The Development Perspective

ESE 6800 / CIS 7000

Antonio Loquercio

Scientific American, Illustration by Simon Prades

AI and Child Development

Computing Machinery And Intelligence
Turing (1950)

Instead of trying to produce a programme to simulate the adult mind, why not rather try to produce one which simulates the child's? If this were then subjected to an appropriate course of education one would obtain the adult brain. Presumably the child brain is something like a notebook as one buys it from the stationer's. Rather little mechanism, and lots of blank sheets. (Mechanism and writing are from our point of view almost synonymous.) Our hope is that there is so little mechanism in the child brain that something like it can be easily programmed. The amount of work in the education we can assume, as a first approximation, to be much the same as for the human child.

AI and Child Development: The Steps

Computing Machinery And Intelligence
Turing (1950)

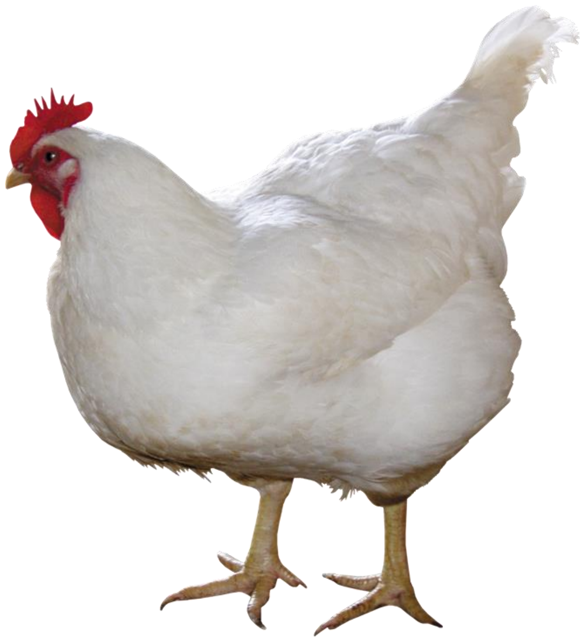
- Structure of child machine = hereditary material
- Changes of the child machine = mutation (learning?)
- Natural selection = judgment of the experimenter

A Critique of Reinforcement Learning

Computing Machinery And Intelligence
Turing (1950)

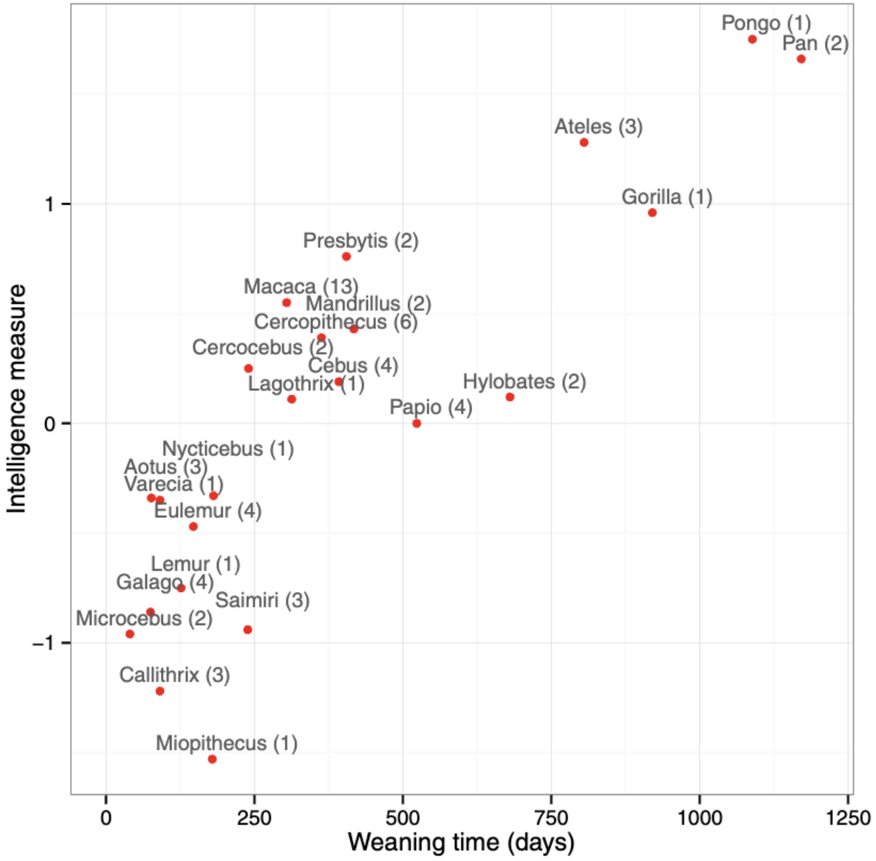
The use of punishments and rewards can at best be a part of the teaching process. Roughly speaking, if the teacher has no other means of communicating to the pupil, the amount of information which can reach him does not exceed the total number of rewards and punishments applied. By the time a child has learnt to repeat "Casabianca" he would probably feel very sore indeed, if the text could only be discovered by a "Twenty Questions" technique, every "NO" taking the form of a blow. It is necessary therefore to have some other "unemotional" channels of communication. If these are available it is possible to teach a machine by punishments and rewards to obey orders given in some language, e.g., a symbolic language. These orders are to be transmitted through the "unemotional" channels. The use of this language will diminish greatly the number of punishments and rewards required.

The Evolution of Childhood



Reaches maturity
in about 2 weeks

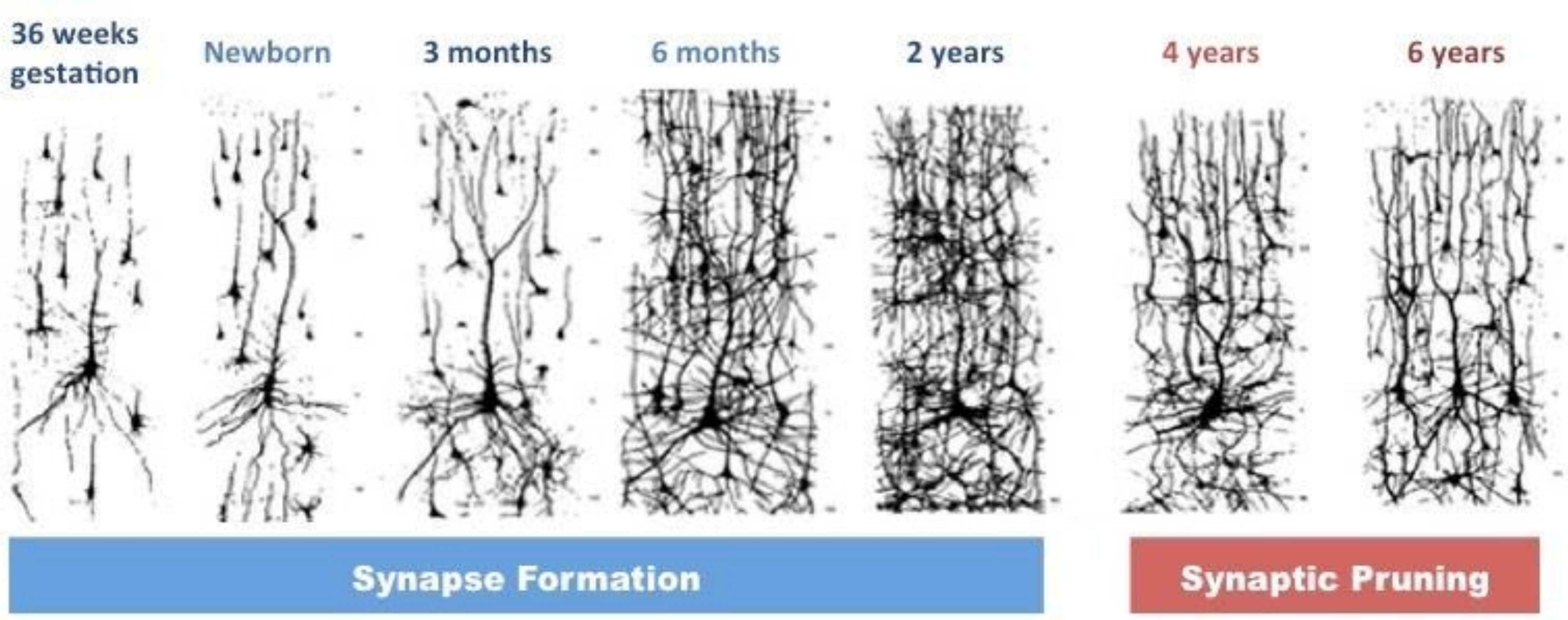
Reaches maturity
in approximately 2 years



Piantadosi and Kidd, 2016

Slide by Allison Gopnik

Synaptogenesis and Pruning



Late Development of Pre-Frontal Cortex

- Pre-frontal Cortex allows for efficient "exploitation"
- Working memory / learning strategies
- Cognitive flexibility / planning / inhibition

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Exploration vs. Exploitation Trade-off

- Childhood evolution is a way of performing simulated annealing
- As we grow elder, we are less likely to adopt an initially unfamiliar hypothesis that is consistent with new evidence.
- Adults learners prefer a familiar hypothesis that is less consistent with the evidence. -> Do NOT always trust your advisor's opinion!

Changes in cognitive flexibility and hypothesis search across human life history from childhood to adolescence to adulthood.
Gopnik et al., PNAS 2017

Explore Features, Exploit Bugs

- Noisiness, variability, randomness
- Risk-taking
- Impulsivity
- Play
- Curiosity

Slide by Allison Gopnik

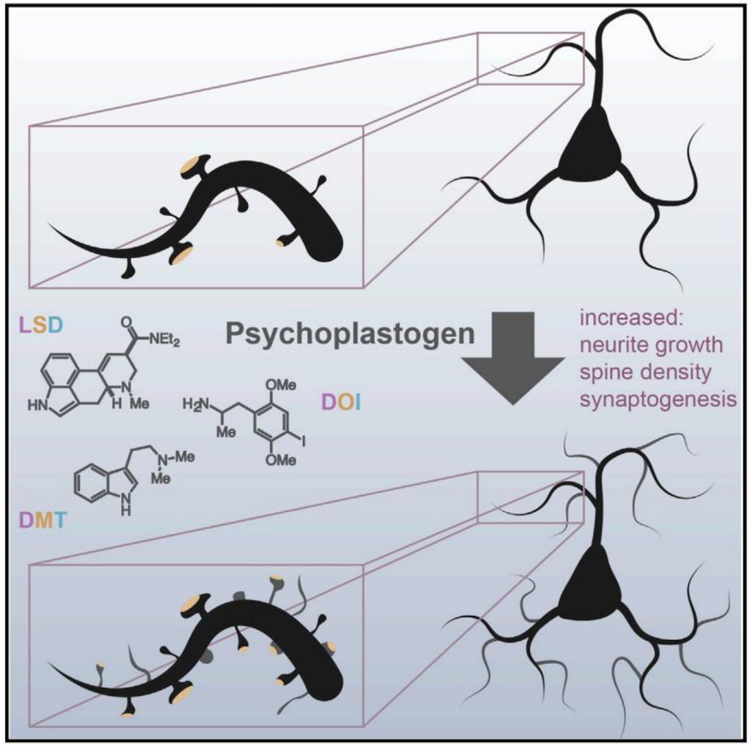
What is like to be a toddler?

Cell Reports

Article

Psychedelics Promote Structural and Functional Neural Plasticity

Graphical Abstract



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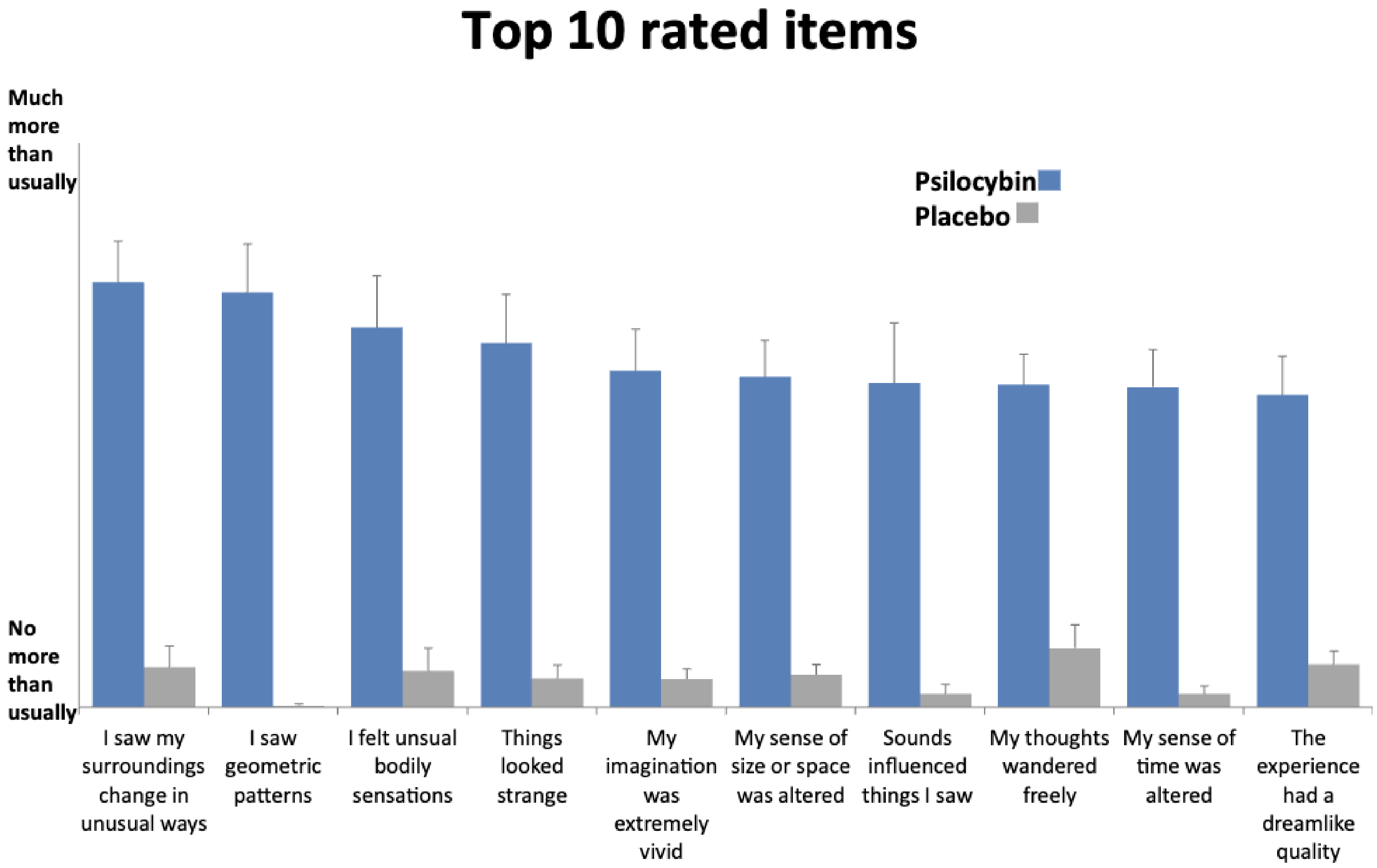
In Brief

Ly et al. demonstrate that psychedelic compounds such as LSD, DMT, and DOI increase dendritic arbor complexity, promote dendritic spine growth, and stimulate synapse formation. These cellular effects are similar to those produced by the fast-acting antidepressant ketamine and highlight the potential of psychedelics for treating depression and related disorders.

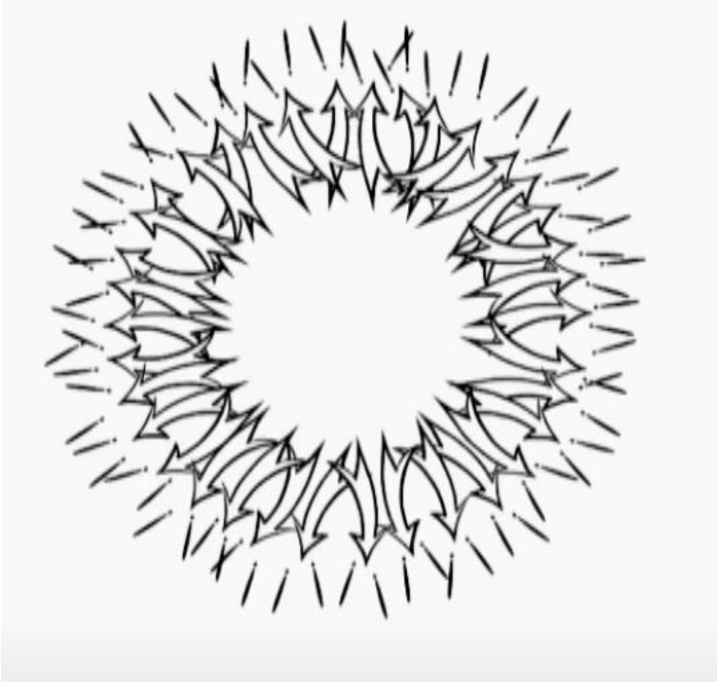
Psilocybin weakens pre-frontal control



Neural correlates of the psychedelic state as determined by fMRI studies with psilocybin, Carhart-Harris et al., PNAS 2012

Consciousness narrows as we age

Infant Lantern



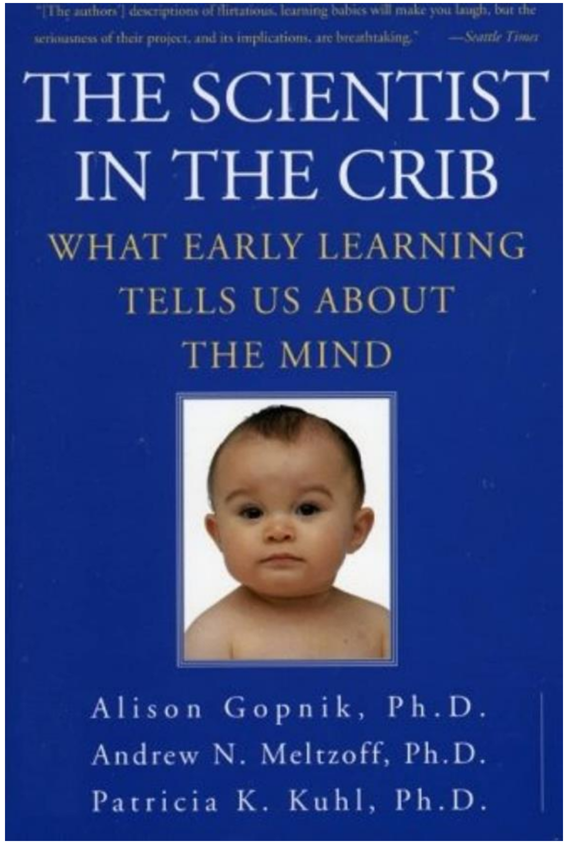
Adult Spotlight

The more we know, the less we see

Slide by A. Gopnik & A. R. Smith

Children: Scientists in the Crib

- Causal Learning and Exploration



Casual Hypothesis Testing

- Variable X causes Variable Y iff an intervention on X changes the value of Y
- Freely willed intentional actions are a good proxy for interventions

Causal Learning 101

1. Formulate Hypothesis:

- Propose causal structure of the data

2. Test Hypothesis:

- Check whether (possibly new) data is compatible with the hypothesis by comparing predicted outcomes with observed outcomes.

3. Update Hypothesis:

- Change causal structure to improve the data fit.

What is the problem with this?

Causality: Models, Reasoning, and Inference, Pearl (2000)
Making Things Happen: A Theory of Causal Explanation, Woodward (2003)

Reinforcement Learning vs Causal Learning

- RL is motivated by utility, CL by "predictability".
- RL is more effective in narrow environments and/or clearly defined tasks.
- CL has (potentially) the ability to generalize better in open-ended high-dimensional environments thanks to its structured hypotheses.
- Both suffer from explore/exploit trades-off.

Intrinsically Motivated Reinforcement Learning

- Train an RL agent with intrinsic epistemic rewards: information gain, curiosity, novelty.

- Can easily lead to over-exploration: the TV problem.

- Does not seem to work in practice (yet?).

Slide by Allison Gopnik

Empowerment

- Maximize mutual information between action and outcomes.
- Controllability as an intrinsic reward.
- Rewards exploration and discovery of environmental structure.

Klyubin et al., 2005, Abril et al, 2021, 2023

Empowerment for Hypothesis Selection

- Variable X is causally related to Y if, holding all else constant, intervening to wiggle X leads to Y wiggle.
- Gaining empowerment leads to gaining causal knowledge, and vice versa.
- Bridge between causal and reinforcement learning.

Empowerment as Causal Learning, Causal Learning as Empowerment
Gopnik et al., 2024

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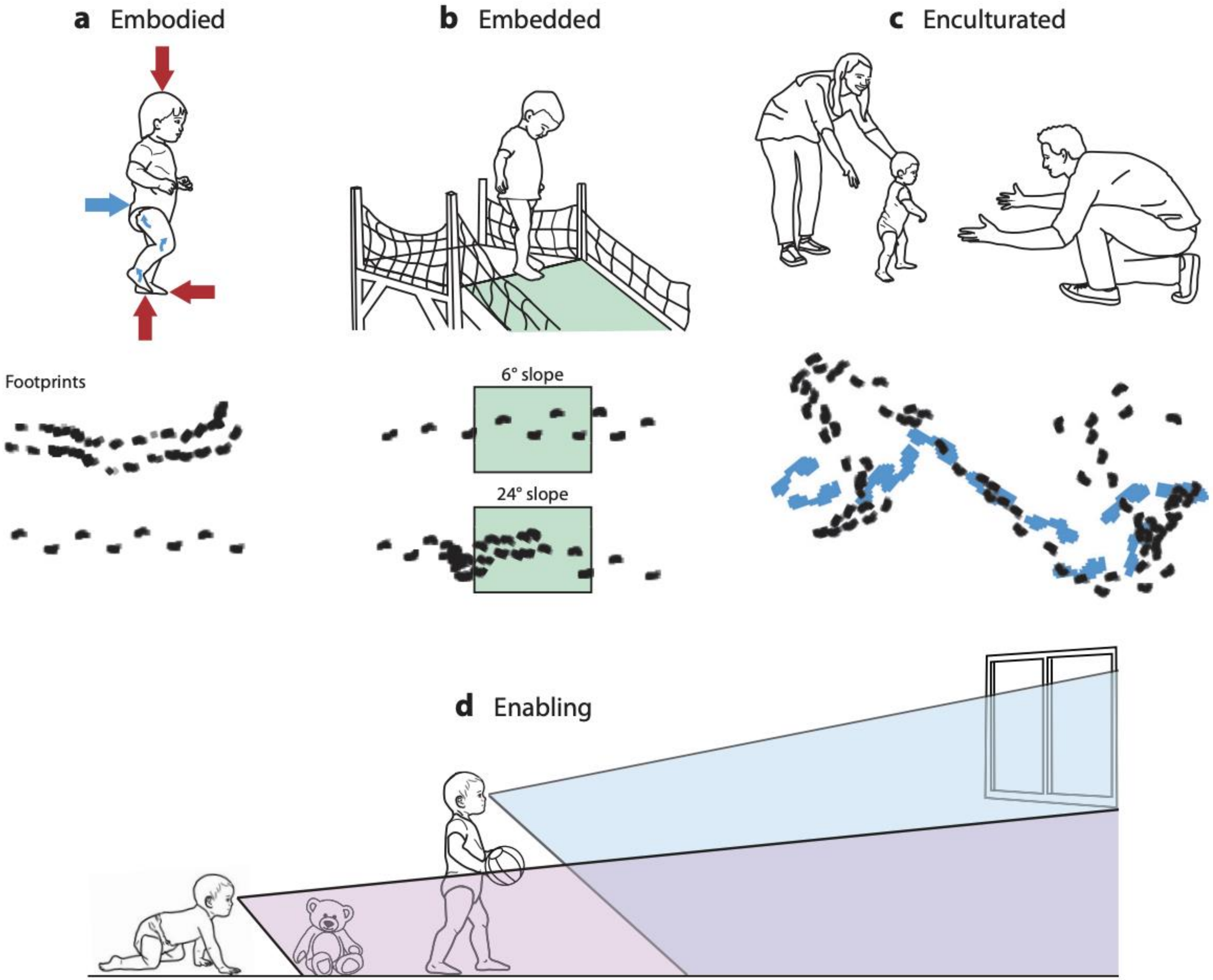
Psychology and Empowerment

- Toddlers initially only infer causal relations if they are a result of human agency.

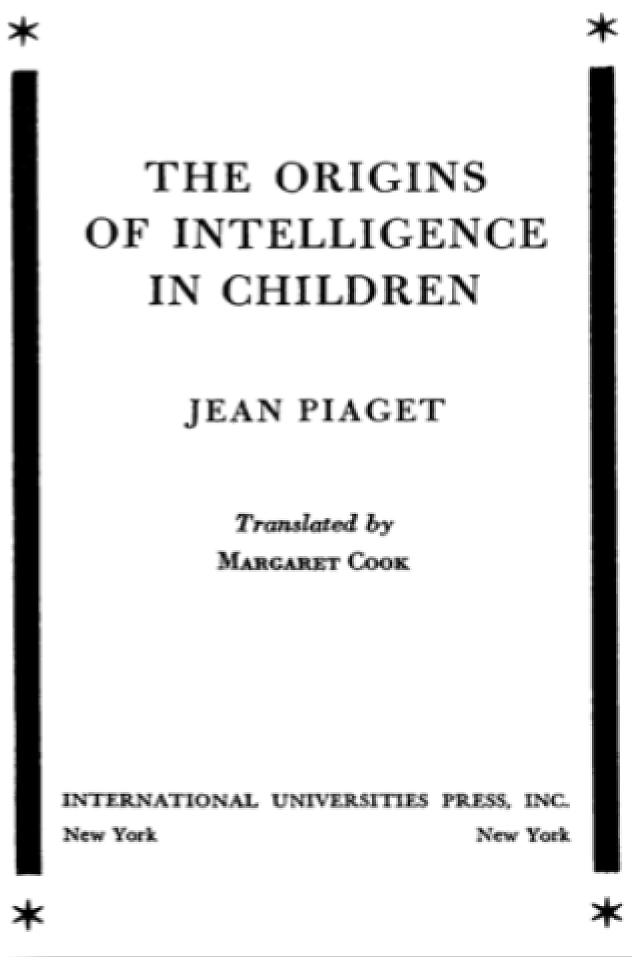
- Waismeyer et al 2012, Bonawitz et al. 2010.

Motor Development



Motor Development: Embodied, Embedded, Enculturated, and Enabling. Annual Review of Psychology
K. E. Adolph and J. E. Hoch

Travel Broadens the Mind



THE ORIGINS
OF INTELLIGENCE
IN CHILDREN

JEAN PIAGET

Translated by
MARGARET COOK

INTERNATIONAL UNIVERSITIES PRESS, INC.
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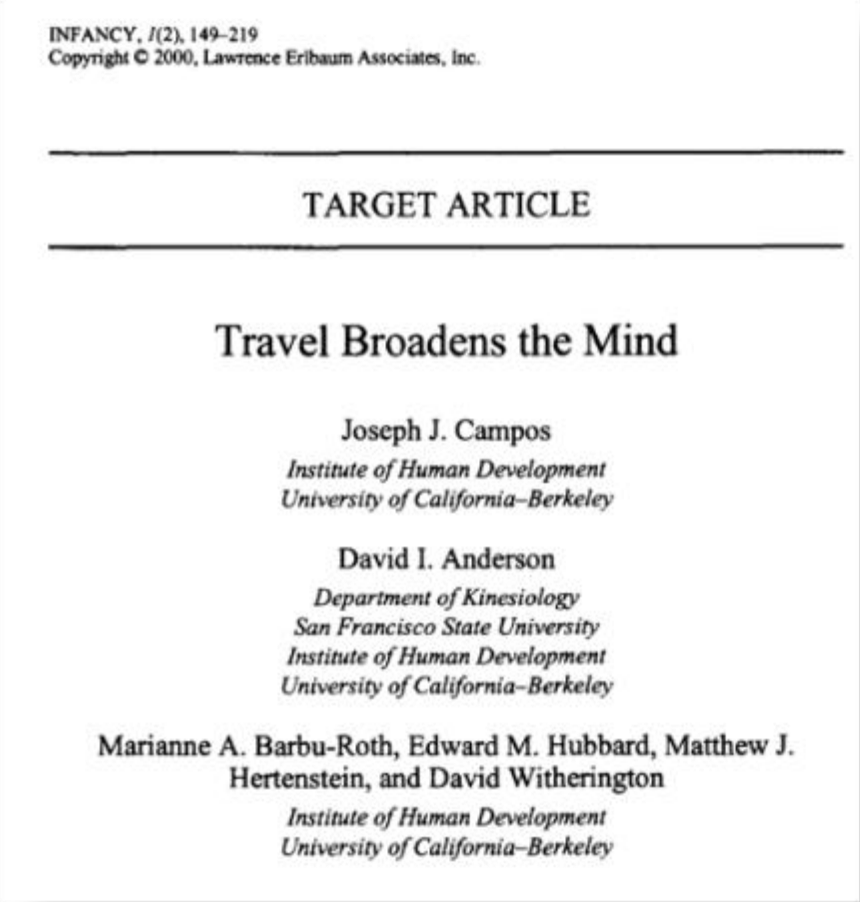

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TARGET ARTICLE

Travel Broadens the Mind

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Motor development as foundation and future of developmental psychology

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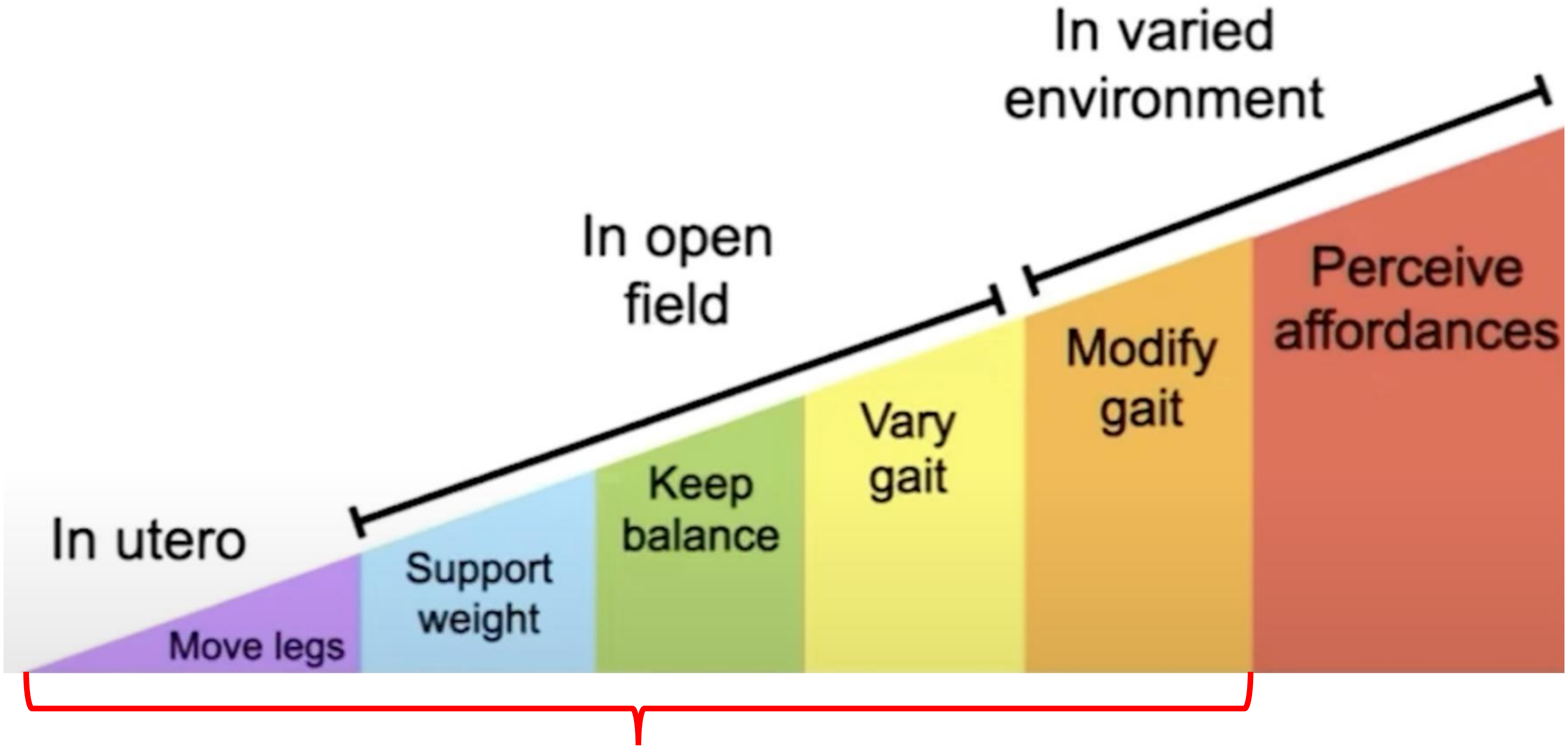
The study of how infants and children come to control their bodies is perhaps the oldest topic in scientific developmental psychology. Yet, for many years the study of motor development lay dormant. In the last two decades, however, there has been an enormous resurgence of interest. As at the time of the very beginnings of our field, the contemporary study of motor development is contributing both empirically and theoretically to the larger questions in development and especially to our understanding of developmental change. In this essay, I trace the course of the changing fortunes of motor development, evaluate where we have been, what we are doing, and speculate on some critical issues for the future. The purpose of this essay is to comment on the general themes and influences that have been a part of motor development's "rise-fall-and-rise-again" history. For a more comprehensive review of substantive topic areas in motor development, readers are referred to the authoritative treatment recently published by Bertenthal and Clifton (1998) and to the excellent monograph by Goldfield (1995).

are born with very little control over their
a year or so, they are able to sit, stand, walk,
objects, feed themselves, gesture, and even
s. A year later, toddlers are adept at running,
ing, riding a tricycle, and talking in simple
arents, these new motor skills are the most
ible changes in the first few years of life,
and commented on. For those interested in
mental processes, this sequential unfolding of

(1935) well-known and still contentious s
Jimmy and Johnny, and the Nancy Bayley
Study (1935). In 1946, Carmichael's
Psychology contained two seminal articles
and McGraw (1946), attesting to the th
motor studies in the field.

There were three important and related
golden age of motor development research
from these pioneers is their theoretical c

Components of Functional Walking



What we mistakenly call walking in robotics.

Young, Cole, and Adolph, 2024

Perceiving Affordances

- The Gibson Visual Cliff
- Designed to test when can babies correctly perceive affordances.
- Not the best way to run multiple experiments.
- Results often mis-interpreted.

Walk, Gibson, & Tighe (1957) Science; Gibson & Walk (1960) Sci Amer; Walk & Gibson (1961) Psych Monog; Gibson (1991) Odyssey

Perceiving Affordances

From K. Adolph's lab

Infants must learn to perceive affordances

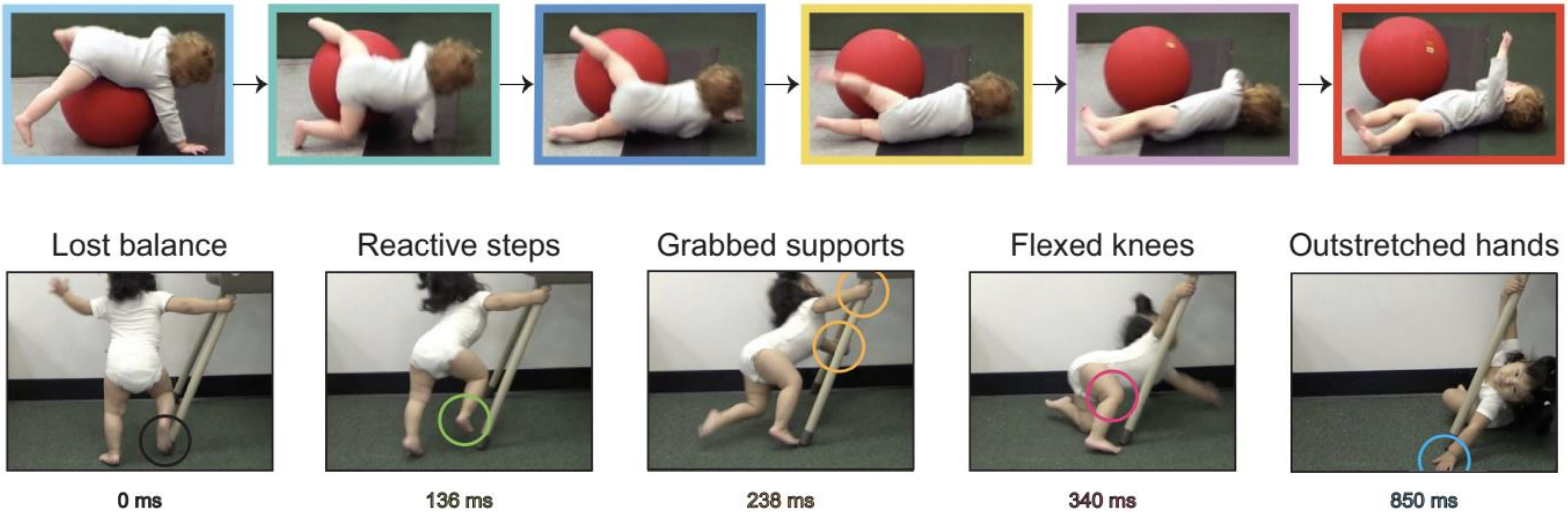
- Novice walkers do not perceive affordances.
- They get better and better with experience.
- What happens during the transition from crawling to walking?
- Behaviors in a changing body with changing skills in a changing world.

Image from Karen Adolph

What about precocial animals?

Images from Karen Adolph

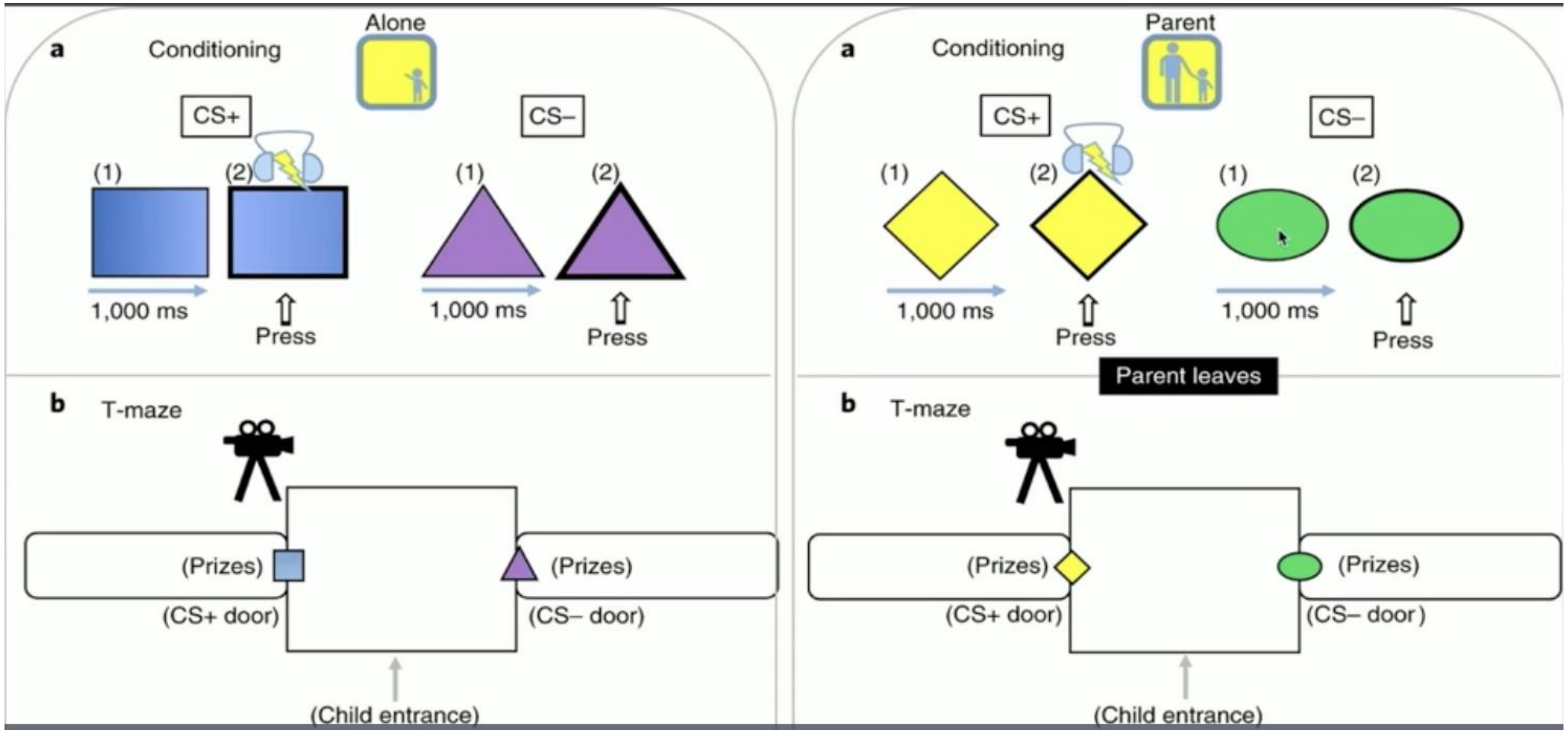
Learning by falling



The impact of errors in infant development: Falling like a baby,
Han & Adolph, Dev Science, 2020

The importance of caregiving

- Babies (not only human) take more risks when caregivers are around.



Love and Learning,
Tottenham et a. 2019, Nature Hum Beh

Slide by Allison Gopnik

Multiple Intelligences

- Exploration – Children
- Exploitation – Adults
- Care / Teaching - Elders

Discussion

- Is development diversity a condition for intelligence?
- Is the exploration/exploitation trade off unescapable?
- Is embodiment a feature or a bug?