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Research report

A purely confirmatory replication study of structural brain-behavior correlations

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ABSTRACT

A recent 'crisis of confidence' has emerged in the empirical sciences. Several studies have suggested that questionable research practices (QRPs) such as optional stopping and selective publication may be relatively widespread. These QRPs can result in a high proportion of false-positive findings, decreasing the reliability and replicability of research output. A potential solution is to register experiments prior to data acquisition and analysis. In this study we attempted to replicate studies that relate brain structure to behavior and cognition. These structural brain-behavior (SBB) correlations occasionally receive much attention in science and in the media. Given the impact of these studies, it is important to investigate their replicability. Here, we attempt to replicate five SBB correlation studies comprising a total of 17 effects. To prevent the impact of QRPs we employed a preregistered, purely confirmatory replication approach. For all but one of the 17 findings under scrutiny, confirmatory Bayesian hypothesis tests indicated evidence in favor of the null hypothesis ranging from anecdotal (Bayes factor < 3) to strong (Bayes factor > 10). In several studies, effect size estimates were substantially lower than in the original studies. To our knowledge, this is the first multi-study confirmatory replication of SBB correlations. With this study, we hope to encourage other researchers to undertake similar replication attempts.

1. Introduction

In the last few years, the need for confirmatory replication studies has become increasingly evident. Recent studies have suggested that the empirical sciences are bedeviled by the use of questionable research practices (QRPs; John, Loewenstein, & Prelec, 2012; Simmons, Nelson, & Simonsohn, 2011). These practices include, for instance, optional stopping (i.e., continuing data collection until $p < .05$) and cherry-picking (e.g., reporting only those variables, conditions, or analyses that yield the desired result). In combination with the ubiquitous file drawer problem (Rosenthal, 1979), the use of these QPRs results in a high false-positive rate, such that many significant findings may in fact be false (Ioannidis, 2005). This

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realization has brought about a crisis of confidence in the replicability and reliability of published research findings (Ioannidis, 2012; MacArthur, 2012; Pashler & Wagenmakers, 2012). A recent study by Button, Ioannidis, Mokrysz, Nosek, Flint et al. (2013) showed that this crisis of confidence extends to the neurosciences. The crisis of confidence can be reduced in several ways. One powerful remedy is to eliminate QRPs by preregistering experiments prior to data acquisition and analysis, resembling the standard operating procedure mandated in the case of clinical trials (Chambers, 2013; De Groot, 1969; Goldacre, 2009; Wagenmakers, Wetzels, Borsboom, van der Maas, & Kievit, 2012; Wolfe, 2013). In this article we apply study preregistration to assess the replicability of a series of findings in cognitive neuroscience.

Research in cognitive neuroscience aims to investigate the link between brain and behavior. Recently, researchers have exploited significant advances in anatomical magnetic resonance imaging (MRI) to detect subtle differences in brain structure associated with differences in behavioral measures (Kanai & Rees, 2011). For example, in a study that received much attention in science and the media, Kanai, Bahrami, Roylance, and Rees (2012) found that individuals with a relatively large grey matter (GM) volume in specific brain regions have more Facebook friends. Other studies have reported structural brain-behavior (SBB) correlations between properties of grey and/or white matter (WM) and behavioral measures such as choice reaction time (RT) (Tuch et al., 2005), control over speed and accuracy in decision making (Forstmann et al., 2010), percept duration in perceptual rivalry (Kanai, Bahrami, & Rees, 2010; Kanai, Carmel, Bahrami, & Rees, 2011), components of attention (i.e., executive control and alerting; Westlye, Grydeland, Walhovd, & Fjell, 2011), response inhibition (King et al., 2012), metacognitive ability (i.e., the ability to evaluate one's perceptual decisions; Fleming, Weil, Nagy, Dolan, & Rees, 2010), aspects of social cognition (i.e., social network size; Bickart, Wright, Dautoff, Dickerson, & Barrett, 2011; social influence; Campbell-Meiklejohn et al., 2012), distractibility (Kanai, Dong, Bahrami, & Rees, 2011), political orientation (Kanai, Feilden, Firth, & Rees, 2011), sensitivity to reward and approach motivation (Xu et al., 2012), moral values (Lewis, Kanai, Bates, & Rees, 2012), and empathy (Banissy, Kanai, Walsh, & Rees, 2012).

Motivated by the increase in number and prominence of SBB correlations, as well as the general uncertainty regarding the reliability of non-preregistered research findings, we attempted to replicate a subset of the above-mentioned studies in a purely confirmatory fashion. It should be noted that conceptual replications, wherein a hypothesis from the original study is tested in a different experimental paradigm, do not provide reliable evidence for or against the robustness of the respective finding. Instead, only direct replications, wherein all relevant aspects of the original study are repeated can support or oppose the original finding (Pashler & Harris, 2012).

Here, we report a preregistered, purely confirmatory replication of a subset of five SBB correlation studies selected from recent literature based on the brevity of their behavioral data acquisition. The transparency conveyed by a confirmatory design helps to avoid common pitfalls in neuroscience (and other sciences) such as the use of nonindependent analysis (Vul, Harris, Winkielman, & Pashler, 2009), double dipping (Kriegeskorte, Simmons, Bellgowan, & Baker, 2009), obscure data collection and analysis techniques which increase false-positive rates (Simmons et al., 2011), confirmation and hindsight bias on the part of the researcher (i.e., the tendency to confirm instead of disconfirm one's beliefs and the tendency to judge events more predictable after they have occurred, respectively; Wagenmakers et al., 2012). A strictly confirmatory framework was ensured by publishing a 'Methods and Analyses document' (M&A; http://confrepneurosci.blogspot.nl/2012/06/advanced-methods-and-analyses_26.html) online before any data were inspected or analyzed (as recommended by several researchers, e.g., Chambers, 2013; De Groot, 1969; Goldacre, 2009; Wagenmakers et al., 2012; Wolfe, 2013). This M&A document was sent to the corresponding authors of the original studies. All authors agreed to the replication attempt and the processing pipeline as outlined in the M&A document. Any analysis not outlined in the M&A document will be labeled 'exploratory' (as recommended by Wagenmakers, Wetzels, Borsboom, & van der Maas, 2011). We confined our hypotheses to the direction and location of the SBB correlations reported in the original articles. For instance, Kanai et al. (2012) reported a positive SBB correlation between GM density in left amygdala and the number of friends on Facebook; consequently the to-be-replicated hypothesis postulates a positive SBB correlation between the same variables in our sample. This order-restriction of the hypotheses has two benefits. First, it allowed us to use one-sided as opposed to two-sided hypothesis tests, which are more specific and statistically more powerful. Second, it allowed us to focus our analyses on specific regions in the brain, i.e., regions of interest (ROI), instead of searching the whole brain for SBB correlations. This way we circumvent the need for multiple comparisons corrections that are required in whole-brain analyses.

In order to quantify the evidence that the data provide for and against the null-hypothesis, we opted for a Bayesian hypothesis test for correlations and computed Bayes factors (BF; Jeffreys, 1961) instead of p-values (for a discussion of problems with p-values, see Edwards, Lindman, & Savage, 1963; Wagenmakers, 2007). Note that in contrast to Bayes factors, p-values are unable to quantify support in favor of the null hypothesis; a non-significant p-value indicates no more than a "failure to reject the null hypothesis". The replication attempts will be considered successful if the corresponding Bayes factor supports the hypothesized relationship. Accordingly, a Bayes factor that supports the null hypothesis suggests a failed replication. In addition to this preregistered analysis, exploratory analyses examine estimates of effect size. It is possible that the Bayes factor supports the null hypothesis, but the estimated effect size is nevertheless close to the original effect size. To address this concern, an additional exploratory Bayes factor analysis compares the null hypothesis to an alternative hypothesis that incorporates the knowledge obtained from the original study (cf. Verhagen & Wagenmakers, 2014). These exploratory analyses occasionally provide a more nuanced perspective on the extent to which SBB correlations can be replicated.

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