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The functional-cognitive framework as a tool for accelerating progress in cognitive neuroscience: On the benefits of bridging rather than reducing levels of analyses

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The subject matter of neuroscience research is complex, and synthesising the wealth of data from this research to better understand mental processes is challenging. A useful strategy, therefore, may be to distinguish explicitly between the causal effects of the environment on behaviour (i.e. functional analyses) and the mental processes that mediate these effects (i.e. cognitive analyses). In this article, we describe how the functional-cognitive (F-C) framework can accelerate cognitive neuroscience and also advance a functional treatment of brain activity. We first highlight that cognitive neuroscience can particularly benefit from the F-C approach by providing an alternative to the problematic practice of reducing cognitive constructs to behavioural and/or neural proxies. Next, we outline how functional (behaviour–environment) relations can serve as a bridge between cognitive and neural processes by restoring mental constructs to their original role as heuristic tools. Finally, we give some examples of how both cognitive neuroscience and traditional functional approaches can mutually benefit from the F-C framework.

Keywords: Functional-cognitive framework; cognitive neuroscience; cognitive proxies; reductionism.

In this article, we will outline some ways in which the functional-cognitive (F-C) framework (De Houwer, 2011) may serve to accelerate theoretical progress in cognitive neuroscience and advance a functional treatment of brain activity. This article is organised into three main sections. First, we highlight how measurement problems at the heart of cognitive psychology subtly foster two types of reductionism within cognitive neuroscience: (a) the reduction of cognitive (mental) constructs to behavioural proxies and (b) the reduction of cognitive constructs to neural proxies via behavioural proxies. In particular, we argue that *cognitive reductionism*—any attempt to equate mental constructs with measurement of brain structure or function (see Fodor & Pylyshyn, 1988; Meehl, 1978; Miller, 2010; Quine, 1951)—prevents the theoretical synthesis of neurocognitive data. Second, as a solution, we suggest that the F-C framework can bridge neural and mental processes using behavioural functions (i.e. the causal impact of elements in the environment on behaviour) as a distinct intermediary. Briefly, behavioural functions are a natural intermediary between cognitive and neural processes because both cognitive and neurocognitive theories are ultimately focused on explaining environment–behaviour dynamics. In the third section, we illustrate how cognitive neuroscience and functional approaches are mutually supported by the F-C framework.

COGNITIVE NEUROSCIENCE UNDER STRAIN FROM TENSIONS AMONG ITS THREE LEVELS OF ANALYSIS

Cognitive neuroscience aims to describe how cognitive processes depend upon brain structure and activity (see Miller, 2010; Poldrack, 2010; Poldrack et al., 2011). However, without some means of measuring mental processes in the first place, cognitive neuroscience has no criterion for judging the accuracy of any theoretical predictions it makes about brain–cognition relationships. Therefore, even though mental processes are predicated upon neural processes *within* any neurocognitive theory, theory-building throughout cognitive neuroscience is itself predicated upon the precision with which mental processes can first be described. Crucially, this means

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that cognitive neuroscience can only achieve theoretical consensus to the extent that there is consensus about the nature of mental processes (see Miller, 2010; Poldrack et al., 2011).

Mental processes are typically inferred from measurement of behavioural (including neural) proxies (see De Houwer, 2011; Poldrack, 2010; Poldrack et al., 2011 for critiques of this approach). For example, the mental construct of "value" for a particular stimulus can be defined in terms of its "attractiveness," its "utility" in the economic sense, its "motivational" properties for action or its subjective "pleasure" (see O'Doherty, 2014 for a review). This renders any choice of definition with "non-trivial implications for how one interprets value signals in the brain" (O'Doherty, 2014, p. 260). However, despite the widespread rejection of naive cognitive reductionism in principle, in practice some degree of reductionism is necessary, in proportion to how precisely the relevant mental constructs are coupled with particular proxies. However, *relying* on reductionism creates fundamental barriers to theoretical development in cognitive neuroscience because it fosters theoretical fragmentation. That is, each mental construct (e.g. dissociable components of working memory) must be identified with an ever narrower range of proxies (i.e. particular brain regions) if those mental constructs are to be measured with increasing precision. Such reductionism affirms the consequent by equating a cognitive *explanans* in a logically circular fashion with the proxy it was designed to explain in the first instance (i.e. an *explanandum*; see Hempel, 1970). And yet, in practice, with no alternative for measuring mental processes, some degree of compromise to cognitive reductionism is justified on pragmatic grounds when it comes to empirically testing mental constructs—as when researchers distinguish among constructs by showing double dissociations of activity in the brain (see Miller, 2010; Poldrack, 2010; Poldrack et al., 2011).

At a conceptual level, reductionism erodes the intended *raison d'etre* of mental constructs; namely to parsimoniously explain different behavioural patterns (i.e. to achieve *scope* in explaining behaviour; De Houwer, 2011; Roediger, 2003, p. 15). At a practical level, methods such as functional magnetic resonance imaging have an inherent spatial limitation (approximately 2 mm) and will ultimately aggregate over single units or ensembles, thus placing a lower bound on the refinement of theory. Further, in the absence of objective criteria to balance contradictory tensions between the precision versus scope of mental constructs, the particular range of proxies identified with each mental construct must be determined in an ad hoc manner. Each construct can be reduced to a different proxy, depending on the scope or precision required by a given theoretical argument from case to case. Overall, therefore, using measurement proxies directly encourages theoretical fragmentation. For example, it has been shown many times, in both human and animals, that the ventromedial orbitofrontal cortex (vmOFC) is involved during tasks involving probabilistic feedback to choice (e.g. the Iowa Gambling Task, IGT; Bechara, Damasio, Tranel, & Damasio, 1997). However, vmOFC activity can be explained in terms of a variety of mental constructs, each varying in scope and focus (e.g. emotion, decision-making and reversal learning), and it has proven difficult to aggregate information over findings and methodologies (Stalnaker, Cooch, & Schoenbaum, 2015). Competing theories can empirically self-fulfil regardless of each other (e.g. whether deficits in IGT performance support either the emotional or cognitive decision-making accounts), with competing sets of selective research data (see Yong, 2012; for a very similar overall account; see also *confirmation holism*, Quine, 1951). A commonly offered solution for cognitive reductionism, "conceptual replication," facilitates the decoupling of specific-brain regions with specific-mental constructs (i.e. thereby reducing the compromise to naive reductionism; see Yong, 2012). However, this practice has been likened to building "a house of cards on potentially shaky foundations" (Yong, 2012, p. 299) because it allows each individual to retain only those proxies supporting a preconceived perspective. Moreover, reliance on reductionism implies that even if there was agreement on the particular ranges of proxies applied to each construct, any further development of that construct would require the addition of new proxies, leading to theoretical impasse (see Roediger, 2003, p. 15, with reference to implicit memory and false memories and for detailed reviews in other cognitive domains see De Houwer, 2011; De Houwer, Barnes-Holmes & Moors, 2013; De Houwer, Gawronski & Barnes-Holmes, 2013; Meehl, 1978; Payne & Gawronski, 2010).

The problematic aspects of proxy measurement are further compounded when both neural and behavioural measurements are used as proxies, by adding another layer of theoretical impasses about the degree to which mental constructs are identified with particular proxies. Indeed, as reviewed in detail by Miller (2010; see also Poldrack et al., 2011), this reductionism leads to two of the most pivotal theoretical impasses in cognitive neuroscience: dialectics between localism versus holism and dialectics between innateness versus neural plasticity; respectively, the degree to which mental constructs should be identified with particular neural processes and/or areas of the brain, and the degree to which those neural proxies are immutable versus modifiable. Neurocognitive researchers are therefore faced with an impossible choice when it comes to investigating how mental processes depend upon neural processes: cognitive reductionism appears necessary in order to empirically verify theory, yet doing so perpetuates theoretical indeterminacy and fragmentation.

THE F-C FRAMEWORK AS A TOOL FOR DETERMINING THE EMPIRICAL MEANING OF COGNITIVE THEORY

The F-C approach makes a strict conceptual distinction between behavioural functions that are identified by the causal impact of the environment on behaviour, versus mental constructs that do not have a physical instantiation. Thus, rather than advocating for the measurement of cognitive constructs using proxies, the F-C approach stipulates that mental processes are grounded in terms of behavioural functions, reinstating mental constructs to their original purpose as heuristic tools for understanding behaviour (see De Houwer, 2011; Fodor & Pylyshyn, 1988; Meehl, 1978; Miller, 2010). Behavioural functions are experimentally controlled environment–behaviour interactions and are thus distinct from individual instances of topographically defined behaviour. By implication, this means that each mental construct is *functionally replicated* in terms of the same particular behavioural function from study to study (i.e. as opposed to conceptual replication which involves confirming a given cognitive theory using different ad hoc behavioural proxies from study to study). Note that, within a functional explanation, there can be multiple, often hierarchical, levels of analysis: encompassing overt behaviours (e.g. a button press), but also ranging from single-neuron recording to large scale activity and interactions among brain areas (i.e. from molecular to systems neuroscience). In contrast, mental explanations are heuristic tools for explaining environment–behaviour dynamics and are as such fundamentally distinct from functional explanations. Accordingly, the appropriate means of increasing the precision and scope of a mental construct is thus to improve the precision and scope of the behavioural function it is based upon. For example, performance on tasks such as the IGT, which involve probabilistic feedback following the choice of a particular card from an array, can be defined functionally in terms of the change in behaviour because of the past and present feedback contingencies. Indeed, such behavioural variations in tandem with environmental changes can serve as the basis for abstract functional knowledge. From the current example, we could abstract that when people experience an unexpected large monetary loss (i.e. negative feedback) from a particular card choice they have a higher probability of choosing an alternate card on their next trial. In contrast, individuals with vmOFC lesions tend *not* to choose alternate cards following a change in contingencies. Thus, once an abstract behavioural function is experimentally established to a certain degree of precision and scope, it becomes possible to identify its neural mediators, such as vmOFC function, to a corresponding degree. And, likewise, mental constructs related to emotion or executive control obtain a corresponding degree of precision and scope in attempting to explain the relevant behavioural or neural dynamics.

Crucially, unlike cognitive constructs based upon behavioural proxies, it is possible to improve the precision of constructs based on behavioural functions without sacrificing scope or vice versa. Functional replications create ever more precise distinctions about how environmental variables influence particular types of behavioural responses, a process that facilitates the identification of environment–behaviour relations in an ever wider range of contexts (i.e. scope is increased). Therefore, by basing cognitive constructs upon behavioural functions, a major advantage of the F-C framework is that it dissolves any theoretical tensions between the precision versus scope of cognitive constructs measured using proxies. Indeed, there are already two extensive reviews detailing how the F-C approach dissolves various longstanding theoretical impasses within the literatures on cognitive evaluating (De Houwer, Gawronski et al., 2013) and on cognitive learning (De Houwer, Barnes-Holmes et al., 2013). The F-C approach not only promotes greater theoretical synthesis of cognitive theory but also greater theoretical creativity as experiments are not constrained by pre-ordained behavioural proxies (see De Houwer, 2011; De Houwer, Barnes-Holmes et al., 2013). What follows are a series of examples to illustrate just how the F-C framework can achieve these things by gradually providing an unambiguous empirical basis within which to ground cognitive theory.

THE MUTUALLY SUPPORTIVE NATURE OF FUNCTIONAL AND COGNITIVE APPROACHES FOR NEUROSCIENTIFIC RESEARCH

Systematically manipulating environmental variables using established methods from functional psychology can augment cognitive approaches. For example, it is possible to manipulate, intra-experimentally, the learning histories of particular stimuli (summarised in Whelan & Schlund, 2013), and this affords the opportunity for describing the underlying environmental relations that give rise to particular patterns of behaviour and consequently inform cognitive theorising. Neurofeedback, which involves training individuals to control their own brain activity, is commonly employed for attention-deficit hyperactivity disorder but also has useful applications for brain–computer interfaces (e.g. Li et al., 2010) and in downregulating epileptic seizures (Sterman & Egner, 2006). The utility of neurofeedback could be improved even further by the application of methods from functional psychology, such as intermittent reinforcement, fading and stimulus control. Other methods, such as reversal designs to demonstrate environmental influence, could also be employed to greater effect in cognitive neuroscience research (e.g. Schlund & Ortu, 2010).

Similarly, functional accounts can benefit from the cognitive approach, because the cognitive approach can generate questions for functional researchers. For example, an unanswered question concerns why "semantic distance" effects and "symbolic distance" effects occur in opposite directions. That is, reaction time increases as semantic distance increases whereas given stimuli related by comparison (i.e. more than or less than) the symbolic distance effect is usually observed (e.g. Acuna, Sanes, & Donoghue, 2002) whereby accuracy increases, and RTs decrease, the further apart stimulus pairs are. Taking this research question, inspired by cognitive psychology, and applying a method from functional psychology (experimental control of the learning history), could facilitate the disentangling of semantic priming effects from symbolic distance effects by removing confounding variables such as syntax, polysemy and each subject's idiosyncratic pre-experimental semantic histories. Recently, efforts to better describe and aggregate relationships among task parameters, the resulting brain activity and mental constructs (e.g. the Cognitive Atlas, www.cognitiveatlas.org, Poldrack et al., 2011; Neurosynth, www.neurosynth.org, Yarkoni, Poldrack, Nichols, Van Essen, & Wager, 2011) have helped identify abstract regularities in functional relations. This abstract, functional, knowledge—separate to any mental constructs—can then provide the input upon on which mental explanations are built. "A strong functional approach therefore allows for a strong cognitive approach: The more we know about when a behavioral effect occurs, the more precise we can be about the mental constructs that mediate this effect" (De Houwer, 2011, p. 205; for caveats in this regard see Barnes-Holmes & Hussey, 2015).

In conclusion, cognitive neuroscience is a discipline that produces large volumes of research data with major implications for cognitive psychology and mental health policy (see Miller, 2010). However, the reductionism when relating mental constructs to brain structure and function is problematic and hinders progress. The F-C framework, with its emphasis on grounding mental constructs specifically in terms of particular behavioural functions can therefore serve as an important basis for the theoretical synthesis of neurocognitive data.

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