Open Science as a Better Gatekeeper for Science and Society: A Perspective from Neurolaw

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1 In 2011, a court near Milan, Italy, reduced the sentence of a convicted murderer from life
2 to 20 years in jail, after considering results from neuroimaging and genetic tests. These tests had
3 been used to convince the judge that the trial's female defendant, Stefania Albertani, was
4 suffering from partial mental illness (Feresin, 2011). The structural MRI images showed that
5 Albertani's grey matter volume was different from the average volume of a randomly-selected
6 group – 10 healthy women with no history of mental or neurological disorders – in brain areas
7 including the anterior cingulate gyrus (ACC) and insula. The expert testimony concluded that
8 “these alterations (of brain structures) have to be considered in causal relation to the psychiatric
9 symptomatology of the murderer.”

10 This is one of the many cases where structural or functional brain imaging results have
11 been cited as evidence in the courtroom, alongside other evidence, in order to support claims that
12 a defendant was mentally ill (Farahany, 2016). Which findings from cognitive neuroscience can
13 be used as evidence in the courtroom (in the form of expert testimony) is thus a central question
14 of the interdisciplinary area between cognitive neuroscience and law, known as ‘neurolaw’ or
15 ‘neuroscience and the law’, e.g. (Gazzaniga, 2008; Hu, Deng, Zhou, & Deng, 2011; Jones,
16 2004). Judges must assess the scientific validity and reliability of the cited scientific evidence in
17 order to decide its admissibility. This constitutes a significant challenge, since judges may have
18 limited training in science (Grove, Barden, Garb, & Lilienfeld, 2002).

19 The recent reproducibility crisis in science, affecting medical science, neuroscience, and
20 behavioral science among other fields, has made this situation worse (Begley & Ellis, 2012; Hu
21 et al., 2016; Open Science Collaboration, 2015; Szucs & Ioannidis, 2017). (For a comprehensive
22 reference list, please see the reading list compiled by Brent Robert and Dan Simons:
23 <https://osf.io/xunpj/>). Studies suggest that the false positive rate in the psychological and

neuroscience literature is surprisingly high (Szucs & Ioannidis, 2017). The legal system, which relies on the scientific community to provide scientific evidence (see Figure 1), must thus now consider how to deal with this low reproducibility rate in published results (Chin, 2014).

Figure 1. A simplified illustration of the role of science gatekeeper (i.e. the scientific community) and the legal gatekeeper (e.g. the judges and other legal practitioners) in evaluating the admissibility of scientific evidence.

Irreproducible science compromises the admissibility standards for scientific evidence

The *Daubert* standard (*Daubert v. Merrell Dow Pharmaceuticals, Inc.*, 1993, p. 2797) from the US legal system offers one example. It requires judges to evaluate the expert evidence (scientific evidence included) when deciding whether this evidence is admissible, and has been intensively studied both in the United States (Faigman & Monahan, 2009) and in other countries (Page, Taylor, & Blenkin, 2011).

The standard requires that judges evaluate the validity of scientific evidence based on four criteria: (i) Is the opinion testable and has it been tested? (ii) Is the error rate associated with the technique or opinion acceptable? (iii) Has the basis for the opinion survived the peer review process and been published? (iv) Is the technique or procedure for generating the opinion generally accepted among scientists in that field?

1 The *Daubert* standard suggests that, even though the judges are required to assess the
2 scientific evidence themselves, they still rely heavily on input from the scientific community.
3 Standards (iii) and (iv) require that the theory or technique behind the relevant scientific
4 evidence has been approved by scientists. Thus, the scientific community acts as a gatekeeper for
5 science in the first stage (Fig. 1).

6 According to the *Daubert* standard, if scientific results are flawed and yet nonetheless
7 published, judges may have difficulty in excluding any evidence based on such results. To
8 illustrate this impact of *published but irreproducible* results on the admissibility of scientific
9 evidence, we can consider the Albertani case mentioned earlier. In this case, as in many others
10 (Farahany, 2016; Hughes, 2010), the observation of abnormal brain structures in a single MRI
11 scan was cited as evidence in expert testimony to infer the mental state of the offender.

12 Before analyzing how irreproducible research compromises the *Daubert* standard, we
13 need to first assume that claims from experts are testable and have been tested, i.e. that the
14 relationship between the ability to control one's behavior and the brain structure underlying this
15 ability can be tested. At first glance, many published studies seem to report cognitive
16 neuroscientific findings that are linked to defendants' self-control. For example, behavioral
17 flexibility, the ability to control one's attention, is a cognitive process frequently studied in
18 psychology and cognitive neuroscience, and is supposedly related to self-control. Studies found
19 that variation in behavioral flexibility is correlated with the thickness of grey matter in the lateral
20 prefrontal cortex and ACC (Westlye, Grydeland, Walhovd, & Fjell, 2011). However, the
21 concepts of self-control in law and in psychology and cognitive neuroscience are not always the
22 same thing: while self-control in the law is associated directly with behaviors, criminal behaviors
23 in particular, self-control in psychological and cognitive neuroscience studies is operationalized

1 with some specific task that might not be directly associated with behaviors (Buckholtz &
2 Faigman, 2014; Saunders, Milyavskaya, Etz, Randles, & Inzlicht, 2017). In other words, when
3 considering expert opinion on offenders' ability to exert self-control, at worst this opinion may
4 not even be testable, and at best it has not yet been tested.

5 Further, even if we assume that the operationalized tasks in psychology and neuroscience
6 are indeed related to self-control ability in the legal sense, as many lawyers assume when citing
7 brain imaging results, irreproducible results can still compromise the *Daubert* standard.

8 First, it is difficult to estimate the error rate based only on published papers, hence
9 compromising the second standard of *Daubert*. The error rate indicated in the *Daubert* standard
10 is in most cases interpreted as statistical error and method error (Christensen, Crowder, Ousley,
11 & Houck, 2014). While the former error mainly refers to the differences between the predicted
12 and the real values, estimated by measure of uncertainty (e.g. standard deviation), the latter error
13 is more inherent to the methods itself (i.e. the sensitivity, meaning the proportion of true
14 positives that are correctly identified by the method, and specificity, meaning the proportion of
15 true negatives that are correctly identified by the method) (Trafimow & Earp, 2017). The
16 sensitivity of a brain imaging technique in detecting the relationship between brain structures and
17 behavior might be low if the relationship reported in one brain imaging study cannot be
18 reproduced in a direct replication. Indeed, the above mentioned study about the relationship
19 between behavioral flexibility and the volume thickness of grey matter in the lateral prefrontal
20 cortex and ACC (Westlye et al., 2011) has not been replicated successfully (Boekel et al., 2015).
21 Further, it would be impossible to estimate the sensitivity and specificity of using the brain
22 imaging technique to detect brain-behavior relationship if the publicly reported results have been
23 selected by publication bias (Ioannidis, Munafò, Fusar-Poli, Nosek, & David, 2014). The

1 existence of publication bias means that the literature does not reflect positive and negative
2 results in an objective way. For example, on the relationship between brain structure and self-
3 control, if only positive results have been published, we would not be able to evaluate the
4 reliability and robustness of these results (Ioannidis et al., 2014).

5 Second, the peer review and publication standard of *Daubert* is compromised by
6 publication bias, which has inflated the false positive rate in the cognitive neuroscience literature
7 (Fusar-Poli et al., 2014; Ioannidis et al., 2014). Recent studies have revealed that the flexibility
8 researchers have when selecting their own analytical approach to generate results is of a high
9 level (Carp, 2012; Chen, Lu, & Yan, 2018; Simmons, Nelson, & Simonsohn, 2011). The
10 combination of researchers' flexibility and publication bias may have resulted in inflation of
11 false positives in the cognitive neuroscience literature. In this situation, the published results are
12 untrustworthy, and therefore compromise the peer review and publication standard.

13 Third, in the field of cognitive neuroscience, especially for neuroimaging studies, there is
14 no generally accepted standard for methods. Almost every paper reports having used a different
15 workflow to process the data (Carp, 2012; Yeung, 2018). The standardization of data processing
16 has not received sufficient recognition, though a recent publication calls a consensus to be
17 developed in data processing routine (Nichols et al., 2017). Given this proliferation of different
18 research procedures, it is difficult to say that any procedure referenced in a legal case is generally
19 accepted among the community of cognitive neuroscientists or not.

20 In sum, the reproducibility problems in cognitive neuroscience undermine the legal
21 gatekeeping process (the *Daubert* standards). The situation becomes even worse if both the
22 experts (clinical psychologists or neuroscientists) and the judges lack necessary training in
23 statistics (Lyu, Peng, & Hu, 2018; Tavris, 2014).

The open science movement can benefit the gatekeeper system

Fortunately, the scientific community has taken actions to address the credibility crisis caused by the reproducibility issue. The most prominent approach is the open science movement, which is characterized by openness, transparency, and reproducibility in scientific research practice (Munafò et al., 2017). Direct replications are encouraged (Zwaan, Etz, Richard E., & Donnellan, 2018); pre-registration before collecting data is becoming a new norm, e.g. (Chambers, Dienes, McIntosh, Rotshtein, & Willmes, 2015; Nosek, Ebersole, DeHaven, & Mellor, 2018); open data, materials and code are required (Nosek et al., 2015); new inferential statistical techniques are introduced and new tools developed, e.g. (Hu, Kong, Wagenmakers, Ly, & Peng, 2018; Wagenmakers, Wetzels, Borsboom, & van der Maas, 2011); and standard protocols to analyse data and report results are proposed, e.g. (Liu et al., 2018; Nichols et al., 2017; Poldrack et al., 2017; Shamseer et al., 2015). In sum, the *open science movement* has started to clean out the influential but irreproducible studies, and increase the transparency, rigor and reproducibility of new studies (Milham et al., 2018; Nosek et al., 2015; Nosek, Ebersole, DeHaven, & Mellor, 2017), so as to enhance science's ability to describe, explain and predict.

The benefit of the open science movement to science itself has been discussed at great length recently, and is beyond the scope of the current discussion (see: <https://osf.io/xunpj/> for a comprehensive reference list). Below we will focus on how the open science movement can benefit the gatekeeping process for admitting scientific evidence into the courtroom.

First, the open science movement may help to build a better system for evaluating error rates. In the current publishing culture in the field of cognitive neuroscience, as well as across science generally, direct replications are discouraged. As a result, novel findings are seldom replicated, which makes it hard to estimate the error rate. The open science movement has

1 addressed this issue by emphasizing the value of direct replication (Zwaan et al., 2018). Thus,
2 open science allows the development of a more cumulative science, and helps us evaluate the
3 error rate of a particular technique or method. In addition, open data itself provides greater
4 opportunity to evaluate methods and techniques. For example, the Consortium for Reliability and
5 Reproducibility (CoRR) has developed a range of useful resources to assess the reliability and
6 validity of many methods used in neuroimaging research (Poldrack et al., 2013; Zuo et al., 2014;
7 Zuo & Xing, 2014).

8 Second, the open science movement may help to build a better peer review system, which
9 not only includes the usual pre-publication review but also a post-publication review (Earp &
10 Wilkinson, 2017). Previously, the scientific community relied only on pre-publication peer-
11 review, which cannot fully evaluate the reliability and validity of a study since only the results
12 are visible to reviewers. The open science movement not only enhances the pre-publication
13 review, but also emphasize the value of post-publication review. The pre-publication review is
14 enhanced by pre-registration, open materials, scripts and data because in this case the evaluation
15 of a study is based on the entire research process. The post-publication review, which is
16 encouraged by the open science movement, also become valuable if the open scripts and open
17 data are made public along with the publication (e.g. [http://www.russpoldrack.org/2013/04/how-
18 well-can-we-predict-future-criminal.html](http://www.russpoldrack.org/2013/04/how-well-can-we-predict-future-criminal.html)).

19 Third, the open science movement helps to build generally accepted standards which can
20 then lessen researcher flexibility (Gorgolewski et al., 2016; Pernet et al., 2018). Currently, nearly
21 every neuroimaging study uses its own workflow and its own standard for analyzing the
22 neuroimaging data (Carp, 2012; Yeung, 2018), and this granting of full flexibility to researchers
23 inflates the false positive rate. In the open science movement, a set of best practice is

recommended (Nichols et al., 2017), and the whole field is beginning to establish a generally accepted standard. These best practice standards may in time constitute a scientific routine that helps experts to better evaluate the reliability of scientific evidence in the courtroom.

In sum, the open science movement increases the rigor and reproducibility of science, and renders the whole research process more transparent to both researchers and the public. In this way, open science may help scientists to become better gatekeepers for science, which in turn will help judges to use the *Daubert* standard for better decision-making.

Conclusion and Suggestions

Based on the above analyses, we suggest that both cognitive neuroscientists and legal practitioners would benefit from welcoming the open science movement. The open science movement is not a simple standard, but “a set of beliefs, research practices, results, and policies that are organized around the central roles of transparency and verifiability in scientific practice” (Frank, 2018), involving a dynamic, upward spiral process. We suggest that both cognitive neuroscientists and practitioners adjust their practices so that they are based on the best available standards.

For cognitive neuroscientists, it is not easy to follow the newly established standards, which require the preregistration of a study, complete reporting, and the opening of all data and scripts. Fortunately, many practical guides have been published to help researchers navigate through open science, e.g. (Hardwicke et al., 2018; Veldkamp et al., 2018). Professional organizations have also begun to develop standards to enhance the rigor of science, e.g. the Organization for Human Brain Mapping (OHBM) has created the Committee on Best Practices in Data Analysis and Sharing (COBIDAS; <http://www.humanbrainmapping.org/cobidas>) to guide analysis and sharing of MRI (Nichols et al., 2017) and M/EEG data (Pernet et al., 2018);

1 while the American Psychological Association has also published standards for reporting both
2 quantitative (Appelbaum et al., 2018) and qualitative studies (Levitt et al., 2018). These practical
3 primers and standards provide researchers with a guide on how to do better as gatekeepers of
4 science.

5 For legal practitioners, it is crucial to be aware of the current irreproducibility problem
6 and its potential challenge to the credibility of scientific evidence. However, scientific journal
7 articles, including those on reproducibility and open science, are often too technical and cannot
8 be easily understood even by researchers, let alone legal practitioners (Tavris, 2014). Therefore,
9 to be better gatekeepers, it is important for legal practitioners to collaborate closely with
10 researchers. In neurolaw, there is a tradition of neuroscientists working closely with legal
11 scholars and legal practitioners. For example, in 2010, with the support of the MacArthur
12 Foundation, a group of neuroscientists edited a guidebook, *A Judge's Guide to Neuroscience*,
13 which explained the basics of neuroimaging studies in plain language (Bloom et al., 2010). It
14 would be helpful if there were similar guides for judges and other legal practitioners about
15 reproducibility and open science. If judges are made aware that published results can be false
16 positive and irreproducible, and that researchers may, intentionally or not, *p*-hack for publication,
17 they are likely to be more cautious when using scientific evidence from experts in their decision-
18 making. This awareness, further raising the bar set by the *Daubert* standard (Faigman &
19 Monahan, 2009), may prevent additional unreliable scientific evidence from entering the
20 courtroom.

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