

[Pepperberg & Brezinsky 1991] to the additional spontaneous use for describing the absence of a specific numerical set in a collection [a zero-like concept; Pepperberg & Gordon 2005]).

The authors note that  $g$  has “robust correlates to brain structure and function” (sect. 1.1, para. 3), yet do not mention significant research on avian brains. Recent studies, although not always performing the correlations themselves, have shown that avian brain anatomy would correlate with many  $g$ -related abilities; see, for example, in addition to those references cited, Iwaniuk et al. (2009) or Jarvis et al. (2005). Specifically, Olkowitz et al. (2016) have found that parrots and corvids have forebrain neuron counts equal to or greater than primates with much larger sized brains, and argue that this finding likely explains the advanced cognitive abilities found in these avian species.

In general, the authors only partially consider parallel/convergent evolution of  $g$  with respect to avian species, again particularly concerning corvids and parrots. For example, K-selected traits (e.g., long lives, few offspring that are relatively slow to mature, etc.), are discussed at various points in the target article as being associated with the evolution of  $g$ ; these traits are found in most corvid and parrot species. The authors highlight the importance of sociality in driving intelligent behavior (sensu Jolly [1966] and Humphrey [1976]): Notably, the majority of parrot and corvid species live in complex social groups, and evidence exists for several types of learning that are enhanced via conspecific or allospecific social influences (e.g., corvids: Miller et al. 2014; New Zealand kea parrots: Heyse 2012). Myriad papers on corvid social cognition have been published by Bugnyar and his colleagues (e.g., Bugnyar & Heinrich 2006). Acquisition of referential use of human speech by Grey parrots occurs through social learning (e.g., Pepperberg 1981; 1999); similarly, “bilingual” songbirds learn the form and likely use of hetero-specific vocalizations via intense social interaction (e.g., Baptista 1981).

Furthermore, as with nonhuman primates, the dominance hierarchies that are prevalent in social groups of corvids (e.g., Chiarati et al. 2010) require an understanding of advanced cognitive processes such as individual recognition (e.g., Izawa & Watanabe 2008) and transitive inference (e.g., Paz-y-Miño et al. 2004). Granted, the references I cite involve different corvid species; nevertheless, the cognitive requirements across species would likely be quite similar given their similar ecology/ethology. And, although dominance hierarchies in parrot flocks have not been studied in the wild, hierarchies have been observed in captivity (Szabo et al. 2016; parrots in my lab also exhibit a hierarchy), and understanding linear ordering can also be related to cognitive capacities such as the spontaneous comprehension of ordinality (Pepperberg 2006).

Tests used as evidence of general intelligence, even by the authors’ admission, are mostly basic, but other tests, even if performed on only a limited number of subjects, strongly demonstrate advanced avian capacities. For example, evidence for executive function (planning, delayed gratification) is evident in corvids (Hillemann et al. 2014; Raby et al. 2007). One cannot argue that such behavior is modularly related to caching, as success on the same tasks can be seen in parrots that do not cache (Auersperg et al. 2013; Koepke et al. 2015). Grey parrots understand not only categories (e.g., what is or is not green), but also concepts such as “color,” “shape,” and “matter” (i.e., the existence of these hierarchical concepts, under which categories such as green and wood are sorted; Pepperberg 1983) and that two objects can be related based on just a subset of these concepts; that is, for second-order concepts of same-different (Pepperberg 1987). The authors mention reasoning by exclusion: for such abilities in parrots and corvids, see Pepperberg et al. (2013), Schloegl (2011), and Schloegl et al. (2009). Likewise, for advanced avian understanding of number concepts, see Smirnova (2013) and Ujfalussy et al. (2014); these abilities are often at a level more advanced than those shown to date for nonhuman primates (e.g., Pepperberg 2006; Pepperberg & Carey 2012). Research

papers on tool use by corvids that do not use tools in nature are too numerous to mention; for aspects of physical cognition in parrots, note van Horik and Emery (2016).

The authors have, essentially, performed a meta-analysis on a number of meta-analyses, and I have no arguments about their basic thesis – my criticism is merely that readers interested in this thesis, particularly readers with little knowledge of nonhuman capacities, would unfortunately be left unaware of a large number of striking *avian* abilities that provide considerable evidence for  $g$ .

## General intelligence is an emerging property, not an evolutionary puzzle

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**Abstract:** Burkart et al. contend that general intelligence poses a major evolutionary puzzle. This assertion presupposes a reification of general intelligence – that is, assuming that it is one “thing” that must have been selected as such. However, viewing general intelligence as an emerging property of multiple cognitive abilities (each with their own selective advantage) requires no additional evolutionary explanation.

As the authors acknowledge, the concept of general intelligence is empirically grounded solely in the observation of positive correlations between all test scores, as reflected by a general factor termed  $g$  explaining a large share of variance in all tests (Spearman 1904). All other accounts are simply debatable interpretations or hypotheses attempting to relate  $g$  to some other cognitive or biological constructs. They run the risk of reifying what is primarily a statistical construct, and also of seriously confusing the search for an evolutionary explanation. For instance, Gottfredson’s (1997) definition of intelligence is little more than a scholarly formulation of the folk concept of intelligence, but offers no guarantee of matching psychometric  $g$ . Burkart et al. initially conflate  $g$  with executive functions, but this changes the nature of the problem. If general intelligence reduced to executive functions, then to the extent that each executive function offers a selective advantage, the evolution of general intelligence would not be a major puzzle. Similarly, general intelligence is also identified with domain-general cognitive processes, which is a different, and unnecessary, hypothesis as we will show. Furthermore, many putative domain-general cognitive functions turn out to be less general than they seem. For instance, there are separate working memory systems for verbal, visuospatial, and other modalities. Similarly, words such as *inhibition* and *attention* wrongly suggest unitary phenomena, whereas they are used to describe a host of distinct processes, none of which can be said to be truly domain-general, and none of which is an evolutionary puzzle. Finally, certain cognitive functions can serve domain-general purposes while having been selected for more specific adaptive value. This may be the case of language, which serves as a mediator across many cognitive functions, yet may have evolved for purely communicative purposes (Jackendoff 1999; Pinker & Bloom 1990).

More generally, every attempt to reduce general intelligence to a single cognitive (processing speed, working memory, etc.) or biological (brain volume, nerve conduction velocity, etc.) construct has failed, each construct showing moderate correlation with  $g$  and being best described as simply one contributor to the  $g$  factor (e.g., Mackintosh 2011). Thus, trying to tackle the evolution of general intelligence by addressing the evolution of any of these constructs is a form of attribute substitution (Kahneman & Frederick 2002).

Understanding the evolution of psychometric  $g$  requires understanding how it comes about. As early as 1916, Thomson (