Chapter 83
A Neurorobotics Approach to Investigating Word Learning Behaviors

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ABSTRACT

This chapter presents two examples of how neurorobotics is being used to further understanding of word learning in the human infant. The chapter begins by presenting an example of how neurorobotics has been used to explore the synchrony constraint of word-referent association in young infants. The chapter then demonstrates the application of neurorobotics to free looking behavior, another important basic behavior with repercussions in how infants map visual stimuli to auditory stimuli. Neurorobotics complements other approaches by validating proposed mechanisms, by linking behavior to neural implementation, and by bringing to light very specific questions that would otherwise remain unasked. Neurorobotics requires rigorous implementation of the target behaviors at many vertical levels, from the level of individual neurons up to the level of aggregate measures, such as net looking time. By implementing these in a real-world robot, it is possible to identify discontinuities in our understanding of how parts of the system function. The approach is thus informative for empiricists (both neurally and behaviorally), but it is also pragmatically useful, since it results in functional robotic systems performing human-like behavior.

INTRODUCTION

Human infants are capable of incredible feats of learning and behavior from birth. These behaviors, such as the allocation of gaze, or the encoding of auditory and visual input over time, form the foundation for more complex learning abilities that manifest later in development. There are many approaches to investigating these behaviors, including behavioral studies, neurophysiology, and behavioral/cognitive modeling. However, until recently, few approaches have modeled these behaviors in a bottom-up fashion with the goal of understanding how neural circuits and bodily constraints combine to produce the behaviors. The neurorobotics approach attempts to do exactly

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this. Evidence is gathered about the maturity and function of neural circuits at play in an organism. This evidence is used to construct artificial neural circuits, which drive robotic bodies to produce the same behavior as the original organism.

The neurorobotics approach has the advantage that it can verify a model's correctness at multiple "vertical" levels of abstraction, from the level of individual neurons up to the level of overt behavior. To do so, a neurorobotics model takes into account knowledge and results from the many approaches investigating the behavior and neural mechanisms of human infants. A neurorobotic model that simultaneously addresses the results from all these approaches is an important existence proof for the plausibility and real-world functionality of the findings from each approach. It shows that findings from one approach do not contradict findings from another approach. This is because the neurorobotic model is a single system that satisfies both of them. Additionally, the model is constructed to be as accurate as possible in terms of neural implementation. This constraint makes neurorobotic models more useful than ad-hoc models for understanding certain aspects of the original organism, such as constraints caused by the specifics of the neural implementation. It also lends validity to results produced by the neurorobotic model, which can be used for predicting the behavior of the original organism in novel situations. A final advantage of neurorobotics research is that it produces functional robotic models of natural human-like behavior. These robots have real-world applications in areas that require human-robot interaction, such as personal assistance for the elderly or as therapies for children with developmental disorders. Natural behavior, especially language behavior, will make it possible for laypersons with no special training to take advantage of robots in everyday life in the near future.

This chapter presents two neurorobotic models related to word learning in human infants. The first model, *MultiHab*, was created to explore multimodal habituation. It was created to complement results from a set of studies performed on 2-month-olds by Gogate et al. (2009). In the original studies, infants were habituated to arbitrary audio-visual (word-object) pairings. The looking response of each infant was then measured in two test conditions. In one condition, the same audio-visual pairing was presented ("same"). In the other condition, the same audio-visual pairing was presented, but with one component substituted for a novel one ("switch"). The measured looking response was different between these two test conditions only for infants who were habituated to pairings where the audio-visual components were "synchronous." This constraint hints at the mechanisms responsible for infants' ability to perform this interesting behavior. *MultiHab* was proposed to better understand the synchrony constraint and its causes. The neural circuits are based on literature regarding the visuo-motor, auditory, and learning systems of 2-month-old infants. *MultiHab* was tested in a set of experiments that mimicked the infant experiments, but also tested a wider range of stimulus timings. The results of the neurorobotic experiments are discussed in context of the infant results.

The second model, *VisMotor*, is a more detailed model of the visuo-motor system, which was not fully implemented in *MultiHab*. The purpose of *VisMotor* is to understand the visuo-motor system, which controls looking behavior at the level of eye movements and fixations. Looking behavior is often used as a measure in infant studies. However, the neural underpinnings of looking behaviors are not well understood. Additionally, it is not clear what effect each eye movement/fixation has on aggregate looking behavior measures, such as are used in habituation studies. The eventual goal of this model is to elucidate the role of visuo-motor behavior in more complex infant experiments, such as those involving stimulus familiarity or multimodal biases. However, before engaging the more complex cases, it is necessary to have a strong footing in the baseline visuo-motor be-

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