The developing sense of agency:
Implications from cognitive phenomenology

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I. INTRODUCTION

How do children come to experience themselves as agents who can cause events in the world by acting? This ability—known as 'sense of agency'—cannot be taken for granted in infancy. Yet, somehow, it rapidly develops from infancy into childhood. Children's understanding of the causal efficacy of their own actions is of such sophistication that they can use their own actions as interventions to learn about the causal structure of the world. In other words, a sense of agency allows children to learn from interacting with their social and physical world in ways that would not be possible otherwise [1], and may thus be crucial for human cognitive development in general.

Contemporary cognitive neuroscience postulates neural-computational mechanisms for the sense of agency in adults that can inform developmental research into the early sense of agency and its development in infants. For instance, one of the most basic mechanisms believed to subserve the sense of agency in adults is rooted in learned sensorimotor contingencies. Given the importance of sensorimotor experience in infancy, assumed by many developmental psychologists [2], such a mechanism seems to provide a good starting point for research into the development of the sense of agency [3]. However, an extrapolation from adults' to infants' sense of agency mechanisms presupposes that this mechanism is indeed sufficient to explain sense of agency in both infants and adults. This is where the conceptual methods of cognitive phenomenology and the computational tools of developmental robotics can provide us with valuable insights. Cognitive phenomenological research can yield characterizations of the representational structure of the sense of agency [4], and developmental robotics can test the computational sufficiency of different candidate mechanisms for explaining those representational structures and how they can develop [5], [6]. In this presentation, we set out to illustrate the utility of this interdisciplinary approach.

II. CONCEPTUAL ANALYSIS OF THE COMPARATOR MODEL OF THE SENSE OF AGENCY

One of the most influential models put forth to explain the sense of agency is the 'comparator model' [7]. This model postulates a mechanism that can detect a match between the predicted sensory consequence of an action and the actual sensory feedback. When it does, an individual is presumed to experience a sense of agency [8]. This model was inspired by an explanatory mechanism of an organism's ability to distinguish self-produced from externally produced signals, which uses the comparison between efference and reafference signals as a cue to classify signals as being self-produced [9]. The comparator mechanism has been studied in the context of the sense of agency in behavioral and neuroscientific experiments in adults. These studies show that when a match between the predicted sensory consequence of an action and the actual sensory feedback occurs, adults indeed report experiencing a sense of agency, e.g. [10]–[12]. Consequently, empirical findings of infants' ability to detect sensorimotor regularities have been interpreted as a sign that a sense of agency was present [13], [14].

Given that infants cannot describe their experiential states, the question of what they experience remains difficult to tackle. A cognitive phenomenological analysis of what is required of a mechanism to explain a particular experience could clarify what can and cannot be concluded from the empirical data. Such an analysis can also be used to explore the sufficiency and explanatory value of the comparator model for the sense of agency. In particular, here we will argue that the comparator mechanism may lack the representational capacities required to produce the sense of agency. We furthermore note that the detection of a match does not always lead to a sense of agency.

As explained, a sense of agency is assumed to be experienced whenever the comparator mechanism detects a match between the predicted sensory consequence of an action and the actual sensory feedback. Although this detection may allow for functionally distinguishing self-produced from externally produced signals, it is not evident why and how a match would generate a sense of agency. After all, it may be a mere categorization mechanism that classifies signals as belonging to distinct classes of events without representing those events as 'caused by oneself' vs. 'caused by another'.

By building on the cognitive phenomenological assumption that experiential states have their qualitative character at least in part in virtue of their content (representing the world as being a certain way) [4], we are in a position to assess the explanatory sufficiency of the comparator model as an account of the sense of agency. For instance, the experience that 'my actions cause events' presupposes a representation of events as being *caused* by actions that are *mine*. The 'match' in the comparator mechanism lacks this, as it merely codes for an equality relation (i.e., equal(predicted, observed)), whereas the

representation of the content *my actions cause events* presupposes the representation of causal relations (e.g., cause(action, events)), ownership predicates (e.g., mine(actions)), and relations between them.

Moreover, even granting that the comparator mechanism would somehow have the expressive power of representing this content, it seems that the mapping to those representations cannot be defined solely based on the presence of a match. Consider the following two scenarios that demonstrate that the detection of a match between the predicted sensory consequence of an action and the actual sensory feedback does not always produce a sense of agency:

(1) *I make my hand into a fist, and hit the table.*

(2) *I look at a green wall, close my eyes, and re-open them.*
The comparator mechanism forms a prediction about the sensory consequence of the action, i.e hearing a sound for (1) and seeing a green wall for (2). Although in both scenarios there is a match between the predicted sensory consequence and the actual sensory feedback, the experiences that arise from them are qualitatively different. In the first scenario, we experience ourselves as causing the sound to occur. Conversely, in the second scenario, we do not experience ourselves as causing the wall to be green. Regardless of whether or not our feelings are accurate, the presence of a match does not yield a sense of agency in both situations. These scenarios demonstrate that a match (even granting representational capacity) only leads to the sense of agency when additional conditions are met. As these conditions are not considered in the comparator model, the postulated mechanism alone is insufficient to explain the sense of agency. Importantly, the issue that we raise is distinct from issues raised by others, which pertain to the degree of confirmation and scope of current models of the sense of agency [15].

Many questions, for both adult and infant research on the sense of agency, arise from the analysis above. What representational capacities are required for the sense of agency, and what type of mechanisms can develop these capacities? Furthermore, the different experiences that we have in the scenarios given above yield new topics of research, for instance to examine what the conditions are under which we experience a sense of agency? How do agents develop a model of themselves and the world that tells them what these conditions are? How does the mechanism map the sensorimotor and contextual cues onto the representational content? We propose that these questions can ideally be studied by developmental science and robotics. Developmental psychology and robotics could guide the quest of finding the mechanism of the sense of agency by posing constraints on plausible designs [5]. Thinking about the required representational contents for particular experiences provides us with a useful window into what mechanisms need in order to explain those experiences.

III. Conclusion

The development of the sense of agency is essential for understanding the causal structure of the world. Developmental psychologists have turned to the comparator model as a starting point for research into the development of the sense of agency. Our conceptual analysis shows that the mechanism postulated by the comparator model is insufficient to produce a sense of agency: The match lacks the capacity to represent the content of the experience 'my actions cause events'. Moreover, a match between the predicted sensory consequence of an action and the actual sensory feedback does not always lead to the sense of agency. This analysis shows that a mechanism that explains the sense of agency minimally requires the capacity for representing the content characteristic of sense of agency, as well as context-sensitivity to the conditions under which it is experienced. Moreover, the mechanism must be such that those properties can develop. Hence, a joint effort between researchers from cognitive neuroscience, cognitive phenomenology, developmental psychology and developmental robotics may be crucial to get a full scientific understanding of the developing sense of agency.

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