Goal babbling as model for infants' early motor learning

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Fig. 1: A seven-day old neonate tries to reach for an object, image from (Rönnqvist & von Hofsten, 1994).

When infants learn to reach they have to coordinate hundreds of muscles in a continuously changing body. How do infants learn to coordinate their body under such challenging circumstances? In 1953, Piaget suggested that development is organized in distinct stages and that, at first, infants do not perform purposeful actions, which implies "that the early behavior of the neonate is essentially random and insensitive to contextual information" (Bertenthal, 1996). In that way, infants could initially discover relations between actions and their observable outcomes, and learn to coordinate their own body. Random exploration essentially corresponds to an exhaustive exploration which cannot succeed for many degrees of freedom because there are too many different ways to activate so many muscles. This substantially reduces the explanatory power of random "motor babbling" with respect to human learning. In fact, "recent research suggests that some re-thinking of [Piaget's] extreme position is necessary" (Bertenthal, 1996). Contrary to Piaget's suggestions, and the random motor babbling approach, infant studies have found conclusive evidence for coordinated behavior even in newborns. Infants to not move randomly when learning to reach. Rather, they attempt goal-directed movements already days after birth (von Hofsten, 1982). "Before infants master reaching, they spend hours and hours trying to get the hand to an object in spite of the fact that they will fail, at least to begin with" (von Hofsten, 2004).

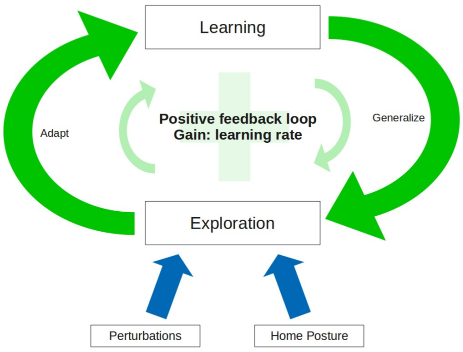

Fig. 2: Computational models reveal a positive feedback loop between exploration and learning that explains both the speed of learning and stage-like learning curves.

What is the purpose of these early goal-directed movement attempts? Are they an early exploitation of (innate) knowledge, or are they the very mechanism to learn successfully? Recent research in artificial learning suggests the latter. A recent concept named *goal babbling* (Rolf, et al., 2010) describes the bootstrapping of motor skills by means of early goal-directed exploration. We will discuss the relevance and explanatory power of this approach along three particular aspects. Firstly, it has been shown that goal babbling can deal with *many degrees of freedom*. Many motor tasks, like reaching, provide enormous redundancy: there are many different motor commands that have the same outcome, such as different arm postures that result in the same position of the hand. If there are multiple ways to achieve some behavioral goal, there is no inherent need to know all of them. Goal babbling focuses on just enough solutions to solve the task, which is possible even when too many degrees of freedom are involved to explore all solutions. Secondly, computer simulations (Rolf, et al., 2011) revealed that goal babbling allows for learning with a *speed that is comparable to human learning* (Sailer, et al., 2005). This speed is possible because goal babbling constitutes a positive feedback-loop: learning leads to an improved reaching attempt, which in turn leads to more effective learning. Thirdly, this positive feedback-loop can account for the apparently stage-like progress of infants' learning: a mathematical analysis (Rolf & Steil, 2013) of goal babbling revealed that the learning curves are inherently S-shaped. Initially there is not much progress, until the feedback-loop causes a very rapid acceleration of learning. From a distal perspective these learning curves can be seen as *emergent developmental stages*, which fits the dynamic system perspective of infant development (Smith & Thelen, 2003).

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