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Subliminal or not? Comparing null-hypothesis and Bayesian methods for testing subliminal priming

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ABSTRACT

A difficulty for reports of subliminal priming is demonstrating that participants who actually perceived the prime are not driving the priming effects. There are two conventional methods for testing this. One is to test whether a direct measure of stimulus perception is not significantly above chance on a group level. The other is to use regression to test if an indirect measure of stimulus processing is significantly above zero when the direct measure is at chance. Here we simulated samples in which we assumed that only participants who perceived the primes were primed by it. Conventional analyses applied to these samples had a very large error rate of falsely supporting subliminal priming. Calculating a Bayes factor for the samples very seldom falsely supported subliminal priming. We conclude that conventional tests are not reliable diagnostics of subliminal priming. Instead, we recommend that experimenters calculate a Bayes factor when investigating subliminal priming.

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1. Introduction

Exposure to a perceivable stimulus may influence or ''prime'' a response to another stimulus, even when the priming stimulus is just noticeable. More controversial are claims of priming induced by imperceptible or ''subliminal'' (i.e., below the threshold of perception) stimuli. Although many studies claim to have demonstrated subliminal priming, the phenomenon is still debated (Newell & Shanks, 2014). The debate continues because it is difficult to prove the subliminal part of the claim–that the prime stimulus was not perceived, not even slightly, by any observer–and thereby to rule out an alternative explanation of the observed priming: that it is solely attributable to the responses of observers who just barely perceived the prime.

The main strategy to find support for subliminal priming has been to try to demonstrate a dissociation between a direct measure of prime stimulus perception and an indirect measure of prime stimulus processing (Reingold & Merikle, 1988). Two statistical methods are conventionally used to find statistical support for dissociation: a double *t*-test and a regression method. Here we simulate these methods and a less often used method based on Bayesian statistics. The simulations suggest that the latter method, but not the former methods, is suitable for evaluating whether experimental data support subliminal priming.

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1.1. Experiments on subliminal priming

In a typical experiment examining subliminal priming, a sequence of stimuli is shown in each trial. First, one of two priming stimuli is briefly flashed, followed by a masking stimulus (to allow the priming stimulus to be processed but not perceived), and then a target stimulus is shown. Observers have two tasks in the experiment, one direct task regarding the prime stimulus (the direct measure) and one indirect task regarding the target stimulus (the indirect measure). In a typical experiment, the tasks are performed in separate blocks, beginning with the indirect task.

In the direct task, observers decide which of the two possible priming stimuli was presented. For example, in a study by Kiefer, Sim, and Wentura (2015), the priming stimulus was an emotionally positive or negative stimulus and the direct task was to decide whether the prime stimulus was positive or negative. In analyzing data from such tasks, one of the two stimuli may be arbitrarily designated the "signal" and the other the "non-signal," and the four possible stimulus answer combinations may be classified as hits (responding "signal" to the "signal stimulus"), misses, false alarms (responding "signal" to "non-signal" stimulus), and correct rejections. According to signal detection theory, the observer's sensitivity, d', to differences between the two stimuli is $d' = \Phi^{-1}(p_h) - \Phi^{-1}(p_f)$, where p_h is the proportion of hits, p_f the proportion of false alarms, and Φ^{-1} is the inverse standard normal cumulative distribution function (Macmillan & Creelman, 2005). Response bias, that is, the tendency to choose one over the other stimulus, may be quantified as the response criterion, i.e., $c = -½[\Phi^{-1}(p_h) + \Phi^{-1}(p_f)]$. For an unbiased observer, $c = 0$, because the proportions of hits and correct rejections are equal. In typical experiments, the direct measure of prime stimulus perception is d'.

The indirect task varies depending on the type of priming the experimenter is examining. In a typical experiment, the indirect measure of prime stimulus processing is a congruency effect on reaction time for responses to the indirect task. Kiefer et al. (2015), also used a positive or negative stimulus as the target stimulus and the direct task was to decide whether the target stimulus was positive or negative. When the priming stimulus was incongruent with the target stimulus, the reaction time in the task was slower than if the priming and target stimuli were congruent. This type of congruency effect is the indirect measure of prime stimulus processing in typical experiments.

1.2. Statistical analysis of subliminal priming

The most common analytical method, here called the double t-test method, is to apply two t-tests, one for each of the two measures, and decide for or against subliminal priming based on the pattern of the p-values (see Table 1), typically using $\alpha = 0.05$. Specifically, the double t-test method declares subliminal priming if (a) mean performance in the direct measure does not differ statistically significantly from chance ($p > \alpha$) and (b) the mean effect in the indirect measure does differ statistically significantly from zero ($p < \alpha$).

The double t-test method is open to criticism on statistical grounds, because deciding whether the prime stimulus is subliminal is based on an unjustified interpretation of how the obtained p-values relate to the tested null hypothesis, H_0: "True mean $d' = 0$." Specifically, the p-value is the conditional probability of obtaining the data or more extreme data given H_0 [$P(D|H_0)$], and therefore say nothing about the probability of H_0 [$P(H_0)$] (see e.g., Dienes (2014) and Gallistel (2009) for a good discussion of null hypothesis testing in the context of non-significant results). The double t-test method has also been criticized as the method often lacks the power needed to support that observers were subliminal (e.g., Finkbeiner & Coltheart, 2014; Gallistel, 2009; Macmillan, 1986; Rouder, Morey, Speckman, & Pratte, 2007; Wiens, 2006). Proponents of the double t-test method are also of course aware of this, but would argue that the strategy still can, and indeed does, do a good job of identifying subliminal priming. Therefore, the double t-test remains the most popular analytical method in research into subliminal priming (e.g., González-García, Tudela, & Ruz, 2015; Huang, Tan, Soon, & Hsieh, 2014; Jusyte & Schönenberg, 2014; Kido & Makioka, 2015; Kiefer et al., 2015; Lin & Murray, 2015; Marcos Malmierca, 2015; Norman, Heywood, & Kentridge, 2015; Ocampo, 2015; Ocampo, Al-Janabi, & Finkbeiner, 2015; Schoeberl, Fuchs, Theeuwes, & Ansorge, 2015; Wildegger, Myers, Humphreys, & Nobre, 2015).

The double t-test method tests for subliminal priming at a group level. Observers, however, differ in their thresholds (e.g., Albrecht & Mattler, 2012; Dagenbach, Carr, & Wilhelmsen, 1989; Greenwald, Klinger, & Schuh, 1995; Haase & Fisk, 2015; Sand, 2016). To take individual differences in thresholds (and thus perception, given a specific prime stimulus intensity) into account, another conventional analysis is regression analysis (e.g., Jusyte & Schönenberg, 2014; Ocampo, 2015; Schoeberl et al., 2015; Xiao & Yamauchi, 2014). In regression analysis, the direct measure is used as the regressor and the indirect measure is the outcome variable. Specifically, the regression method declares subliminal priming if the intercept is statistically significantly above zero. Because these two conventional methods (double t-test and regression) remain popular today, we tested their robustness through simulations in which we assumed no dissociation between the direct and indirect measures.

One analytical strategy not yet in widespread use is to calculate a Bayes factor to test whether or not a prime stimulus is subliminal at a group level. Calculating a Bayes factor, B, is the Bayesian equivalent of a null hypothesis significance test. The improvement of Bayesian statistics over null-hypothesis testing here is that B can lend support to H_0 (which the p-value cannot) and H_0 is what experimenters in this field want to support (Dienes, 2015). To calculate B, an *a priori* model of H_1 ("True mean d' slightly above 0") needs to be specified. (See Dienes, 2015, for a discussion of how H_1 can be specified with regard to subliminal priming.) Once H_1 is specified, B can be calculated and it is the ratio of the likelihood of the observed data based on the two hypotheses, that is, $P(D|H_1)/P(D|H_0)$. $B > 1$ thus indicates that the data support H_1 over H_0, while $B < 1$ indicates that the data support H_0 over H_1, and a B of approximately 1 suggests that the experiment was not sensitive. Although B is

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