Commentary on *Cognitive Gadgets: The Cultural Evolution of Thinking* by Cecilia Heyes

Executive functions are cognitive gadgets

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Abstract (max. 60 words)

Many psychologists and neuroscientists still see executive functions as independent, domain-general, supervisory functions, that are often dissociated from more "low-level" associative learning. Here, we suggest that executive functions very much build on associative learning, and argue that executive functions might be better understood as culture-sensitive cognitive gadgets, rather than ready-made cognitive instincts.

Main text (max. 2000 words)

In her cognitive-gadgets theory, Heyes (2019) argues that many of the cognitive mechanisms that make humans special are not produced by genetic evolution, as commonly believed, but by cultural learning. We are largely sympathetic towards this theoretical move, not the least because the mechanics of cultural learning are much better understood than the genetics of human cognition. This renders theorizing in terms of cognitive gadgets more transparent and empirically accessible than the common attributions to a mechanistically not-yet-understood, underspecified genetic basis. However, we feel that Heyes underestimates the explanatory power of her own theory when it comes to executive functions – which she considers to be part of a genetically-given cognitive starter-kit. As we will argue, there is converging evidence that executive functions are no genetic given but can be considered cognitive gadgets acquired through social and cultural learning.

Executive functions are considered higher-order functions that support goal-directed, flexible behavior, like quickly alternating between offence and defense in sports or stopping to smoke. Executive functions are often distinguished from other, seemingly lower-level processes like perception, attention, response selection, or learning (Evans & Stanovich, 2013; Kahneman, 2003). In particular, executive functions and learning have been portrayed as opposite forces (will vs. habit) since the beginnings of experimental investigations on action control (Ach, 1910) until today (e.g., in the disguise of model-based/model-free control: Dolan & Dayan, 2013). Heyes (2019) uses this same dichotomy to characterize executive functions and associative learning, respectively, as two "cognitive instincts" of genetic origin. However, there are reasons to consider this an unnecessary choice that only complicates her otherwise straightforward gadget approach.

First, the distinction between smart executive functions and dumb associative mechanisms implies a higher (to-be-paid-back) "loan of intelligence" (Dennett, 1978) than necessary. While the mechanics of associative mechanisms are reasonably well understood, assuming some opposing force, that apparently operates in an independent, unspecified way runs straight into the homunculus problem, leaving it open how executive functions work and what is regulating them.

Second, executive functions have been shown to be as malleable as imitation, for which Heyes takes malleability as a strong indicator of its cultural origin. In particular, Heyes (2019) argues that imitation is a cognitive gadget because it can be enhanced or even reversed in functionality by means of novel sensorimotor experience or training. Interestingly, the same holds for executive functions. For example, people tend to repeat rather than switch between tasks, possibly because the latter is cognitively more demanding (Arrington & Logan, 2004). However, this tendency can be considerably diminished or even abolished by reinforcing or simply increasing the frequency of task alternations (Braem, 2017; Fröber & Dreisbach, 2017).

Third, executive functions share another characteristic with imitation: contextual dependency, which Heyes takes as a strong argument to consider it a cognitive gadget. Just like imitation, which has been shown to be very effector- and task-specific, executive functions have also been demonstrated to be specific to effector and context (e.g., Crump et al., 2006). For example, Braem and colleagues (2011) demonstrated how the ability to adjust task focus following cognitive conflict is constrained by the effectors used to perform the previous task (e.g., hand versus feet; see also, Janczyk & Leuthold, 2018). Executive functions are also tightly connected to, and associated with the stimuli they were operating on (Waszak, Hommel & Allport, 2003), and even with irrelevant stimuli that merely covaried with the particular executive function (Spapé & Hommel, 2008). In a similar vein, practicing to inhibit a response to a certain stimulus slows down responding to that same stimulus in a subsequent unrelated task (Verbruggen & Logan, 2008). Additional evidence for this highly contextualized nature of executive functions also comes from "brain training" studies, which indicate that executive functions can be trained but rarely show transfer (Melby-Lervåg, Redick, & Hulme, 2016; Simons et al., 2016).

Fourth, latent factor analyses seem to fail in identifying consistent replicable factors indicating independent executive functions (Karr et al., 2018). This makes executive functions "hard to grasp", which already lead some to consider the nature of executive functions elusive (Jurado & Rosselli, 2007). In fact, the distinction between inhibitory control, working memory and cognitive flexibility that Heyes relies on has also been partly challenged by the very authors that originally introduced this distinction (Friedman & Miyake, 2017). Therefore, there is increasing evidence that executive functions are highly contextualized and "sticky" (Mayr & Bryck, 2005), which we take as a strong hint that they might be grounded in associative learning (Abrahamse et al., 2016; Braem & Egner, 2018; Egner, 2014). This makes executive functions ideally suited to develop through social communication and transfer to meet contextual and cultural demands (Hommel & Colzato, 2017).

Fifth, the idea that executive functions might be grounded in culturally transmitted associative processes is consistent with developmental studies showing that executive functions mature no earlier than around adolescence (e.g., Blakemore & Choudhury, 2006), and that parenting plays a considerable role in their development (Hughes & Ensor, 2009). Furthermore, executive-control styles have trait-like, sticky characteristics that reflect people's (sub-)cultural background, such as religion or sexual orientation (Hommel & Colzato, 2017). For example, the impact of response conflict on action control is considerably smaller in Calvinists, and larger in Catholics, than in matched control groups (Hommel et al., 2011), and a similar pattern can be found for the control of temporal attention (Colzato et al., 2010). Along the same lines, measures of cognitive flexibility systematically covary with religious disbelief (Zmigrod et al., 2019). Cultural differences can also be found on a larger scale, with young East Asian children often outperforming Western children on a range of executive function indices (Lan, Legare, Ponitz, Li, & Morrison, 2011; Oh & Lewis, 2008; Sabbagh, Xu, Carlson, Moses, & Lee, 2006).

Taken together, executive functions are not well-defined, which holds for both empirical bottom-up and theoretical top-down approaches, and there is increasing evidence that they show characteristics that are typical for culture-related associative processes: malleability, context-dependency, lack of transfer, and cultural dependency. Heyes' key argument for classifying executive functions as cognitive instincts rather than cognitive gadgets seems to be heritability: if executive functions were a product of culture rather than genes, why have they been shown to be heritable, observable in other animals too, and to be enhanced in humans? Interestingly, a closer look reveals that these signs of heritability are not inconsistent with a cultural basis of executive functions either.

First, executive functions indeed seem to be heritable, at least to some degree (Friedman et al., 2016). Notably, however, more targeted studies on this genetic contribution suggest they rely on a complex interplay of different neurotransmitter functions (Logue & Gould, 2014), with a particularly important role of dopamine (Cools & D'Esposito, 2010). Given that the efficiency of the frontal and striatal dopaminergic pathways is heritable to some degree (Colzato et al., 2011), there are at least two ways how executive functions might be heritable even if they rely on associative processes. For one, various forms of associative learning rely on monoaminergic processes (Schultz, 2013; Tully & Bolshakov, 2010), so what looks like the heritability of executive functions might actually reflect the heritability of the domain-general associative learning mechanisms they rely on. For another, the online operations of executive functions have been shown to rely on dopaminergic efficiency (Cools & D'Esposito, 2010), suggesting that frontal and striatal control pathways rely on the dopaminergic fuel provided by the ventral tegmental area and the substantia nigra. If so, what might be heritable might not be the engine being driven (i.e., executive functions proper) but the (amount, availability and/or quality of the) fuel driving it. In any case, it is important to consider that signs of heritability do not determine whether it is the function of interest that is heritable, or just the infrastructural factors it needs to operate on. As an example, while the ability to acquire language is heritable (Byrne et al., 2007; Kovas, Haworth, Dale, & Plomin, 2007), this is not in and of itself a reason to conclude that language itself must be genetically coded (Deacon, 1997; Heyes, 2019).

Second, Heyes (2019) further pointed towards observations that executive functions can also be observed in non-human animals, which would suggest they have a longer genetic history. Still, the fact that executive functions can be observed in animals does not invalidate executive functions as cognitive gadgets (as also argued for imitation processes, Heyes, 2019). Instead, it merely suggests that in animals too, (rudimentary forms of) these processes can develop. Interestingly, in reviewing recent evidence comparing human and non-human primates, researchers have concluded that similarities in executive functions often reflect similarities in domain-general reinforcement learning mechanisms (e.g., as during reward learning), and that certain basic control processes may actually rely on different brain regions across species (Eisenreich, Akaishi, & Hayden, 2017; Heilbronner & Hayden, 2016; Mansouri, Egner, & Buckley, 2017). Therefore, similar to how language might have latched itself onto the brain as a parasite to its host (cf., Deacon, 1997), certain culture-specific executive functions could have developed onto partially different brain networks in different species.

Third, executive functions do not only seem to be heritable and observable in other animals, there are reasons to believe they have evolved into more superior or enhanced functions in humans. However, this enhancement could be culture-driven, or rely on other genetic benefits (e.g., enhanced associative learning or the ability to develop symbolic representations). This aside, the superior nature of these functions has also been questioned altogether. For example, Heyes (2019) cites evidence that self-control – the ability to inhibit one's impulses – might be enhanced in humans. However, others have argued that this ability is still rather poor in humans, and its seemingly enhanced nature could be partially due to procedural differences in measuring self-control across species (Hayden, 2019). As for working memory capacity, some have argued this ability to be comparable (Carruthers, 2013), or even inferior to some of our closest ancestors (Inoue & Matsuzawa, 2007). In fact, Lotem and colleagues (2017) suggest that while having a larger working-memory buffer in humans could be possible, having a smaller working memory capacity might be more adaptive. Last, it is true that humans show a remarkably higher proficiency in switching between different tasks, and thus enhanced cognitive flexibility. However, this difference has been attributed to differences in language proficiency, rather than switching abilities per se (e.g., Hermer-Vazquez, Moffet, & Munkholm, 2001). In fact, a set of recent studies using a nonverbal computer task showed that baboons and children, as well as seminomadic adults from north Namibia, were better at switching away from a certain strategy to select more optimal strategies, than adults from North America (Pope et al., 2015, 2019).

Heyes (2019) emphasizes that no mental process is likely to be the product of nature, nurture, or culture alone, and she admits that "learning and cultural inheritance play major roles in the development of human executive function". We suggest taking these roles somewhat more serious and consider executive functions not cognitive instincts but cognitive gadgets. Ultimately, this question will depend on one's exact definition of executive functions, one's level of analysis, and the specific executive function of interest, but we suggest that executive functions can be considered an emergent property arising from a complex interplay of different basic reinforcement learning processes, working at the level of more distributed or abstract representations (e.g., Abrahamse et al., 2016; Eisenreich et al., 2017). Such a perspective could further promote the study of how executive functions emerge through development, how they can be acquired and become conditioned and bound to context, and how this can lead to substantial inter-individual and cultural differences in the development of these particularly interesting "cognitive gadgets".

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