Extending cognitive development into the body and the environment

Christian Kliesch*

Abstract: Development is a fundamentally embodied and enacted process, and human development cannot be understood outside of the embodied and extended context in which it takes place. A number of perspectives on the study of philosophy, perception, action and cognition in general have argued that cognition extends into the body and the environment. This paper provides a brief introduction on these perspectives, focusing on Gibson's *Ecological Perception* and Varela, Thompson and Rosch's *Enactivism*, as well as Clark's *Predictive Coding* framework. Despite their differences, all three approaches share a focus on explaining cognition beyond the limits of the brain. Studying cognition as part of a general system that includes body and environment has important implications for the explanations generated by developmental psychology. The paper reviews and contextualizes research that engages with these implications, and provides suggestions for further research in the hope of stimulating systematic research into how body and environment shape cognition during development.

Keywords: Ontogeny, Embodiment, Enactivism, Ecological Psychology, Predictive coding.

1. *Introduction*

The last decades have seen the emergence of theoretical work in the areas of Ecological Psychology,[1] Predictive Processing[2] and Enactivism[3] that has taken a radical reinterpretation of the relationships between an organism's cognitive system, its body and the external world. Rather than focusing on

* christian.kliesch@uni-potsdam.de
Department of Psychology, Cognitive Sciences, University of Potsdam.

[1] James J. Gibson, *The Ecological Approach to Visual Perception*, Psychology Press, 1986.

[2] Andy Clark, *Whatever Next? Predictive Brains, Situated Agents, and the Future of Cognitive Science*, "Behavioral and Brain Sciences", 36, 2013, pp. 181-204.

[3] Francisco J. Varela, Eva Thompson and Eleanor Rosch, *The Embodied Mind: Cognitive Science and Human Experience*, MIT Press, 1992.

abstract cognitive abilities that can be discussed with minimal reference to external processes, work in these fields has made the case that internal cognition cannot be separated from external processes involving the body-in-the-world. Whilst these questions are relevant for psychology as a whole, they are particularly relevant for the field of developmental psychology: during the early years of life, children's cognitive development is shaped by their physical development. Children's changing body and motor abilities constrain and scaffold their cognitive abilities and have a profound impact on the structure of information provided by the environment. Although there has been a sizeable body of recent research that has found unique and novel ways of linking cognitive and motor development, this has often happened without explicit reference to these theoretical models of cognition. At the same time, theoretical work that explicitly discusses the links between cognition, body and environment has commonly neglected early cognitive development as a source of the emergence of behavior. However, the changing environment provided by children's emerging motor abilities potentially provides interesting case studies of the externalization of cognition.

In the current paper, I argue that developmental psychology can benefit from the perspectives provided by these approaches, but that theories extending cognition can also benefit from a deeper understanding of developmental processes. I will discuss examples from developmental research from the first years of life that has taken into account how motor, body and cognitive development are linked, as well as potential avenues for further research.

2. *Cognitive development extended and enacted*

Developmental processes are strongly intertwined with the environment and cannot be understood without each other. This perspective is shared by a number of theoretical perspectives that emphasize the constitutive role of the body and the external world in cognition. In the current paper I focus on the perspectives provided by James Gibson's Ecological perception[4] and Enactivism, as proposed by Varela, Thompson and Rosch[5] and the Predictive Coding framework, by Andy Clark[6]. All three accounts share three main themes: (1) an emphasis on the role of the body in shaping behavior, perception and learning, (2) a tight integration of the environment and the agent, and (3) the individual as an active agent as part of the sense-making process. Although the resulting descriptions of development are more complex, tak-

[4] J.J. Gibson, *The Ecological Approach*, cit.
[5] F. Varela *et al.*, *The Embodied Mind*, cit.
[6] A. Clark, *Whatever Next?*, cit.

ing into account the interactive and embodied nature of development addresses some problems inherent in accounts of development that focus on cognitive development on its own, or work along traditional lines of the nature-nurture debate.

3. *Ecological psychology*

James Gibson argued that perception cannot be understood without explicit reference to the individual within their environment and the actions that are afforded to the individual within their specific actions, because the purpose of perception is to engage with the world, properties of the world are perceived directly in terms of the actions they afford, rather than abstracted internal representations. James Gibson also recognized the importance of identifying invariants of information in the environment, and which of their features remain stable or change systematically as the agent moves in space. For example, the information provided for depth perception in a static picture is very limited compared to the information available to an agent embedded in the environment that is able to move around. The perspective of the agent, which provides a point of reference in the world, provides information on the relationship of the agent to their environment. Taking into account the full complexity of the information available actually reduces the inferences the cognitive system is required to make. Eleanor Gibson similarly applied Ecological Psychology to developmental questions; further criticizing the distinction between perception, knowledge and action[7] and tracing cognitive development along motor development[8]. Ecological psychology emphasizes the learner as an active agent in learning: "We don't see, we look"[9].

4. *Enactivism*

According to the enactivist literature, cognition is a process that emerges from agents engaging and acting in an environment[10]. Building on the con-

7 Eleanor J. Gibson, *Exploratory Behavior in the Development of Perceiving, Acting, and the Acquiring of Knowledge*, "Annual Review of Psychology", 39, 1 1988, pp. 1-42. James J. Gibson, Eleanor J. Gibson, *Perceptual Learning: Differentiation or Enrichment?*, "Psychological Review", 62, 1, 1955, pp. 2-41.

8 E.J. Gibson, *Exploratory Behavior*, cit.

9 *ivi*, p. 5.

10 F.F. Varela *et al., The Embodied Mind,* cit.

cept autopoesis, it describes agents as autonomous beings that aim to sustain themselves in their environment. Agents make sense and bring about meaning by engaging with the environment, and their opportunities to engage with the environment is determined by their embodied interactions with it. Strong versions of enactivsm[11] claim that because of the extent of the conceptual continuity between cognition, body and environment, the notion of that cognitive processes require internal mental representations is not meaningful, and cognition, in general, can be explained without them. Cognition is tightly coupled to the environment; there is nothing to be represented[12].

5. *Clark's Extended Mind and Predictive Processing*

The extended mind hypothesis proposes that at least some cognitive processes extend into the environment and rely on external processes using the body and the environment[13]. For example, by placing the bin bag in front of the door, I will remember to take out the trash when I stumble out of the house in the morning. Although the underlying process of remembering is different, this approach fulfills the same *function* as using the memory in the brain. In nature, a lot of cognitive processes rely on embodied mechanisms and allow agents to solve complex problems that would otherwise require considerable cognitive resources[14]. Furthermore, by extending cognition beyond the brain, Clark and Chalmers argue that they:

> […] allow a more natural explanation of all sorts of actions. One can explain my choice of words in Scrabble, for example, as the outcome of an extended cognitive process involving the rearrangement of tiles on my tray. Of course, one could always try to explain my action in terms of internal processes and a long series of 'inputs' and 'actions', but this explanation would be needlessly complex[15].

A related perspective is shared by the predictive processing framework. Clark argues that according to the predictive processing framework, living beings attempt to predict their environment. The brain is the center point of the "prediction engine", predicting the incoming information streams on different hierarchical levels, where higher levels are attempting to predict lower levels. Rather than feeding sensory signals forward, only the error

[11] D. Hutto, D. Abrahamson, *Embodied, Enactive Education*, cit.

[12] Julian Kiverstein, *Extended Cognition*, in Albert Newen, Leon De Bruin, and Shaun Gallagher (eds.), *The Oxford Handbook of 4E Cognition*, Oxford University Press, 2018, pp. 19-40,

[13] Andy Clark, David Chalmers, *The Extended Mind*, "Analysis", 58, 1, 1998, pp. 7-19.

[14] Andy Clark, *Being There: Putting Brain, Body, and World Together Again*, The MIT Press, Cambridge 1997.

[15] A. Clark, D. Chalmers, *The Extended Mind* cit., pp. 9-10.

signal (i.e. the difference between the incoming and the predicted signal) is passed on to higher levels. As in the other two accounts, cognition can draw upon action and perception equally, and can extend into the world to include external features, such as tools. The predictive coding framework is more lenient towards mental representations and does not object to their existence in principal. For example, mental representations emerge out of engaging and interacting with the environment in ways that produce models of the external world that are partially decoupled from the world around them[16].

5.1 *Common themes of Ecological Psychology, Enactivism, and Predictive Processing*

There are a number of shared themes between all three approaches. These include the embodied nature of experience, the relevance of an agent's agency in exploring their environment and a tight integration of cognition, action and environment. The cognitive system, as described by Clark, Gibson and Varela *et al.* includes the body and the external world, either just functionally (Clark), or playing a constitutive role in cognition (Gibson, Varela *et al.*). These differences are subtle theoretical arguments, and potentially difficult to resolve empirically[17]. However, despite these disagreements, there is agreement that cognition extends beyond the brain in ways beyond traditionally considered by cognitive psychology. Furthermore, the tight link between environment and agent reduces (Clark) or does not require cognitive representations (Gibson, Varela *et al.*). Historically, the arguments that the child is an active participant in its learning and the role of environmental scaffolding can be found in the works by Jean Piaget[18] and Lev S. Vygotsky[19]. Indeed, all three extended perspectives[20] reference their works.

6. *What does it mean to be an agent in a body?*

A central theme of enactivist perspectives is that cognition takes place within a body that determines the way we can interface with the world and what opportunities for learning we will receive. The developing body con-

[16] A. Clark, *Predicting Peace*, "Open MIND", 2015, pp. 1-7.

[17] J. Kiverstein, *Extended Cognition*, cit.

[18] Jean Piaget, *The Construction of Reality in the Child*, Routledge, London 1954.

[19] Lev S. Vygotsky, *Mind in Society: Development of Higher Psychological Processes*, Harvard University Press, Cambridge 1978.

[20] A. Clark, *Being There*; Varela *et al.*, *The Embodied Mind* cit.; E.J. Gibson, *Exploratory Behavior*, cit.

strains and shapes the perceptual information and provides a rich and highly structured environment[21]. Whilst these effects have been shown on small scales, future theoretical work needs to describe how these developmental trajectories contribute to species-specific behavioral phenotypes. For example, compared to their closest evolutionary relative, human infants spend almost twice the amount of time *not* being able to walk. According to the post-natal dependency hypothesis[22], infants' delayed motor abilities lead to a radically different developmental trajectory during which social signals are meaningful indicators of potential opportunities for action with others and with the environment. Accordingly, it is human infants' comparatively long period of dependency that provides the foundation of social learning in humans.

Understanding the developmental trajectories from an ecological-enactivist perspective also allows us to develop a stronger understanding about the development of cognitive skills and their underlying foundations. Often, debates have focused on innate compared to learned skills and behaviors. Extending development beyond the cognitive skills and understanding the contributions of body and environment as *constitutive*, shifts our understanding of what it means to acquire species-specific behaviors. Focusing on the role of specific genes and innate modules merely serves as a placeholder for developmental processes and fails to adequately describe development, both ontogenetically and evolutionary[23]. The process of development is fundamentally emergent, accounting for higher order explanations of behavior based on lower order of information, but this requires describing the processes that mediate between these different levels. Bodily development plays an important mediating and constituting role in structuring information during development.

Because of this, enactivist, extended and ecological approaches to cognitive development are by default skeptical of poverty of stimulus arguments. The information landscape available to children is rich and taking the multifaceted input into account, provides structures that simplify, rather than complicate the information that needs to be processed. Because the egocentric perspective provides *relevant* information readily accessible to the agent, it simplifies the information the agent needs to process. Similar mechanisms that structure spatial perception from the perspective of an active agent, as described by Gibson, are also at play in the descriptions of the information available to infants when learning words: here, the baby's view is better[24]. More information does not lead to more complex information processing, but is nat-

[21] Elizabeth Ray, Cecilia M. Heyes, *Imitation in Infancy: The Wealth of the Stimulus*, "Developmental Science", 14, 1, 2011, pp. 92-105; L.B. Smith *et al., The Developing Infant*, cit.

[22] C. Kliesch, *Post-Natal Dependency*, cit.

[23] Susan Oyama, *The Ontogeny of Information*, Duke University Press, 2000.

[24] D. Yurovsky, L.B. Smith, C. Yu, *Statistical Word Learning*, cit.

urally meaningful. A sceptic might ask whether these strong notions of embodiment and extendedness are actually necessary, or whether they represent a shift from innate to learned explanations of development. But these distinctions hide the complex interactions between innate and learned behaviors, as argued by developmental systems biology[25]. Developmental explanations of behavior need to take into account body development and the environmental context where it takes place. Learned cognitive abilities can still be genetically determined by physiological phenotypes, and cognitive skills learned later in life can still systematically affect physiological phenotypes.

One might worry that tracing these relationships leads to an unnecessarily complex description; as Patrick Bateson self-mockingly writes: "Never use a simple explanation if a more complicated one will do instead"[26]. Eschewing complexity for complexity's sake can lead to vacuous theorizing that everything, everywhere all at once is relevant for an agent, defying scientific falsifiability[27]. Enacted, ecological and extended arguments are strongest when they can make concrete predictions about how an agent should respond given a specific context and opportunities for action. Often, we will find that the resulting picture is not actually more complex, but that traditional representational perspectives rely on implicit assumptions that are not necessary when taking into account the perspective of an organism in its environment. This is evident in Gibson's description of visual perception where understanding the visual perspective of an animal provides ample information and does not require the reconstruction of the environment. We also find it in enactivist accounts of social cognition that question that others' mental states are not accessible to an observer and need to be inferred. Rather, the social context provides rich information on social interactions allowing the interaction and interpretation of behavior even without access to their mental states[28].

7. *Learning environments shape information before and after birth*

Human development is characterised by a unique developmental trajectory, providing what Linda Smith *et al.*[29] coined "a curriculum for statistical

[25] S. Oyama, *The Ontogeny of Information*, cit.

[26] Patrick Bateson, *The Nest's Tale. A Reply to Richard Dawkins,* "Biology & Philosophy", 21, 4, 2006, p. 557.

[27] Karl R. Popper, *Conjectures and Refutations*, Routledge, London 2002.

[28] Jeremy Carpendale, Charlie Lewis, *What Makes Us Human: How Minds Develop Through Social Interactions*, Routledge, New York 2020; Shaun Gallagher, *Action and Interaction*, Oxford University Press, New York 2020.

[29] Kenneth J. Gerhardt, Robert M. Abrams, *Fetal hearing: Characterization of the stimulus and response*, in "Seminars in Perinatology", 20, 1, pp. 11-20. Linda B. Smith, Swapnaa Jayaraman, Eliza-

learning". This curriculum is shaped by the environment and the changes provided by infants' emerging motor abilities that affect opportunities for action and interaction. This developmental process starts even before birth, but our current understanding of the contribution of the fetal environment of later cognitive capacities is only emerging. Concepts, such as the understanding of self, do not just suddenly come online when the child reaches a certain milestone or age; rather they emerge out of interaction with the environment and the opportunities it provides. However, early in development, and particularly so in utero, the self of the child is better described as nested within their mother's self[30], and this interdependence continues after birth[31]. The fetal environment differs in many important aspects from the one after birth. The womb provides an environment with specific features; whilst light can travel through, it is diffused by the tissue surrounding the fetus[32]. Likewise, sound can be heard, but higher frequencies are attenuated[33]. Human fetuses spend a long time in the womb, close to their mother's source of vocalizations and already learn features of human speech and can use these features to identify the faces of their mothers based on their speech[34] and recognize stories previously heard in the womb after birth[35].

The transition from pre to post-natal environment might facilitate learning beyond direct association between pre- and post-natal information through curiosity-driven learning. According to this literature, information is learned most effectively when it is sufficiently novel to be interesting, but familiar enough to be integrated into existing knowledge. This balance between old and new has been referred to as the "Goldilocks effect"[36]. For example, in-

beth Clerkin, and Chen Yu, *The Developing Infant Creates a Curriculum for Statistical Learning*, "Trends in Cognitive Sciences", 1767, 22, 2018, p. 4.

30 Anna Ciaunica, Axel Constant, Hubert Preissl and Katerina Fotopoulou, *The first prior: From co-embodiment to co-homeostasis in early life*, "Consciousness and Cognition", 91, 2021, pp. 103-117.

31 Aikaterini Fotopoulou, Manos Tsakiris, *Mentalizing Homeostasis: The Social Origins of Interoceptive Inference*, "Neuropsychoanalysis", 19, 1, 2017, pp. 3-28.

32 Marco Del Giudice, *Alone in the Dark? Modeling the Conditions for Visual Experience in Human Fetuses*, "Developmental Psychobiology", 53, 2, 2010, pp. 214-19.

33 M.A. Vince, A.E. Billing, B.A. Baldwin *et al., Maternal Vocalisations and Other Sounds in the Fetal Lamb's Sound Environment*, "Early Human Development", 11, 2, 1985, pp. 179-90; Melanie J. Spence and Anthony J. DeCasper, *Prenatal Experience with Low-Frequency Maternal-Voice Sounds Influence Neonatal Perception of Maternal Voice Samples*, "Infant Behavior and Development", 10, 2, 1987, pp. 133-42.

34 Fatma Z. Sai, *The Role of the Mother's Voice in Developing Mother's Face Preference: Evidence for Intermodal Perception at Birth*, Infant and Child Development", 14, 1, 2005, pp. 29-50.

35 Anthony J. De Casper, Melanie J. Spence, *Prenatal Maternal Speech Influences Newborns' Perception of Speech Sounds*, "Infant Behavior and Development", 9, 2, 1986, pp. 133-50.

36 Jacqueline Gottlieb *et al.*, *Information-Seeking, Curiosity, and Attention: Computational and Neural Mechanisms*, "Trends in Cognitive Sciences", 17, 11, 2013, pp. 585-93.

fants' pre-natal experience of attenuated sounds might facilitate their interest in similar sounds that include higher pitch but are otherwise similar to the ones previously experienced in the womb, and might contribute to infants' preference for infant-directed speech[37]. Likewise, the visual experience in the womb is characterized by low contrast, which might lead to a preference for specific combinations of high-contrast stimuli, potentially explaining neonates' preference for eye-like contrast polarity[38].

8. *The importance of the peripersonal space and its social extension*

For agents in the environment, being able to exert change in the environment is crucial, and this ability is determined by the body and context. Studies with adult humans have shown that proficiency to act in the environment fundamentally affects perception[39], and objects within the proximity of our influence are processed differently. For example, right-handers perceive objects within reaching distance as further away if they are presented on the left, compared to the right side of the body[40]. As I argued elsewhere[41], infants perceive others as providing affordances otherwise not available in the environment. Others' helping hand might literally extend the affordance space provided to infants.

Taking the perspective that acting with the help of objects and others is similar to acting on the environment on our own forces us to rethink how infants will learn about their environment. This perspective represents an extension of Andy Clark's description of the parity principle[42], according to which structures in the environment can supplement or even replace cognitive processes in ways that are functionally the same. Similar arguments have also been made by Gibson[43] and Merleau-Ponty[44], who argue that proficient tool users integrate tools into their perceptual system. Hands, tools, words

37 Anne Fernald, Patricia Kuhl, *Acoustic Determinants of Infant Preference for Motherese Speech*, "Infant Behavior and Development", 10, 3, 1987, pp. 279-93,

38 Teresa Farroni, Gergely Csibra, Francesca Simion, and Mark H. Johnson, *Eye Contact Detection in Humans from Birth,* "Proceedings of the National Academy of Sciences", 99, 14, 2002, pp. 9602-9605.

39 Dennis R. Proffitt, Sally A. Linkenauger, *Perception Viewed as a Phenotypic Expression*, in Wolfgang Prinz, Miriam Beisert, and Arvid Herwig (eds.), *Action Science: Foundations of an Emerging Discipline*, 171, MIT Press Scholarship Online, 2013.

40 Sally A. Linkenauger *et al.*, *The Effects of Handedness and Reachability on Perceived Distance*, "Journal of Experimental Psychology: Human Perception and Performance", 35, 6, 2009, pp. 1649-1660.

41 C. Kliesch, *Post-Natal Dependency as the Foundation of Social Learning in Humans*, submitted.

42 A. Clark, D. Chalmers, *The Extended Mind*, cit.

43 J.J. Gibson, *The Ecological Approach*, cit.

44 Maurice Merleau-Ponty, *The Structure of Behaviour*, Beacon Press, Boston 1967.

and others afford interaction[45] and effect change in the environment.

Children explore the world using their mouths, eyes and hands. Once manual and oral exploration cease to provide much novel information (either because it has been done or is unachievable) and eye-hand coordination improves, proximal visual inspection becomes more interesting. Observing objects in the distance becomes more rewarding, particularly in the presence of caregivers. Caregivers provide novel information and can support curiosity-driven learning by providing information that is relevant to the child at that particular moment[46]. Before infants are able to walk at around 12 months, they spend a comparatively long time being dependent on caregivers. Human walking onset is much later than that of other species[47]. This dependency means that children's experience is modulated by others for a much longer time. Others are therefore a fundamental aspect of engaging with the environment, for example by providing the opportunities to engage with objects[48] or reach objects that would otherwise be too far away[49]. In referential interactions and communication with others, many languages distinguish between objects that are under the direct influence of the self or the respective partner, or that outwit the reach and therefore no longer can be exerted control[50]. Such control is not restricted to objects within the own space, but can also be exerted through others. This is apparent in 8-month-olds reaching for objects in the presence of others[51]. In adults, instructing a partner to carry out an action produces a readiness potential similar to carrying out the action oneself[52].

45 Paul Watzlawick, Janet Beavin Bavelas, Don D Jackson, *Pragmatics of Human Communication*, W.W. Norton, New York 1967.

46 Sumarga H. Suanda Meagan Barnhart, Linda B. Smith, and Chen Yu, "The Signal in the Noise: The Visual Ecology of Parents' Object Naming," *Infancy*, 24, 3, 2018, pp. 455-76.

47 Patrizia Potì, Giovanna Spinozzi, *Early Sensorimotor Development in Chimpanzees (Pan Troglodytes)*, "Journal of Comparative Psychology", 108, 1, 1994, pp. 93-103.

48 Kaya de Barbaro, Christine M. Johnson, Deborah Forster, Gedeon Deák, *Sensorimotor Decoupling Contributes to Triadic Attention: A Longitudinal Investigation of Mother-Infant-Object Interactions*, "Child Development", 87, 2, 2015, pp. 494-512.

49 Verónica C. Ramenzoni and Ulf Liszkowski, *The Social Reach: 8-Month-Olds Reach for Unobtainable Objects in the Presence of Another Person*, "Psychological Science", 27, 9, 2016, pp. 1278-85.

50 Kenny R. Coventry *et al., Language Within Your Reach: Near–Far Perceptual Space and Spatial Demonstratives*, "Cognition", 108, 3, 2008, pp. 889-95; Kenny R. Coventry *et al., Spatial Communication Systems Across Languages Reflect Universal Action Constraints*, "Nature Human Behaviour", 7, 2023, pp. 2099-2110.

51 V.C. Ramenzoni and U. Liszkowski, *The Social Reach*, cit.

52 Isabella Boux *et al. Brain Signatures Predict Communicative Function of Speech Production in Interaction*, "Cortex", 135, 2021, pp. 127-145.

9. *Freeing the hands*

Freeing the hands allows for objects that are manipulated to be visible, and allows for a close integration of vision-hand motor coordination. Having the hands free for interacting with the environment allows for the exploration of objects, and coordinates object handling and vision for further exploration. Being able to see the effects of one's actions allows for a better understanding of the potential actions necessary to achieve the desired outcomes. Human children can start to manipulate objects whilst being able to see the effects of their manipulation directly, providing a much-improved ability to investigate the causality of manual actions. Unlike young chimpanzees, they are not able to get up and start exploring other objects that are potentially more interesting yet, and therefore show different patterns of object exploration[53]. Shifts in body morphology are not coincidental, they are important aspects of shaping the affordance space in humans.

Changes in body morphology and action opportunities are difficult to investigate experimentally. However, the importance of embodied contributions to cognition becomes particularly evident in comparative work, such as corvids' ability to use tools to retrieve food. New Caledonian Crows are skilled tool users[54], however, their species-specific adaptations are not (just) cognitive. Cross-species comparisons amongst other birds suggest that tool use correlates with the bird's forward-facing eyes and the length of the beak. These features reduce task complexity by allowing visual guidance since the tip of the beak is visible during object manipulation[55]. It is likely that human morphology contributes in similar ways.

The link between body development and action also plays a role in children's ability to engage in pointing. Human index finger pointing is a universal gesture used across all known communities and cultures. Some have argued that finger pointing emerges from children attempting to grasp objects in the presence of caregivers[56]; whilst others suggest that pointing emerges from touch[57]. Being able to extend and grasp objects helps direct attention to them, and already by the age of 8 months, infants will reach for out-of-reach objects in the presence of caregivers and other potential helpers, but not when on their own[58].

For humans, pointing provides an important ability to interact with the

[53] P. Potì, G. Spinozzi, *Early Sensorimotor* cit.

[54] Christian Rutz *et al.*, *The Ecological Significance of Tool Use in New Caledonian Crows*, "Science", 329, 5998, 2010, pp. 1523-1526.

[55] Jolyon Troscianko *et al., Extreme Binocular Vision and a Straight Bill Facilitate Tool Use in New Caledonian Crows*, "Nature Communications", 3, 1, 2012, A1110.

[56] V.C. Ramenzoni, U. Liszkowski, *The Social Reach*, cit.

[57] C. O'Madagain, G. Kachel, B. Strickland, *The Origin of Pointing*, cit.

[58] V.C. Ramenzoni, U. Liszkowski, *The Social Reach*, cit.

environment and emerges around 12 months of age. Several embodied explanations have been put forward: according to the reaching hypothesis, infants learn to point through a stylized reach, through which they get caregivers to pass objects[59]. Cathal O'Madagain and colleagues[60] provide an alternative explanation by suggesting that, provided the way that 18-month-old children interpret and use pointing gestures, as an extended touch with the index finger, rather than an arrow in space. Using the index finger to touch objects indicates the location of the exploration and provides information on its texture and physicality, but does not bring the object under direct control. A further contributing factor to the prevalance of finger-pointing is young children's failure to understand object size and attempt to touch far-away objects. Children between 15-30 months try to climb into a mini version of a full-sized toy car, failing to appreciate the affordance of size[61]. Younger infants might also struggle to appreciate the correspondence between distance and size, and attempt to use a pincer grip (typically used for small objects) for bigger objects that are far away. Index-finger pointing might emerge because far objects are perceived as smaller, requiring a pincer touch, rather than a full hand grasp.

10. *Walking: A shift in perspective*

Human infants learn to walk at around 12 months of age[62]. Walking shifts the perspective of the agent and allows the transportation of objects, for example for sharing attention with caregivers[63]. A walking learner is more likely to encounter novel objects or use their freed hands to interact with them, providing an opportunity for carrying and sharing attention with caregivers[64] and expanding the vocabulary.[65] Walking allows for exploration and

[59] *Ivi*.

[60] Cathal O'Madagain, Gregor Kachel, Brent Strickland, *The Origin of Pointing: Evidence for the Touch Hypothesis*, "Science Advances", 5, 7, 2019, eaav2558.

[61] Judy S. De Loache, David H. Uttal, Karl S. Rosengren, *Scale Errors Offer Evidence for a Perception-Action Dissociation Early in Life*, "Science", 304, 5673, 2004, pp. 1027-29; Mikako Ishibashi, Yusuke Moriguchi, *Understanding Why Children Commit Scale Errors: Scale Error and Its Relation to Action Planning and Inhibitory Control, and the Concept of Size*, "Frontiers in Psychology", 8, 2017, A826.

[62] Karen E. Adolph, Justine E. Hoch, *Motor Development: Embodied, Embedded, Enculturated, and Enabling*, "Annual Review of Psychology", 70, 1, 2019, pp. 141-64.

[63] Lana B. Karasik, Catherine S. Tamis-LeMonda, and Karen E. Adolph, *Transition from Crawling to Walking and Infants' Actions with Objects and People*, "Child Development", 82, 4, 2011, pp. 1199-1209.

[64] Lana B. Karasik Karen E. Adolph, Catherine S. Tamis-LeMonda, and Alyssa L. Zuckerman, *Carry on: Spontaneous Object Carrying in 13-Month-Old Crawling and Walking Infants*, "Developmental Psychology", 48, 2, 2012, pp. 389-97.

[65] Ora Oudgenoeg-Paz, M. (Chiel), J. M. Volman, and Paul P. M. Leseman, *Attainment of*

discovering new affordances in the world, but is rewarding on its own.[66] In a room full of toys, children roam from toy to toy; in an empty room, they use a similar amount of steps just cycling around their caregivers[67].

The development of walking emerges primarily out of the physical ability and toddler's curiosity. Toddlers explore their emerging walking abilities despite facing many challenges that, for an adult, would be penalizing[68]. Frequent falls, like those experienced by newly walking infants, would potentially be painful or result in serious injury for adults. However, toddlers' falls are a lot less severe due to their smaller size and body fat distribution[69]. The emergence and control of many aspects of the walking movement is provided by the structure of the muscles and tendons, rather than direct cognitive control[70]. Infants' body weight initially constrains walking, and infants that are provided the ability to practice their walking (e.g. by walking on a treadmill) will show the appropriate stepping actions at 3-5 months, before being able to walk on their own[71]. Individual and cultural differences that impact toddler mobility, such as body weight, wearing diapers or long periods of cradling that affect body development[72] could have knock-on effects on the trajectories of children's cognitive development.

11. *How embodied is the "curriculum for learning"?*

Recent works in developmental psychology have made use of modern technologies that allow the collection of large amounts of data that can be analyzed using modern machine-learning technologies. This line of research takes the importance of the embodied, egocentric position of children as a

Sitting and Walking Predicts Development of Productive Vocabulary Between Ages 16 and 28 Months, "Infant Behavior and Development", 35, no. 4 (December 2012, pp. 733-36).

66 Yuri Burda *et al.*, Large-Scale Study of Curiosity-Driven Learning," *arXiv*, 2018.

67 Justine E. Hoch, Sinclaire M. O'Grady, and Karen E. Adolph, *It's the Journey, Not the Destination: Locomotor Exploration in Infants*, "Developmental Science", 22, 2, 2018, e12740.

68 Danyang Han, Karen E. Adolph, *The Impact of Errors in Infant Development: Falling Like a Baby*, "Developmental Science", 24, 5, 2021, e13069.

69 Karen E. Adolph *et al., How Do You Learn to Walk? Thousands of Steps and Dozens of Falls Per Day*, "Psychological Science", 23, 11, 2012, pp. 1387-1394.

70 Esther Thelen, Beverly D. Ulrich, Peter H. Wolff, *Hidden Skills: A Dynamic Systems Analysis of Treadmill Stepping During the First Year*, University of Chicago Press, 1991; A. Clark, *Being There*, cit.

71 E. Thelen, B.D. Ulrich, P.H. Wolff, *Hidden Skills*, cit.

72 Whitney G. Cole, Jesse M. Lingeman, and Karen E. Adolph, *Go Naked: Diapers Affect Infant Walking*, "Developmental Science", 15, 6, 2012, pp. 783-790; Meghan Slining *et al.*, *Infant Overweight Is Associated with Delayed Motor Development*, "The Journal of Pediatrics", 157, 1, 2010, pp. 20-25.e1; Lana B. Karasik *et al., Gahvora Cradling in Tajikistan: Cultural Practices and Associations with Motor Development*, "Child Development", 94, 4, 2023, pp. 1049-1067.

fundamental starting point to study the input a child receives[73], mirroring the description of the visual world from an egocentric perspective by Gibson[74]. These studies have revealed the rich environments where children grow up, and allow the specification of the information available to children at any point in time; this prompted some authors[75] to discuss children's early environment as a "curriculum for learning". Yet, current theoretical discussions rarely go beyond descriptions of the information available and do not provide a full assessment of the importance of the specific motor and body developmental factors beyond the emergence of specific skills. Here I will provide a brief analysis based on embodied aspects of word learning and face processing.

Learning the relationship between a word and the object it refers to is a potentially complex process, since the world contains a large number of potential referents. However, the problem space for 18-20 month-old toddlers' is greatly reduced because the number of potential referents in their visual field is limited by their short arms[76]. The cognitively complex problem of identifying the correct object is simplified by an embodied process, just as described by the accounts by Gibson, Clark, Varela and colleagues. However, even though there is evidence that input from the child's perspective is indeed easier to learn[77], it is not clear whether this reduction is necessary for learning words by non-embodied means. The three accounts also differ in their description of the extent of the externalization of this process. Whereas for Clark, internal cognitive processes are supplemented by external, embodied processes, Gibson and Varela *et al.* would suggest that children's short arms *are* part of the child's cognitive system.

In other cases, embodied contributions are not just supplementing learning and development, they provide its very foundation, as exemplified by the acquisition of a face model during infancy. Experience of faces appears to be necessary – children born with visual cataracts that are not treated within a specific time frame will fail to acquire a fully developed face model[78]. However, children's exposure to faces is enabled by their long period of dependency where they experience faces on a frequent basis during caregiver-infant interac-

[73] Jeremy I. Borjon *et al., A View of Their Own: Capturing the Egocentric View of Infants and Toddlers with Head-Mounted Cameras*, "Journal of Visualized Experiments", 140, 2018, A58445.

[74] J.J. Gibson, *The Ecological Approach*, cit.

[75] L.B. Smith *et al., The Developing Infant*, cit.

[76] Chen Yu *et al.*, *Two Views of the World: Active Vision in Real-World Interaction,* "Proceedings of the 29th Annual Meeting of the Cognitive Science Society", 29, 2007, pp. 731-736.

[77] Daniel Yurovsky, Linda B. Smith, Chen Yu, *Statistical Word Learning at Scale: The Baby's View Is Better*, "Developmental Science", 16, 6, 2013, pp. 959-966.

[78] L.B., Smith *et al., The Developing Infant*, cit.

tions[79]. This aspect of their development is potentially constitutive of their social experience of others by contributing to the development of face perception in general[80]. There are also cases where embodied processes constrain learning in ways that are not anticipated by non-embodied learning accounts. For example, Morse *et al.*[81] found that children's referential understanding of words to hidden referents can be interrupted by changes of posture, as predicted by simulations using robots. Here, embodied accounts of learning provide novel predictions about children's learning that go beyond cognitive explanations.

12. *A developmental perspective on extended cognition*

Developmental psychology can also contribute to a better understanding of extended processes. Gibson[82] described the ecological information available to different organisms in great detail. The spirit of this research continues in the works of many other developmental researchers[83]. Many of these works have focused on specific motor and embodied abilities and specific skills, such as word learning or exploration. The emphasis on ecologically relevant behaviors and skills is a strength of this line of research, but makes it difficult to compare its results with more traditional research investigating more abstract forms of learning. Developmental research has been explicitly referenced in foundational texts of the enactivist literature. Varela *et al.* specifically identify Piaget as a predecessor of enactivist thinking in development due to his focus on the child as an explorer of learning opportunities. A developmental perspective can also help to disentangle the underlying processes that lead to enacted and extended forms of behaviour. For example, the broader field of embodied cognition has accumulated a number of failed replications for embodied accounts of cognition[84] and providing develop-

[79] Swapnaa Jayaraman, Caitlin M. Fausey, L.B. Smith, *The Faces in Infant-Perspective Scenes Change over the First Year of Life*, "PLOS ONE", 10, 5, 2015, e0123780; Swapnaa Jayaraman, L.B. Smith, *Faces in Early Visual Environments Are Persistent Not Just Frequent*, "Vision Research", 157, 2019, pp. 213-221.

[80] L.B., Smith *et al.*, *The Developing Infant* cit.

[81] Anthony F. Morse, Viridian L. Benitez, Tony Belpaeme *et al.*, *Posture Affects How Robots and Infants Map Words to Objects*, "PLoS ONE", 10, 3, 2015, e0116012.

[82] J. J. Gibson, *The Ecological Approach to Visual Perception*, cit.

[83] L. B. Karasik, C. S. Tamis-LeMonda, K. E. Adolph *Transition from Crawling*, cit.; Chen Yu and Linda B. Smith, *Embodied Attention and Word Learning by Toddlers*, "Cognition", 125, 2, 2012, pp. 244-62; K. E. Adolph, J. E. Hoch, *Motor Development*, cit.

[84] Dermot Lynott *et al.*, *Replication of 'Experiencing Physical Warmth Promotes Interpersonal Warmth' by Williams and Bargh (2008)*, "Social Psychology", 45, 3, 2014, pp. 216-222; Lincoln J. Colling *et al.*, *Registered Replication Report on Fischer, Castel, Dodd, and Pratt (2003)*, "Advances in Methods and Practices in Psychological Science", 3, 2, 2020, pp. 143-162.

mental accounts can help to specify under which contexts and what forms of embodiment we can expect to find[85]. However, by investigating developmental trajectories it is also possible to test the underlying assumptions of embodied accounts. For example, it had been suggested that spatial biases in number representation are due to the directional biases in finger counting or reading. However, developmental research showed that these biases are present before children learn to read or count, and are even present in newborns. Instead they might be better explained by anatomical differences in hermispheric responses to different spatial frequencies[86]. Although the new account places the explanation for directional biases back in the head, it rests on anatomical features that have knock-on effects on how a number learner acts and interacts with the environment, allowing for a rich account of the acquisition of number understanding later in life.

13. *Conclusion*

Extending developmental psychology beyond the brain into the body and the environment provides a fruitful avenue into understanding development and generating novel hypotheses on the emergence of human (and non-human) cognitive abilities. Understanding development from the perspective of the learner as an active agent embedded in their environment can provide us with descriptions of the input available to learners that provide a more complete and relevant description of the information learners have at their disposition. But as much as these extended and embodied perspectives inform developmental psychology, they can profit from rich descriptions provided by developmental psychology.

[85] Samuel Shaki, Martin H. Fischer, *How Do Numbers Shift Spatial Attention? Both Processing Depth and Counting Habits Matter*, "Journal of Experimental Psychology: General", 153, 1, 2024, pp. 171-183.

[86] Arianna Felisatti *et al., A Biological Foundation for Spatial–Numerical Associations: The Brain's Asymmetric Frequency Tuning*, "Annals of the New York Academy of Sciences", 1477, 1, 2020, pp. 44-53.