Empirical Hardness of Neuroscience Today Remains Confined to Sensorimotor Systems

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Abstract

Psychology as a discipline operates on the boundary between science and metascience. Neurosciences can be thought of as the cognitive sciences’ underlying biological counterpart. Together, they research the link between established biological models and complex cognitive phenomena.

I argue that the empirical hardness of neuroscience today remains confined to sensorimotor systems. Criteria for scientific research, when applied to the cognitive branch of neurosciences, pose more questions than they provide answers. Brain research has become a muse of contemporary pop-art, dominated by pseudoscience and sociologically looping back to the scientific process. Following ethical considerations, these combinatorial theories on reductionist models are far from desirable.

The Scientific Status of Neuroscience Today Remains Substantially Unclear

When scanning through the comprehensive content directory of Jessel, Kandel, & Schwartz's classic on neural science, two observations are striking. One, Neuroscience has grown into a vast field with many branches. Two, the more one advances from specific sensory and motor circuits that are tightly tied to the biology toward complex mental phenomena, the more "likely", "being important factors", or "contributing" the discussed topics become. This gradient characterizes the scientific state of neuroscience. (2000, pp. vii-xxxiii)

Criteria for Empirical Science

The boundary between science and pseudoscience is discussed as *demarcation problem*. Its modern perspective started to take form with Karl Popper questioning the principle of induction as a criterion for demarcation. Induction, deriving universal statements from singular ones, may never be complete in real-world scenarios. Only inductions drawn from finite sets may ever be verified. Knowledge by experience can only be of singular nature, refuting induction as *a priori* truth. The latter had been postulated by Immanuel Kant, trying to bridge the gap between empiricism (everything is causal experience) and rationalism (all knowledge is rational knowledge). Popper, opposing both sensationalism (everything boils down to experience) and positivism (information is derived from deductions thereof operating under general laws), demands "that all statements of empirical science […] must be such that to verify them and to falsify them must both be logically possible."

Empirical methods are not eligible to validate theories. Thus, experience only serves as a test for a theory's *falsification*. Theories count as refuted if their falsifiability consistently proves reproducible. Falsification methods must again be empirical, introducing recursivity. Similarly, simplicity cannot validate theories but only contribute to the ease of their falsifiability (2005, "A survey of some fundamental problems"; ibid., "Theories"). In 1963, Popper still considers “our latest and best theory […] an attempt to incorporate all the falsifications ever found in the field, by explaining them in the simplest way; and this means […] in the most testable way.” (2002, “The Third View: Conjectures, Truth, and Reality”)

Thagard considers theories “scientific only if […] verifiable”. Even astrology may be “vaguely testable”. Questioning Popperian falsification to eliminate any dubious theory as a whole, he suspects falsification to produce derivatives that solely conform to the testing procedure. Thagard demands a three-dimensional domain for demarcation: theory, community, and historical context. Within, he distils two criteria for pseudoscientific theories: minor progress opposed to its alternatives considering long spans and lack of focus towards problem-solving or evaluation by its practitioners. (1978, pp. 226, 227)

According to Robert Merton (1948), empirical science serves serendipitous originating, refinement, and testing of hypotheses. Merton develops idea generation as sociologically evolving consensus within the scientific community. Original ideas must be unanticipated, surprising and strategic, i.e. permit generalization. Perceived sincerity in the actions of promoters of ideas needs to be questioned to detach from faith and remain skeptical (p. 510-11). Following Talcott Parsons, numerical data must match predefined analytical categories to be of value. An initial variation (e.g. generation of data) is followed by processes of selection and purposeful retention. Therefore, Merton demands that the concept and variables of research need to be well-defined and conceptually clear. (Merton, 1948, p. 514; Weick, 1995, p. 179) Merton defines an ethos of science consisting of “disinterestedness [absence of egoistic motives], universalism [generalized principles to be verified by everybody], organized criticism [detachment from faith], communism of intellectual property and humility [towards the priority problem of scientific attribution]”. (Merton, 1957, p. 646, explanations added)

Thomas Kuhn extends this sociological view to *paradigm shifts* happening in scientific revolutions, separating *normal science* from *extraordinary science*. Normal science elaborates on past scientific achievements and compares to puzzle-solving. Following Kuhn, “paradigms can guide research even in the absence of rules”. When an anomaly transcends these puzzles, a crisis calls for extraordinary science, challenging and fundamentally reconstructing prevailing paradigms. Qualifying precondition is “persistent failure to solve a noteworthy puzzle.” In turn, attempts at falsification of candidates challenge newly accepted paradigms. (2012, pp. 41, 143-45)

Methodologically, research is typically done qualitatively or quantitatively. Quantitative studies frame the conditions and data necessary to establish causality by comparing dependent and independent variables, e. g. in randomized, parallel-group, placebo-controlled, multiple-dose, or double-blind studies. Qualitative studies are descriptive and bound to their respective context. To prove the reliability of scientific studies, Goldacre demands fair trials, blinding, and randomization together with a ruthless policy for publication of applied methods and collected data. *Reliability* refers to the replicability of a study’s results by different scientists, *validity* to the appropriateness of the used techniques to study the problem as well as the representativeness of the chosen sample for the population to be studied. Across many studies, meta-analyses harden quantitative results. (2009, pp. 36-54; Lowhorn, 2007)

The Cognitive Branch as the Neurosciences’ Problem Child

The branches of neuroscience differ in the subjects they investigate and the methodology applied.

At the cellular level, biological models have been qualitatively and quantitatively well-established leaving little doubt in the general function of single neurons, nerves, or their microscopic building blocks. Functional sensory and motor units can be singled out in laboratory conditions in animal models. However, it remains unclear, whether neurons are task-specific or multi-purposely part of many circuits. Single neurons may multitask and respond differently across contexts. (Churchland, Kaufman, Raposo, 2014; Jessel, Kandel, & Schwartz, 2000, pp. xxxv-xxxvi, 6-11)

Cognitive and behavioral neurosciences investigate the interdependence between cognitive phenomena and biological units. Their models bridge high levels of abstractions. Cognitive questions are used to bracket macroscopic experiments and microscopic functional units. As the brain is increasingly accepted as a complex network, multiple layers of emergent effects may invalidate contemporary quantitative and qualitative attempts, calling for contextual, longitudinal studies following developmental methodology to identify *patterns*. (Maruyama, 2003, p. 20; Uttal, 2012, p. x; Vygotsky, 1978, p. 45-49)

Validity of Contemporary Empirical Methods in Neuroscience

Uttal (2012) conducted meta-meta analyses of studies in cognitive neuroscience, identifying four fundamental issues: *intraindividual* differences, *interindividual* differences, *pooling* and *variable outcomes* from comparable meta-analyses. (p. 84) Interpersonal differences persisted testing the same individual in the course of several days in the same setting (p. 91). These differences question the applicability of predominant topological studies to cognitive problems. They invalidate universal localization and point to individual patterns of activation consuming the whole brain. Their multi-dimensional analysis is complex. Uttal questions the suitability of imaging techniques that investigate the brain on a macroscopic level to answer cognitive questions. Although they deliver the numeric data necessary for quantitative research, topological correlations or nodes may not be valid across large cohorts of subjects and studies. (Uttal, 2012, p. 84)

The investigation of activation patterns requires (e.g. Gaussian) methods to eliminate noise, introducing methodological bias. Nodes found from multi-patient correlation may be artifacts. To link cognitive questions to operations of massively parallel interacting neurons may be “combinatorially intractable”. Cognitive processes, originating in subjective experience, according to Uttal, lack sufficiently concise definitions for empirical research. Due to the inappropriateness of noise elimination methods, the applicability of meta-analyses themselves must be questioned. Concluding from research on the Williams Syndrome, Farran & Karmiloff-Smith emphasize the importance to include developmental trajectories, as “the performance of [an] atypical group might resemble a pattern observed somewhere along the developmental trajectory of typical children.” (2012, “Introduction”). So from a methodological point of view, the question of whether cognitive neuroscience is science or pseudoscience must remain open. The availability of these meta-studies indicates the presence of critical reflection. (Uttal, 2012, p. 186-190)

The Brain as Pop-Art’s Modern Muse Loops Back on Scientific Investigation

Popova calls the brain a “pop culture fixture in and of itself”. The neurosciences have exploded into a jointed patchwork of emerging popular theories. Existing fields are prefixed “neuro-” to reclaim contemporary authority. Pseudoscientific literature promises increase of overall performance in life by “’rewiring’ and ‘training’ their brains” or “using the latest brain research.” Complex problems are distilled into easily communicable icons and poured out to vast lay audiences. Therefrom, desire for self-optimization promotes brain-based healthism “to produce themselves as better parents, workers, and citizens,” based on “enhancement technologies.” Neuroscientific claims, pseudoscientific or not, come with persuading authority that alludes to medicine and exerts an impact on society. They emerge on a “rhetoric of plasticity,” describing mutual causal influences of mind and brain. (Popova, 2011; Thornton, 2011, “The Rhetorical Brain”, “The Rhetoric of Plasticity”)

Colorful digital images from brain scans became icons of popular media culture. They "substantiate biological determinism" and "emphasize individual agency and responsibility", producing prevalent dissonance that keeps people involved in the illusion of proof that is ubiquitously understandable. Pseudoscientific tools like Brain Age or Brain Gym have conquered computer games, app stores, classrooms, and workplaces. Together with even professionally practiced routines like Neuro-Linguistic Programming, they lack scientific validation. On similar considerations, Popper dismissed Freud's psychoanalysis and Adler's individual psychology. Other prominent pseudoscientific examples include attachment therapy, conversion therapy, graphology, phrenology, and polygraphy. Pseudoscientific methods feign their progress on one-dimensional measures with simplistic explanations to transcend from normation (following predefined ideals) to normalization (open-ended improvement devoid of preset standards). Some of them try to copyright common sense. Extending this normalization to politics of labor promotes new forms of Taylorism with humans as malleable actors. (Thornton, 2011, "Visualizing the new brain"; Goldacre, 2009, pp. 13-19; Popper, 2002, ch. 1)

Scientific research happens in society, as science's individuals and organizations are society's members. Decisions on prioritization of research, funding, and availability of scientists occur in socio-cultural contexts. Oligopolies exert substantial influence on scientific practice by funding and public relations. Thus, science is not unbiased in its decision-making. Media and the movement of popular neuroscience influence this informational selection problem. Research organizations necessarily participate in media networks shaped by for-profit companies to promote scientific findings. The Media's interest also promotes marketing new pseudoscientific methods. Research has even been proposed to be designed to confirm a predefined, marketable outcome. (Goldacre, 2009, pp. 198-238)

Ethical Considerations

Ethical considerations with respect to pseudo-neuroscience concern socio-cultural, scientific and interpersonal contexts. Socio-culturally, statistically firm methods must be guaranteed prior to their communication, i.e. by being self-reflective and separating personal, professional, scientific and monetary interests. Consequences may arise from public trust in a defective method's scientific character. Eldeib (2013) reported three wrongful convictions of murder based on mere belief in polygraph tests. Public spending on fraudulent therapies undermines systems of social security. To extend available technology to higher cognitive processes challenges the taboo of the inviolability of human thinking. Thus, neurosciences are obliged to promote the welfare of living beings, not de-humanize them with industrial pressures of trivialization. (Frost, & Lumia, 2012, p. 460; The British Psychological Society, p. 10)

Scientific findings must be subject to review processes that should be independent, ensure ethical practices, transparent and accountable, and its members be competent. Research itself must appreciate personal dignity and autonomy, e.g. when selecting participants or educating on research goals and procedures, and respect the right of participants to redraw and demand deletion of their data at any point. The design of studies should safeguard the quality and integrity of the obtained knowledge. Research questions must not follow data generation but precede it. In interpersonal contexts, promoting beneficiary and avoiding adverse effects may serve as guiding principle, minimizing the risks for all participants. Mutual relationships must be based on educated consent, respect individual differences and honor applicable laws and regulations. Services must be confined to areas of expertise and appropriately referred as is necessary. (ibid., p. 8-16; American Psychological Association, 2010)

Conclusion

Having followed constructivist footsteps within western society, I am not free from bias. I thus remain skeptical about the investigation of cognition in terms of building blocks, mingled in recipes or process chains. Questioning my stream of thoughts, I started out considering cognitive neurosciences as the frontier between science and metascience, reaffirming popular culture's beliefs. However, as there are varying views on the progression of empirical science, stances have to be taken, even if with caution to give them up as contradictory evidence becomes persistent. In my understanding, this frontier is not of topological nature. To me, a perspective on the brain as morphogenetic closed-loop network that needs to be approached using contextual methodology and developmental research focusing on the investigation of patterns across life-cycles seems to be the most promising alternative to-date. Meanwhile, a *neuroconstructivist* approach emerged rendering my aspirations into yet another cliché of popular science. Summing up the debate, the empirical hardness of neuroscience today remains confined to sensorimotor systems.

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