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Embodied cognition: dimensions, domains and applications

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Abstract

This article is intended as a response to Goldinger et al. and to all those, an increasing minority in the sciences, who still belittle the contribution of embodied cognition to our understanding of human cognitive behaviour. In this article (section 1), I introduce the notion of embodiment and explain its dimensions and reach. I review (section 2) a range of embodied cognition theories and highlight the principles and criteria on which they rely or draw from. I focus (section 3) on three crucial empirical domains in which an embodied perspective has driven novel insights about the relationship between mind and cognition. I argue that embodiment is not just a philosophical mantra empty of empirical content. I draw attention (section 4) to some of the recent ways in which principles underlying embodied cognition have begun to be applied in different fields (contemporary psychology). I review some of these interventions and suggest that discussing these applications not only provides additional evidence against any poverty claim but can also help moving the field forward in important ways. Contra Goldinger et al., I therefore conclude (section 5) that embodied cognition is a very fruitful research programme for the empirical sciences and that can adequately explain many aspects of human cognitive behaviour.

Keywords

Embodiment, cognitive science, cognitive psychology, human cognition, philosophy of mind

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1. Introduction

In a recent article, Goldinger et al. (2016) have argued that 'for the vast majority of classic findings in cognitive science, embodied cognition offers no scientifically valuable insight' (p. 959). In particular, these authors claimed that 'the theory has no logical connections to the phenomena, other than some trivially true ideas and that beyond classic laboratory findings, embodiment theory is unable to adequately address the basic experiences of cognitive life' (Goldinger et al., 2016, p. 959).

In their article, Goldinger et al. (2016) distinguish between what they call 'mild embodiment' (the view that 'all cognitive experiences are grounded in the sensory and motor contexts of their occurrence' – Goldinger et al., 2016, p. 962) and 'radical embodiment'(the view that asserts 'that mental representations are an empty and misguided notion' – Goldinger et al., 2016, p. 962). On the basis of a subsequent detailed analysis (based on that distinction) aimed at individuating the limitations and problems of the abovesaid research programme, the authors go on to claim that embodied cognition as a research paradigm 'is theoretically vacuous with respect to nearly all cognitive phenomena' (Goldinger et al., 2016, p. 961).

In addition, Goldinger et al. (2016) also claim that 'embodied cognition cannot replace cognitive psychology, nor can it illuminate a path toward unifying myriad branches of psychology' (p. 961) and, more importantly, that for nearly all classic topics it is almost impossible to find 'logical or empirical support for embodied cognition' (p. 964). To confirm this claim, the authors examine nine classic research domains (ranging from concepts and prototypes and priming

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effects to face perception, word frequency and sentence processing) that allegedly demonstrate that embodied cognition has nothing interesting or meritorious to say about standard examples of research from cognitive science.

This review article is intended as a response to Goldinger et al. (2016) and to all those, an increasing minority in the sciences, that still belittle or trivialise the contribution of embodied cognition to our understanding of human cognitive behaviour. There are three central claims being made against Goldinger et al. (2016) here: (a) that actually lots of embodied cognition work has produced strong results for the empirical sciences and is not therefore vacuous at all; (b) that by artificially dividing the field into only ‘mild’ and ‘radical’ embodiment, Goldinger et al. (2016) miss out some of the most plausible, powerful and promising views that more adequately describe many aspects of human cognitive behaviour; and (c) that Goldinger et al. (2016) rely on an overly conservative and restrictive understanding of what counts as cognition, that this understanding should be replaced by a broader one, which is exemplified by the examples I discuss in this article, and that this more liberal understanding is instrumental to appreciate the contribution of embodied cognition to cognitive science.

Embodied cognition is a growing research programme in cognitive science that emphasises the formative role the environment plays in the development of cognitive processes. Advocates of embodied cognition (such as Anderson, 2003) take as their theoretical starting point the idea that cognitive processes are deeply rooted in the body’s interactions with the world. Embodied cognition theorists therefore aim to explain the full range of perceptual, cognitive and motor capacities we possess as capacities that are constitutively dependent upon aspects of an agent’s body. In recent years, the terms ‘embodied cognition’ or ‘embodiment’ have been used interchangeably to refer to a wide range of ideas and approaches that range from minimal to radical embodiment, and encompass a number of positions in between.

More specifically, these terms have been used to describe either standard claims about how bodily actions or movements provide a format for neuronal representations (Goldman & de Vignemont, 2009) and help reduce computational load (Clark, 2008; Wheeler, 2005), or more radical proposals such as the idea that sensorimotor know-how is a constitutive part of perceptual experience (O’Regan & Noë 2001), the thought that phenomenal consciousness supervenes on the whole embodied organism in dynamic interaction with the environment (Thompson & Varela, 2001), the belief that social sensorimotor interactions and social pattern of experience can be constitutive parts of social cognition (Di Paolo & Thompson, 2014; Froese & Di Paolo, 2011; Torrance & Froese, 2011) or the thought that living systems are autopoietic (self-contained, self-organising) systems (Maturana et al., 2005).

In this article, I review a range of embodied cognition theories and highlight the principles and criteria on which they rely or draw from (section 2). This is instrumental to build an informative spectrum, a taxonomy, through which one can classify such theories and better understand their relations.

Having done this, I discuss (section 3) three empirical domains (vision, robotics and sport psychology) where research on embodiment has shed new light on the relation between mind, brain and cognition.[1] I demonstrate that such research is crucially important to contemporary cognitive science and therefore argue (against Goldinger et al., 2016, poverty claim) that the notion of embodiment is not just a ‘philosophical mantra’ empty of empirical content. I also claim that Goldinger et al. (2016) operate with a very restrictive understanding of cognition and that the examples I discuss here show that we necessarily need a more encompassing and liberal characterisation of it.

I then draw attention (section 4) to some of the recent ways in which principles and tenets underlying embodied cognition have begun to be applied in different fields (in contemporary psychology). I briefly review some of these interventions and practices and suggest that discussing and embracing these applications (not only attests to the power of research on embodiment) but can also help moving the field forward in important and unexpected ways. I claim that this discussion is also instrumental to show the significance of embodied cognition outside of the philosophical arena. Contra Goldinger et al. (2016), I therefore conclude (section 5) that embodied cognition is a very fruitful research programme for the empirical sciences and that can adequately explain many aspects of human cognitive behaviour.

2. Varieties of approaches to embodied cognition

Varela et al. (1991) were among the first to propose the ‘embodied cognition’ approach in cognitive science. Through a cross-fertilisation of disparate fields of study, their book explored the connections between phenomenology, science, Buddhist practices and human cognition. The book became so influential in the literature that we can probably say that – in one way or another – all modern embodied cognition theorists can be considered as interpreters or continuators of Varela’s initial proposal.

Embodied cognition theorists (such as Clark, 1999; Gallagher, 2005; Rowlands, 2006; Shapiro, 2007; Sutton et al., 2011) typically study the role the body plays in cognition.

What does it mean that cognition is embodied? A rough, very general preliminary answer comes from R. A. Wilson and Foglia (2011), who write

> cognition is embodied when it is deeply dependent upon features of the physical body of an agent, that is, when aspects of the agent's body beyond the brain play a significant causal or physically constitutive role in cognitive processing.

Embodiment is the idea that the brain is not the exclusive cognitive resource we possess to solve problems (A. D. Wilson & Golonka, 2013). So, in embodiment the body is

> an open spatio-temporal horizon, a place of opportunities for action and discovery, a dynamical boundary that defines the self and world in processual, relational, and reciprocal terms, i.e., as elements of a precarious stability that emerges from a context of continuous unfinished negotiation between organism and environment. (Cappuccio & Ilundáin-Agurruza, in press, p. 4)

Embodied cognition has, at least, five major tenets or principles. First, embodied cognition is anti-internalist in character. On Fodor's (1980) methodological solipsism, which is probably the most famous form of internalism in contemporary philosophy, the world is just a source of input to the true cognitive system which is located in the head, and the body is simply a courier system for sensory and motor messages.

> In place of the resulting classical cognitivist assumption that perception, thought, and action must be temporally distinct and theoretically separable embodied cognition theorists thus want us to think of cognition as essentially a matter of change in time and to acknowledge the spread or distribution of cognitive states and processes across the porous and metaphysically insignificant boundaries of brain, body, and world. (Sutton, 2015, p. 416)

This means that second, embodied cognition attempts to explain cognition as relying heavily or constitutively on bodily properties. Third, rather than conceptualising cognition as the churnings of a brain disincarnated from its body and its environment, embodied cognition explains the content of cognition by appealing to the nature of the body containing the brain. Fourth, instead of viewing cognition as starting with stimulation of afferent nerves and ending with signals to efferent nerves, embodied cognition conceives cognitive processes or states as actively extending into the environment in which the organism is situated (Shapiro, 2007). Fifth, and related to fourth above, embodied cognition affirms that cognition can often be off-loaded to the environment.

As it should be clear from the introduction (section 1), embodied cognition is a broad church and comes in many different varieties (Kiverstein & Clark, 2009). In this section, following Gallagher (2011), I discuss a range of embodied cognition theories, and highlight which principles and criteria they rely or draw from. The goal of this general preliminary discussion is to build an informative spectrum which can be used to roughly classify the different approaches or theories produced so far and to better understand their tenets and mutual relations. This taxonomy is important because it allows me to show that Goldinger and colleagues' (2016) understanding of embodied cognition theories is trivial, erroneous and quite superficial.

I start my discussion by briefly summarising a minimally embodied approach to cognition recently proposed by Goldman and de Vignemont (2009); see also Goldman (2012) – this approach is exclusively presented in this context as an example of claims about embodiment that most researchers (even those sceptic about the power of embodied cognition like Goldinger et al., 2016) could probably accept; proceed with an analysis of fully embodied theories (such as Clark & Chalmers, 1998) that argue for the crucial (constitutive) role of extra-neural structures in shaping up cognitive processes; and finish up this section by presenting a wide spectrum of more radical approaches to embodiment (falling under the umbrella of enactivism, more on which below), that are antirepresentationalist and anticomputationalist in character.

2.1. Minimal embodiment

Goldman and de Vignemont (2009) ask us to reflect on how we should understand embodied cognition and on what are the most promising ways of characterising it. Their starting point is that almost everything that is important to human cognition takes place within the brain. The brain is, they write, 'the seat of most, if not all, mental events' (Goldman & de Vignemont, 2009, p. 154). Goldman and de Vignemont (2009) then (rather oddly) define embodied cognition as not comprising the brain:

> embodiment theorists want to elevate the importance of the body in explaining cognitive activities. What is meant by body here? It ought to mean: the whole physical body minus the brain. Letting the brain qualify as part of the body would trivialize the claim that the body is crucial to mental life.[2] (p. 154)

Not only do Goldman and de Vignemont (2009) ask us to remove the brain from the body, but they also argue we should isolate the body from the environment and understand it literally that is 'not in relation to the situation or the environment in which the body is embedded' (p. 154). In other words, Goldman and de Vignemont (2009) claim that real-time actions and bodily-environmental loops (such as agent-object coupling, skills and expertise and other various embodied activities) are not decisive for constituting cognitive processes. In placing so many constraints on how we ought to understand embodied cognition and in isolating the body from both the brain and the environment, Goldman and de Vignemont (2009) end up defending a minimal approach to embodied cognition that many embodied cognition theorists (radical and less radical) would probably not recognise as truly and genuinely embodied.

The reason why I discussed Goldman and de Vignemont's (2009) approach is that the discussion of their work allows us to better understand how their account differs from truly and fully embodied views, which I present next.

2.2. Full embodiment

A number of theorists (e.g., Clark, 2008; Rowlands, 2006; Sutton, 2007, among others) have explicitly described embodiment as a means through which extra-neural (bodily and environmental) structures come to actively shape and forge cognitive processes. Among these theorists, philosopher Andy Clark (1997, 2001, 2008) is probably the one who has spent more efforts in articulating this idea.

Clark argues that the body plays an important role as part of the extended mechanisms of cognition (Clark & Chalmers, 1998). On his account, known as the Extended Mind Thesis (EMT henceforth), cognition doesn't exclusively take place inside the biological boundary of the individual but, on the contrary, can arise in the dynamical (real-time) interplay between neural structures, body and world. Clark therefore claims that the cognitive processes that make up our minds can reach beyond the boundaries of individual organisms to include as proper parts aspects of the organism's physical and socio-cultural environment (Kiverstein et al., 2013). In other words, structures and processes located outside the human head can become part of the machinery of cognition. This claim, on Clark's view, applies to enduring states as well as to transient processes.

EMT is often depicted as flowing naturally from functionalist views concerning the 'multiple realizability' of cognitive processes and some EMT theorists (e.g., Wheeler, 2005) are, in general, quite sympathetic to functionalist and mechanistic accounts of the mind in that 'they stress that intra-cranial (neuronal, usually organic) and extra-cranial (non-neuronal, possibly artificial) components and processes have in principle the same capability to realize cognitive processes and produce cognitive states' (Cappuccio & Ilundáin-Agurruza, in press, p. 9). Indeed one strand of argument for EMT is based on the so-called parity principle (PP), which states,

> If, as we confront some task, a part of the world functions as a process which, were it done in the head, we would have no hesitation in recognizing as part of the cognitive process, then that part of the world is (so we claim) part of the cognitive process. (Clark & Chalmers, 1998, p. 2)

In brief, PP tells us that a state may count as a belief, in part, on the basis of the causal role it performs. An illustration of this principle is the famous case of Otto and Inga discussed by Clark and Chalmers (1998), where the differences between Inga's biological and Otto's artificial memory are deemed to be irrelevant to the cognitive task of retrieving information about the location of the Museum of Modern Art in New York (see Kiverstein & Farina, 2011, for an extensive discussion of this point).

Significant objections have been moved against EMT (see Adams & Aizawa, 2001; Rupert, 2009; Sprevak, 2009). EMT, for instance, has been accused to confuse the claim that 'some problem-solving behaviour is causally dependent on a part of the external environment for the claim that a part of the external environment can form a part of a cognitive process' (Farina, 2010, p. 227). This is the causal-constitutional conflation (also known as constitution/coupling fallacy Hurley, 2010), which points to the problem of how exactly to draw the boundaries of a cognitive system in a way that ensures the constitutive contribution of artefacts or other individuals.

EMT theorists have developed a number of responses to deal with the constitution/coupling fallacy. Menary (2007) and Kiverstein and Farina (2011), for instance, attempted to formulate a diachronically based version of EMT, which delivers metaphysical constitution claims about current cognitive states and processes via diachronic explanations. Other theorists (such as Clark, 2010, and Sutton et al., 2011) more explicitly highlighted the need to go beyond parity and add another dimension to EMT. Sutton et al. (2011), for instance, who wanted the best argument for EMT to be independent of functionalism, tried to shift the debate away from Parity and focused on the rich scaffolding in the context of complementarity to show that once this rich scaffolding is established embedded pretty much collapses into extended.

On these grounds, a second strand of research characterising EMT, complementarity-based, slowly begun to emerge.

> Complementarity approaches (Sutton et al., 2011) investigate the many different ways in which different components (neural and non-neural) of a cognitive system interact in producing sophisticated cognitive behaviours that would not otherwise be experienced by the user's brain on its own (Farina, 2019).

In truth, complementarity themes can also be found in Clark's (1997) seminal work harking back to and building on R. A. Wilson (1994) and Haugeland (1998).

See Farina and Levin (2020) for an extensive discussion of this point.

At the core of Clark's account therefore lie two fundamental principles. (a) The idea that cognition is often the product of enduring and persistent (often complementary) couplings between brain, body and world. Otherwise put: distinct kinds of extra-bodily (worldly) features (such as technological wetware, cultural artefacts, culture-bound and socially entrenched practices) can cause (via brain plasticity) important structural and functional changes in the cognitive organisation of our brains; and (b) the idea that bodily actions or movements, often in the forms of proceduralized skills, can profoundly shape our cognitive abilities and guide and regulate our behaviours (see Clark, 2015, in particular, for confirmation of the centrality of proceduralized skills in the basic extended cognition thesis).

Cognition, on Clark's view, is therefore best explained by looking at the acting embodied cogniser and the (complementary) context in which she operates as a single, unified and profoundly entangled system of cognitive analysis (Kiverstein & Farina, 2011; Menary, 2007). The point is nicely illustrated by research conducted on tool use (Iriki et al., 1996), which has provided a springboard for embodied cognition theorists to study the many ways in which humans couple with cultural artefacts or pieces of technological wetware so as to enhance or augment their cognitive, motor and perceptual skills (Auvray & Farina, 2017; Clark, 2008; Kiverstein et al., 2015; Kiverstein & Farina, 2012).

In this context, it is crucial to note that Clark's view, despite its heavy commitment to embodiment, neither renounces the notion of representation (quite the opposite) nor undermines the role of computation in cognitive processes. However, in understanding the mind as 'arising' from many brain-body-world interactions, this view clearly rejects Goldman and de Vignemont's (2009) suggestion that embodied approaches to cognition ought to give up the brain. Thus, cognition – on Clark's account – depends on the computational power of our brains but also on bodily experiences that are often constitutively embedded in biological, psychological, technological and cultural contexts or environments. This latter idea is also embraced by proponents of the radical embodied account (see Gallagher, 2005; Varela et al., 1991, pp. 172–173) to which we turn next.

2.3. *Radical embodiment*

Proponents of the radical embodiment approach share with theorists of full embodiment the idea that bodily processes and actions in the world may well constitute cognition. This account, however, usually comes with more radical calls to change the way we conceive of the human mind and the practice of cognitive science as a whole (e.g., Chemero, 2011; Hutto & Myin, 2013).

Similar to fully embodied theories, radically embodied approaches to cognition claim that human cognition is not realised entirely in the head. Both accounts also share the premise that 'minds are causally co-determined and essentially co-constituted by the physical contingencies in which the body is contextually situated' (Cappuccio & Ilundáin-Agurruza, in press, p. 9), so there is a continuity between these approaches. In contrast to Clark's view, however (and here is the discontinuity), proponents of the thesis of radical embodiment argue that bodily processes contribute constitutively not just to cognition but also to other cognitive phenomena (such as consciousness) in an irreducible way. They also typically claim that mental faculties are neither fully localizable (because cognition is not a property or a component of an agent, rather what an active agent does) nor language-like in character (because basic cognising is not syntactically structured and does not involve propositional contents separable from their linguistic vehicles).

In most cases, these approaches (emphasising this idea of radical embodiment) coincide or draw substantially from enactivism, the view that asserts that cognition is deeply rooted in our engaged, bodily lives (Varela et al., 1991). As Gallagher (2011) put it, 'on the enactive view, biological aspects of bodily life, including organismic and emotion regulation of the entire body, have a permeating effect on cognition, as do processes of sensory-motor coupling between organism and environment' (p. 65).

Enactivism thus sees cognition as emerging holistically from the continuous and adaptive interplay between the organism and its ecological surroundings. On this view, the constitutive role played by the sensorimotor coupling between the active cognitive agent and her surrounding environment is emphasised over offline forms of cognising (Cappuccio & Ilundáin-Agurruza, in press).

Radically embodied (enactive) views, however, come in varieties, with different degree of radicality and focus (Ward et al., 2017). The 'autopoietic' strand of enactivism (Varela, 1997), for instance, attempts to ground cognition in the biodynamics of living biological systems and thereby commits to defending the view that the organisational structure of the human mind is an enriched version of the principles grounding life itself (life-mind continuity thesis). The sensorimotor strand of enactivism (O'Regan & Noë, 2001) – inspired by Gibson (1979) – tries to explain the intentional and phenomenal characteristics of perceptual experience and it does so by formulating an account of perception that emphasises the role of sensory-motor dependencies (patterns of contingencies that hold between the movements the perceivers make and what they are able to perceive) in the construction of perceptual experience. Other enactivist theorists (such as Gallagher, 2005; Thompson & Varela, 2001; Zahavi, 2002) – more informed by phenomenology and pragmatism – have emphasised the crucial role of affective factors of embodiment (such as emotions) and intersubjective affordances for social interactions (such as facial expression/ recognition, posture and gestures) in the production of cognition. Finally, radical enactivists (such as Hutto & Myin, 2013) argued that the notion of representation (as traditionally construed in the cognitive sciences) is not needed to account for basic forms of cognition and tried to show that many cognitive processes are neither content-involving nor representation hungry. This move was accompanied by a contextual progressive repudiation of computationalism.

As a possible recent application of some of the ideas proposed by the radically embodied (enactive) views discussed above, consider next a series of recent neuroscientific studies[3] (e.g., Raichlen & Alexander, 2014; Raichlen et al., 2020), which demonstrated a direct link between movement (in the form of aerobic exercises) and development of specific cognitive functions in adults. These studies, and others with them,[4] showed that exercises can profoundly change the structure of our brain, leading to expansion of the prefrontal cortex, of the hippocampus and of other brain areas, directly enhancing our memories and improving our cognitive functions (including specific aspects of planning and even of decision making).

Susan Polgar, the third woman to be awarded the title of chess grandmaster in 1991 and Women's World Champion between 1996 and 1999, is a second interesting application of the ideas discussed above. Joy Hirsch, a neuroscientist based at Yale, studied Polgar's brain and found out that in Susan's brain the area normally dedicated to face processing (the fusiform area) is strongly activated when she imagines a familiar chess game. Hirsh (2016) observed that Polgar uses exactly the same area of her brain for both faces and chess and that her brain has hijacked the fusiform face area and adapted it to chess. In particular, Susan can recognise a familiar chess game in just under 0.8 seconds, almost as fast as the face of an old friend. Years of intense training during childhood moulded Susan's brain for the game (for a complete discussion of this case study, see Farina & Cei, 2018). Polgar's case therefore shows how the sort of body-environmental loops, triggered by intense practice and training that are envisaged by enactivists, can forge and deeply shape an individual's cognitive processes. As such, this case study can be taken as a nice illustration of the radical embodied approach to cognition illustrated above.

This quick analysis of theories or varieties of embodied cognition reveals a real, crucial difference between fully embodied approaches and radically embodied or enactivist ones. The difference lies in the way cognition is understood. For fully embodied theories, the idea that cognition requires brain-body-environment interactions is compatible (or better complementary) with the existence of minimal computational processes and internal representations in the brain. Radical embodied accounts instead propose to abandon computationalism and believe that representations are often not needed to make sense of cognition.

As I mentioned at the beginning of this article, these important differences between full and radical embodied theories (and even the internal differences between the different versions of enactivism we discussed) are overlooked by Goldinger et al. (2016), who collapse the former within the most radical version of the latter. This move is illegitimate and problematic for at least two reasons: (a) it reduces the richness, depth and complexity of the theory; (b) it polarises the theory between just two extremes (what Goldinger calls 'minimal' or 'mild embodiment' and 'radical embodiment'), thereby giving an erroneous superficial, and rather unfair account of what research on embodied cognition is really about.

From the analysis of the range and varieties of embodied cognition approaches conducted in the paragraphs above, it is nevertheless clear that embodied cognition is more varied than presented by Goldinger et al. (2016) and that work on embodied cognition can provide fruitful insights for empirically informed philosophers of mind. This is because of the wide range of phenomena that embodied cognitive science has studied. But how does this research programme look in practice, what are its main domains of application and how might we go about experimentally testing claims about embodied cognition?

3. Empirical domains for embodied cognition

In this section, I analyse three empirical domains (robotics, vision and sport psychology) in which research on embodied cognition has been particularly successful. I focus on these domains extensively, among many possible ones (e.g., language and thought, memory, or self and agency), for two reasons mainly: (a) I do not have space to focus on all the others in detail, and (b) these domains are, most probably, the most successful domains in which embodied cognition has been applied to date and hence can somehow be considered paradigmatic. Before we proceed any further, however, the reader may legitimately ask to specify what makes the examples I am going to be discussing in this section distinctively 'embodied'.[5] Next, I briefly address this point.

Intelligent systems typically learn from experience to function in complex nondeterministic environs. Thus, these systems must be able to update their knowledge on the fly to function, survive or develop. Such systems, to carry out much of their sophisticated cognitive functions (such as seeing, performing an action, or acquiring a skill), must also adapt autonomously to arbitrary situations, must be responsive to the environment and even be capable to deal with new variants of behaviour. In addition, they must be able to deal with incremental changes in context and – when needed – to offload relevant cues into the environment. To do all this successfully, such systems must have a lived body. As H. L. Dreyfus (1979) noted, 'an embodied agent can dwell in the world in such a way as to avoid the . . . task of formalising everything' because its 'body enables [it] to by-pass this formal analysis' (p. 255). In other words, it is necessary for such systems to have cognitive processes realised in the body. Many intelligent systems must therefore be deeply embodied to properly function and this is the reason why the three domains I discuss below, which can be understood as processes of intelligent systems (vision and skills) or intelligent systems on their own (situated robots), are not just examples that might be presented as embodied but are actually examples that require deep and profound embodiment to be fully explained, comprehended and understood.

Having specified what makes the examples I discuss below specific examples of embodiment, I next turn to analyse them in more details. The analysis I conduct below is instrumental to undermine the 'poverty claim' put forward by Goldinger et al. (2016) that says that embodied cognition 'falls woefully short – on simple, logical grounds – of addressing any aspect of cognitive life' (p. 973).

3.1. Situated robotics

Situated robotics arose in the early 1990s as a reaction to the so-called GOFAIR approach (Good Old Fashioned Artificial Intelligence Robotics). GOFAIR envisaged the capacity of building disembodied robots capable of solving problems serially in a context where perception was needed only to determine the initial state of the system (for an interesting overview on this topic, see Boden, 2006). This approach was based on the assumption that the fundamental aspects of intelligence could be achieved by manipulation of symbols. The instructive failure of the GOFAIR (see H. L. Dreyfus, 1979; Minsky, 1961; Searle, 1980, for compelling criticism) paved the way for the development of situated robotics. Situated robotics (otherwise known as behaviour-based robotics) is the study of robots embedded in complex, often dynamically changing environments.

Situated robotics is based on the idea that intelligence is for doing things and thus focuses on building robots capable of displaying complex intelligent behaviours in the absence of centralised control or planning (Brooks, 1991; Pfeifer & Bongard, 2006). Situated robots typically exist in rapidly changing environments, which they can manipulate through their actions. The central tenets underlying research on situated robotics can be summarised as follow:

1. *Bottom-up approach*. The idea that robots are built with a repertoire of simple behaviours, which, when coupled and combined together, produce sophisticated actions.
2. *Behaviour-based approach*. The system does not always rely on a symbolic description of the environment and does not require a high level of control or organisation; rather, it determines its actions via sensory-motor links.
3. *Subsumption architecture*. An architecture that decomposes the behaviour of the systems into sub-behaviours and organises them into a hierarchy of layers with specific level of behavioural competence coupling the sensory information obtained in the world with each layer at different time in a bottom-up fashion. The goal of such architectures is to build complex, robust, real-time behaviours, which emerge as the result of simple interactions between relatively self-contained (sub)-behaviours (Clark, 1997).

Situated robots are therefore physically embodied systems, which 'perceive', 'act' and 'learn' (by artificial means) in interaction with their environment through the use of artificial evolutionary and learning techniques. These are thus robots grounded in interactions with the physical environment through the robot platform's sensorimotor capacities (Ziemke, 2016). Having described the theoretical assumptions underlying situated (embodied) robotics, I now briefly review some of the most successful research programmes in 'situated' robotics developed to date.

Dario Floreano's Lab in Lausanne has conducted ground-breaking research in the field of mini-robots (Miehlbradt et al., 2018). Such robots, wing and rotor based – with weights between 1.5 and 30 g – can fly indoor with minimal human intervention. Outdoor small flying robots (weight up to 300 g rams), capable of flying in swarm formation without the need of a GPS and autopilot systems, have also been successfully tested (Daler et al., 2015). These mini-robots are interesting because they exhibit surprisingly complex intelligent behaviours, involving capacities for networking/planning and real-time navigation skills.

The cognitive neurorobotics research unit at the Okinawa Institute of Science and Technology led by Professor Jun Tani constitute another successful example of work in embodied robotics. In conducting synthetic brain-inspired enactive modelling and by using situated robots as an experimental platform, the group tries to understand the principles underlying mind and cognition. The long-term goal of the group is to reconstruct the development of cognitive minds of infants in synthetic neurorobotics experiments (Tani, 2016).

However, the most fascinating examples of situated robots are probably found among humanoid robots such as *Atlas*. Atlas is a bipedal, anthropomorphic, highly mobile, humanoid robot built in 2013 by Boston Dynamics. The robot stands at 1.8 metre and has 28 hydraulically actuated degrees of freedom (which allow it to achieve, among other things, sophisticated hands and wrist movements). *Atlas* also has independently moving arms, legs, feet and a torso, an articulated sensor head that includes stereo cameras, a wireless router that enables untethered communication, and a laser range finder. This humanoid robot is capable of performing a number of actions (such as walking across rocky and undulating terrain, navigating debris or slippery/hazardous surfaces, climbing stair steps, or even staying upright on one foot while being pushed over by a weight) that clearly extend into the realm of the cognitive and involve – for instance – real-time negotiation of balance, planning, coordination and forms of attention and so on.

Another interesting example of humanoid robot is *Kengoro*. *Kengoro*, recently developed by a team of researchers at the University of Tokyo (Asano et al., 2017), is a human mimetic humanoid that anatomically resembles the musculoskeletal intricacy of a human boy. This robot can move its head from side to side like it is cracking its neck. It can stand on its tippy toes, and because it has a flexible spine, it can even do sit-ups and push-ups. *Kengoro's* most interesting development is perhaps its artificial perspiration system. Water circulates through its metal frame, which is made of a special porous aluminium and allows the heated water (heated by its 116 mechanical actuators) to vent out of small vents as vapour. Like *Atlas, Kengoro* is able to perform a series of actions (involving coordination and negotiation of balance) that clearly require cognitive components.

The iCub is yet another captivating example of a humanoid robot (Natale et al., 2014). iCub is shaped as a 4-year-old kid and was originally developed by a consortium of 11 partners under the guidance of Professor Giorgio Metta of the Italian Institute of Technology. The robot has 53 motors, which allow to move its head, arms, hands, waist and legs. iCub possesses distributed tactile and force/torque sensors, has movable head equipped with microphones, speaker, actuated eyes, eyelids and lips, which are used for speech and human–robot interaction. It can crawl on, sit up, and its hands allow dexterous manipulation. iCub also has visual, vestibular, auditory and tactile sensory capabilities, which allow it to develop a deep sense of proprioception (body configuration).[6]

How does this work on situated, embodied robotics presented in this sub-section relate to the taxonomy of approaches to embodied cognition I introduced above (section 2)?

It may prima facie seem that lots of work in situated robotics is 'radical' (in the sense of giving up computationalism and favouring bottom-up approaches, thereby renouncing representations). This is true and surely enactivism inspired the development of situated robotics. However, one must acknowledge that a crucial tenet underlying situated robotics is that the system (the situated robot) does not always need to rely on a symbolic description (a representation) of the environment to work (see above). 'Not always' does not mean that the representation is 'not needed, or that it is preferably avoided' by the system; rather, it means that the system may containing minimal information about the current world state and that on the basis of that information it can subsequently learn on the fly, via sensory-motor links. Thus, it seems to me that situated robotics is not completely subsumable within the radically embodied approach (at least with the most radical versions of it (Hutto and Myin's style)) but rather seems to be more compatible with a fully embodied perspective and, in particular, with the theory of minimal robust representationalism (Clark & Grush, 1999), which says that A.I. accounts can (and must) be deeply grounded in real-world physical embodiment and situatedness, but that robots facing real-world problems do not only work in a bottom-up fashion but can also be endowed with necessary, robust cognitive skills (this approach is known as 'situated cognitive robotics', see again Clark & Grush, 1999).

In other words, learning in situated robots surely happens on the fly but it is still based, in most cases at least, on a minimal mapping of the surrounding world (what is known as environmental modelling). Processing such data and storing it in a representation of the world is thus still crucial to much of research on situated robotics, as shown by the case of autonomous driving systems (also known as *autonomous robotic* vehicles). Such systems typically exploit metric representations (2D or 3D) and topological maps to allow the successful functioning of the mobile – situated – robot and these contribute to improve the robot's ability to carry out sophisticated tasks (such as localisation, navigation, object detection) in human – often – over-populated environments (Premebida et al., 2018).

Next, I discuss the domain of vision, which is another domain where research on embodied cognition has thrived in recent years.

3.2. Vision

A substantial body of research on so-called animate vision (Ballard et al., 1997; Churchland et al., 1994) has demonstrated the embodied and active nature of this process. Vision, it has been argued, is a highly complex and intelligent process, which involves the active retrieval of useful information as it is needed from the constantly present real-world scene. Works on animate vision rejected what Churchland et al. (1994) dubbed the paradigm of pure vision 'the idea that vision is largely a means of creating a world model rich enough to let us throw the world away' (Clark, 1999, p. 345), and by contrast, gave action a starring role. Vision, Churchland and colleagues (1994) write, 'has its evolutionary rationale rooted in improved motor control' (p. 25). Research on animate vision thus endorsed a view in which a perceiver uses her body and various other structures in the environment to offload perceptual processing onto the world.

As an illustration of this point, consider next Dana Ballard's work. Ballard et al. (1997) described a series of experiments which demonstrated how saccades (eye movements) could be used to access task-relevant information in the world and demonstrated that to avoid maintaining and updating costly, enduring and detailed internal models of our visual surroundings, we normally end up sampling the environment in ways suited to the particular needs of the moment.

This embodied approach to vision has been further developed by Jan Lauwereyns (2012). His 'intensive approach to vision' is a combination of classic computational theories of perception (a la, Marr, 1982) that say that vision is essentially a top-down process, and less conservative accounts that emphasise the pervasive sensorimotor nature of perceptual experience and the role that (bottom-up) sensorimotor engagements play in visual processes.

> In accepting these rich, full-blooded, neo-computationalist views of visual experience, and by taking into account much of the Gibsonian's lesson (1979) about proactive agent-environment interactions, the intensive approach to vision aims to combine phenomenology and philosophy with functional taxonomy and computational cognitive neuroscience, by focusing on the active role that gaze and intentions play in perception, and by explaining information processing in terms of responses to biases, predictions, expectations, and sensitivities. (Farina, 2012, p. 1036)

The relation between perception and action (decision making) has also been widely investigated within the embodied cognition movement. Cisek (2007), for instance, formulated the so-called affordance competition model. The model proposes that the brain (through the dorsal visual system) processes sensory information to specify, in parallel, several potential actions that are available. These potential actions compete for further processing within the fronto-parietal cortex, while information is gathered to bias this competition until a single response is selected. This essentially means that although the biases that influence the decision may come from different sources, including the activity of higher cognitive regions, it is in the sensorimotor system that the final decision is ultimately taken.

Inspired by Cisek (2007), Donnarumma et al. (2017) proposed a fascinating computational model of vision that describes action perception as an *active, embodied* inferential process based on motor predictions and hypothesis testing. More recently, Pezzulo et al. (2018) further developed this model and proposed that control hierarchy enable deep inferences based on prior preferences or goals, but their precision is always informed by both control context (which includes information that determines the action–outcome contingencies), and motivational context (which establishes the desirability of choice outcomes). Their proposal thus emphasises the centrality of goals and goal directedness for motivated control, which – they argue – operates to reduce exteroceptive, interoceptive and proprioceptive prediction errors.

The moral emerging from the discussion of all these works is clear: vision is a deeply embodied phenomenon, which 'makes the most of the persisting external scene, while gearing its computational activity closely and sparingly to the task at hand' (Clark, 1999, p. 346). It thus seems to me that all this research, once again, can probably be best framed within a fully embodied perspective (one that combines minimal computationalism/representationalism with the principles of ecological psychology) and therefore further demonstrates the argumentative importance of the taxonomy I proposed in section 2.

Having presented two of the most important empirical domains in which embodied cognition has been successfully applied, I conclude this section by briefly analysing work on sport psychology which – albeit more recent – has also provided important confirmations for the validity of the embodied approach in sport science.

3.3. Sport psychology

Embodied cognition resonates, at least in part, with a number of psychological theories in sport science. For example, the description of skill acquisition 'as progressive automatization of complex action patterns', offered by some of the precursors of the embodied cognition programme (S. E. Dreyfus & Dreyfus, 1980), is in substantial accord with the cognitive-computational approach formulated by Fitts and Posner in the late 1960, which argued for a less cognitively demanding understanding of motor execution (in terms of unreflective habitual actions). Also, some of the key ideas put forward by embodied mind theorists in the early 1990 (such as Varela et al., 1991) echoed influential doctrines in developmental psychology (such as Gibson's ecological psychology) that paved the way to the foundation of sport psychology. It is therefore not surprising that many psychologists and cognitive scientists working in the field of sport performance are often keen to accept the core tenets of embodied cognition (Cappuccio, 2018).

One particularly clear example of this tendency is represented by the work of Sian Beilock and colleagues, who have identified numerous ways in which embodied cognition can be applied to sport psychology (e.g., Beilock, 2009). Their studies demonstrated, among other things, that

> the ability to perceive and predict the actions of others; the ability to comprehend action-related language; and the judgements individuals make about objects and events in their environment arise from and are modulated by the variations in individuals' motor skill repertoires. (Beilock, 2009, p. 20)

In an interesting neuroimaging study, Beilock et al. (2008) further showed that fans of a sporting activity with scarce or limited experience on the field and athletes who play the sport professionally display significantly different patterns of brain activation when asked to watch clips of the game they play or support. Specifically, compared with fans, the players' brains activation is considerably higher in motor-planning and motor-control regions – the areas that would be active if the subjects were playing the game, rather than merely watching it. These results (and analogous ones, for example, those concerning motor resonance during observation of basketball tasks; see Aglioti et al., 2008) have been taken as providing evidence for the existence of a shared embodied root of motor execution, imagination and action understanding (Beilock, 2015). Other researchers also demonstrated the crucial role that embodied cognition plays in various other sport-related activities (such as perception, understanding, Calvo-Merino et al., 2005; concentration, Farina & Cei, 2019; and training, Moreau et al., 2012).

In accord with the principles and tenets underlying embodied cognition, all these studies therefore showed that many athletic skills should be understood as non-conceptual, pre-linguistic capabilities that do not necessarily rely on rules or a priori models, but are rather normed by the motoric and perceptual contingencies of executive control and real-world interactions (Cappuccio, 2015). Work in sport psychology is thus clearly anti-internalist in character, as it recognises that cognitive activities are not merely intellectual but also affective, perceptual and motoric.

Beilock, for instance, notoriously claimed that sensorimotor experiences play a pivotal role in sport psychology and argued for a separation between systems that use working memory (e.g., language) and systems that do not use it (e.g., affordances and motor intentionality). This is a typical enactivist move. However, she never explicitly subscribed to enactivism and never claimed that we ought to abandon computationalism or drastically rethink our understanding of the role of representations in cognitive science.[7] Likewise, Christensen and colleagues (2016) also developed a very influential, anti-internalist theory of skill acquisition, which they call *Mesh*. The theory 'proposes that cognitive control plays an important ongoing role in advanced skill, with cognitive and automatic processes being closely integrated' such that performative responsibilities are assigned hierarchically (p. 280). This theory, while fully embracing ecological psychology and some aspects of enactivism, strongly relies on the conceptual framework provided by EMT (the theory does not give up the idea of cognitive control) and it is motivated but also indeed justified by the complementarity approach to EMT that I outlined above. Indeed, one of the proponents of this model (John Sutton) is a leading EMT theorist. For these reasons, it seems safe to say that a lot of leading research in embodied sport psychology can be optimally framed within the fully embodied perspective I presented above (section 2).

Having reviewed three empirical domains where research on embodied cognition has been particularly successful, I am now in a position to draw (contra Goldinger et al.'s 2016, poverty claim) a preliminary conclusion. Embodied cognition is not just a philosophical mantra empty of empirical content, rather it is a strong paradigm of research spanning several disciplines in both the humanities and the cognitive sciences. This paradigm is deeply and profoundly rooted in scientific practice and can indeed explain many aspects of cognitive behaviour.

Having analysed some of the domains where embodied cognition has been particularly successful and arrived at such a conclusion, I now want to face a potential objection, which Goldinger et al. (2016) might raise in response to the argument I sketched above. Goldinger et al. (2016) may well say ok, these examples are all fine and interesting but none of the cases you discussed are really examples of cognition. This is because cognition, for us, is best understood as what classical cognitive psychology studies (in the areas I listed in the introduction). This is a fair objection, I reckon, but one that ultimately does not hold. It does not hold, I believe, for two reasons: (a) it relies on a very restrictive (limiting), self-referential and conservative (almost insular) account of what counts as cognition and (b) it goes against the spirit of modern, inclusive, interdisciplinary and integrative science. I say something more about this potential objection and about my responses to it next.

Cognitive psychology is traditionally defined as the discipline that studies the mental processes (such as attention, language use, perception, problem solving, decision making, computation) that affect cognitive behaviour. The examples that Goldinger et al. (2016) discuss (ranging from concepts and prototypes and priming effects to face perception, word frequency and sentence processing) are examples that fall in the domain of standard cognitive psychology. If, however, embodied cognition does not play any substantial role in these specific examples, Goldinger et al. (2016) argue, then embodied cognition cannot say anything interesting about cognition in general. This is because cognition is whatever is successfully studied in cognitive psychology.

(a) A possible answer to this objection is that much of the work originally derived from cognitive psychology has been integrated into various other disciplines (such as linguistics, neuroscience, psychiatry, psychology, education, philosophy, robotics, economics, anthropology, biology, systemics, logic and computer science) and has produced important advancements in our understanding of human cognitive behaviour. Thus, one could say that it seems very reasonable and even helpful to expand the scope of the concept of cognition outside of the traditional field of cognitive psychology.
(b) Another possible answer is to notice that the claim that cognition is whatever is studied in cognitive psychology is limiting. Embodied cognition is successfully studied in many standard domains of cognitive psychology (such as language, perception, decision making and computation, albeit – admittedly – not so successfully in some of the sub-areas that Goldinger et al., 2016, discuss in their article) but also in many more (see discussion below, for instance). So, why shall we restrict our understanding of cognition to those specific areas?
(c) A third answer, which is a direct consequence of the first two, is to notice that Goldinger et al.'s (2016) overly conservative understanding of cognition (cognition is whatever is studied in cognitive psychology) goes against the spirit of modern, integrative and interdisciplinary science. The best science is interdisciplinary in character and comes from the realization that there are pressing questions/issues/problems that have proved unwilling to yield to conventional approaches or cannot be adequately addressed by people from just one discipline (cognition is certainly one of such problems) and therefore need to be studied from a multidisciplinary perspective.[8]

Next I turn to analyse recent, existing applications of embodied cognition in contemporary psychology (section 4) and argue that discussing these new applications (not only further attests to the power of the theory giving precious, additional evidence against the poverty claim put forward by Goldinger et al. (2016) but might also help move the field forward in important and unexpected ways. This discussion, bristling with a lot of brand-new ideas, is also instrumental to show the significance of embodied cognition outside of the philosophical arena, in our daily lives.

4. Applications of embodied cognition in contemporary psychology

Within the field of contemporary psychology numerous clinical interventions and practices that utilise body-mind principles have been recently developed (for a helpful review, see Leitan & Chaffey, 2014). In particular, embodied therapies for children's disorders such as autism are nowadays quite popular and relatively well established (Ollendick & King, 2004). These practices and interventions have been largely developed due to the influence of prominent developmental theories (such as Piaget's (1954) theory of cognitive development) that asserts that kid's cognitive abilities are strongly and directly linked with their embodied behavioural/emotion experiences.

Education is yet another field in which embodied cognition has achieved substantial success (see Glenberg, 2008), mostly because the field directly relates to children; and, as shown above, children's cognitive capabilities are thought to be deeply linked with their embodied, behavioural/emotional experiences. It is therefore not surprising that most Western educational programmes for children are based on prominent developmental learning models that emphasise environmental, embodied and experiential learning and that teaching methods for young children often use the body and the senses to engage in specific cognitive activities. One particularly successful example of this approach is the '*Moved by Reading Program'*. The *Moved by Reading Program* (Glenberg, 2008) is an effective intervention that was developed to facilitate the construction of meaning by utilising the child's motor and perceptual systems during reading. Its goal is to teach children how to map words and phrases onto current and remembered experiences.

Embodiment has also important potential applications in social psychology, where researchers investigated how one's own bodily states affect how we understand and interact with other people. Williams and Bargh (2008), for instance, provided a powerful demonstration of how bodily states influence social judgements and behaviour. Mussweiler (2006) asked subjects to engage in motor movements that typified a particular social category and showed that these movements primed the use of that category in social judgement. For instance, in one study 'participants who were unobtrusively induced to move in the portly manner that is stereotypic of overweight people subsequently ascribed more overweight-stereotypic characteristics to an ambiguous target person than did control participants' (Mussweiler 2006, p. 17).

Emotion is another area where research on embodiment has been particularly successful. Havas et al. (2007) showed a link between emotional reactivity and language understanding. Niedenthal (2007) made a convincing case that emotions are profoundly embodied. That is, that emotions involve bodily changes that have strong effects on cognition and action. As an instance of how bodily states may affect emotions in a social context, consider – for instance – a study by Oberman et al. (2007), who tested the hypothesis that facial mimicry may influence emotion recognition. This hypothesis predicts that if activity in a facial muscle used in producing (or mimicking) a particular emotional expression is blocked, then the recognition of the relevant emotion is correspondingly reduced. To test this hypothesis, Oberman et al. (2007) used four expressions (happy, disgust, fear and sad) and two mimicry-interfering manipulations (a) biting on a pen and (b) chewing gum, as well as two control conditions. Results showed 'that impairing one's ability to use facial muscles leads to a selective deficit in the recognition of the emotions that engage those muscles' (Oberman et al. 2007, p. 177).

All the studies reviewed here demonstrate that embodied cognition is a mature and very powerful research programme with original, potential applications which can spread in various, disparate research fields. These findings also show that embodied cognition can open a new kind of window of research into these fields, by predicting the interaction of mind, body and environment in unconventional and often original ways. These research fields can, in turn, offer new profitable ways of testing out theoretical claims developed within the embodied paradigm, thus contributing to build an even richer, multidimensional and increasingly integrative and truly interdisciplinary framework to explain human cognitive behaviour.

Despite many successes, embodied cognition still faces important challenges. Careful reflection is needed, for instance, to understand the relationship between embodied cognition and classical computationalism, which is still somehow predominant in the cognitive sciences (see Goldinger et al., 2016). Will embodied cognition ever become mainstream? To do so, must embodied cognition abandon computationalism? Are these two approaches mutually incompatible? More pressingly, embodied cognition owes a clearer account of why many of its findings cannot be subsumed within traditional cognitive science. Perhaps then cognitive scientists have failed to acknowledge the importance of our bodies in determining cognitive processes – but if so, does this failure really demand a new paradigm for the study of cognition (Shapiro, 2007)? In other words, could all this embodied research (full and radical) not be accommodated within a more liberal computationalist view?

We do not have definite answers for all these questions yet and we are aware of the need to device even more empirical tests to verify and strengthen the claims put forward by embodied cognition theorists. Nevertheless, it should be clear that, pace Goldinger et al. (2016), embodiment has already begun to change the practice of scientists and the way we conceive of cognition. The future successes of embodied cognition ultimately depend on its capacity to broaden its horizons and on the ability to articulate, more precisely, why the study of human cognitive behaviour should not or cannot be implemented within the framework of traditional cognitive science (Shapiro, 2007).

My hunch is that a fully embodied perspective may help settle this debate and answer those pressing research questions. A fully embodied perspective (Clark's style approach) seems (as we have seen above) to allow us to get the best of both worlds; that is, it kills two completely different birds with one stone, as it is capable of powerfully explaining many sophisticated cognitive capacities (including higher-order-thinking) from an ecological perspective while not giving up representations or renouncing the brain's computational power. Other more radical (antirepresentationalist, anticomputationalist) alternatives may perhaps achieve analogous explanatory power but it seems to me that that may come at a cost for the embodied cognition movement. Such alternatives, in their paraded radicality (especially Hutto & Myin, 2013), may further prompt the sort of reaction – among some scientists – that Goldinger et al. (2016) proposed in their article. Thus, on balance, to avoid further misunderstandings, uninformed, or worse uncharitable readings of the embodied cognition movement, I end this article with a call for moderation and prudence, which I believe can only do good to a relatively young, yet fast-growing research paradigm like that on embodied cognition.

5. Conclusion

I showed, pace Goldinger et al. (2016), that there is a substantial body of empirical work showing how embodied activities constitutively shape many aspects of human cognitive life. This empirical evidence includes data collected from laboratory studies, naturalistic field observations, neuropsychological case studies, artificial intelligence and various phenomenological reports.

I showed that Goldinger et al. (2016) operate with an overly conservative notion of cognition and that this notion goes against the spirit of modern, inclusive, interdisciplinary, and integrative science.

I also showed that Goldinger et al. (2016) inexplicably do not target and perhaps deliberately ignore one of the most promising views among all approaches to embodiment, the fully embodied perspective (Clark's style approach). However, that perspective is genuinely different from (a) standard non-embodied cognitive science (the view Goldinger et al., 2016, subscribe to) and (b) radical embodied cognitive science (the view that Goldinger and colleagues mock and attack, which – as we showed in section 2 above – is also far more varied and complicated that he acknowledged).

It is hoped that this article will contribute to highlight the potential reach of embodied cognition outside of the traditional philosophical arena, thereby increasing its visibility and inspiring studies that could open up new avenues for research.

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Notes

1. I limit the discussion to these three domains for reasons of space (other possible domains include language, gestures, consciousness, concepts, memory, understanding of other minds, and moral cognition).
2. Gallese and Lakoff (2005) would probably fall in the same camp, as all the embodiment in their work is realised in and by neural motor systems in the brain. Various other 'weak, or middle-ground' approaches have been proposed in recent years (e.g., Barsalou, 2008).
3. Thanks to the anonymous reviewer for these helpful suggestions.
4. For a detailed summary of all these studies, please refer to https://www.scientificamerican.com/article/why-your-brain-needs-exercise/
5. Thanks for an anonymous reviewer for pressing this point.
6. For an overview of the progress made on this robot in the last 10 years, see https://www.youtube.com/watch?v=ErgfgF0uwUo (last accessed January 2020).
7. Some enactivists (such as Hutto and Myin) may disagree with my interpretation and still argue that Beilock's work can be best interpreted within the framework provided by enactivism. I recognise this possibility here but I am not willing to engage in a critical discussion on this point with these theorists (at least in this article), as my target here is Goldinger. In other words, the substantiation of my argument against Goldinger does not require a falsification of enactivism, a theory I have elsewhere defended.
8. https://www.nature.com/news/mind-meld-1.18353

References

Adams, F., & Aizawa, K. (2001). The bounds of cognition. *Philosophical Psychology*, *14*(1), 43–64.

Aglioti, S. M., Cesari, P., Romani, M., & Urgesi, C. (2008). Action anticipation and motor resonance in elite basketball players. *Nature Neuroscience*, *11*(9), 1109–1116.

Anderson, M. L. (2003). Embodied cognition: A field guide. *Artificial Intelligence*, *149*, 91–130.

Asano, Y., Okada, K., & Inaba, M. (2017). Design principles of a human mimetic humanoid: Humanoid platform to study human intelligence and internal body system. *Science Robotics*, *2*(13), eaaq0899.

Auvray, M., & Farina, M. (2017). Patrolling the boundaries of synaesthesia: A critical appraisal of transient and artificially-acquired forms of synaesthetic experiences. In O. Deroy (Ed.), *Sensory blending: On synaesthesia and related phenomena* (pp. 248–274). Oxford University Press.

Ballard, D. H., Hayhoe, M. M., Pook, P. K., & Rao, R. P. (1997). Deictic codes for the embodiment of cognition. *Behavioral and Brain Sciences*, *20*, 723–742.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, *59*, 617–645.

Beilock, S. L. (2009). Grounding cognition in action: expertise, comprehension, and judgment. *Progress in Brain Research*, *174*, 3–11.

Beilock, S. L. (2015). *How the body knows its mind*. Hachette.

Beilock, S. L., Lyons, I. M., Mattarella-Micke, A., Nusbaum, H. C., & Small, S. L. (2008). Sports experience changes the neural processing of action language. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(36), 13269–13273.

Boden, M. (2006). *Mind as machine: A history of cognitive science*. Oxford University Press.

Brooks, R. A. (1991). Intelligence without representation. *Artificial Intelligence*, *47*, 139–159.

Calvo-Merino, B., Glaser, D. E., Grèzes, J., Passingham, R. E., & Haggard, P. (2005). Action observation and acquired motor skills: An fMRI study with expert dancers. *Cerebral Cortex*, *15*, 1243–1249.

Cappuccio, M. L. (2015). Introduction: When embodied cognition and sport psychology team-up. *Phenomenology and the Cognitive Sciences*, *14*(2), 213–225.

Cappuccio, M. L. (2018). *Handbook of embodied cognition and sport psychology*. MIT Press.

Cappuccio, M. L., & Ilundain-Agurruza, J. (in press). Embodied cognition and sport psychology. In D. Hackfort, & R. Schinke (Eds.), *The Routledge international encyclopedia of sport and exercise psychology*. Routledge.

Chemero, A. (2011). *Radical embodied cognitive science*. MIT Press.

Christensen, W., Sutton, J., & McIlwain, D. J. (2016). Cognition in skilled action: Meshed control and the varieties of skill experience. *Mind & Language*, *31*(1), 37–66.

Churchland, P. S., Ramachandran, V. S., & Sejnowski, T. J. (1994). A critique of pure vision. In C. Koch, & J. L. Davis (Eds.), *A Bradford book: Large-scale neuronal theories of the brain* (pp. 23–58). MIT Press.

Cisek, P. (2007). Cortical mechanisms of action selection: The affordance competition hypothesis. *Philosophical Transactions of the Royal Society of London B, Series B: Biological Sciences*, *362*(1485), 1585–1599.

Clark, A. (1997). *Being there: Putting brain, body, and world together again*. MIT Press.

Clark, A. (1999). An embodied cognitive science? *Trends in Cognitive Sciences*, *3*, 345–351.

Clark, A. (2001). *Mindware: An introduction to the philosophy of cognitive science*. Oxford University Press.

Clark, A. (2008). *Supersizing the mind: Embodiment, action, and cognitive extension*. Oxford University Press.

Clark, A. (2010). Coupling, constitution, and the cognitive kind: A reply to Adams and Aizawa. In R. Menary (Ed.), *The extended mind* (pp. 81–101). MIT Press.

Clark, A. (2015). What 'extended me' knows. *Synthese*, *192*(11), 1–19.

Clark, A., & Chalmers, D. (1998). The extended mind. *Analysis*, *58*, 7–19.

Clark, A., & Grush, R. (1999). Towards a cognitive robotics. *Adaptive Behavior*, *7*(1), 5–16.

Daler, L., Mitchev, S. C., & Floreano, D. (2015). A bioinspired multi-modal flying and walking robot. *Bioinspiration & Biomimetics*, *10*, 016005.

Di Paolo, E., & Thompson, E. (2014). The enactive approach. In L. Shapiro (Ed.), *The Routledge handbook of embodied cognition* (pp. 68–78). Routledge.

Donnarumma, F., Costantini, M., Ambrosini, E., Friston, K., & Pezzulo, G. (2017). Action perception as hypothesis testing. *Cortex*, *89*, 45–60.

Dreyfus, H. L. (1979). *What computers still can't do*. MIT Press.

Dreyfus, S. E., & Dreyfus, H. L. (1980). *A five-stage model of the mental activities involved in directed skill acquisition*. California University Berkeley Operations Research Center.

Farina, M. (2010). Review: 'Supersizing the mind: Embodiment, action and cognitive extension'. *Humana.Mente: Journal of Philosophical Studies*, *14*, 225–233.

Farina, M. (2012). Critical notice: 'Brain and the gaze'. *Biology and Philosophy*, *28*, 1029–1038.

Farina, M. (2019, June 9). Critical notice of sensory substitution and augmentation. *Notre Dame Philosophical Reviews*. https://ndpr.nd.edu/news/sensory-substitution-and-augmentation/

Farina, M., & Cei, A. (2018). Neither genes nor deliberate practice: An embodied and multidimensional approach to talent. In M. L. Cappuccio (Ed.), *Handbook of embodied cognition and sport psychology* (pp. 303–330). MIT Press.

Farina, M., & Cei, A. (2019). Concentration and self-talk in football. In E. Konter, J. Beckmann, & T. Loughead (Eds.), *Football psychology: From theory to practice* (pp. 241–254). Routledge.

Farina, M., & Levin, S. (2020). The extended mind thesis: Domains and application. In R. Michael, & L. Thomas (Eds.), *Embodied psychology: Thinking, feeling, and acting*. Springer.

Fodor, J. A. (1980). Methodological solipsism considered as a research strategy in cognitive psychology. *Behavioral and Brain Sciences*, *3*(1), 63–73.

Froese, T., & Di Paolo, E. A. (2011). The enactive approach: Theoretical sketches from cell to society. *Pragmatics & Cognition*, *19*, 1–36.

Gallagher, S. (2005). *How the body shapes the mind*. Clarendon Press.

Gallagher, S. (2011). Interpretations of embodied cognition. In W. Tschacher, & C. Bergomi (Eds.), *The implications of embodiment: Cognition and communication* (pp. 59–70). Imprint Academic.

Gallese, V., & Lakoff, G. (2005). The brain's concepts: The role of the sensory-motor system in conceptual knowledge. *Cognitive Neuropsychology*, *22*, 455–479.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Houghton Mifflin.

Glenberg, A. M. (2008). Embodiment for education. In P. Calvo, & A. Gomila (Eds.), *Handbook of cognitive science: An embodied approach* (pp. 355–372). Elsevier Science.

Goldinger, S. D., Papesh, M. H., Barnhart, A. S., Hansen, W. A., & Hout, M. C. (2016). The poverty of embodied cognition. *Psychonomic Bulletin & Review*, *23*(4), 959–978.

Goldman, A. I. (2012). A moderate approach to embodied cognitive science. *Review of Philosophy and Psychology*, *3*, 71–88.

Goldman, A. I., & de Vignemont, F. (2009). Is social cognition embodied? *Trends in Cognitive Sciences*, *13*, 154–159.

Haugeland, J. (1998). *Having thought*. Harvard University Press.

Havas, D. A., Glenberg, A. M., & Rinck, M. (2007). Emotion simulation during language comprehension. *Psychonomic Bulletin & Review*, *14*(3), 436–441.

Hirsh, J. (2016). http://web.chessdailynews.com/national-geographic-chess-documentary-my-brilliant-brain/

Hurley, S. (2010). The varieties of externalism. In R. Menary (Ed.), *The extended mind* (pp. 101–154). MIT Press.

Hutto, D. D., & Myin, E. (2013). *Radicalizing enactivism: Basic minds without content*. MIT Press.

Iriki, A., Tanaka, M., & Iwamura, Y. (1996). Coding of modified body schema during tool use by macaque postcentral neurones. *Neuroreport*, *7*, 2325–2330.

Kiverstein, J., & Clark, A. (2009). Introduction: Mind embodied, embedded, enacted: One church or many? *Topoi*, *28*, 1–7.

Kiverstein, J., & Farina, M. (2011). Embraining culture: Leaky minds and spongy brains. *Teorema*, *32*, 35–53.

Kiverstein, J., & Farina, M. (2012). Do sensory substitution devices extend the conscious mind? In F. Paglieri (Ed.), *Consciousness in interaction: The role of the natural and social context in shaping consciousness* (pp. 19–40). John Benjamins.

Kiverstein, J., Farina, M., & Clark, A. (2013). *The extended mind*. Oxford University Press. http://www.oxfordbibliographies.com/view/document/obo-9780195396577/obo-9780195396577-0099.xml

Kiverstein, J., Farina, M., & Clark, A. (2015). Substituting the senses. In M. Matthen (Ed.), *The Oxford handbook of the philosophy of perception* (pp. 659–678). Oxford University Press.

Lauwereyns, J. (2012). *Brain and the gaze: On the active boundaries of vision*. MIT Press.

Leitan, N. D., & Chaffey, L. (2014). Embodied cognition and its applications: A brief review. *Sensoria: A Journal of Mind, Brain & Culture*, *10*(1), 3–10.

Marr, D. (1982). *Vision: A computational investigation into the human representation and processing of visual information*. W.H. Freeman.

Maturana, H., Varela, F., Sousa, D., Sternberg, R. J., Eysenck, M. W., & Keane, M. T. (2005). *The realization of the living*. ScienceDaily.

Menary, R. (2007). *Cognitive integration: Mind and cognition unbounded*. Palgrave Macmillan.

Miehlbradt, J., Cherpillod, A., Mintchev, S., Coscia, M., Artoni, F., Floreano, D., & Micera, S. (2018). Data-driven body–machine interface for the accurate control of drones. *Proceedings of the National Academy of Sciences of the United States of America*, *115*, 7913–7918.

Minsky, M. (1961). Steps toward artificial intelligence. *Proceedings of the IRE*, *49*, 8–30.

Moreau, D., Clerc, J., Mansy-Dannay, A., & Guerrien, A. (2012). Enhancing spatial ability through sport practice. *Journal of Individual Differences*, *33*, 83–88.

Mussweiler, T. (2006). Doing is for thinking! Stereotype activation by stereotypic movements. *Psychological Science*, *17*, 17–21.

Natale, L., Nori, F., Parmiggiani, A., & Metta, G. (2014). Sensorimotor coordination in a humanoid robot: Building intelligence on the iCub. In R. Cingolani (Ed.), *Bioinspired approaches for human-centric technologies* (pp. 155–197). Springer.

Niedenthal, P. M. (2007). Embodying emotion. *Science*, *316*(5827), 1002–1005.

Oberman, L. M., Winkielman, P., & Ramachandran, V. S. (2007). Face to face: Blocking facial mimicry can selectively impair recognition of emotional expressions. *Social Neuroscience*, *2*(3–4), 167–178.

Ollendick, T. H., & King, N. J. (2004). Empirically supported treatments for children and adolescents: Advances toward evidence-based practice. In P. Barrett, & T. H. Ollendick (Eds.), *Handbook of interventions that work with children and adolescents: Prevention and treatment* (pp. 3–27). John Wiley.

O'Regan, J. K., & Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences*, *24*, 939–973.

Pezzulo, G., Rigoli, F., & Friston, K. J. (2018). Hierarchical active inference: A theory of motivated control. *Trends in Cognitive Sciences*, *22*, 294–306.

Pfeifer, R., & Bongard, J. (2006). *How the body shapes the way we think: A new view of intelligence*. MIT Press.

Piaget, J. (1954). *The construction of reality in the child*. Basic Books.

Premebida, C., Ambrus, R., & Marton, Z. C. (2018). Intelligent robotic perception systems. In S. Kolski (Ed.), *Mobile robots* (Vol. 1). IntechOpen.

Raichlen, D. A., & Alexander, G. E. (2014). Exercise, APOE genotype, and the evolution of the human lifespan. *Trends in Neurosciences*, *37*(5), 247–255.

Raichlen, D. A., Klimentidis, Y. C., Bharadwaj, P. K., & Alexander, G. E. (2020). Differential associations of engagement in physical activity and estimated cardiorespiratory fitness with brain volume in middle-aged to older adults. *Brain Imaging and Behavior*, *14*, 1994–2003.

Rowlands, M. (2006). *Body language: Representation in action*. MIT Press.

Rupert, R. D. (2009). *Cognitive systems and the extended mind*. Oxford University Press.

Searle, J. R. (1980). Minds, brains, and programs. *Behavioral and Brain Sciences*, *3*, 417–424.

Shapiro, L. (2007). The embodied cognition research programme. *Philosophy Compass*, *2*, 338–346.

Sprevak, M. (2009). Extended cognition and functionalism. *The Journal of Philosophy*, *106*(9), 503–527.

Sutton, J. (2007). Batting, habit and memory: The embodied mind and the nature of skill. *Sport in Society*, *10*, 763–786.

Sutton, J. (2015). Remembering as public practice: Wittgenstein, memory, and distributed cognitive ecologies. In D. Moyal-Sharrock (Ed.), *Mind, language & action: Proceedings of the 36th international Wittgenstein symposium* (pp. 409–443). De Gruyter.

Sutton, J., McIlwain, D., Christensen, W., & Geeves, A. (2011). Applying intelligence to the reflexes: Embodied skills and habits between Dreyfus and Descartes. *Journal of the British Society for Phenomenology*, *42*, 78–103.

Tani, J. (2016). *Exploring robotic minds: Actions, symbols, and consciousness as self-organizing dynamic phenomena*. Oxford University Press.

Thompson, E., & Varela, F. J. (2001). Radical embodiment: Neural dynamics and consciousness. *Trends in Cognitive Sciences*, *5*, 418–425.

Torrance, S., & Froese, T. (2011). An inter-enactive approach to agency: Participatory sense-making, dynamics, and sociality. *Humana.Mente: Journal of Philosophical Studies*, *15*, 21–53.

Varela, F. (1997). Patterns of life: Intertwining identity and cognition. *Brain and Cognition*, *34*, 72–87.

Varela, F., Thompson, E., & Rosch, E. (1991). *The embodied mind: Cognitive science and human experience*. MIT Press.

Ward, D., Silverman, D., & Villalobos, M. (2017). Introduction: The varieties of enactivism. *Topoi*, *36*(3), 365–375.

Wheeler, M. (2005). *Reconstructing the cognitive world: The next step*. MIT Press.

Williams, L. E., & Bargh, J. A. (2008). Experiencing physical warmth promotes interpersonal warmth. *Science*, *322*, 606–607.

Wilson, A. D., & Golonka, S. (2013). Embodied cognition is not what you think it is. *Frontiers in Psychology*, *4*, Article 58.

Wilson, R. A. (1994). Wide computationalism. *Mind*, *103*(411), 351–372.

Wilson, R. A., & Foglia, L. (2011). Embodied cognition. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy*. http://plato.stanford.edu/archives/fall2011/entries/embodied-cognition/

Zahavi, D. (2002). First-person thoughts and embodied self-awareness: Some reflections on the relation between recent analytical philosophy and phenomenology. *Phenomenology and the Cognitive Sciences*, *1*, 7–26.

Ziemke, T. (2016). The body of knowledge: On the role of the living body in grounding embodied cognition. *BioSystems*, *148*, 4–11.

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