Primate tool use and the socio-ecology of thinging: how non-humans think through tools

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Abstract
While ecological psychology and embodied approaches to cognition have gained traction within the literature on non-human primate tool use, a fear of making assumptions on behalf of animal minds means that their application has been conservative, often retaining the methodological individualism of the cognitivist approach. As a result, primate models for technical and cognitive evolution, rooted in the teleological functionalism of the Neo-Darwinist approach, reduce tool use to the unit of the individual, conflating technology with technique and physical cognition with problem-solving computations of energetic efficiency. This article attempts, through the application of material engagement theory, to explore non-human primate technology as a non-individualistic phenomenon in which technique is co-constructed through the ontogenetic development of skill within a dynamic system of structured action affordances and material interactions which constitute an emergent, species-specific mode of technical cognition.

Keywords
Material engagement theory, cognition, primate evolution, agency, ecological psychology, animal tool use

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1. Introduction
Embodied, distributed and extended (4E) theories of cognition are increasingly incorporated into human and non-human primate (NHP) studies of technical evolution as a means of contextualising cognition and behaviour within species-specific evolutionary trajectories (e.g. Barrett et al., 2007; Barrett & Henzi, 2005; de Resende et al., 2008; Fragaszy & Mangalam, 2018; Johnson & Oswald, 2001; Mangalam & Fragaszy, 2016; Mosley & Haslam, 2015; Sterelny, 2010; Tan, 2017). Yet their application remains conservative, constrained by Neo-Darwinian frameworks, and a tendency in Primate Archaeology (cf. Carvalho et al., 2007; Haslam et al., 2009, 2017) and anthropocentric cognitive archaeology more generally, to talk around rather than about technical cognition. In the broader biological context, both ‘tool use’ and ‘cognition’ are inherently unstable concepts (Bayne et al., 2019; Preston, 1998), which, despite intuitive simplicity, evade strict definition; proving problematic for both anthropocentric and ethnographic applications alike (Lestel & Grundmann, 1999; Preston, 1998). Nevertheless, tool use as a broad functional category has been ecologically stretched from New Caledonian crows shaping and using Pandanus probes (Hunt, 1996; Hunt & Gray, 2004), to female water-striders using copulating males as living floats (Pierce, 1986), and in extremis, fungal parasitism (Lestel & Grundmann, 1999), so cognitive processes have been extended, not simply metaphorically, to include behavioural, material and plant processes (Malafouris, 2013; Shettleworth, 2010).

With ‘cognition’, for the lack of broader consensus, having become ‘whatever cognitive scientists study’ (Allen, 2017) – a ‘gesture towards a domain of investigation’ (Bayne et al., 2019, p. R611) – approaches to primate technology, in their explicit assumptions about ‘what’ and ‘where’ tool use is and takes place, implicitly beg the same questions of technical cognition and the...
mind. Commonly accepted ethological definitions which, wishing to avoid anthropocentrism, have attempted to bound tool use a-cognitively, as a physical phenomenon adjacent to, yet apart from, the body and environment (e.g. St. Amant & Horton, 2008; Shumaker et al., 2011), circularly reinforce an implicit analogous assumption, prevalent in Neo-Darwinian approaches, that technical cognition (as mental content/representation) is something which takes place in the brain (as an internal processor), causally constrained by, yet constitutively detached from, the body and environment (Lombard et al., 2019; Povinelli, 2000; Seed & Byrne, 2010; Seed & Call, 2019; Tomasello & Call, 1997; Vaesen, 2012).

In teleonomic functionalism of the Neo-Darwinian evolutionary framework, tool use is reduced to the unit of the individual, conflating technology (a shared body of general methods and principles) with technique (idiosyncratic practice),1 social cognition with information transfer and physical cognition with problem-solving computations of energetic efficiency (O'Grady, 1984). Tools and techniques, which, on one hand, are treated as static manifestations of internally represented problem-solving processes and, on the other, by virtue of their materiality,2 denigrate subjective agency, choice and individual experience to being treated as secondary phenomena, 'expressed only in the last degrés du fait' (Audouze, 2002, p. 14). In seeking to highlight cross-species psychological continuity at the expense of taking bodily discontinuity seriously, we exchange anthropocentrism of one kind, with anthropocentrism of a deeper, more insidious kind (Barrett, 2015). As tools and materials are treated as peripheral to organism-based agency, so species’ perceptual capacities are treated as peripheral to their psychologies.

Material engagement theory (MET) encourages the bridging of the mind–material gap, in order to recognise the primacy of material interaction in processes of species psychological becoming in and with their environments (Malafouris, 2004, 2008, 2009, 2013, 2015, 2016, 2019; Malafouris & Renfrew, 2010; Renfrew, 2004). Taking cognition to be embodied in a radical sense, in which the body and environment are considered constitutive to the cognitive process, MET develops the three interrelated hypotheses of extended mind, enactive signification (Malafouris, 2013) and material agency (Knappett & Malafouris, 2008; Malafouris, 2008), to call for a reorientation of the boundaries of the mind and a recognition of the material dimensions of cognition (Iliopoulos & Garofoli, 2016). While the last few years have seen MET drive a paradigm shift in anthropocentric cognitive archaeology (e.g. Iliopoulos & Garofoli, 2016; Overmann & Wynn, 2019a, 2019b; Roberts, 2016), the implications of its framework are yet to have a similar impact in non-human research contexts.

With more radical 4E and perception–action theory (cf. Lockman, 2000) having made space for the body-grounded socio-cultural aspects of primate cognition, MET, in its breakdown of subject/object agential relationships, presents a non-individualistic and fundamentally non-anthropocentric framework, in which to re-approach and consolidate existing theories of primate tool use with pragmatist, enactivist and radically embodied theories of agency and material cognition, with the aim of providing a meaningful way of describing technical behaviours as a species-specific cognitive mode of engaging with the environment. This article begins with an outline of MET's particular view of agency, as the emergent ‘ecology’ of situated action, distributed across the organism–environment system, before moving to explore the implications of this viewpoint for our understanding of human and NHP tool use. Critical to the development of the argument are J. J. Gibson’s (1979) concept of affordance and the concept of metaplasticity (Malafouris, 2010, 2015).

2. Reconceiving perceiving: radical embodiment, enactive cognition, metaplasticity and affordance

MET takes its starting point in the phenomenological (Husserl, 1931/2012; Merleau-Ponty, 1962), and ecological–psychological (J. J. Gibson, 1979), notion that perception and agency are processes grounded in situated action. Perception, being fundamentally tied with intentionality, and intentionality with the capacity for action (as an organism’s primary means of achieving its intent), is taken as a form of skilful interactive engagement with the environment, so that the sentence of the world is seen as in its relation to an organism’s particular mode of being-in-it (following Heidegger, 1927/1996). With agency lying in between, not a property of ‘who’ or ‘what’, but a matter of ‘when’ (Malafouris, 2013, p. 51), the mind (as an agential perspective) is seen as the emergent product of the organism–environment system and as co-constituted through their mutual transaction (following Dewey, 1944/2002).3 In short, intention is seen as in action and to act, to perceive (Gibson, 1979; E. J. Gibson, 1988).

2.1. Affordance, transaction and the ecology of agency

In his theory of ‘affordances’, J. J. Gibson (1979) argues that the perception of the environment occurs directly, and without the need for mental representation, in terms of the environment’s situational affordance of the perceiver’s physical capabilities (see also Chemero, 2009). While there are numerous interpretations of what (and where) an ‘affordance’ is— including by Gibson himself, over the course of his career – the
interpretation adopted here is as a quasi-ontology; ‘affordance’ is taken as neither a property of the environment nor the effectivity\(^4\) (\textit{sensu} Turvey, 1992) of the organism, but a potentiality arising from their situational complementarity (Stoffregen, 2003). Objects may afford many things to many perceivers; a field of flowers, for instance, might afford pollination to a bee, nesting material to a field-mouse and making daisy-chains to children; as a mug might afford drinking coffee in the morning, tea in the afternoon and, in the absence of a glass, beer in the evening. The most important aspect of ‘affordance’ is that it points both ways – between the organism and environment (J. J. Gibson, 1979, p. 129), and looks both forward and back – with the action potential as rooted in the historicity of the organism’s own socio-material experience (Costall, 1995, 2012), as it is made contextually relevant by the perception–action and intention–action coupling occurring in the moment of affordance solicitation (Baber et al., 2014, p. 5).

For proponents of MET, perception is an active process through which intent and meaning are \textit{enactively and emergently substantiated} (following Renfrew, 2001). With perception and intent rooted in affordance, intentionality is characterised as purposive and non-representational, ‘an attitude of the whole organism expressed in their behaviour’ (Hutto, 2008, p. 57), and cognition as produced rather than processed. In this respect, the interpretation of ecological information describing affordances adopted here is more in line with the radical enactivist view (Hutto & Myin, 2013, 2017) than with that of Neo-Gibsonianism (Turvey, 1992).\(^5\)

Although ecological information about affordances might be considered as a property of the environment in order to be able to discuss potential affordances relative to an ideal organism (following Bagg & Chemero, 2018), ecological information is considered to exist in a meaningful sense, only in the precise compatibility between the organism and environment which occurs at the moment of affordance solicitation. Since cognitive and agential processes are constitutively dependent on the organism’s body situated within the environment and cannot be separated from either context, the ‘mind’ is ‘embodied in our entire organism and embedded in the world, and hence is not reducible to structures inside the head’ (Thompson, 2005, p. 409).

### 2.2. Metaplasticity: a developmental system with multiple temporalities

Malafouris (2010, 2015) outlines this idea of mutualistic organismic-material transaction and co-constitution with the concept of \textit{metaplasticity}. Taken from the neuro-scientific literature, in which the term is used to define behaviourally dependent higher-order synaptic plasticity (Abraham & Bear, 1996), ‘metaplasticity’ is used by Malafouris (2009, 2010, 2015, 2016, 2019) to describe the flexible integration of material things and plastic brains/bodies which takes place in the ongoing becoming of the human mind. Critical to the concept is the notion that, to the extent that cognition and action occur in the world and alter both the organism and environment through their occurrence, organisms’ perceptual ‘lenses’ are as much determined by their species-typical ‘forms of life’ (Rietveld & Kiverstein, 2014; following Wittgenstein, 1953) – that is, their biology, socio-ecology and sensory apparatus – as by their unique developmental pasts and affective presents (Adolph, 2020; Adolph & Kretch, 2015; Rietveld & Kiverstein, 2014).

As organisms and their environments develop relative to one another, the field of affordances and their relevance is in constant flux (Adolph, 2020), with new ways of being, leading to (or, alternatively, perhaps constraining) novel ways of thinking and perceiving, and vice versa. The development of agential perspective, although predisposed by phenotypes, through situated action, becomes a metaplastic process of transformation, an unfolding and refolding of past and present material engagements (Deleuze & Strauss, 1991), so that, in the development of material associations, we see a gathering of skills and materials (or ‘mind-stuffs’; Malafouris, 2019) around the body in ever-increasing patterns of perceptual complexity.

### 3. Situating causal cognition: \textit{thinging} and the ecology of material agency in tool use

Understanding perception as a skilful form of ‘interactive engagement’ with the environment enables a reframing of causal cognition – typically treated as the representation of causal relationships (Bender, 2020; Kronenfeld, 2014; Lombard & Gärdenfors, 2017) – as a \textit{direct} (and \textit{directed}) perceptual learning capacity (cf. E. J. Gibson, 1963, 1988; Lockman, 2000), a \textit{skilful form of causal perception} and the interactive means by which an animal becomes receptive to solicitation by the \textit{effective} affordances of objects. Where, at its most basic level, causal cognition might facilitate the discovery of basic object and target object affordances (e.g. ‘grip-ability’ or ‘consume-ability’) by direct proprioceptive handling (via dynamic touch), or perhaps by observation of a conspecific’s object manipulations (via enactive social learning),\(^6\) the understanding of causal perception as a mode of active probing of the external world also extends to \textit{tools as continuous prosthetic parts of the perceptual process}, a notion expounded by Malafouris (2014, 2016, 2019), in the concept of \textit{thinging}, as the skilful ability to think \textit{with or through} (rather than \textit{about} objects).
Building from J. J. Gibson’s (1979) theory of affordance, and echoing Clark and Chalmers’ (1998) ‘parity principle’, Malafouri (2013; Malafouri & Renfrew, 2010) argues that as causal effectivity shifts beyond the skin, so do cognitive and agential processes. From an ecologically embodied perspective, tools, as and where they function to alter scope and or effectivity of bodily skills, are considered constitutive parts of the cognitive process, and as active extensions of the perception–action cycle (Mangalam & Fragaszy, 2016; Smitsman, 1997; Smitsman & Bongers, 2012). J. J. Gibson (1979) alludes to this co-constitution in referring to tools as a ‘special kind of detached object’ (Susi & Ziemke, 2005, p. 11), which, once attached (i.e. when in use), are no longer environmental objects, suggesting that, through constitution, a continuum of organism and tool exists such that if a tool-using goal is intended by the tool user, it is intended by the tool also. As Gärdenfors and Lombard (2018) draw a correlation between grades of causal cognitive complexity and degrees of force extension and transmission, so we can see tools as more ‘complex’ forms of direct perception, agential vectors extending and transmitting the ‘manipulatory area’ (cf. Mead, 1938) through their plastic shaping of the user’s perception of peri- and extra-personal space (Maravita & Iriki, 2004; Scandola et al., 2019).

Ihde (1979, 1990) relates a similar idea with his concept of ‘technics’, as the ‘symbiosis of artefact and user within a human action’ (p. 73, emphasis added), which he uses to describe the perceptual transparency typical of skilled tool use, in which, through time and an extended period of habituation (following Bourdieu, 1977), the causality of a tool is experienced as an extension of the agential self, so that material interaction through skilled tool use is as epistemic as it is pragmatic. If, as Ingold (2000) argues, technical enskilment is a process of explorative material engagement whereby affordances arise, then skilled tool use is the cultivated causal cognitive ability to be solicited by the appropriate affordances of a given task as they arise.

3.1. Primate thinging in practice: an example in capuchin use of a digging tool

While we might see this, in a quite literal sense, in primate investigatory probing, for instance, when chimpanzees probe snares (Sugiyama & Humle, 2011) and smelly substances on the ground (Ohashi, 2006), or when capuchins use probe tools to poke potentially dangerous predators (Falótico & Ottoni, 2014; Falótico et al., 2018), foraging tools frequently appear to combine functionally exploratory and extractive activities into the same actions. In capuchin (Sapajus libidinosus) use of stone pounding tools to excavate underground storage organs (USOs; Falótico et al., 2017; Moura, 2004) and invertebrates from behind bark (Falótico & Ottoni, 2016; Mannu & Ottoni, 2009), for example, tool use not only functions to remove the dirt substrate, extending the agential self by amplifying the user’s mechanical force, but in so doing produces haptic and/or acoustic feedback by which the user is able to refine the focus of their effort and locate hidden food resources.

The salience of this kind of stone pounding tool use is not its particular complexity (or lack thereof), nor its exoticism, but its resonance with capuchin non-tool-assisted foraging strategy. Capuchins are destructive foragers, who rely primarily on visual cues to locate sites and food items which afford searching (Fragaszy et al., 2004; Terborgh, 1983). When visual information is insufficient, capuchins generate acoustic information through epistemic actions such as tap scanning and tapping of hard items onto surfaces, by which they are able to locate hidden resources and test for fruit/nut ripeness (Panger et al., 2002; Phillips et al., 2003, 2004). Tools used to dig for hidden resources, and to crack open tree bark and rock complexes, it is argued, are essentially tool-extended forms of the same behaviours, which functionally combine exploratory and extractive activities like ripping off of bark and removal of soil into the same manual gesture. In the excavation of USOs of plant species like Thila, for which not all plants have USOs at their roots, a correlation between prolonged digging time and success of the digging bout suggests that digging tools may act to reinforce the affordance relevance, confirming the presence of the food resource even when the capuchin cannot see it (Moura, 2004), as if tool use by revealing the nature of the foraging problem were also drawing forth the intent to solve it (following Ihde & Malafouri, 2019, p. 4).

The ‘symbiosis’ seen in capuchin ‘digging’ reflects a gathering-together of ‘mind-stuffs’ (Malafouri, 2019) and an emergent ‘ecology of agency’ (Costall, 2008) in action, indicative of the broader nature of technical cognition and tool use. As we see the skillful incorporation of the digging tool as a novel form of bodily sense-making, an emergent effectivity arising from ‘capuchin-tool-world’, so we see its tool-using ‘affordance’ as a functional intent, not as extending from the capuchin to the tool, but arising from the ongoing dynamics of the ‘[capuchin-tool]-environmental’ system. Perception of the tool-using problem is not about the stone’s relation to the concealed resource, but of the concealed resource through the stone’s use.

4. Extension and incorporation: ontogeny as a metaplasmatic temporality

What is so evocative about Ihde’s (1979, 1990) theory of technics, from an MET perspective, is its sense of ‘symbiosis’ and perceptual transparency taking extended time and material engagement to achieve.
Phenomenological osmosis, rather than being immediate, must be learned, with the length of the period of enskilment reflecting the relative ergonomic ‘fit’ between the tool and task, and the tool and user (Ihde, 1990, p. 73). The more optimum the ergonomic interface between the tool and task, the more complete transparency can be achieved: the more intuitive the tool to its user, the quicker that transparency can be realised.

Longitudinal studies of NHP technical behavioural ontogeny suggest that perceptual learning of task contingencies is the product of protracted interactive experience, with more hierarchically complex tool methods typically associated with greater periods of development (for reviews, see Biro et al., 2006; Fragaszy et al., 2013; Meulman et al., 2013). Indeed, juvenile NHP tool users, even when able to achieve successful tool use, appear to lack the fluency and precision shown by more experienced individuals (e.g. Bril et al., 2012; Mangalam & Fragaszy, 2015); their techniques are often clumsy or inefficient, and more frequently interspersed with purely epistemic interruptions such as exploratory handling of tools/targets between tooling actions (e.g. de Resende et al., 2008; Fragaszy et al., 2020; Lonsdorf, 2005; Tan, 2017). In capuchin digging stone tool use, juvenile tool users typically did not target more hidden food resources unless visibly exposed by another conspecific prior to tool use, or by non-conspecific foraging activity (Faló´tico et al., 2017). Taken in combination with captive study results (e.g. Heimbauer et al., 2012; Paukner et al., 2009), it is seems likely that the perceptual learning of auditory feedback in digging stone tool use takes time and practice to achieve.

For Fragaszy and Mangalam (2018), since technical enskilment (i.e. perceiving to learn) takes place in the context of learning to perceive, both being functions of experience, learning of tool-using affordances should be enhanced when tool actions are congruent with species-typical explorative and play behaviours, and constrained when incongruent with ecologically relevant behaviours. As one of the most intuitively complex NHP tool behaviours (Matsuzawa, 1996), chimpanzee (Pan troglodytes verus), capuchin (Sapajus spp.) and macaque (Macaca fascicularis aurea) individuals spend years practicing isolated components of the nut-cracking technique, with patterns of component expression postulated to reflect species-specific ecological bias (de Resende et al., 2008; Tan, 2017). For chimpanzees and macaque juveniles, ontogeny begins with the performance of simple object manipulations of nuts and stones from c.1.5 years and 4–6 months, respectively, gradually transitioning into the performance of non-functional object associations (e.g. placing of objects on anvils), followed by functional object combinations (e.g. ineffective percussive actions), prior to the manifestation of successful nut-cracking tool use at c.3.5 and 2.5–3.5 years of age, respectively (chimpanzees: Boesch & Boesch-Achermann, 2000; Inoue-Nakamura & Matsuzawa, 1997; macaques: Tan, 2017). In contrast, the exhibition of percussive actions by tufted capuchin juveniles appears at a comparatively high frequency early in development (from c.5 to 8 months), while placement and release of food items onto anvil surfaces appears comparatively late, anticipating the realisation of successful nut-cracking (at c.2 years), and with a proficient technique typically expressed c.6 months later (de Resende et al., 2008).

De Resende and colleagues (2008) argue that differences in the relative ease of affordance recognition are explained by comparative feeding ecology. Robust capuchin species are often described as specialised feeders, with hard or encased food resources, many of which were processed through percussion against a substrate, making up a substantial part of their diets (Fragaszy et al., 2004). As mentioned above, the percussion of objects onto surfaces is also a routine aspect of capuchin exploratory foraging behaviour and is highly prevalent among juveniles of the species (de Resende et al., 2008; Fragaszy & Adams-Curtis, 1991), to a degree which captive studies (e.g. Takeshita et al., 2005; also cited by de Resende et al., 2008), and a diet of predominantly unencased, fleshy fruits, suggest, for chimpanzees it is perhaps not. Similarly, comparative difficulty in recognising the affordance relevance of releasing food resources onto anvils, as opposed to gripping them tightly, which for capuchins takes consistent time and practice to realise, is likely a factor of their more arboreal foraging context and the increased risk of loss; in non-tool use contexts, capuchin juveniles tend only to release encased food resources having either successfully broken them open, or having lost interest (de Resende et al., 2008, p. 836).

5. Social distribution of tool use traditions: an education of attention by master-apprentice

Matsuzawa and colleagues (2001) famously described the ontogenetic process of tool use among the chimpanzees at Bossou as an ‘education by master-apprentice’. ‘Education’ derived from the Latin word ‘educere’, meaning ‘to extract’, reflecting a careful choice of word on their part, to describe the way in which chimpanzee education through exposure to the tools and the tool use of others, though perhaps not educational in the ‘intentional sense’ observed by Boesch (1991) at Taf, nonetheless results in a ‘drawing forth of potential abilities’ (Matsuzawa et al., 2001, p. 573). As development of the mind is situated in practice, so it is distributed across the social system (as equally composed of organisms as objects).
In the juxtapositioning of developing minds and materials, the shaping of perception becomes a process of both enculturation and cultural production in which artefacts become ‘the focus of enduring, and cumulative, social influence’ (Costall, 1995, p. 471). Organisms develop in worlds inherited from and still developed by the skilled practices of others (cf. Leont’ev, 1981; Mauss, 1936; West et al., 1988; West & King, 1987) so that, deliberately or not, the skilled community directs others’ attention towards particular aspects of their practice, increasing the perceptual relevance of particular affordances and encouraging particular modes of environmental openness (J. J. Gibson, 1979; Ingold, 2000). With each act, material engagement shapes the environment as it is perceived by others, feeding back into the broader meshwork (cf. Ingold, 2011), so that the development of proficiency is as much the development of technique as it is the development of place within the broader constellation of conspecifically available technologies (Gowlland, 2019; Lave & Wenger, 1991). As Lemonnier (1993) puts it, ‘techniques are first and foremost social productions’ (p. 3): to ignore the interactive nature of tool use is to ignore the technology’s social relevance.

5.1. NHP techniques as cross-generational metaplastic co-constructions

Social learning is often considered a defining aspect of primate technological tradition (e.g. Whiten et al., 1999, 2001), with significant research effort having been directed towards adaptive learning strategies as factors in the modelling of technical diffusion and evolution (e.g. Coussi-Korbel & Fragaszy, 1995; Hoppitt & Laland, 2013; J. Kendal et al., 2009; R. L. Kendal et al., 2018; Sanz & Morgan, 2013; van Schaik & Pradhan, 2003). Although studies of causal reasoning in ‘theory of mind’ (cf. Premack & Woodruff, 1978) suggest that NHPs are unlikely to perceive tools as agential extensions of a tool-using other (i.e. to ‘mind read’; cf. Lombard & Gärdenfors, 2017), the observation of others’ material interactions nevertheless produces directly perceptible information describing the affordances of tools and target objects (Call et al., 2005; Fragaszy & Visalberghi, 2004; Penn & Povinelli, 2007; Tomasello, 1996; though see Froese, 2015; Froese & Leavens, 2014; Whiten et al., 2009). For example, juvenile chimpanzees observing a conspecific’s leaf-folding (e.g. Toonoka, 2001) behaviour might perceive that ‘inserting the leaf into the tree hollow affords water-consumption’, or that ‘the leaf material affords folding’, even if unlikely to perceive the tasks embedded affordances12 (following van Leeuwen et al., 1994), such as that ‘the folded leaf afforded water absorption for extraction’. Perception of embedded tool affordances likely only occurs in the active subjective experience of a tool as an extension of the agential self, an experience which is only achieved through independent practice.

Proximity to tool users brings access to suitable tool materials and opportunities for individual learning through engagement with the materials used in others’ tool-using processes. Tool reuse scaffolds the learning processes in more complex tool-using behaviours, such as chimpanzee pestle pounding (Yamakoshi, 2011; Yamakoshi & Sugiyama, 1995), leaf folding/sponging (Tonooka, 2001; Tonooka et al., 1997) or NHP probe tool use (Faló´tico & Ottoni, 2014; Musgrave et al., 2016), providing the appropriate practical context in which to hone perceptual skill, while bypassing the need for delicate or physically challenging tool acquisition/ modification (Fragaszy et al., 2017; Musgrave et al., 2020).

The sustained attention and interaction with tool materials, required for the development of more complex behaviours, is often indirectly incentivised in these scenarios by proximity to tool-using others. Where the immediate rewards of unskilled tool use are low, attention and working memory are enhanced by socially situated practice (Fragaszy et al., 2017), with food rewards scrounged from more skilled individuals (most frequently the preferred observational model) likely providing an incentive to continue engaging with tool and target materials (Ottoni et al., 2005; Ottoni & Izar, 2008). At Fazenda Boa Vista, Eshchar et al. (2016) found that capuchins aged 6 years or younger were significantly more likely to situate themselves near anvils, interact with and perform percussive and striking behaviour with nuts, when other group members engaged in nut-cracking behaviour; with the onset of this effect occurring within 1 min of other conspecifics’ beginning to perform cracking, and diminishing slowly, continuing for minutes after others had stopped cracking (Fragaszy et al., 2017). Juveniles of all primate lithic tool-using species display an interest in the tool materials of conspecifics, frequently touching and sniffing tools, with chimpanzee infants at Bossou having been observed holding their mothers’ hand or arm during her tool use (Biro et al., 2006).

Through their shaping of the ontogenetic niche (cf. Stotz, 2017; West et al., 1988; West & King, 1987), tool-using others’ material interactions direct attention in a longitudinal sense, through the creation of long-lasting tool artefacts, and in the shaping and scaffold of the environment (Fragaszy, 2011). Sites of accumulated tool materials and target resource residues form focal points on the landscape, providing key opportunities to encounter situational affordances in their appropriate use contexts and subverting the more cognitively or physically challenging aspects of tool use such as tool transportation, modification or simply acquisition, particularly in cases where suitable materials are sparse (Fragaszy, 2011; Fragaszy et al., 2013).
As the redistribution of materials can create accumulation sites, so it can deplete the diversity of contexts within which a material is found, drawing attention away from alternative uses and decreasing the likelihood of behavioural innovation in novel contexts.

5.1.1. An example in a comparison of capuchin nut-cracking and probe tool use. ‘Cultural’ influence in the perception of probe tool affordances by tufted capuchins appears manifest at both regional and local levels, with intergroup discrepancies in probe tool use (or lack thereof)\(^{13}\) unlikely to be explained by ecological dissimilarities between sites alone (Ottoni, 2015; Ottoni & Izar, 2008; Spagnoletti et al., 2011), and with demographic distribution showing a significant intra-group sex bias – studies record up to 97% of probe tool episodes as having been performed by males and the remaining 3% as having been performed by sub-adult females (Falótico & Ottoni, 2014; Moura & Lee, 2010).

Captive studies suggest that functional affordances of probe tools are, themselves, more difficult for tufted capuchins to perceive (Visalberghi & Limongelli, 1994; Visalberghi & Trina, 1989; see also Fragaszy et al., 2004). At the macro-level, discrepancies between sites may reflect the relative difficulty of the learning process, exacerbated in the wild by low rates of return (success rates being the lowest of all other tools present in the Serra da Capivara repertoire; Falótico & Ottoni, 2014; Moura & Lee, 2010) and by a lack of rewards from others tool using to scaffold attention towards the sustained interaction necessary for variant uptake and spread. For females, the likelihood of inception may be decreased further by the socio-ecology of the foraging context, probe tool use primarily functioning to expel and predate vertebrates/invertebrates (Falótico & Ottoni, 2014), behaviours in which females at Fazenda Boa Vista typically engage as individuals, in contrast to males, who are significantly more likely to participate in predation events in which two or more individuals target the same prey item, either at the same time, or one after the other (Spagnoletti et al., 2013). Assuming consistency in the socio-ecological context of invertebrate predation between the two sites, a lack of access to materials and models may explain inter-sex differences in probe tool use at Serra da Capivara.

Interestingly, when presented with dipping apparatus, capuchins at Fazenda Boa Vista failed to manufacture, use or reuse pre-inserted probe tools suggesting that the perceived relevance of tool and task affordances was reduced or altogether absent for individuals in the groups (Cardoso & Ottoni, 2016). While this could be a factor of inexperience, failure to recognise or be solicited by the tool affordances, even when made more salient (by pre-inserting the probes), could be more indicative of ‘cultural override’ (sensu Hicks et al., 2020), with cultural preferences, or expertise from the pre-existing technical repertoire, potentially influencing (or inhibiting) the capuchins’ perception of affordance relevance (Cardoso & Ottoni, 2016). Marshall-Pescini and Whiten (2009), Hrubesch et al. (2009) and Gruber et al. (2011) argue that chimpanzee learning of novel technical traits is similarly constrained by cultural ‘conservatism’, with experimental results suggesting that expertise (or at least functional mastery) of a given skill inhibited further exploration and adoption of novel techniques even where those techniques were ergonomically more efficient. An exception to this might be cultural override in the form of ‘conformity’, in which individuals bias towards ‘approved’ technical behaviours, which reflects a social pressure to conform to group norms (e.g. Luncz & Boesch, 2014; Luncz et al., 2012, 2015; van de Waal et al., 2013). That pre-existing technical repertoires can affect and inhibit learning of novel behaviours demonstrates a cultural bias to NHP technical cognition, and a normative affectivity to their technical affordance perception – reinforcing the concept of the technical mind as a particular set of skills which together produce an emergent perspective. In the social situation of technical ontogeny, we see the mind as a developing and distributed process of being, not just in the world, but also with others.

6. Discussion

Recognising the primacy of material engagement means questioning and reframing the direction of causality in classic theories of primate technical and intellectual evolution: it is perhaps at the broadest timescale of metaplasticity that MET offers the most potential for primate studies of tool use. Traditional hypotheses of primate tool evolution typically frame tool use as an adaptive (or epiphenomenal) response to an environmental problem, in which cognitive capacity precedes behavioural application (e.g. Fox et al., 2004; Parker & Gibson, 1977). For MET, as the landscape in which behaviour takes place and in which behaviour shapes, environmental opportunity or scarcity is not a driver of cognitive evolution, so much as they are constitutive parts of it; increasing or decreasing the relevance of tool-using affordances (e.g. Grund et al., 2019), as they increase or decrease contexts for their discovery (e.g. Koops et al., 2014). Neither necessity, nor opportunity, however, is itself accountable for how organisms come to be susceptible to solicitation by tool affordances in the first place. Tool use, as a subset of material engagement, is more than simply a solution to a problem; it is perception of the problem and construction of another, as ontogeny and development of self are processes of perception and reconstruction of the ontogenetic niche.

To accept a cognitivist account of cognition denies both the phenomenology of objects as ‘enactive cognitive prostheses’ (Ihde & Malafouris, 2019; Malafouris,
and portable (Falotico & Ottoni, 2016). Deposition suitable for stone pounding tool use is both abundant and portable (Falotico & Ottoni, 2014). Performance of stone pounding tool use, in contrast, is far more conspicuous – in both the immediate and longitudinal sense. Nut-cracking often takes place in a group context, produces a lot of sound, which attracts attention (Coelho et al., 2015; Eshchar et al., 2016; Fragaszy et al., 2017), and produces profound non-perishable effects on the environment including accumulations of hammers and nut casings, on and around anvils, distinguishable patterns of pitting on anvil surfaces, and in cashew processing, long-lasting CNSL (cashew nut shell liquid) stains on tools and anvils (Falotico et al., 2019; Haslam et al., 2014;Visalberghi et al., 2013).  

7. Conclusion

For evolutionary psychology, the challenge to restore wholeness, to close classic disciplinary boundaries sustaining the alienation of nurture from nature and to present an integrated scientific approach to ‘culture’ remains. Where for technical evolution, as a subset of general material cultural evolution, this might mean the closing of several parallel analytical schisms: of ecological from cultural, individual from societal, or of mind from matter; for studies of non-human tool use (particularly as comparative models for human technical evolution), we encounter additional substantive and semantic borders, those between human and non-human, and between the etic of a modern western ontology of scientific objectivity and the emics of non-human ontologies (Sugawara, 2017; Swanson, 2017). When cognition is divorced from action, by the very nature of the problem, it is impossible to conceive how animals think, or even if they do. MET is in this respect especially useful because it enables a research perspective in which the mind and cognition are a development of canonical affordances, with high perceptual relevance; a stone on anvil, by virtue of its having been previously placed there, might be perceived as for stone pounding as the pits on the anvil might be perceived as for the placement of nuts. Indeed, Borgo et al. (2013) suggest that capuchin stone pounding at accumulation sites at Fazenda Boa Vista is indicative of artefact characterisation, with the functional affordances of hammer and anvil stones taken as apparent from their previous use, whether or not that previous use could be observed. This is evidenced at accumulation sites by a reduction, or absence, of typical preparatory epistemic behaviours prior to tool use/reuse (Borgo et al., 2013). Capuchins with a nut requiring pounding to consume ‘actively search for anvil sites already used in the past’ (Borgo et al., 2013, p. 380) at the site may even ‘wait in queue’ (ibid., p380) to use nut-cracking sites, preferentially reusing the same pit exploited by the previous monkey (see also Spagnoletti et al., 2011).
produced by and producing fundamentally different minds, and that the archaeological (and behavioural) significance of a tool is not necessarily the cognitive capacities it required to create and operate, but it is part of the framework around which the mind and distributed systems of thought develop.

While NHP tool use can never tell us the specific when and where humans began using tools (or really even why), cross-species comparisons nevertheless remain our best link to an invisible behavioural past, offering vital insights into our understanding of how hominin tool use, metacognition and even language might have evolved. Developmental frameworks like metaplasticity demonstrate how simple material agencies and individual tool-using processes can come together to produce emergent levels of cognitive complexity, helping develop a theory on the nature of tool use and technical cognition which is both generalist and species specific, but above all fundamentally non-anthropocentric.

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Notes

1. For an in-depth critique of asocial interpretations of tool use, see Ingold (1993).
2. Material being subject to functional determinism: in the Standard view, form follows function, as though any cultural specificity of form (or even choice) was an afterthought –fait après tendance.
3. For a discussion of MET’s ties with Dewey’s transactionalism (and pragmatism more broadly), see Iliopoulos (2019).
4. See also an organism’s ‘micro-identities’ (Varela, 1999), ‘powers’ (Witherington, 2019). The effectivity of an organism is constituted by its repertoire of bodily skills.
5. For useful comparisons between radical enactivism and ecological psychology, see Segundo-Ortin et al. (2019).
6. For a comparison between theory of mind and interaction theory, and more MET compatible approach to social learning, see Gallagher (2015).
7. The parity principle states that any external process, which were it to take place within the brain would be considered cognitive, should be given equal cognitive (constitutive) status (Clark & Chalmers, 1998).
8. Moura (2004) reports that the local human community uses a similar technique to locate underground tubers of Spondias tuberosa which, when full of water, can be heard beneath the soil by pounding the ground.
9. Captive studies also seem to support this hypothesis. Phillips et al. (2004) found that the frequency of tufted capuchins’ manipulations of a log matrix containing food increased with increasing available sensory information; the authors suggest that increasing the amount of available sensory information incentivises engagement.
10. A similar idea also permeates Heidegger’s (1927/1966) theory of equipment. Unfamiliar objects which are encountered as present-at-hand fade with familiarity, becoming ready-at-hand; so in ‘technics’ the feeling of a pair of glasses on the nose fades from conscious notice as the image seen through them comes into focus. Experienced tool use directs attention (and thereby perception) to a new point of contact, or transactional boundary where cognition is emergent.
11. A duration of 5–8 months is for percussive actions generally, and not specifically for percussive actions with nuts or stones, which de Resende et al. (2008) report took place c.4 months later.
12. See also hierarchical/nested affordances (cf.Wagman et al., 2016). Embedded affordances are the super-ordinate affordances of a tool-using task, that is, those which relate affordances of the tool object to affordances of the task object.
13. SDC is currently the only semi-wild S. libidinosus site at which probe tool use is observed (Falótico & Ottoni, 2014; Ottoni & Izar, 2008; Spagnoletti et al., 2011).
14. There is no evidence that capuchins perceive CNSL stains as a correlate of past tool use.

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