Open Peer Commentaries

on Yuki Sato et al.'s "Investigating Extended Embodiment"

Goal-directed Action and Eligible Forms of Embodiment

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> Upshot • The target article's findings on the focus of attention in extending an agent's body schema are consistent with those in developmental psychology and neuroscience on goal-directed action. The consequences of these findings are that embodiment can be extended in a variety of ways, not all of which require direct physical manipulation.

« 1 » The core thesis in this paper is that the extension of an agent's embodiment through the use of a tool, and the subsumption of that tool into the body schema of the agent, is necessarily accompanied by a shift in the focus of attention by that agent from a tool to the object with which the tool interacts. The empirical studies also suggest that this is a sufficient condition.

« 2 » This commentary makes two observations: (a) that the thesis being put forward is consistent with findings in developmental psychology & neuroscience regarding the goal-oriented anticipatory nature of action, and (b) that there are significant implications insofar as extension of body schema does not entail a specific form of interface between agent and tool, allowing a variety of modes of body augmentation.

« 3 » The authors conclude in §40 that "paying attention to the task to be performed instead of the tool is essential for a tool to be considered part of the body schema." This conclusion is consistent with evidence from different fields of research that suggests that the movements of biological organisms are organized as actions that are initiated by a motivated agent, defined by goals, and guided by prospective information (von Hofsten 2004, 2009, 2013: 255–279; Vernon, von Hofsten & Fadiga 2010). For example, when performing manipulation tasks or observing someone else performing them, subjects fixate on the goals and sub-goals of the movements, not on the body parts, e.g., the hands, or the objects. However, this happens only if a (goal-directed) action is implied. When showing the same movements without the context of an agent, subjects fixate on the moving object instead of the goal. For example, Johansson and colleagues (Johansson et al. 2001) describe an experiment that shows that people fixate on key landmarks such as the point where an object is grasped, the target location of object, and the support surface, but never on their hand or the moving object. This shows that gaze supports predictive motor control in manipulation and provides evidence for the prospective goal-directed nature of action. A related paper (Flanagan & Johansson 2003) shows the same behavior when people observe object manipulation tasks. Similarly, evidence from neuroscience shows that the brain represents movements in terms of actions, even at the level of neural processes. For example, a specific set of neurons, mirror neurons, is activated when perceiving as well as when performing an action. (Gallese et al. 1996; Rizzolatti et al. 1996; Rizzolatti & Fadiga 1998; Rizzolatti & Craighero 2004). These neurons are specific to the goal of actions and not to the mechanics of executing them: they are not active if there is no explicit or implied goal associated with the movement associated with the action.

« 4 » If the shift in focus of attention when using a tool is sufficient for extending an agent's embodiment and body schema, this opens up a wide variety of possible ways that the agent can interface with the tool in questions. Specifically, it admits structural coupling (Riegler 2002), the weakest form of embodiment (Ziemke 2001, 2003; Dautenhahn, Ogden & Quick 2002), as the precondition for embodiment prior to the body augmentation. In turn, this allows the use of tools that are not directly manipulated by forcible physical contact, such as a hand-held cane or screwdriver, but are controlled by other means. In particular, the tool interface does not have to be structurally, kinematically, or dynamically homomorphic with the tool effector, just as, e.g., the controls of a mechanical digger are not intuitively related to the movement of the bucket at the end of the digger's arm. Consequently, the extension of embodiment and body schema can be effected by any means that are capable of controlling the device, including brain computer interfaces (as the authors suggest in §47 where they refer to "new human interface devices … to artificially vary the body boundary"). By extension, the link between the agent and the tool, i.e., the interface, does not have to be proximal and can be distal, as in the case of a telecheric device, and therefore the augmented or extended embodiment can be non-local. The implication of this argument is that the concept of embodiment and body schema is plastic: it applies to any form of body augmentation that is assimilated into the sub-attentive component of the agent's actions.

Received: 15 October 2013
Accepted: 21 October 2013

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Tool-use Leads to Bodily Extension, but not Bodily Incorporation: The Limits of Mind-as-it-could-be?

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> Upshot • Sato and colleagues make use of an innovative method that combines robotics modeling and psychological experimentation to investigate how tool use affects our living and lived embodiment. I situate their approach in a general shift from robotics to human-computer interface studies in enactive cognitive science, and speculate about the necessary conditions for the bodily incorporation of tools.

Putting subjectivity back into the sensorimotor loop

« 1 » Enactive cognitive science (ECS) is founded on the theory that life and mind are integrated within a process of sense-making (Thompson 2007). Following its first extensive presentation by Francisco Varela, Evan Thompson and Eleanor Rosch (1991), the paradigm of enaction was often loosely grouped with embodied, sensorimotor, and dynamical approaches to cognition, while its explicit phenomenological commitments were mostly ignored. And whereas these latter approaches rapidly led to the development of new styles of doing cognitive science and robotics (Wheeler 2005; Clark 2008; Kelso 1995), specifically enactive research continues to face unique challenges today. For if we accept that cognition is a form of sense-making, and that sense-making is the generation and appreciation of meaning from a point of view, then ECS – in contrast to most science and engineering methods – has to place living and lived subjectivity at the center of all its endeavors (Froese 2011).

« 2 » There are therefore some unique methodological challenges for ECS. While embodied and dynamical approaches can be satisfied with AI and robotics to do a lot of their theoretical work (e.g., Pfeifer & Scheier 1999; Beer 2000), enactive AI is specifically confronted by the profound problem of how to design a *sense-maker* – something for which we still lack theoretical and practical knowledge (Froese & Ziemke 2009). Given this impasse, it was to be expected that ECS would shift its methodological focus from constructing and analyzing artificial agents to phenomenological investigations of human experience (Froese 2007). However, there is still plenty of room for innovative use of technology.

« 3 » One of the most resourceful developments in this direction is a hybrid methodology that retains the idea of constructing new technical systems, but for the purpose of investigating how tool use – via its effects on our living embodiment – modulates our lived experience (Froese, Suzuki, Ogai & Ikegami 2012). In analogy with artificial life's objective to use technology to explore life-as-it-could-be, we can refer to this field as "artificial embodiment" and define its aim as mapping out the space of "mind-as-it-could-be."

« 4 » The authors of the present target article, Yuki Sato, Hiroyuki Iizuka, and Takashi Ikegami, make a valuable contribution to this cross-disciplinary method by investigating the phenomenon of extended embodiment – currently a hot topic (Thompson & Stapleton 2009) – by bringing together insights from both robotics modeling and psychological experimentation. They thereby join a new generation of enactive researchers who are just as interested in the dynamics of artificial agents as they are in the sense-making of humans, often relating these two areas in a mutually informing manner by making use of custom-built human-computer interfaces (e.g., Rohde 2010; Iizuka, Ando & Maeda 2009; Suzuki, Wakisaka & Fujii 2012; Suzuki, Garfinkel, Critchley & Seth, in press). In the following, I situate the work by Sato et al. in this wider context. I begin by clarifying their method, and conclude by deriving a new working hypothesis from their results.

Tool use as a method to investigate mind-as-it-could-be

« 5 » While conducting a study of the experiential effects of using a sensorimotor substitution device (Froese, McGann, Bigge, Spiers & Seth 2012), I started working out a basic methodological scheme for an enactive approach to consciousness research based on human-computer interfaces (HCI). This scheme is nicely illustrated by the series of psychological experiments by Sato and colleagues (Figure 1).

« 6 » We can see this scheme at work in the study by Sato et al. as follows. First, they completed the methodological cycle in the domain of artificial life. They synthesized an evolutionary robotics model, analyzed its emergent dynamics, and formulated a hypothesis, i.e., that tool-based extension of bodily sensitivity is correlated with the regularity of the user's movements (§28). To test this hypothesis of lived bodily extension properly, they then conducted a psychological experiment on users' experience. They

1 | synthesized a simplified real version of the single windmill tool to be used with a stick,
2 | allowed the participants to become skilled users,
3 | analyzed the resulting user experience – albeit measured indirectly via objective success, and
4 | received a partial confirmation of their hypothesis.

« 7 » They then embarked on the methodological cycle again. They

1 | constructed a more accurate version of the double-windmill tool,
2 | allowed participants to become sufficiently skilled,
3 | assessed their experience, and
4 | formulated a novel hypothesis.

More specifically, in contrast to their initial assumption, they found that *objective success at the task is not an appropriate indirect measure of the lived experience of bodily extension*. Rather, strong and continuous coupling between user and tool seems to be more important to shifting their attention away from the tool (§37). This hypothesis