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Should metacognition be measured by logistic regression?

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ABSTRACT

Are logistic regression slopes suitable to quantify metacognitive sensitivity, i.e. the efficiency with which subjective reports differentiate between correct and incorrect task responses? We analytically show that logistic regression slopes are independent from rating criteria in one specific model of metacognition, which assumes (i) that rating decisions are based on sensory evidence generated independently of the sensory evidence used for primary task responses and (ii) that the distributions of evidence are logistic. Given a hierarchical model of metacognition, logistic regression slopes depend on rating criteria. According to all considered models, regression slopes depend on the primary task criterion. A reanalysis of previous data revealed that massive numbers of trials are required to distinguish between hierarchical and independent models with tolerable accuracy. It is argued that researchers who wish to use logistic regression as measure of metacognitive sensitivity need to control the primary task criterion and rating criteria.

1. Introduction

Metacognitive sensitivity, also called type 2 sensitivity or resolution of confidence, refers to the efficiency with which participants' subjective reports during an experimental task discriminate between correct and incorrect responses in a primary task (Baranski & Petrusic, 1994; Fleming & Lau, 2014; Galvin, Podd, Drga, & Whitmore, 2003). It relates to a key aspect of metacognition: If participants possessed any knowledge about their performance in the task, their subjective reports about the task should differentiate between correct and erroneous trials. Consequently, measures of metacognitive sensitivity are relevant for all research areas where quantifying participants' insight into their task performance is of interest, including consciousness research (Dienes, 2004). Given the theoretical importance of metacognitive sensitivity, a universally accepted measure is desirable. However, various competing measures of metacognitive sensitivity were proposed in the literature:

- gamma correlation coefficients (Nelson, 1984),
- a′/type 2 d′ (Kunimoto, Miller, & Pashler, 2001),
- type-2 receiver operating characteristic (Fleming, Weil, Nagy, Dolan, & Rees, 2010),
- meta-d′ (Maniscalco & Lau, 2012),
- logistic regression analysis (Sandberg, Timmermans, Overgaard, & Cleeremans, 2010).

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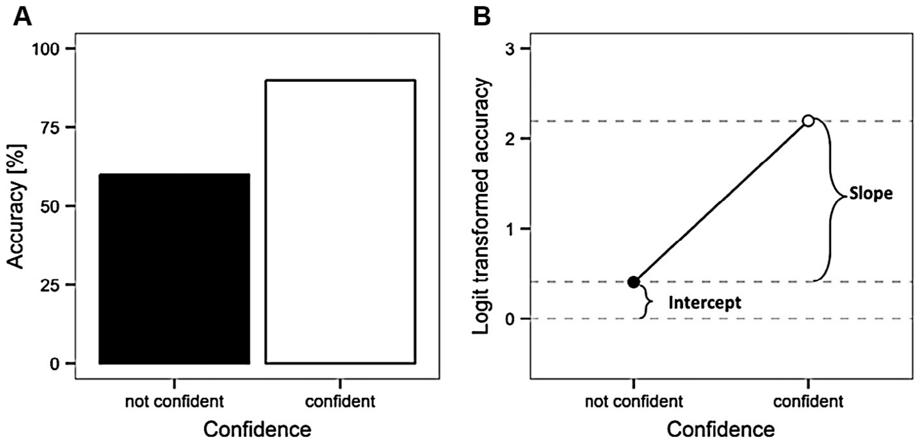

Fig. 1. Quantifying the relationship between trial accuracy and subjective reports by logistic regression. (A) Data of a hypothetical experiment. Task accuracy in % correct is plotted separately for two categories of subjective reports, "not confident" and "confident". (B) Same data, but accuracy transformed into logits. Logistic regression is based on fitting a linear function on such transformed data. The slope of the regression line is interpreted as metacognitive sensitivity, the intercept as criterion.

Logistic regression has been widely used in empirical studies as measure of the association between verbal reports and task accuracy (Rausch, Müller, & Zehetleitner, 2015; Rausch & Zehetleitner, 2014; Sandberg et al., 2010; Siedlecka, Paulewicz, & Wierzchoń, 2016; Wierzchoń, Asanowicz, Paulewicz, & Cleeremans, 2012; Wierzchoń, Paulewicz, Asanowicz, Timmermans, & Cleeremans, 2014). However, while gamma correlations, a′, and meta-d′ have been extensively examined using both empirical and analytical methods (Barrett, Dienes, & Seth, 2013; Evans & Azzopardi, 2007; Galvin et al., 2003; Masson & Rotello, 2009), the conditions for logistic regression to be an appropriate measure of metacognitive sensitivity have never been systematically investigated.

1.1. Logistic regression as measure of metacognitive sensitivity

Logistic regression is a specific case of a generalized linear regression model (GLM). In general, it is a method to quantify the relationship between a binary outcome variable and one or several dichotomous or continuous predictors. The standard approach to quantify metacognitive sensitivity by means of logistic regression is to model the probability of being correct in the primary task $P(T)$ as a linear function of a subjective report C, e.g. a confidence judgment or a visibility rating. A linear relationship between predictors and outcome is obtained by transforming the probability of being correct into the logarithm of the odds of the primary response being correct to being incorrect:

$$\log\left(\frac{P(T)}{1-P(T)}\right) = a + b * C \tag{1}$$

As can be seen from Fig. 1, metacognitive sensitivity is indexed by the slope b of the regression line: the steeper the regression line, the stronger are subjective reports associated with the probability of being correct (Sandberg et al., 2010). Logistic regression is also used to quantify the minimal criteria participants apply when they make a subjective report: The more conservative participants' reporting strategy is, the better they perform while still giving the lowest possible subjective report. As the intercept a is just the transformed accuracy when the subjective report is zero, it is interpreted as measure of criterion (Wierzchoń et al., 2012).

Quantifying metacognition by logistic regression is tempting due to three reasons: First, the hierarchical structure of the data often found in behavioral experiments can be explicitly included into the model by using nested random effects (Sandberg, Bibby, & Overgaard, 2013; Siedlecka et al., 2016): For example, two experimental groups with several participants each contributing a number of trials can be described by a random effect of trial nested within a random effect of participant nested within groups. As such an analysis can be conducted on a single trial level without the need for summary statistics to be computed for each participant, logistic regression may also be a promising way to increase statistical power (Sandberg et al., 2010). Second, using random effects allows the data to be unbalanced, i.e. the number of observations can vary between conditions or there can be empty cells in the design matrix (Rausch et al., 2015; Siedlecka et al., 2016). Consequently, slopes on the group level can be obtained even when not all participants made errors in all experimental conditions. This is particularly useful in studies of metacognitive sensitivity because the number of errors may vary heavily between participants and conditions. Finally, it has been argued that logistic regression, unlike SDT-measures, does not make any assumptions about the sources of the evidence involved in making subjective reports (Siedlecka et al., 2016).

However, logistic regression as measure of metacognition may also suffer from at least two drawbacks: First, it depends on the assumption that the relation between subjective reports and transformed accuracy is linear. A non-linear relationship