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Technical Intelligence Hypothesis

Camilla Cenni and Jean-Baptiste Leca
Department of Psychology, University of Lethbridge, Lethbridge, AB, Canada

Synonyms

Extractive foraging hypothesis; "Technological intelligence" hypothesis

Definition

The "technical intelligence" hypothesis is an evolutionary approach proposing that material innovations and object-oriented behavioral skills (e.g., caching and recovering nonperishable food, detecting and extracting encased food, making and using tools, building shelters) constitute major driving forces in increased relative brain size and intelligence across various animal taxa, through the selection of cognitive features that sustain complex and flexible technical proficiency (Byrne 1997).

Introduction

Why do some animal species have large brains relative to their body size, even though the growth and maintenance of this special organ is associated with significant energetic costs and developmental constraints that jeopardize survival and delay reproduction? There are two main evolutionary hypotheses to explain the emergence of bigger brains and more sophisticated cognitive abilities in humans and nonhuman animals (and particularly nonhuman primates): the "social intelligence" hypothesis (SIH) and the "ecological intelligence" hypothesis (EIH). For both the SIH and EIH, the ultimate drivers of brain evolution are grounded in ecological factors that are essential for survival and reproduction (i.e., finding food and avoiding predators). However, the key difference between these two evolutionary approaches lies in *how* these fundamental ecological goals are achieved. Proponents of the SIH contend that the solutions to these ecological problems belong to the socio-cognitive domain, whereas advocates of the EIH argue that these solutions are found in physico-cognitive abilities (Tomasello and Call 1997).

The rationale of the SIH is as follows: confronted with the two major ecological challenges of finding food and avoiding predators, some animals have evolved two types of social solutions, respectively socially mediated learning of foraging skills (i.e., learning from more experienced group members) and forming stable social groups of bonded individuals who have a greater chance to detect predators and protect each other reliably through cooperative behavior. However, living in large and complex groups led to

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secondary social challenges associated with interindividual competition for physical, social, and sexual resources (i.e., food, shelters, grooming partners, allies, and mates). Such challenges selected for socio-cognitive abilities pertaining to social representation and social memory (i.e., keeping track of one's and others' social relationships including dominance, kinship, and affiliation), social strategizing or Machiavellian skills (e.g., cooperating, forming alliances, predicting others' behaviors and intentions, manipulating/deceiving others), and complex communication skills (e.g., representational, semantic, and arbitrary vocal repertoire, language; Dunbar 1998).

The EIH focuses on two main dietary characteristics: frugivory and embedded foods. The ecological challenges associated with frugivory are due to the fact that fruits vary in space (i.e., they are patchily distributed), time (i.e., they are seasonally available), ripeness, nutritional contents, and toxicity. The corresponding cognitive demands include remembering fruiting locations, predicting fruiting timing, assessing the costs and benefits of eating novel fruits, and identifying their toxic parts. Such challenges selected for physico-cognitive abilities pertaining to mental maps to represent space, time, and quantity-based decision-making, as well as associative learning of food choice. The ecological challenges associated with embedded foods are due to the fact that some high-quality food items are hidden inside tough protective matrices (e.g., protein-rich seeds encased in hard shells) or difficult-to-process foraging substrates (e.g., lipid-rich insect larvae enclosed within bamboo stalks). The corresponding cognitive demands include detecting the presence of these concealed foods, assessing objects' affordances, and food-processing/extracting, sometimes by making and/or using tools. These mental abilities are supported by extractive foraging actions that should be fine-tuned, coordinated, and sequential. Such challenges selected for physico-cognitive abilities pertaining to sensorimotor coordination, complex action planning, and learning about the causal structure of the physical environment and the physical consequences of one's actions. The latter set of extractive foraging-related cognitive skills associated with embedded foods is referred to as "sensorimotor intelligence" or "technical intelligence" (Byrne 1997; Parker and Gibson 1977; Rosati 2017).

The "technical intelligence" hypothesis is thus a subcategory of the EIH. It aims to provide a mechanistic and functional explanation for the evolution of intelligence in humans and non-human animals. Technical innovations based on the ability to combine and use inanimate objects sequentially and instrumentally to solve a variety of problems in the physical domain may have created higher cognitive demands that favored an increase in the encephalization quotient (i.e., brain-to-body weight ratio after controlling for allometric effects as well as the size and organization of specific brain components (e.g., neocortex) which are broadly considered neural proxies for intelligence; Byrne 1997). Cross-species comparative analyses showed a strong positive correlation between relative brain size of birds and primates and their ability to use different objects in novel, instrumental, and flexible ways (Overington et al. 2009; Reader and Laland 2002). More encephalized primate species (i.e., those with a bigger "executive brain," including larger neocortex and striatum) exhibited more tool use in a foraging context than less encephalized ones (Lefebvre 2012). In primates, nontechnical innovations also show positive correlations with relative and absolute brain size, but those relationships are not direct; they are mediated by additional factors, such as social learning, diet, and life-history variables (Navarrete et al. 2016). For instance, dietary generalism (i.e., a broad selectivity for different food resources) predicted enhanced encephalization, suggesting that the ability to exploit novel food sources may have led to an increase in brain size.

In cognitive tasks testing for physical cognition, causal reasoning, working memory, and self-control, tool-using bird species generally outperform closely related non-tool-using species, with some exceptions (Teschke et al. 2013). Advanced forms of sensorimotor intelligence have also been found in non-tool-using animal species that show flexible extractive foraging techniques (e.g., keas, a New Zealand parrot species, exhibit outstanding performance in several physico-cognitive tasks, suggesting good understanding of the physical properties of objects; Huber and Gajdon 2006). Indeed, it is not the *fact* that animals use tools, but the *way* they use it (i.e., in a hierarchically organized sequence of actions) that may shed light on the sophisticated cognitive abilities underlying complex extractive foraging strategies (Byrne 1997).

Factors Responsible for the Emergence of Technical Innovations

Extrinsic Factors

To explain the distribution of material innovations that might have driven the emergence of enhanced cognitive abilities, the "technical intelligence" hypothesis considers a combination of external and internal factors. Exploring the role of extrinsic factors allows us to integrate and refine the "extractive foraging" hypothesis (Parker and Gibson 1977), which focuses on gaining access to embedded foods. Both the *necessity* to exploit novel, energy-rich, and encased food sources (e.g., in periods of food scarcity), and the *opportunity* to express new extractive foraging techniques (e.g., given the presence of instrumentally relevant objects or food sources that can be exploited) are favorable conditions for technical innovations to emerge. However, ecological factors alone only partially explain the limited distribution of tool use among extractive foragers (e.g., Koops et al. 2015a). Even though chimpanzees and bonobos live in similar ecological conditions, they considerably differ in their rates and forms of instrumental object manipulation in the wild, with tool use being virtually absent in bonobos, whereas chimpanzees are the most frequent, versatile, and proficient tool users besides humans.

For years, the "technical intelligence" hypothesis has been seen as an alternative to the SIH, according to which the major drive for the evolution of intelligence may be found in the complexity of species' social systems (Dunbar 1998). However, as indicated before, these two hypotheses are not mutually exclusive, and such a dichotomous view has recently been reconsidered (Parker 2015). In its revised version, the "technical intelligence" hypothesis integrates social influences as fundamental in the expression of material innovations. In a systematic cross-species comparative review, the rates of tool use, innovation, and social learning in primates covary and are all positively correlated with enlarged brains (Reader and Laland 2002). Indeed, although most object-oriented behaviors are performed solitarily, they often occur within a social environment, and social influences affect the *acquisition* and *maintenance* of such technical innovations.

First, social influences mediate the *acquisition* of different instrumental behaviors, by providing means of transmission from older kin individuals (i.e., vertical transmission) or from peers (i.e., horizontal transmission). For example, the population of chimpanzees living in the Goualougo Triangle, in the Republic of Congo, is characterized by a relatively complex tool-use repertoire, together with higher levels of social tolerance and spatiotemporal coordination than other populations of chimpanzees, including numerous instances of coaction (i.e., when the demonstrator of a tool use action allows an observer to touch its hand or tool; Sanz and Morgan 2013).

Second, social cues favor the *maintenance* of technical innovations through direct and indirect influences. Increased social tolerance allows unskilled group members to get exposed to the demonstration of novel foraging techniques by proficient group members (i.e., direct learning via emulation, imitation, and possibly teaching; Boesch et al. 2019) or to the informative presence of half-processed food parts and tool-using ateliers left behind by skilled foragers (i.e., indirect learning via stimulus enhancement; Gunst et al. 2010; Inoue-Nakamura and Matsuzawa 1997). In tool-using primate species, such as capuchins and chimpanzees, encountering previously manipulated foraging artifacts enhances the physical affordances of objects (i.e., their perceived opportunities for action) and the subsequent expression of instrumental object manipulation (Fragaszy et al. 2013). Even the noninstrumental manipulation of objects, such as the culturally maintained stone-directed play behavior performed by Japanese macaques, can be socially influenced, both directly (i.e., through the observation by naïve infants of their mothers as stone play demonstrators; Nahallage and Huffman 2007) and indirectly (i.e., through the stimulating effect of stone play artifacts, such as piles of stones left on the ground by previous stone players; Leca et al. 2010).

Intrinsic Factors

Given that extrinsic factors are not sufficient to fully explain the phylogenetic distribution of technical innovations, the "technical intelligence" hypothesis also points at specific intrinsic factors, such as anatomical features (e.g., dexterous body parts, like hands and beaks) and psychological predispositions (e.g., motivation to manipulate objects), as key evolutionary drivers of the emergence of material innovations. It is not surprising that the highest rates of technical innovations are found in primates, and more specifically in humans, followed by great apes, whose hands possess the greatest potential for movement *complexity* and *dexterity*, as measured by the diversity of gripping and grasping capabilities. In a comparative study of 36 nonhuman primate species, unimanual/bimanual actions, synchronous/asynchronous use of hands and fingers predicted the occurrence of different categories of object manipulation, with species having a greater manual dexterity being able to perform more complex types of object manipulation (Heldstab et al. 2016). However, hands are not necessary for technical innovations; in birds, morphological characteristics of the beak (e.g., depth, shape) play a major role in the manipulative complexity of tool-using corvids (e.g., New Caledonian crows, Goffin's cockatoos, keas; Huber and Gajdon 2006; Kenward et al. 2011).

From both proximate and ultimate perspectives, innovative instrumental object manipulation and tool use can stem from, or at least be facilitated by, the expression and transformation of noninstrumental object-directed behavior patterns, such as object play. In a wide range of animal taxa, functional/"serious" technical innovations (e.g., tool use) and purposeless/"playful" object-oriented actions covary in frequency and share broad structural similarities. For example, object play behavior patterns and tool use actions are significantly more frequent, diverse, and complex in chimpanzees than in their sister species, bonobos, even in their similar natural habitats (Koops et al. 2015a, b). Likewise, within the corvid taxon, there is a high degree of cross-species covariation between material neophilia (i.e., object-directed explorative tendencies and the propensity to engage in versatile and complex object play) and physico-cognitive abilities (i.e., mechanical problem-solving strategies, extractive foraging techniques, and tool use proficiency; Huber and Gajdon 2006). However, the nature of the developmental and evolutionary links between various object-directed activities is far from being unraveled, and the question of whether (and if so, to what extent) noninstrumental object manipulation facilitates the expression of instrumental object manipulation, and thus technical intelligence, is still open.

How Does the "Technical Intelligence" Hypothesis Explain the Role of Object Play in the Emergence of Technical Innovations?

On the one hand, object play behavior may have driven the selection for the functional manipulation of objects by providing preexisting schemata transferable to instrumental contexts (Parker and Gibson 1977). Noninstrumental exposure and handling experience with objects provide opportunities to learn about the properties and affordances of these objects, and help refine sensorimotor coordination, through the acquisition and practice of manipulative dexterity (Lockman 2000). In the Sonso chimpanzee community in Uganda, low interest in, and limited spontaneous manipulation of, sticks may explain the lack of stick-assisted tool use; individuals preferentially explored other objects that were later used as tools (Lamon et al. 2018). Similarly (Kenward et al. 2011) compared the development of noninstrumental object manipulation (i.e., object handling that is not immediately functional) in New Caledonian crows, a tool-using species, and in common ravens, a species that does not seem to use tools in the wild. They found no significant difference in the rates of noncombinatorial object manipulation, which probably results from a general/inherited manipulative tendency in all corvids. However, plastic object-directed playful sequences involving object combinations (e.g., object positioning, inserting, or rubbing in relation to other objects or a substrate) that are considered behavioral precursors of later functional manipulation (e.g., tool use) became significantly more frequent in New Caledonian crows than in common ravens during critical stages of development.

On the other hand, the intrinsic propensity to manipulate objects could facilitate the emergence of technical innovations by maintaining high levels of material neophilia (e.g., sustained interest in, and attention to, objects). Intrinsic motivation for object manipulation may promote the integration and functional use of objects in various behavioral technical domains. In primates, tool use acquisition is a lengthy process, in which learners start reaping extrinsic rewards for their actions after years of unsuccessful practice (e.g., stone tool-assisted nut-cracking behavior in chimpanzees and capuchin monkeys; Fragaszy et al. 2013; Lonsdorf 2006). In the meantime, the intrinsically rewarding nature of non-instrumental object manipulation, including object play, characteristic of immature individuals, may serve the function of maintaining high levels of motivations in unskilled learners. For example, the playful manipulation of lithic material by juvenile monkeys precedes the acquisition of stone tool-assisted shellfish foraging in a free-ranging and coastal population of Burmese long-tailed macaques in Thailand (Tan 2017).

As opposed to instrumental object manipulation (e.g., tool use) which is *product-oriented*, object play is a *process-oriented* activity during which the performer acquires information about an action or an object involved in that action. It is acknowledged that problem-solving performance depends on an individual's motivational state, with low levels of extrinsic motivation being generally associated with poor performance. However, high levels of extrinsic motivation may also reduce an individual's technical performance, by narrowing its attention towards the product, target, or goal, rather than the process to achieve them. A comparative experimental study in great apes showed that learning about action–outcome contingencies preferentially happened during free exploration, whereas the presence of a food reward during the baited-condition distracted the subjects and delayed the acquisition of the solution to the problem (Ebel and Call 2018).

Although object play is generally a solitary activity, some species integrate specific objects into social play interactions, which may enhance interest in these objects and provide an opportunity to understand how they may be used in a social context. In Japanese macaques, branches are often incorporated in social play bouts in which the protagonists engage in role turn-taking (i.e., object holder versus non-object chaser; Shimada 2006). In some groups of the same species, unaimed stone-throwing is considered a form of tool use that serves the function of increasing the effect of agonistic displays during periods of disturbance (Leca et al. 2008).

The proximate and ultimate links among different object-oriented activities and technical innovations remain unclear. The relationships between playful and functional object manipulation have been extensively explored in captive settings but not in the wild (i.e., considering ecologically and socially relevant scenarios, as required by the "technical intelligence" hypothesis). Through a cross-species comparative approach, the "technical intelligence" hypothesis may be used to generate testable predictions about the developmental and evolutionary connections between noninstrumental and instrumental object manipulation.

Conclusion

Even though the SIH has been the predominant explanation for the evolution of primate cognition, the EIH is being revived, and particularly through the "technical intelligence" hypothesis (Rosati 2017). This hypothesis explores the role of ecological and social factors, together with internal predisposition to manipulate objects, in the emergence of material innovations. Still, the relative contributions of each of these factors remain unclear. Overall, EIH and SIH are not mutually exclusive; it has even been proposed that stone tool-making paved the way for the evolution of language in human ancestors, as both activities are underlain by complex, abstract, and sequential thought.

Cross-References

- ▶ Behavioral Flexibility
- ▶ Behavioral Variation
- ▶ Instrumental Learning
- ▶ Learned Affordances
- ▶ Motivation
- ▶ Nut-Cracking
- ▶ Object Play
- ▶ Social Intelligence Hypothesis
- ▶ Stone Tools
- ▶ Tool Use

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