationship is positive (or decreases it when the relationship is negative; see Sprent, 1969, or Wannacott & Wannacott, 1981, for a discussion).

By increasing the variability in x , an example might have been produced that included x -values at or below zero. Such an example (similar to cases in Draine & Greenwald's [1998] data, see next) would have been even more extreme.

To summarize, the presence of measurement error in the predictor variable may lead to an inflated, and significant, intercept even in the absence of any unconscious priming in the true relationship between the indirect and direct measures. In this situation, the intercept estimates are positively biased. Of course, researchers run standard regressions using predictor measures which are known to have measurement error all the time. However, in those applications the purpose is usually to improve the ability to predict the y -variable, and little theoretical importance is placed on the exact value of the zero intercept. And, for the purpose of prediction, standard least squares is the optimal method even in the presence of x -value measurement error (Wannacott & Wannacott, 1981).

Returning to the demonstrations of Draine and Greenwald (1998), one can ask whether there was substantial variation in the predictor variable. The predictor score is the measure

of direct evaluation—a d' score for the discrimination of a prime word from an XG string when masked and shown briefly. This measure is quite likely to include substantial measurement error. For the sample sizes of these experiments, the estimated standard deviation of the hit and false-alarm rates (under the binomial) is in the range of 5%, which produces noticeable d' variability. In Draine and Greenwald's data graphs, some estimated values for the direct judgment are as low as $-0.5 d'$ for prime durations of 33 or 50 ms or $-1.0 d'$ for prime durations of 17 ms, where values below zero theoretically must arise because of measurement error.² The range of measurement error in these cases may be between one third to one fifth the full range of the observed variation in the direct measure (x -values). This is a situation in which the issue of contaminated intercept values should be considered (but see arguments by Greenwald et al., 1995, p. 36).

In response to criticisms such as this one, Klauer, Greenwald, and Draine (1998) have described one possible elaborated regression approach to the problem of measurement error in the predictor variable. The new calculations assume what they call a "truncated normal" (p. 319) distribution for true values of the x and use structural modeling techniques to estimate the true intercept and slope.³ It remains an open issue whether the Klauer method is the best method for correcting for measurement error in the predictor variable, but it certainly is one approach to the problem.

In the Klauer et al. (1998) reanalysis of the Draine and

¹ In this and other examples in Figure I, the data sample is simply illustrative of well-known consequences of violations of the assumptions of standard regression (e.g., Casella & Berger, 1990; Kendall & Stuart, 1977; Sprent, 1969; Wannacott & Wannacott, 1981). The data values were generated by a random procedure, and the set shown was the first such sample generated. Miller (1998), in an independent set of simulations, has shown that these statistical artifacts are highly likely.

² Draine and Greenwald (1998) and Greenwald et al. (1995) have argued that d' has a well-defined zero point that is the logical minimum. However, one can imagine situations where, for example, priming might be negative, perhaps reflecting psychological refractory processes or response incompatibility. The arguments for an absolute zero are often more convincing for direct measures, on the grounds that there is no mechanism that would lead to below-chance performance. One argument that the zero may not be absolute for the Word versus XGXG direct test in Draine and Greenwald is that XGXG becomes a very familiar stimulus because of repeated presentation in the experiment and that at extremely low visibilities this familiarity is confused with wordness.

³ The distribution replaces all values of the normal distribution below zero with a zero value, so this is a truncated normal with an increasingly large spike at zero as the true value of the direct measure goes to zero. These distributional assumptions are somewhat unusual. One alternative would be to assume various forms of a suitable family of distributions, such as the gamma. And a standard alternative that also uses the principles of structural methods is to perform an orthogonal least squares fit to the data (Casella & Berger, 1990; Kendall & Stuart, 1977). These two variants of elaborated regression methods produce somewhat different corrections.

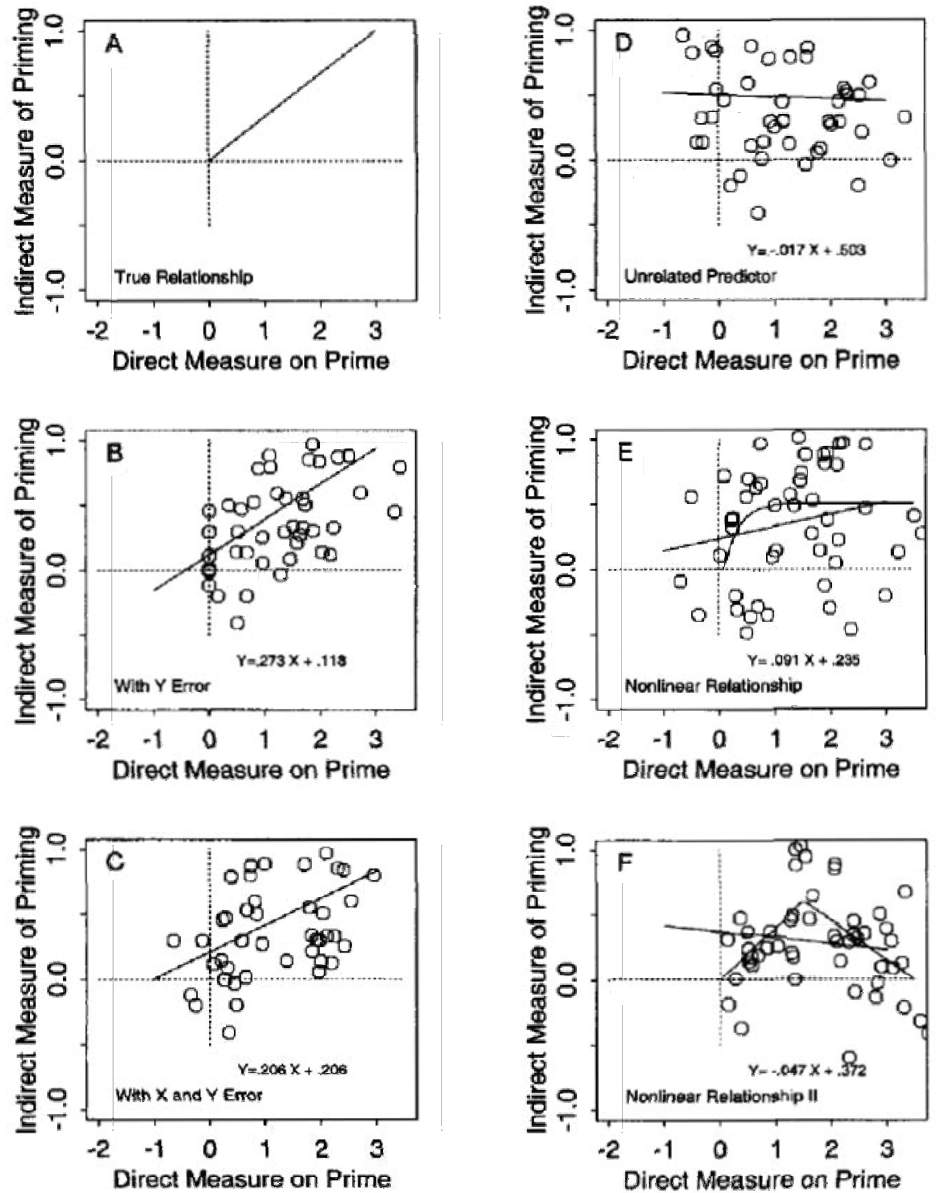


Figure 1. illustrations of the regression analyses under varying assumptions. Unconscious priming is inferred when the regression of indirect priming on a direct measure of prime processing has a significant intercept. (A) Illustration of a true relationship between an indirect measure of priming and a direct measure on the prime that does not assume unconscious priming: The indirect measure and direct measure go to zero together. (B) Data generated from the true relationship in Figure 1A, with measurement error in the y values but not the x-values, consistent with the assumptions of standard regression. The line shows the best fitting regression line, which does not indicate a significant intercept. (C) Data generated from the true relationship in Figure 1A, with the same y-value measurement error as in Figure 1B, and with x-value measurement error as well. This situation corresponds with the empirical applications of the regression method of demonstrating unconscious priming. The line corresponds to the best fitting standard regression, which generates (incorrectly) a significantly above-zero intercept. (D) Data in Figure 1B are regressed on direct measurement (x-value) data from an unrelated predictor. Because the direct-measure predictor is unrelated to the indirect measure, the intercept estimates the mean of the indirect-measure performance. In this case, that mean includes values from ranges of the true relationship with relatively high values on the direct measure, as well as relatively high values on the x-values generated by the unrelated direct measure. This situation is indistinguishable from the situation with the data of Draine and Greenwald (1998) and misleadingly produces significant intercepts. (E) Data are generated from a nonlinear (diminishing-returns) relationship shown as the curved line in the figure. Although indirect priming is reduced to zero before direct-measure performance in the true relationship, the best fitting linear regression yields a significant intercept. (F) Data are generated from another nonlinear true relationship (discounting a visible prime) between indirect and direct measures, shown as the inverted V in the figure. Although indirect priming is reduced to zero before direct-measure performance in the true relationship, the best fitting linear regression yields a significant intercept.

Greenwald (1998) data, some intercepts that were significant under standard regression are no longer significant when corrected for measurement error in the predictor. Overall, however, the data of Draine and Greenwald (1998) yielded similar estimates of the intercept using the standard regression method and the elaborated regression method. This similarity between standard regression solutions and the elaborated regression solutions for the Draine and Greenwald data is a direct consequence of the fact that there is a near-zero correlation between the indirect and direct measures. The estimated slopes from the elaborated regression solutions are very small, and often nonsignificant. If the true regression slopes are already essentially flat, then x-value error cannot flatten them much further and therefore cannot induce large biases. Biases in intercept values are larger when the x-value error occurs in cases with substantial true correlations between the x- and y-values. In Greenwald et al. (1995), the large measurement error in x is explicitly considered and dismissed on the grounds that the regression slopes are essentially zero.

On the one hand, the fact that the relationships between the indirect and direct measures are near zero suggests that corrections using the Klauer et al. (1998) elaborated regression models are not likely to change the intercept results in an important way. On the other hand, the fact that the relationships between the indirect and direct measures are near zero raises questions about the appropriateness of the direct measure. This issue is considered next.

The Assumption of Comparable Indirect and Direct Tasks

Assumption. A significant regression intercept allows the inference of unconscious priming so long as the direct measure is no less sensitive than the indirect measure.

Suggestion. This regression method requires that the indirect measure reflect processing of the prime that is comparable to the processing applied to the prime during the indirect task. Direct demonstration of comparability requires at least a modest correlation between the indirect and direct measures.

Draine and Greenwald (1998) have stated that the condition for producing a valid regression analysis is that "... the direct measure chosen as the predictor in the regression analysis [should] be at least as sensitive as the indirect measure to conscious perception of the prime's semantic category" (p. 290). This is called the *relative sensitivity assumption* (Greenwald et al., 1995; Reingold & Merikle, 1988). In one previous approach to the problem of unconscious priming, conditions were sought yielding significant priming when direct test accuracy does not (significantly) exceed zero. In this nonregression approach, differentially high sensitivity of the direct measure may bolster claims about unconscious priming (although the cost is a test that is biased not to find unconscious priming in some circumstances where it actually occurs). For the regression-analysis method of inferring unconscious priming, this precaution may be inadequate.

Figure ID illustrates the situation in which an unrelated

predictor, x' , is used as the predictor in the regression analysis. An unrelated predictor might result from the poor choice of a direct task. In this example, the estimated regression is $Y = -.01X + .503$. The 95% confidence interval around the estimated intercept is (0.303, 0.703) and the intercept is significantly above zero. Although the confidence intervals around intercepts from unrelated predictors are wider than those obtained from data with strong relationships, they nonetheless often exclude zero. In this regression (as in those of Draine and Greenwald, 1998), the estimated relationship is not significant, and the intercept simply estimates the mean of the indirect priming measures.

Why is a regression analysis of priming possibly inappropriate when the correlation is near zero? The answer is simple: In the absence of a correlation, the regression analysis reverts to the association of a mean value of indirect priming with a mean value of direct priming in a particular condition. It is then necessary to consider whether the mean direct priming level is significantly above zero, or whether above-zero points may be biasing the results. In many of Draine and Greenwald's (1998) experiments, many direct-priming measures are above zero, and hence the mean of the direct measure is likely to exceed zero (see the following).⁴

This example, then, illustrates the dangers of choosing an inappropriate predictor value, or an inappropriate direct task measure. The conclusions of the regression method are strengthened when the indirect and direct measure exhibit a statistically reliable relationship. A strong relationship, or correlation, presumably follows when the direct measure reflects processing of the prime which is as comparable as possible to that which occurs during the indirect task. This view is similar to the position of Reingold and Merikle (1988), who argued for maintaining strict comparability in processing between direct and indirect measures of the prime.

In the Draine and Greenwald (1998) experiments, the relationship between priming and the direct measure is generally nonsignificant, leading to nearly flat regression lines. In the direct task of Draine and Greenwald, the x measure is the accuracy of discriminating a word from an XGXG string in the prime position of the display sequence. This is quite different from semantic categorization, the indirect task. Moreover, the direct task does not impose time pressure on the response, whereas the indirect task uses the response-window procedure. In addition, the direct-measure trials occur near the end of the session in which the indirect task is performed. All of these differences might contribute to the lack of an observed correlation between the indirect

⁴ Greenwald and Draine (1998), in their reply, have claimed not to see why a zero correlation between direct and indirect measures is problematic. They have cited a case of blindsight by analogy to their case of unconscious priming. However, the cases may be quite different. In a clear case of blindsight, the direct measures should be at or near zero. In that case, above-zero indirect measures are associated with essentially zero direct measures. In the general case of regression in unconscious priming, indirect measures are often associated with direct measures that may include clearly above-zero values.

and direct measures. The *XGXG* discrimination may induce a nonsemantic processing strategy, whereas the semantic-priming task requires semantic analysis. The lack of time-controlled processing in the direct task might result in a substantial amount of variability, which reflects how different participants choose to operate in trading speed for accuracy. Finally, different participants may be in different states of fatigue and practice when the direct and indirect measures occur at different times during the session.

None of these factors—the low correlation, the different task quality, the differences in time pressure, differences in time of testing—guarantees that the direct measure is inappropriate. However, the comparability and appropriateness of the direct task must be closely argued in such cases. The argument in Draine and Greenwald (1998) is that the direct task (Word vs. *XG*) surely requires less evidence than semantic evaluation, and hence is presumably more sensitive. (On the basis of the data of Marcel, 1983, one might argue this point.) Nonetheless, the following situation holds in a number of their data sets: The two measures are essentially unrelated, and thus the intercept is estimating the mean over *all* data points of semantic priming (the indirect measure); and a number of these data points have discrimination (direct measure) *d*'s of 0.5–2.5, reflecting relatively high accuracy.

In the situation where there is no relationship between the direct and indirect measure, the regression procedure must be approached with caution. It is essentially exactly equivalent to earlier approaches that looked for significant priming on the indirect measures in a condition in which the direct measure is not statistically greater than chance. It is equivalent to that previous approach because the intercept simply estimates the mean of the indirect-measure priming. However, it is necessary to explicitly consider whether the mean of the direct measure is above zero, and the regression methodology may distract us from that concern.

In conclusion, if the relationship between the indirect and direct measure is not apparent in the data, it is necessary to carefully scrutinize the comparability of the direct and indirect tasks. It is also necessary to consider whether above-chance direct-measure data points suggest that the conditions of the experiment supported above-chance performance in some participants that may have biased the analysis. The need for independent justification for the choice of direct measure is lessened if the data show a strong relationship between the indirect and direct measures. A strong relationship is *prima facie* evidence that the two measures are reflecting some similar processing of the primes. A strong relationship in the data between the indirect and direct measure has another benefit, considered later. However, a strong relationship between the direct and indirect measure may not always be possible to arrange. For example, some theorists feel that conscious and unconscious processes are completely dissociated (Greenwald et al., 1995). And finally, the disadvantage of a significant relationship between direct and indirect measures in the data coupled with measurement error in the predictor values is that this is precisely the condition in which standard

regression yields biased intercept estimates, which must be corrected by an elaborated regression procedure.

The Assumption of Linear Relationship

Assumption. The relationship between the indirect and direct measure is linear.

Suggestion. Indirect and direct measures may not respond in the same way to limited visual information from the prime. Instead, the relationship between the direct and indirect measures may be nonlinear.

Figure 1E illustrates a possible nonlinear relationship between the direct and indirect measure, along with some sample data and an inappropriate linear regression. In this case, the true indirect measure is zero until the direct measure is at 0.1, but then rises sharply. The data points were generated from the nonlinear function drawn in the figure. The best fitting standard regression is $Y = .091X + .235$. The 95% confidence interval around the estimated intercept is (0.022 to 0.448). Figure 1F illustrates another possible nonlinear relation, one in which clear visibility of the prime allows it to be discounted. The data points were generated from the inverted-V function drawn in the figure. The best fitting standard regression is $Y = -.047X + 372$. The 95% confidence interval around the estimated intercept is (0.156, 0.588).

How likely are either of these hypothetical cases? Greenwald et al. (1995) have stated that there are (unspecified) significant quadratic components in their regression analyses. (See also Greenwald & Draine, 1997, and Greenwald et al., 1996, for additional analyses of nonlinear trends. All these analyses are in some degree limited by the lack of correlation between direct and indirect measures.) Greenwald et al. (1995) also have argued specifically from their data on semantic priming that weakly visible primes support priming by semantically related words, whereas priming is eliminated when those words become clearly visible: the hypothetical pattern in Figure 1F (see also Carr & Dagenbach, 1990; Pittman, 1992). In either of these cases, a clear relationship in the data between indirect and direct measures would improve the ability to detect the exact nature of the relationship between direct and indirect measures, and hence strengthen the conclusions. If the relationship is strong, it should be possible to assess directly the appropriateness of the linear regression assumption.⁵

When the indirect and direct measures do not correlate significantly, this might reflect large errors in the *x*- and *y*-values, the fact that there is no relationship between the

⁵ Draine and Greenwald (1998) have considered the issue of nonlinear relationships between the direct and indirect measure by performing a lowess analysis. A lowess analysis performs local regressions on points over a windowed range of *x*-values. A lowess analysis, like standard regression, also assumes no error in the *x*-values and so has exactly the same problem as does standard regression, but more extreme because the measurement error is larger relative to the range of predictor values in the relevant window (Lunneborg, 1994). Because there is little relationship between the indirect and direct measures in these data, the lowess (pointwise local regression) fits are not particularly revealing.

direct and indirect measures, or the fact that there is a nonlinear relationship between the direct and indirect measures. Ideally, the relationship between the indirect and direct measure would be sufficiently strong to allow some validation of the form of the assumed relation.

The discussion of these first three assumptions focuses on the substantive concerns in the statistical application of the method. The next section deals not with the inferences that may be drawn on the basis of statistical method, but on the appropriateness of inferences about content and applicability that follow from the forced-responding component of the method.

The Assumption of Forced Responding

Assumption. The magnitude of unconscious priming can be maximized by forcing relatively early responses.

Suggestion. Often priming is largest for early responses, but this may lead to an overestimate of both the duration and the importance of the influence of the prime.

Draine and Greenwald (1998) have used a forced-responding method to increase the sensitivity to priming. In particular, they require participants to respond to the target or test item within a moderately early response window (e.g., 250 ms \pm 133 ms) for all conditions. This substantially controls response time and moves the effect into response accuracy: "By concentrating the priming effect on the accuracy dimension, sensitivity to priming was increased" (p. 300).⁶ They estimate that the forced-responding method increases the size of the priming effect quite substantially.

Earlier priming results (Doshier, McElree, Hood, & Rosedale, 1989; Doshier and Rosedale, 1989) support the idea that priming is maximally effective early in the response interval. Those studies also used a time-cued response method to measure the effect of the prime on target responding, but instead of measuring accuracy at one time, it

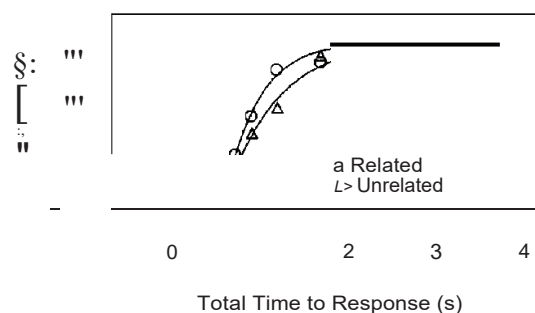


Figure 2. The effects of a priming can be short-lived. The accuracy of judged memory (d') is graphed as a function of the average time between the onset of the test stimulus and the response (in seconds) for a condition with a related prime and a condition with an unrelated prime. Data from Doshier and Rosedale (1989; see also Doshier et al., 1989) suggest that, at least for visible primes, the prime has maximal impact primarily early in the response period. These data are consistent with the assumptions of Draine and Greenwald (1998) that early forced responses maximize the impact of priming but also suggest that the impact of semantic primes may be fairly transitory.

was measured at several controlled response times throughout the full time course of target processing. Figure 2 shows the effect of related primes and unrelated primes in one of these (Doshier & Rosedale, 1989). These data support the idea that the effect of a (in this case clearly visible) prime is maximal early in the response interval. It also suggests that the importance of the prime naturally dissipates in favor of target stimulus processing as the response interval becomes longer. It is not known whether the impact of "unconscious" primes would similarly be discounted during the processing interval. Nonetheless, these data support Draine and Greenwald's (1998) caution that unconscious priming may be quite transient (see also Greenwald et al., 1996).

In discussing the applied significance of the finding of unconscious priming by the regression methodology Greenwald et al. (1995, p. 38) have stated: "The present evidence for dissociation supports public concerns that undetectable communications might cause unwanted influences on people being advertised to, educated, entertained, ... The size and likely transience of the demonstrated effects should be used to contextualize such claims."

Conclusions

Greenwald and colleagues (Draine & Greenwald, 1998; Greenwald & Draine, 1997; Greenwald et al., 1996; Greenwald et al., 1995) have developed a new regression methodology for demonstrating the existence of unconscious priming. However, this methodology relies on a number of assumptions, and the validity of these assumptions should be carefully considered in each new application of the methodology.

In this article, I have argued that an appropriate application of the method would result from a regression analysis in which the data show at least a moderate relationship between the indirect and direct measure. This would allow an evaluation of the form of the relationship and would provide prima facie evidence that the processing of the prime under the direct task is similar to the processing of the prime under the indirect task. The error in both measures and the relationship between the direct and indirect measures would also mandate an appropriate elaborated regression method. At this point, it is not clear exactly which elaborated regression method would be optimal; this is a point that must be settled in subsequent applications of the method.

In general, if there is no relationship between the direct and indirect measure, the regression procedure may simply be inappropriate. It is possible that unconscious and conscious processing in certain domains never produce clear relationships in the data because the two processes are

⁶ Recall that the variation in the measures seen in the Draine and Greenwald (1998) data is participant-to-participant variation. The statement that the method controls response time and moves the effect into response accuracy holds within a participant. One participant may still vary from another substantially because of differences in perceptual sensitivity or information-processing speed. Additionally, recall that forced responding was rejected as a method for collecting information about the direct measure.

stochastically independent (at the level of the participant, the item and the condition). In this case, then the comparability between the direct task and the indirect task must be strongly argued and great care must be taken to exclude data that represents clearly above-zero performance on the direct task. Each of the identified potential artifacts in the method must be considered and ruled out.

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