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Can infants' sense of agency be found in their behavior? Insights from babybot simulations of the mobile-paradigm

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ABSTRACT

The development of a sense of agency is essential for understanding the causal structure of the world. Previous studies have shown that infants tend to increase the frequency of an action when it is followed by an effect. This was shown, for instance, in the mobile-paradigm, in which infants were in control of moving an overhead mobile by means of a ribbon attached to one of their limbs. These findings have been interpreted as evidence for a sense of agency early in life, as infants were thought to have detected the causal action-movement relation. We argue that solely the increase in action frequency is insufficient as evidence for this claim. Computer simulations are used to demonstrate that systematic, limb-specific increase in movement frequency found in mobile-paradigm studies can be produced by an artificial agent (a 'babybot') implemented with a mechanism that does not represent cause-effect relations at all. Given that a sense of agency requires representing one's actions as the cause of the effect, a behavior that is reproduced with this non-representational babybot can be argued to be, in itself, insufficient as evidence for a sense of agency. However, a behavioral pattern that to date has received little attention in the context of sense of agency, namely an additional increase in movement frequency after the action-effect relation is discontinued, is not produced by the babybot. Future research could benefit from focusing on patterns whose production cannot be reproduced by our babybot as these may require the capacity for causal learning.

1. Introduction

The development of a *sense of agency*, the feeling that one's actions cause events, enables infants to learn from interacting with the world in ways that would not be possible otherwise. Developing a sense of agency allows for differentiating one's own efficacy from someone else's, which is an important step for social-cognitive skills such as imitation, theory of mind, and perspective-taking (Burrows, Laird, & Uddin, 2016; David, Newen, & Vogeley, 2008; de Guzman, Bird, Banissy, & Catmur, 2016; Jeannerod, 2003; Rochat, & Striano, 2000). Moreover, learning about one's own efficacy, and actively using this efficacy to intervene and discover causal structures in the world benefits causal learning (e.g., Lagnado, & Sloman, 2002; Pearl, 2000; Schulz, Gopnik, & Glymour, 2007; Steyvers, Tenenbaum, Wagenmakers, & Blum, 2003). Once infants have developed a sense of agency and know that their actions can cause effects, they can change and terminate their behavior to actively explore whether they cause specific effects through intervention. Since developmental science often obtains meaningful information from behavioral measures rather than for example neural measures or verbal report, developmental scientists have attempted to infer the existence of a sense of agency in young infants based on behavioral patterns. In this paper, we argue that the sense of agency cannot be inferred from the behavioral patterns previously taken as evidence. To elucidate our theoretical argument, we supported our line of reasoning with a simple computer simulation that serves as a proof of concept.

Previous studies on the developing sense of agency have shown that 2- to 4-month-old infants increase the frequency of actions that yield an interesting or pleasant effect (e.g., Rochat, & Striano, 1999, 2000). One experimental paradigm in which the behavioral pattern of increasing the frequency of actions that are followed by an effect has been observed is the classic mobile-paradigm (Rovee & Rovee, 1969), in which infants, typically around 3 months of age, lie in a crib with a mobile hanging above their head. In the experimental phase, a ribbon connects the mobile to one of the infant's limbs, and movement of this limb causes the mobile to move ('connect phase'). The infants' movement behavior in this phase is then compared to their baseline movement frequency before the ribbon was attached ('baseline phase'; e.g.,

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Heathcock, Bhat, Lobo, & Galloway, 2004, 2005; Rovee-Collier, Morrongiello, Aron, & Kupersmidt, 1978; Watanabe, & Taga, 2006, 2011), to their behavior after switching the ribbon to another limb (e.g., Rovee-Collier, et al., 1978; Watanabe, & Taga, 2009), or to their behavior following reconnection of the ribbon after a delay (e.g., Heathcock, Bhat, Lobo, & Galloway, 2005; Rovee-Collier, et al., 1978; Rovee-Collier, Sullivan, Enright, Lucas, & Fagen, 1980, Watanabe, & Taga, 2006). Although this paradigm is predominantly known for the insights it provided into infants' memory capacities (e.g., Cuevas, Learmonth, & Rovee-Collier, 2016; Hayne, & Findlay, 1995; Rovee-Collier, et al., 1978; Rovee-Collier, et al., 1980), it has been used in various research domains, including causal learning and the developing sense of agency in young infants (Kelso, 2016; Watanabe, & Taga, 2006, 2009, 2011; Watson, 1972, 1981).

Watson, for instance, reported that 2-month-old infants increased their movement frequency when their leg was connected to the mobile by the ribbon (Watson, 1972) and interpreted this behavior as a sign that infants experienced causal control over the mobile movement (Watson, 1981). More recently, these findings were replicated and extended by Watanabe and Taga (2006, 2009, 2011). Infants again increased their movement frequency when connected to the mobile, but while the 2-month-old infants showed more movement for all limbs when the mobile was connected, the increased frequency of movements became increasingly specific to the connected limb for 3- and 4-month-old infants (Watanabe & Taga, 2006), excluding the possibility of a general arousal effect. Watanabe and Taga (2011) interpreted their findings as evidence that infants learned the causal relation between the self-produced movements and their effects on the environment, and that the change in the infants' behavior may be a result of a sense of self-agency. Recently, Kelso (2016) supported this interpretation, stating that when infants' spontaneous movements lead to mobile motion, movement frequency increases as they discover themselves as causal agents. Based on these behavioral patterns, researchers have thus concluded that infants already in the first few months of life experience a sense of agency.

Although infants' behavioral patterns may indicate that they have learned the causal relation between movements and their effects, it is not self-evident that this behavior is *necessarily* the product of an underlying causal model. While from the perspective of the researcher we objectively know that the infants indeed cause the effect to happen, these young infants may not actually share this representation of the situation. In the context of learning new actions, for instance, Kenward (2010) argued that we should not exclude the possibility of reinforcement learning, leading to actions to be carried out habitually without a representation of the action-effect relation. Since the underlying mechanism of this behavior is unobservable and infants' cognitive capacities are not yet as developed as they are in adults, the interpretation of infants' behavior is not straightforward. Rather than only considering what is happening objectively, the interpretation needs to also take into account whether a displayed behavior necessitates the required representations and processes for the postulated cognitive capacity. Such an approach prevents researchers from over-interpreting infants' behavior and provides a more nuanced view on infants' developmental trajectory by acknowledging what representations infants can build at a given moment in their development.

Here, we address this issue in the context of the sense of agency. We evaluate whether an increased action frequency in the connect phase necessarily implies that infants have built a causal representation of their action and its effects. Putting forth the behavioral data patterns found in the mobile-paradigm as proof for a sense of agency would mean that these data patterns must *exclusively* be produced by a mechanism that has the capacity to generate the requisite causal representation, and not by any other cognitively plausible mechanism. To investigate what underlying mechanisms are capable of producing certain behaviors, computer simulations serve as a useful tool; in a simulation the mechanisms are precisely specified and can easily be manipulated. In this particular case, we used a computer simulation to demonstrate that the increase in limb-specific movement frequency found in mobile-paradigm studies can be accounted for by a non-representational mechanism – a mechanism that *cannot* internally represent cause-effect relations at all – and consequently cannot serve as evidence for a sense of agency. This simulation is not built as a computational model of infant cognition, but serves as a tool to demonstrate whether the behavior can, in principle, be generated by a more parsimonious or even an insufficient mechanism. To that end, we implemented a non-representational learning mechanism in our simulated infant, henceforth 'babybot'. As we made the babybot unable to learn or represent cause-effect relations, any infant behavior that it reproduces is insufficient to be taken as evidence for the presence of causal representations, and hence a sense of agency. While the simulated learning mechanism might explain infants' behavior, this simulation does not aim to test whether this is *the* or the *only* mechanism at work during the mobile-paradigm experiments. Rather, our goal was to challenge the causal interpretation of the observed behavior in infants. We thus assess the claim that the movement increase in the connect phase can only be generated by a causal learning mechanism.

We compared the babybot's behavior to the behavior of infants in the mobile-paradigm (see Fig. 1). We focused specifically on the reproducibility of two patterns of behavior that have previously been interpreted as evidence for having learned about one's own efficacy: (1) the increased movement frequency in the connect phase, and (2) the specificity of this increase to the connected limb. We also examined the babybot's behavior after disconnecting the ribbon. In mobile-paradigm experiments with infants, an additional increase of movement frequency is sometimes observed in this disconnect phase (e.g., Alessandri, Sullivan, & Lewis, 1990; Heathcock, et al., 2004; Rovee-Collier, et al., 1978). The presence of this behavior as well as its potential interpretation has been ignored in previous literature on the developing sense of agency. In fact, the disconnect phase has occasionally even been omitted from the paradigm when used and interpreted in the context of a sense of agency (e.g., Watanabe & Taga, 2011), although we believe it may contain useful information regarding infants' representation of the situation as it could indicate that infants are trying to reproduce the effect and, in fact, did learn the causal relation.

2. Simulation setup

2.1. Babybot

We simulated a simplified version of the mobile-paradigm

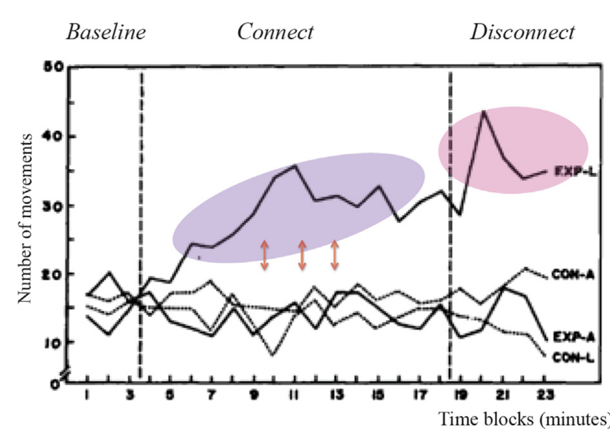

Fig. 1. Empirical data found in a mobile-paradigm experiment with 3-month-old infants (Rovee-Collier, et al., 1978; figure adapted). When the infant's leg was connected, an increase of movement frequency (purple) for legs compared to arms (arrows) was observed. After disconnecting the ribbon, an additional increase took place (pink). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)