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# Affordances from a control viewpoint

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**ABSTRACT**

Perceiving an armchair prepares us to sit. Reading the first line in a text prepares us to read it. This article proposes that the affordance construct used to explain reactive potentiation of behaviour similarly applies to reactive potentiation of cognitive actions. It defends furthermore that, in both cases, affordance-sensings do not only apply to selective (dis)engagement, but also to the revision and the termination of actions. In the first section, characteristics of environmental affordance-sensings such as directness, stability, action potentiation, valence, and phenomenology are re-examined in light of contemporary cognitive science. In the second section, it is proposed that cognitive affordance-sensings can also be characterized along these dimensions. Called "metacognitive feelings" in the metacognitive literature, their function is to select, engage, revise and post-evaluate cognitive actions. A third section discusses alternative views, and responds to objections.

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**Keywords:**

**Action potentiation, cognitive affordance-sensing, control, dual-process theory, evolution, perceptual affordance-sensing, metacognition, phenomenology, valence.**

## Introduction. Extending affordance-sensings to cognitive opportunities ?

Perceived red lights prepare drivers to stop. Spotting delectable mushrooms prepares hikers to pick them up. In many daily situations, specific perceptual configurations control motor systems, independently of agents' plan to act on them. The term of "affordance", used to characterize such relational dispositions, however, was very differently interpreted, by

psychologists (Lewin, 1935, Gibson, 1979), neuroscientists (Cisek, 2022, Jeannerod, 1994) and philosophers (Dreyfus & Kelly, 2007, McLelland & Jorba, 2022).

The hypothesis defended here is that metacognitive experiences have the function of detecting cognitive affordances: they immediately "tell" cognitive agents -- including 18-month infants (Goupil et al., 2016) and non-human primates (Beran, 2019) -- that cognitive tasks are doable, mildly difficult, or hopeless. These findings provide a prima facie reason to consider that perceptual and cognitive affordances have a similar role in controlling organisms' interactions with their environment by evaluating respectively external or cognitive opportunities available in a context. Affordance sensitivity in both cases occurs at three control junctures: detecting an opportunity, adjusting one's b*ehaviour to it, and assessing final outcome (*Goupil & Proust, 2023). This parallel suggests that the mechanisms of adaptive interaction with one's environment could have been re-deployed and differentiated through phylogenetic evolution in order to maximize the efficiency of information utilization (Anderson, 2007, Cisek, 2022, Pezzulo & Cisek, 2016). Section 1 discusses the characteristics of perceptual affordances in the light of contemporary cognitive science. Section 2 defends that these characteristics have a counterpart in the case of cognitive affordances. Section 3 discusses alternative views and addresses objections.

**Perceptual affordances: conflicting views**

The meaning of the term of "affordance", an English neologism coined in 1979 by James Gibson presumably draws on the German term of "Aufforderung" used by Kurt Lewin (Lewin, 1935). The term has been adapted by philosophers and psychologists to their own theoretical needs, in a variety of fields ranging from phenomenology (Dreyfus & Kelly, 2007, Rietveld, 2013), the naturalization of consciousness (Dennett, 2014), the evolution of intentionality (Millikan, 2017), evolutionary neuroscience (Cisek, 2021), animal technical intelligence (Huber & Gajdon, 2006), animal metacognition (Proust, 2013), design (Masoudi et al., 2019), musical cognition (Krueger, 2014) and tool use (Osiurak et al., 2017. The main arguments and controversies about the nature of perceptual affordances will be reviewed in this section in order to prepare our discussion of cognitive affordances.

### 1.1 Directness

"Affordance" is the cornerstone of Gibson's theory of ecological perception.

> The perceiving of an affordance, Gibson writes, is not a process of perceiving a value-free physical object to which meaning is somehow added in a way that no one has been able to agree upon; it is a process of *perceiving a value-rich ecological object*. (Gibson, 1979, p. 131-2, my emphasis)

On his view, we *directly* perceive the opportunities of action offered by the environment-- , rather than infer them from the sensory properties of objects (such as forms and colors). Vision is supposed to:

a) pick up affordances presented in the visual array;

b) pick them up as part of a constantly active exploration: perceiving entails head, limb and locomotion movements, aimed to result in grasping, ingesting, fleeing etc.

c) pick them up "directly", on the basis of an attunement between environment and vision. Vision extracts invariants "related at one extreme to the motives and needs of an observer, and at the other extreme, to the substances and surfaces of a world" (1979, p. 143). For example, perceiving the distance of a target depends, for terrestrial distance, on texture versus terrain ratios, but for aerial distance, on horizon ratios (1979, pp. 168-169). Instead of concluding from this evidence that the brain computes distance on a *basis of multiple predictive cues*, Gibson took it to demonstrate that *no computation or goal representation is needed*.

Information-processing theorists, however, understood "direct pick up" in their own terms (Chong & Proctor, 2020). They identified two kinds of perceptual affordances, with different functions and cerebral pathways. The dorsal pathway (i.e. projections from the striate cortex to the posterior parietal region) non-consciously tracks low-level *motor affordances* in an egocentric frame of reference (for example the grip needed to grasp a glass); the ventral pathway (i.e., projections from the striate to the inferotemporal cortices) identifies high-level object affordances (for example, the fruits in a basket that should be eaten first) as a function of their consciously perceived properties, in a frame that can be either egocentric or allocentric.

This view revises Gibson's claims in two major ways. The complex processing mechanisms found to underly low-level or high-level visuomotor tasks offer evidence that vision depends on multilevel *computations* (based on a number of environmental regularities).

Furthermore, Gibson's claim that vision exclusively targets affordances conflicts with the identification of allocentric forms of perception (e.g. for perceiving a person as to the right of another).[1] A full discussion of the merits and weaknesses of ecological theories of perception cannot be conducted here; we will merely assume that the dual-pathway view refutes Gibson's two arguments in favor of directness: that affordance perception is non-computational and that it is constitutive of vision.

It is arguable, however, that affordance perception is direct, not in the sense that it bypasses computations – as no mental function has such properties –, but in the sense that, in a number of cases, it potentiates programs of action *upstream from object recognition and reasoning*. Walking in a forest, you jump to avoid walking on a snake even before you consciously identify a snake-shaped stick. Experimental evidence shows that the affordance of a presented object can be detected only milliseconds after perceptual inputs have impacted the retina, i.e. before the categorization of perceived objects is completed (Barrett & Bar, 2009) (more on this in section 1.3).

### 1.2. Stability

From Gibson's viewpoint, an important property of affordances is their *stability*. For him, while observer's subjective needs change across time, the affordances of objects do not change across action contexts. Object affordances are specified in stimulus information rather than inferred from object properties, as claimed in classical theories of perception. For example, perceiving a mailbox *consists in* perceiving an affordance.

Are affordances unchanging elements of a niche, whether or not attended to? Are they rather made manifest by an active search in the context of a specific need? In order to address these questions, more needs to be known about their evolution, their development, and their neural correlates. The next three subsections will summarize some important proposals. To anticipate, we will examine in section 1.4. the competition hypothesis, which suggests that stability is the outcome of a competition between affordances, which largely depends on the context of action.

### 1.3. Valence

[1] On these various critical points, see Jacob & Jeannerod, (2003), pp. 180 sq.

For Lewin and the other Gestalt theorists, to perceive an affordance is to recognize an object or a situation as having a *positive or a negative* character, which potentiates an approach or an escape behaviour. Lewin's *Aufforderungscharakter,* (literally: "invitation-character") was translated by Edward C. Tolman through "valence",[2] now a central explanans in emotion theory. In Lewin's work, behavioural dispositions are *explained by* the phenomenal character of affordance perceptions: the specific "tension" between the phenomenal "self-in-action" with objects, he claims, is experienced as supportive or obstructive, as a function of one's present goals. A mailbox, for example, "invites" to post a letter only when a letter is to be posted.[3] The information carried by felt valence is not limited to a rough positive/ negative appraisal. The subjective nuances of engagement are modulated by the embodied features associated with exercising skilled activities in all kinds of material environments. Each environment thus offers an "affordance landscape" for selective engagement (Rietveld & Kiverstein, 2014). Pezzulo & Cisek, (2016, p. 415) define it "as a temporally extended space of possible affordances, which changes over time due to events in the environment but also – importantly – due to the agent's own actions."

A major disagreement among early theorists, however, has to do with perceivers' sensitivity to affordances. Commenting Lewin, Gibson insists that positive and negative affordances (benefits, injuries) are "*taken with reference to an observer* but not properties of the *experiences of the observer"*; affordances are coupled to bodily and behavioural configurations, but they "are not feelings of pleasure or pain added to neutral perceptions" (1979). For Gibson, an affective mediation would compromise the direct character of affordance perception (see also Silberstein & Chemero, 2012).

Can one ignore the evaluative dimension of affordance-sensings, and would it compromise the direct character of affordance perception? To settle the debate between Gibson and Lewin, three questions must be addressed:

a) Why is valence a crucial component in affordances?
b) What is the informational source of valence?
c) What are the mechanisms of evaluation that determine and recalibrate valence?

[2] For a review of the uses of valence in emotion theory, see Colombetti (2005).
[3] Except in patients who manifest an untimely sensitivity to perceived affordances, in utilization behavior. (Lhermitte, 1983)

**a) Why is valence crucial?**

It is crucial because it allows animals to detect survival opportunities and to learn how to behave adaptively. In short, the orbitofrontal cortex determines perceivers' focus of attention and sensitivity to opportunities and risks, in association with the amygdala, which controls "arousal" – i.e. emotional intensity (Lewis et al., 2007). Valence and intensity together determine what to attend to, and what to do about it (Gawronski & Mitchell, 2014). Valence, then, is the key to affordance sensitivity and behavioural flexibility.

**b) What is the informational source of valence?**

The information that makes affordance detection possible is the set of cues that predict a specific opportunity (positive or negative) in the environment. For example, an alarm call means predator, a sign on the freeway means gas. How is an alarm call perceived *as a threat*? To address this question, two accounts need to be combined. A first account explains how a given emotional signal works (what is the *proximal* source of affordance-sensitivity). A second account explains how a prediction is at all possible (what is the *distal* mechanism involved).

- *The proximal* source of affordance sensitivity consists in the sensorimotor embodied information associated to an opportunity: the way it looks, sounds, smells, etc. along with evaluative signals related to valence and intensity: affects of pain, pleasure or disgust, determine the valence of a given perceptual input. The related arousal level determines the perceived intensity of an opportunity, whether positive or negative.[4]
- The *distal source* consists in reinforcement learning. Associative learning allows multiple sensory cues to predict an affordance sensing.[5] Learning, crucially, supports calibration, i.e. the ability to modify threshold decisions for affordance detection, as a function of observed outcomes.

**c) What are the mechanisms that allow predictive cues to be picked up?**

Affective evaluations detect what to expect given the cues currently available (Barrett, 2006). An affordance is detected only milliseconds after perceptual inputs have impacted the retina,

[4] Braver et al., 2014, Proust, 2014.

[5] Genetic predispositions might first bias affordance detection (Davis & Whalen, 2001). Predictive cues are also learned by conditioning (Fanselow, 2018).

i.e. outside the agents' awareness of the object currently perceived (Barrett & Bar, 2009). More specific mechanisms include innate species-specific reactions to inputs, such as inspecting, moving away, fleeing, in conjunction with emotions such as anxiousness, fear and panic. In most cases, the association of an emotional cue with the relevant motor program is learned either through subcortical pathways involving the amygdala or through cortical pathways involving the cingulate and the medial prefrontal cortex (Fanselow, 2018, Sander et al., 2005).

Let us take stock. Although affordance-sensitivity is a universal feature of cognition, its specific targets are learned as a function of the characteristics of organisms' physical and social environments. *Emotional appraisal* plays a central role in this process. The valence of opportunities and risks must be assessed for an appropriate action to be potentiated. Prior evaluations enable quick, direct reactivity – in an informational sense that is foreign to Gibson's ecological theory.

### 1.4. Affordances and effectivities

Are motor (re)actions (i.e. "effectivities") parts or consequences of perceived affordances? Turvey (1992) considered that the capacity to perceive affordances in the environment and to respond to them are distinct dispositions, but that their conjunction generates an actualization of both (see also Michaels, 2000). Perceived affordances, on this view, are among the *causal conditions* of the instantiation of a motor program. Tucker and Ellis (1998) claimed that affordances are not environmental properties, but rather motor attributes directly included in the representation of visual objects. Chemero (2001, 2003) also objected that a metaphysical contrast between affordances and effectivities is incompatible with the view that a combination of environmental agentive dispositions generates affordance sensitivity. Is this metaphysical point validated by evidence?

As seen above in section 1.1, evidence for a dual-pathway in vision demonstrates that, pace Gibson, perceptual affordances do not organize all kinds of perception. Goal-directed *behaviour* partly relies on motor affordances for executing actions: for example, hands are pre-shaped to grasp a glass (Jacob & Jeannerod, 2003). At higher levels, however, goal representations may also influence affordance pick up (even though lower-

level perceived affordances still play a role). Chemero's single structure view would tend to *limit the scope* of affordances to low-level sensorimotor representations.[6]

A detailed understanding of the evolution of control structures within brain organization (Cisek, 2012, 2021), helps clarify the debate. From our early *eumetazoan* ancestors to primates, brains evolved to *optimize control* of species-typical resources. Affordance sensitivity indeed relies on the two routes, but *at different steps in a processing sequence*. Affordance based selection of action (what to do?) and specification of action (how to act?) operate in parallel, which maximizes reactivity (Cisek, 2007, p. 1586). Competition of control systems activated in parallel allows actions *with the highest inclusive affordance* value to be selected. Motor (lower-level) affordances and object-centered (higher-level) affordances thus *compete* in guiding reactive behaviour. In other words, trade-offs between motor fluency and goal value regulate perceived affordances. For example, agents tend to pick a fruit at arm-length.[7] This theory elegantly solves the issue raised in this section: lower-level dorsal affordances regulate the motor side of effectivity; higher-level ventral affordances allow global preferences to emerge, but both kinds of affordances are integrated in behaviour control.

An additional question, however, is whether affordance-sensings only contribute to action engagement, or also potentiate revision (disengagement for error), and stopping decision (disengagement for success) (Logan, 1985). For example, changing a pointing gesture as the target moves, or changing one's grip on an object, constitute revisions of former low-level motor affordances. This suggests that error signals potentiate revisions exactly as engaging signals do. Similarly, is there not a stopping affordance-sensing related to an evaluation of goal completion? Arguments in favor of this view are to be found in the motor control literature (Gallivan et al., 2016). For lack of space they will not

[6] An alternative construct to Turvey's proposal claims that the emotions embodied in perceptual inputs "allow us to literally perceive that situations afford a range of possible behavioral responses" (Prinz, 2004, p. 228). However, Prinz observes, emotions are themselves *not* literally *perceived*: "valence markers are not perceptual states" (p. 229).

[7] Recent evidence is compatible with the competition view. The visuomotor neurons activated both when looking at an object and when grasping represent potential motor acts (Maranesi et al., 2014). See also Gallivan et al., 2016, and Osiurek et al., 2017 examining further evidence in favor of the competition theory.

be discussed here. This issue will be taken up in section 2, however, in connection to cognitive actions.

### 1.5. Phenomenology

There are two closely connected phenomenological dimensions in affordance detection. The first is an experience of a thing to do, i.e. a sense of *goal*- or *task-relevance*: it immediately and specifically presents an external opportunity to be acted upon. In Dreyfus & Kelly's description, "the environment is calling for a certain way of acting" (Dreyfus & Kelly, 2007, p. 52). The other is an immediate affective feeling of *self-relevance*, experienced in the "giving in" to a solicitation coming from outside. These two aspects are experienced by agents as inherent to an environmental opportunity, rather than to their own subjective appraisal (Kenny, 1963, Proust, 2014). The affects experienced in sensing environmental affordances target the expected rewards or losses attached to the situation as perceived. They consist in feelings such as usefulness, attractivity, availability, disgust and danger attributed to an environmental feature.

It is arguable, however, that valence does not need to be consciously experienced for affordances to be detected and used in action guidance. In the case of environmental affordances, two arguments speak in favor of a negative response.

a) The dual pathway argument.

As discussed in section 1.4, motor specifications and object affordances compete in action selection. The former, however, are mostly nonconscious: agents are not aware of preparing their grip at the start of their arm extension. Even when agents are deliberately pointing to a specific object in their own peripersonal space, they non-consciously revise their motor trajectory if the object moves slightly during the pointing (Prablanc & Pélisson, 1990, p. 668). *Limited* adjustments to pointing, then, can be performed by the lower, "specification" system, with no specific awareness.

b) Timing evidence

Timing evidence shows that valence is first sensed non-consciously (Barrett & Bar, 2009). Based on magnocellular input, the "gist prediction" of the emotional value of a stimulus occurs in the orbitofrontal cortex only milliseconds after the perceptual input impacts the retina. The dorsal stream prepares the relevant action before a threatening object is consciously recognized by the ventral stream about 300 msec. later.

In summary, higher-level affordances ("what"- affordances) are consciously recognized only when perceptual inputs are fully processed. In lower-level motor affordances ("how" affordances), action control in the peripersonal space can remain non-conscious, while still detecting valence.

Is the proposed construct useful to characterize cognitive affordance-sensings? In other terms, are there direct opportunity-sensings whose function is prepare agents to perform cognitive actions?

## 2. From perceptual to cognitive affordance-sensings

It is arguable that sensitivity to perceptual and informational forms of affordances respectively control pragmatic and in cognitive actions, i.e. actions with environmental or informational goals. Taking a control viewpoint on cognitive affordances clarifies the difference between the *objects or situations in the environment that have incidentally triggered a cognitive affordance* from the *cognitive affordances so triggered*. For example, the title of a book may arouse the interest of a potential reader. A book affords knowledge in a loose sense of the word, by making reading factually possible. But the cognitive affordances associated with books consist in predicted informational gains: *interest*, *curiosity* for their content, sense of *ease or difficulty of reading them*: books are environmental causal preconditions for these cognitive affordances.

This analysis diverges from that the view that the act of counting is afforded by a jar full of marbles. (McClelland, 2020, p. 17). A jar of marbles may be an instrumental precondition for experiencing an affordance of counting, but it does not in itself potentiate the act of counting. Agents need to be curious to know the number of marbles in the jar; if the number of marbles feels easy to count, they might predict that their exploration will be successful. In this example, two cognitive affordances are involved: one based on the detection of a knowledge lacuna to be repaired by counting. The other is based on the feasibility of the counting process.[8] This functional distinction does not entail that environmental triggers play no role in detecting cognitive affordances (several forms of feedback are used in this detection, as will be proposed in section 3.1). The present point is rather that cognitive affordance-sensings consist in predictive internal feedback, rather than in objects or tools.

[8] See Goupil & Proust, 2023.

Although the affordance literature focuses on the role of affordance-sensings in engaging in action, we considered in section 1.4 the possibility that they operate at three control junctures: *selecting what to do, correcting pathway to goal, and assessing outcome*. In the cognitive case, subjective experiences also have a triple distribution over time:

- Before acting: *Sensing a* learning affordance (curiosity) motivates an *upcoming* exploration behaviour
- During the action: *Sensing a mistake* interrupts activity until the error is repaired.
- After the action: *Retrospective evaluation* allows determining whether the action is completed or needs to be redone ( *feeling of confidence or uncertainty).*

### 2.1. Directness as a feature of adaptive control .

At each juncture, cognitive affordances are sensed through specialized metacognitive feelings that present an action as feasible, interesting, valuable, difficult, boring or unimportant. Sensed affordances "directly" potentiate action control in the revised meaning discussed In section 1.1: they are sufficient to motivate agents' decision to engage in an action, to revise or to stop it – agents do not need to describe their feelings or to articulate their reasons to decide to act. Directness so understood is inherent to "procedural metacognition" (Shea et al., 2014, Proust, 2012) – an ability for selecting and revising cognitive tasks adaptively, present in nonhumans and human infants (Couchman et al., 2012, Goupil et al. 2016, Proust, 2019), an ability that, in contrast to "explicit metacognition", *does not depend* on a concept-based representation of the task (Koriat & Levy-Sadot, 1999).

### 2.2. Stability in cognitive affordances

As proposed in section 1.2., we're not constantly hungry, thirsty, or tired. Still, we always non-consciously perceive a loaf of bread as food, water as drink, a chair as a seat. Competition between affordances determines the winning opportunity on which to act (Pezzulo & Cisek, 2016). This also holds for cognitive affordances. Stable algorithms are implicitly acquired, that predict opportunities to learn, to remember, or to detect and correct errors.[9] Context largely determines which thresholds to apply in a given decision. Will a student read her mail or study? Will she prepare her exam or attend a social event? Competition determines what can

[9] Evidence accumulation models such as the diffusion model are a dominant framework for understanding perceptual and cognitive decision-making (Logan et al., 2023, Yeung & Summerfield ,2012).

be learned and gained in each case. A soccer game can be boring, a conversation instructive, for you and not for me. The *relative stability* of cognitive affordances is manifest in the fact that individual agents have learned how to assess and cope with their subjective uncertainty, and learned to prioritize their own cognitive goals. Their *relative instability* again originates in the adaptive competition between action goals across contexts.

### 2.3. Valence of cognitive affordances: source and mechanisms

In contrast to perceptual affordances, the informational source of cognitive affordances are cues that predict informational outcomes of one's actions, rather than extrinsinc rewards (such as fame or money). Is the name of this bird promptly retrievable? Can I learn this poem? Is there anything interesting for me to read here? Feelings of knowing, of curiosity, of ease of processing, and many others, help agents quickly decide what to do, what to revise, and when to stop.

The parallel defended in the introduction of this section between cognitive and perceptual affordances respectively involved in cognitive and pragmatic action has been rejected by Peter Carruthers (2008). Our cognitive affordances are nothing else than the first-order outcome of a competition process between alternative responses to a situation – our perceptual affordances. Discussing a perceptual discrimination task proposed by Smith et al. (1996) to nonhuman primates, for example, Carruthers proposes that, around the discrimination threshold, animals are oscillating between two beliefs, e.g. [*that the pattern is sparse*] and [*that the pattern is dense*]. In this case, the belief that wins is the stronger one. A cognitive affordance, on this view, plays no role. Similarly, a conflict between alternative opportunities equally attractive automatically motivates the animal to switch modes of responses.[10] Here again, reward is the relevant causal factor, not the agents' subjective uncertainty.

This objection, however, conflicts with the evidence of the subjectively sensed autonomy of informational gains compared to pragmatic rewards (Goupil and Proust, 2022). Non-humans and humans alike have an intrinsic motivation to explore their environment, that is not contingent on their present instrumental needs. In particular, the need to perform

[10] Carruthers, (2008), section 3.2.

correct cognitive (self) predictions makes *recalibration* of confidence a specific learning target, served by distinct brain pathways (Kepecs et al., 2008).

So what are the source and mechanisms of cognitive valence? A major difference with perceptual affordances is that valence, here, signals opportunities to discriminate, to remember, to learn, etc. Hence an opportunity is not detected through sensorimotor cues (e.g., the color and shape of a fruit), but through a set of embodied experiences (backed up by predictive heuristics). Heart rate (Park & Tallon-Baudry, 2014), proprioceptive cues, such as postural and facial reactions (Gawronski & Mitchell, 2014), shorter or longer time freely allocated to a task (Koriat & Ackerman, 2010), track cognitive affordances. The reliability of these embodied cues, obviously, depends on their nonconscious informational basis (Schwarz, 2020). The convincing power of gurus, propagandists and conspiracy theorists demonstrates that cognitive affordance-sensings may fail to predict genuine knowledge opportunities.

In summary, cognitive affordances, are informational opportunities sensed through specialized affective appraisals based on nonconscious heuristics. Sensing a cognitive affordance of retrievability, of discriminability, of learnability, prepares the corresponding action; sensing a rightness affordance disposes the agent to accept her own conclusion (Ackerman & Thompson, 2017); a feeling of ignoring tends to suspend retrieval effort (Metcalfe, 2009).

Although functionally distinct, pragmatic and cognitive affordances can cooperate or compete in controlling decision (as proposed in 2.1). Various risk/benefit schedules determine the winning options in a given context, on the background of present motivations, socially acquired habits and environmental predictability. As is the case for perceptual affordances, a competition of control systems, activated in parallel, allows cognitive actions *with the highest inclusive affordance* value to be selected. This competition, again, directly controls decision-making. But how can action potentiation work for cognitive affordance-sensings?

### 2.4. **Cognitive affordances and effectivities**

As discussed in section 1.4., action potentiation is part of what it is to *perceive* an environmental affordance. Does *sensing* a cognitive affordance also automatically pre-selects

the associated command, as suggested in 2.3.? If so, what are the mechanisms through which monitoring intrinsically guide execution?

Erwin Feinberg (1978) speculated that the control of cognitive actions might also rely on motor control. In favor of this hypothesis, impairments in the efference copying mechanism in a forward-model of action might explain both difficulties in distinguishing self- from non-self-produced effects, and cognitive delusions, such as thought insertion. The motor aspect of cognitive actions might consist in covertly articulating words in inner speech (Campbell, 1999, Proust, 2009). A major argument against the inner speech view, however, is that nonverbal agents, such as nonhuman primates (Couchman et al., 2012, Proust, 2019) and human infants (Goupil et al., 2016), are sensitive to cognitive affordances: they can be curious to know, they can predict how difficult it will be to discriminate two target stimuli, or to retrieve a previously learned sequence. They can sense whether a given trial was correct or not. Cognitive regulation, then, does not seem to belong to motor regulation.

An alternative view is that cognitive regulation first started with error monitoring. The latter might be functionally compared with low-level motor "how-affordances" discussed in section 1.4. Nonhumans and humans alike monitor their performance errors on the basis of the gradient of uncertainty they experience. This allows them to correct and optimize their on-going and future cognitive actions (Ullsperger et al., 2014). Felt errors have a negative valence that solicits repair. This is one of the earlier forms of potentiation by cognitive affordances. Furthermore, nonhuman primates learn to rely on their own internal feedback and past experience to select or inhibit perceptual or memorial actions (Middlebrooks & Sommer 2012). Here again, feasibility signals have a valence that potentiate action or inaction. Hence, motor control, initially dedicated to behavioural guidance, might have evolved, across phyla, from the control of motor activity toward a metacognitive control based on appraisals of subjective uncertainty. What are the evolutionary arguments in favor of this picture?

Thanks to the mechanism of affordance competition between lower and higher affordance discussed above (section 1.4), lower-level forms of metacognition (e.g. evaluating one's own visual categorization) might have been re-deployed to serve higher-level cognitive actions, such as problem-solving or communicating. Neural evidence indeed suggests that the mechanisms for evaluating one's cognitive actions in various domains (such as perception vs memory) are in part common and in part anatomically diversified (McCurdy et al., 2013). Their

hypothetical redeployment might have occurred in phylogenetic lineages as a consequence of environmental changes affecting foraging opportunities, depending on the type of species-specific foods. Consistent with this hypothesis, executive functions in a species seem to have been shaped by the demands of foraging in an environment (Rosati, 2017). Sensing a variety of cognitive affordances – i.e. using internal feedback -- might result from the extension of foraging goals from food to information (Cisek, 2019). Foraging for information, in turn, allowed cognitive affordances to drive and control decision-making in new task domains, such as the control of memory and perceptual categorization.

Verbal communication, however, introduced new pressures on information foraging. The ability to verbally describe one's metacognitive feelings considerably improved collective decision-making (Fusaroli et al., 2012). In this process, a new form of metacognition, called "explicit metacognition", has developed (Proust, 2022, Shea et al., 2014). It engages a normative sensitivity to the cognitive affordances that regulate verbal exchanges: under the social pressures for clarity and learnability (Bicchieri & Mercier, 2013), new cognitive affordances have emerged from cultural accumulation, such as truth and consistency (Proust, 2022, Shea, 2023).

### 2.5. Phenomenology of affordance-sensings

Perceiving an external affordance and sensing a cognitive affordance both *feel like* an immediate attraction to act in a certain way (see section 1.5). Curiosity, for example, combines a feeling of ignorance and a learning affordance to motivate knowledge acquisition (Goupil & Proust, 2023).

The two connected phenomenological dimensions of valence discussed in section 1.5 play a crucial role in cognitive affordance-sensings. One is the sense of self-relevance of a cognitive decision (for example a math course may be felt as a learning opportunity by male, not female students[11]). The other is the sense of task-relevance: it specifically presents an activity as to be pursued or to be interrupted. For example, a feeling of knowing prompts one to retrieve knowledge, a feeling of incoherence prompts one to clarify, a feeling of progress encourages perseverance in one's cognitive action. Self-relevance and task-relevance are simultaneously experienced by cognitive agents, but experimental evidence shows that they

[11] Huguet & Régner, 2009.

have different sources, different neural correlates, and different effects on cognitive decisions (Seow et al., 2021).

Is phenomenological (i.e. conscious) awareness a condition for action potentiation? Researchers have offered different responses (positive in Koriat 2000, negative in Reder and Schunn, 1996). A main type of evidence consists in the neural signatures of conscious and non-conscious pathways of error-based cognitive corrections.

As we saw in section 1.5., the case of perceptual affordances might suggest that non-conscious affordance-sensings can guide cognitive decisions. Against this view, however, it has been objected that non-conscious error monitoring is not sensitive to gradiency. The EEG signal called "error-related negativity" (ERN), occurring within 100 ms. of an incorrect response, indexes an *occurrent error correction*, not a graded evaluation of the divergence between expected and observed action outcome (Yeung & Summerfield, 2012). In contrast, the amplitude of error-positivity signals (Pe) varies with the gradient of subjective confidence. These signals occur within 200 to 400 msecs of an incorrect response, a duration associated with the integration of various informational sources, including the posterior cingulate, the parietal and prefrontal cortices (Charles et al., 2013).

Another interpretation of this evidence has been proposed, however. Granted that ERN expresses the sensitivity to *post-error* conflict between responses, it is arguable that ERN reflects the role of anterior cingulate in performance monitoring (Yeung et al., 2004). This qualifies ERN markers as metacognitive, although with a low-level affordance profile, similar to that found in low-level motor comparators (see section 1.5). On this interpretation, a cognitive affordance can be detected and acted on even if it is not consciously accessible and hence, with a nonconscious phenomenal character. Whether all sensations of cognitive affordance are consciously experienced remains a matter of debate.

Interim summary

On the view defended, a structural analogy between the two kinds of affordance sensitivity suggests a common function in action control. Perceptual affordance-sensings assess opportunities for acquiring resources or avoiding risks. Cognitive affordance-sensings assess opportunities for acquiring knowledge and avoiding error. In both cases, prompt decision to act is potentiated by the corresponding valence. Adaptive control theory accounts for this parallel: negative feedback loops respectively regulate pragmatic behaviour and informational

processing. In other words, the effects of prior motor responses or prior cognitive decisions determine what now counts as an affordance in a context (Cisek, 2019, p. 2270).[12] Affordance-sensings, then, respectively maximize use of external (i.e., environmental) or of internal (i.e. informational) resources.

Evidence suggests that control mechanisms have been redeployed in two steps over evolutionary time. A first redeployment allowed lower-level, non-conscious error correction to detect not only performance error, but also, probably, task feasibility and final success. This redeployment seems to result from enhanced connections between the emotional system and the prefrontal areas involved in decision-making (see 1.3.). The non-conscious and conscious forms of performance evaluation, far from being exclusive, still cooperate in orienting different action sequences (Soto et al., 2011) .

A second redeployment, described in 2.4, allowed consciously sensed cognitive affordances (metacognitive feelings) to be redescribed in verbal, conceptual terms. “Concept-based”, socially transmitted affordances –“explicit metacognition” – might have in turn increased agents’ awareness of potential failures and misuses of communication (Frith, 2012, Planer, 2023). Non-humans are aware of what they can perceive or remember, and of their cognitive success in such tasks. Humans are, in addition, consciously confronted to the requirements of higher-level forms of justification such as truth, coherence, or relevance (Proust, 2022). In humans, an additional layer in the control hierarchy is created by representations of how others perceive one's own value as a cognitive cooperator (Seow et al., 2021, Shea et al., 2014).

## 3. **Responses to objections**

### 3.1. **Divergences in defining cognitive affordances**

The present proposal agrees with McClelland & Jorba (2022) that affordances are neither reflex responses, nor propositional attitudes such as beliefs, desires, or imperatives. However, a divergence exists about whether objects are perceived as providing cognitive opportunities. McClelland & Jorba take an automatic motor activation, elicited by context, to be in both cases

[12] Dewey (1896), p. 363, noted that "the motor response determines the stimulus" (quoted in Cisek, 2019, p. 2270). The parallel phrasing works for cognitive affordances: "the cognitive response determines the relevant predictive cues.

a source of motivational force (p.14). Objects and cognitive tasks (e.g., solving a problem), then, might qualify as cognitive affordances.

Discussing this suggestion requires clarifying the relations of cognitive affordances to objects. Among the multiple contextual elements that can trigger affordance-sensings, without being directly involved in the appraisal mechanism (2.5), three types deserve to be distinguished: *sensorimotor cues, cognitive tools and metacognitive tools*. Let's take the cognitive action of counting as our test case. *Environmental cues* help detect the contextual features (stored in episodic memory) that, in the past, were associated with counting: marbles in a jar, flowers in a vase, paper and pen, coins etc.[13] On the present view, such cues signal a type of cognitive context, not an affordance-sensing. They do not potentiate an action unless associated with a sense of task relevance and personal relevance. *Cognitive tools* are transmitted instrumental mediators for cognitive actions. Arithmetic examples include teaching strategies for how to formulate problems in order to promote conceptual understanding.[14] Schematic representations of arithmetic problems have been shown to scaffold students' numerical reasoning (Gvozdic & Sander, 2019). However, it is not these schemas, but the reasoning activity thus scaffolded, that elicits affordance-sensings (for example, feelings of understanding). *Metacognitive tools* are transmitted strategies for enhancing reliability in informational search and for revising error in a non-threatening way. For example, students are informed that a quickly found solution is often unpromising. (Ackerman & Thompson, 2017), or that learning performance is lower on screen than on paper (Ackerman & Goldsmith, 2011). Educational, legal and scientific institutions are cultural sources of metacognitive tools. To the extent that individuals internalize recommended rules and procedures for demonstrating, explaining, defining, etc. they learn to detect new cognitive affordances (Proust, 2020, Zawidzki, 2021).

One might object, however, that cognitive affordance-sensings, in adult humans, are finally replaced by concept-based judgments. In other terms, emotion-controlled cognitive decisions ("system 1") are progressively controlled by argument-based judgments ("system 2") (Frankish, 2010). The shaping role of epistemic institutions seems to suggest that higher-level cognitive affordances are rationally redescribed, rather than non-conceptually sensed

[13] Wilson-Mendenhall et al., (2013).

[14] Scheibling-Sève et al., (2020). Although it is often believed that teaching arithmetic should rely upon children's intuitive ways of representing addition and substraction (as resource acquisition versus loss), this turns out to seriously impede arithmetic reasoning.

(Shea et al. 2014). In this interpretation, they are transformed into explicit rules, which replace affect-driven decisions with meta-reasoning or meta-communicational strategies.

Against this interpretation, one can observe that conceptual redescription does not relieve agents of the need to contextually evaluate cognitive affordances, such as concept dependability (Shea 2018), applied to a given strategy. Furthermore, professional mathematicians and expert chess-players report detecting promising moves or lines of action without being able to explain why. These two arguments suggest that cognitive affordances are assessed non-conceptually, i.e., on the basis of nonconscious predictive heuristics, even within paradigmatic cases of reasoning.

### 3.2. Cartesian dualism ?

Bruineberg & van den Herik (2021) objected to McClelland's (2020) discussion of cognitive affordances that the contrast between environmental or bodily opportunities and mental ones is inspired by a rampant Cartesian dualism. On their view, McClelland's distinction between affordances fails to acknowledge that our mind is embodied, and that action control is distributed across the brain and the environment. Is the present view exposed to a similar objection?

The critiques' first worry can be cleared by emphasizing the causal role of embodied markers in both cases of affordance sensitivity. Somatic changes contribute to predicting available information and preparing an appropriate cognitive reaction (section 2.3). Control theory is based on the recognition that sensory feedback is the basis of cognition.[15] Somatosensory cues such as heart beats, cold sweats, dry throat, jaws contraction, predict and prepare confrontation. Positive social communication is both predicted and enhanced by rised eyebrows, smiles, leg trepidation, vocalizations. Cognitive affordance-sensitivity has been similarly found to depend on interoceptive cues such as increased activity in the facial muscles for frowning (corrugator supercilli) or smiling (zygomaticus major) (Stepper & Strack, 1993, Winkielman & Cacioppo 2001). These cues, however, do not only have a social function. Metacognitive research suggests rather that evolution recycled these internal emotional cues

[15] As Cisek (2022) points out, the term of "embodied cognition" "gets things backwards". Actually bodily control is the basis of cognition. On the role of sensorimotor information in conceptual activity, see Wilson-Mendenhall et al., (2013).

to to evaluate present cognitive opportunities on a number of dimensions (for a full review, see Schwarz, 2020).

The present proposal agrees with the authors' second observation. Cognitive control indeed depends on distributed information across brains and their physical and social environments. From the physical viewpoint, it has been found that metacognitive evaluations depend on the statistical predictability of the external environment (Schwartenbeck et al., 2013). From the social viewpoint, suprapersonal (collective) forms of metacognition are a major source of alignment in cognitive affordance-sensings and cognitive cooperation (Heyes, 2017).

This recognition of the influence of the physical and social environment on subjective uncertainty, however, does not dissolve the functional difference between perceptual and cognitive affordance-sensings. While the former evaluate an external opportunity with a view to exploiting it, the latter evaluate a cognitive opportunity with a view to maximizing knowledge. The fact that multiple cues influence subjective prediction does not affect this essential difference.

### 3.3. **Cognitive affordance-sensings and metacognitive feelings**

A reviewer observed that "metacognitive information doesn't seem to be exactly the kind of information that affordances provide the agent with, which is a solicitation to act in a certain way: it is not mere information about an object, event or process." Admittedly, the "meta" terminology, inherited from past theorizing, is misleading (see Proust, 2007). The solicitation to act described here, however, correctly characterizes how metacognitive *feelings* influence cognitive decision-making. The view that metacognition requires beliefs about one's cognition has been found incompatible with comparative and developmental evidence (see 2.3, above, Proust, 2019, Goupil & Proust, 2023). Nonhuman animals, Infants and young children are able to evaluate their ability to perceive or remember in the absence of concepts about their own mental activity. It also fails to account for the respective roles of experience and belief in adults' predictions of learning (Koriat & Ackerman 2010). On a dual-process view of human metacognition, the control of cognitive actions occurs either through affect-based evaluations, or through theory-based predictions (Koriat & Kevy-Sadot, 1999). On this revised understanding of metacognition, it is consistent to argue that cognitive affordance-sensings are another name for metacognitive feelings."

A similar misunderstanding about the meaning of "metacognition" leads to object that cognitive affordances are "located in the cognitive process, not the metacognitive process". Rather, analysis of the control structure of cognitive actions suggests that control and monitoring are intrinsic components of any cognitive action. This is also the case of pragmatic actions: valence monitoring is causal in action selection, revision, and final evaluation (Braver et al., 2014). As argued above, this common feature justifies the parallel between cognitive affordance-sensings (involved in the control and monitoring of informational goals) and perceptual affordance-sensings (involved in the control and monitoring of pragmatic goals).

### 3.4 Do affordance-sensings qualify as an alternative kind of representations?

For Chemero (2003, 2009, 2011), an ecological, embodied theory of perception dispenses with representations in a propositional sense of the term. However cognitive science uses the term of "representation" more liberally. In conformity with this use, it is defensible to claim that shapes, colors, proprioceptive cues, and informational patterns represent (detect, predict) affordances. However, we need to be more precise about how affordances-sensings are represented. In 1959, Peter Strawson coined the term "feature" to provide a semantic analysis of what we now call "perceptual affordance-sensings" (Chemero, 2003, p. 185).[16] A feature, as opposed to a property, can be *represented as exemplified* with *no sense of a contrast* between a representing subject and a represented object. This contrast licenses a non-propositional use of the term "representation": "placing a feature" can be rephrased as the process of detecting an affordance perceptually salient *to me, here and now.*[17] It can be generalized into a "feature-*based"* semantics, applicable to the control of cognitive actions (Proust, 2013, p. 119 sq, 2016). An argument in favor of this analysis is that competition among affordance-sensings presupposes action models. There must be a common currency for comparing expected values and action costs across alternative models (Cisek, 2012). The underlying semantic medium, however, far from

[16] "Perceiving that it is time to flex the elbow is like perceiving that it is raining: It is a matter of perceiving that the situation as a whole has a certain feature, that the situation as a whole supports (perhaps demands) a certain kind of action. All of this is to say that perceiving affordances is placing features, and because features are not properties, any view of affordances that takes them to be properties is mistaken." (Chemero, 2003, p. 185)

[17] These terms are used in their nonconceptual meaning. Chemero welcomes Strawson's features, but apparently does not endorse them as providing a genuine semantic structure.

being "abstract", is based on the coordination of valence, sensorimotor mechanisms and predictive heuristics.

## Conclusion

The goal of this article was to propose that cognitive affordances, in close parallel to perceived affordances, can be sensed and memorized in a specific nonpropositional structure, cognitive affordance-sensing. The latter is the informational process through which agents experience metacognitive feelings such as feelings of fluency, of curiosity or of confidence. Their function is to engage promising cognitive actions, disengage from unpromising ones, monitor errors and assess final success.

The view that cognitive affordances are sensed through metacognitive feelings is consistent with the structure of cognitive control, and the functional duality between the two forms of reinforcement that independently shape decision-making: expected reward and self-reliability. Although cognitive affordances can be subjectively associated with objects, situations, authors, books, schools, masters, religious practices, technologies, the proximate factor that makes these associations meaningful is the valence gained in individual agents' experience of learning, remembering, and understanding. Hence social contexts and cultural practices can enhance, scaffold or detract from cognitive affordance-sensings. But only active brains can benefit from such enhancement or scaffolding, if they so choose.

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## References

Ackerman, R., & Goldsmith, M. (2011). Metacognitive regulation of text learning: on screen versus on paper. *Journal of experimental psychology: Applied*, *17*(1), 18-32

Ackerman, R., & Thompson, V. A. (2017). Meta-reasoning: Monitoring and control of thinking and reasoning. *Trends in cognitive sciences*, *21*(8), 607-617.

Anderson, M. L. (2007). Evolution of cognitive function via redeployment of brain areas. *The Neuroscientist*, *13*(1), 13-21.

Barrett, L. F. (2006). Valence is a basic building block of emotional life. *Journal of Research in Personality*, *40*(1), 35-55.

Barrett, L. F., & Bar, M. (2009). See it with feeling: affective predictions during object perception. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1521), 1325-1334.
Bicchieri, C., & Mercier, H. (2013). Self-serving biases and public justifications in trust games. *Synthese*, *190*(5), 909-922.
Braver, T. S., Krug, M. K., Chiew, K. S., Kool, W., Westbrook, J. A., Clement, N. J., ... & Momcai Group. (2014). Mechanisms of motivation–cognition interaction: challenges and opportunities. *Cognitive, Affective, & Behavioral Neuroscience*, *14*, 443-472.
Bruineberg, J. P., & Van den Herik, J. C. (2021). Embodying mental affordances. *Inquiry*, 1-21.
Campbell, J. (1999). Schizophrenia, the space of reasons, and thinking as a motor process. *The Monist*, *82*(4), 609-625.
Carruthers, P. (2008). Meta-cognition in animals: A skeptical look. *Mind & Language*, *23*(1), 58-89.
Charles, L., Van Opstal, F., Marti, S., & Dehaene, S. (2013). Distinct brain mechanisms for conscious versus subliminal error detection. *Neuroimage*, *73*, 80-94.
Chemero, A. (2003). An outline of a theory of affordances. *Ecological Psychology, 15*, 181–195.
Chemero, A. (2001). What We Perceive When We Perceive Affordances: Commentary on Michaels (2000)" Information, Perception, and Action". *Ecological Psychology*, *13*(2), 111-116.
Chong, I., & Proctor, R. W. (2020). On the Evolution of a Radical Concept: Affordances According to Gibson and Their Subsequent Use and Development. *Perspectives on Psychological Science*, *15*(1), 117–132. https://doi.org/10.1177/1745691619868207
Cisek, P. (2007). Cortical mechanisms of action selection: the affordance competition hypothesis. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *362*(1485), 1585-1599.
Cisek, P. (2012). Making decisions through a distributed consensus. *Current opinion in neurobiology*, *22*(6), 927-936.
Cisek, P. (2019). Resynthesizing behavior through phylogenetic refinement. *Attention, Perception, & Psychophysics*, *81*(7), 2265-2287.
Cisek, P. (2021). An Evolutionary Perspective on Embodiment. In *Handbook of Embodied Psychology* (pp. 547-571). Springer, Cham.
Cisek, P. (2022). Evolution of behavioural control from chordates to primates. *Philosophical Transactions of the Royal Society B*, *377*(1844), 20200522.
Cisek, P., & Kalaska, J. F. (2010). Neural mechanisms for interacting with a world full of action choices. *Annual review of neuroscience*, *33*, 269-298.
Colombetti, G. (2005). Appraising valence. *Journal of consciousness studies*, *12*(8-9), 103-126.
Couchman, J. J., Beran, M. J., Coutinho, M. V., Boomer, J., & Smith, J. D. (2012). Evidence for animal metaminds. In M. Beran, J. Brandl, J. Perner & J. Proust (eds.), *Foundations of metacognition*, 21-35. Oxford : Oxford University press.
Daprati, E., Franck, N., Georgieff, N., Proust, J., Pacherie, E., Dalery, J., & Jeannerod, M. (1997). Looking for the agent: an investigation into consciousness of action and self-consciousness in schizophrenic patients. *Cognition*, *65*(1), 71-86.
Davis, M., & Whalen, P. J. (2001). The amygdala: vigilance and emotion. *Molecular psychiatry*, *6*(1), 13-34.
Dennett, D. C. (2014). Why and how does consciousness seem the way it seems?. In *Open mind*. Open MIND. Frankfurt am Main: MIND Group.

Dreyfus, H., & Kelly, S. D. (2007). Heterophenomenology: Heavy-handed sleight-of-hand. *Phenomenology and the Cognitive Sciences*, *6*(1), 45-55.
Fanselow, M. S. (2018). The role of learning in threat imminence and defensive behaviors. *Current opinion in behavioral sciences*, *24*, 44-49.
Feinberg, I. (1978). Efference copy and corollary discharge: implications for thinking and its disorders. *Schizophrenia bulletin*, *4*(4), 636-40.
Frankish, K. (2010). Dual-process and dual-system theories of reasoning. *Philosophy Compass*, *5*(10), 914-926.
Fusaroli, R., Bahrami, B., Olsen, K., Roepstorff, A., Rees, G., Frith, C., & Tylén, K. (2012). Coming to terms: Quantifying the benefits of linguistic coordination. *Psychological science*, *23*(8), 931-939.
Gallivan, J. P., Logan, L., Wolpert, D. M., & Flanagan, J. R. (2016). Parallel specification of competing sensorimotor control policies for alternative action options. *Nature neuroscience*, *19*(2), 320.
Gawronski, B., & Mitchell, D. G. (2014). Simultaneous conditioning of valence and arousal. *Cognition & Emotion*, *28*(4), 577-595.
Gibson, J. J. (1979, 1986). *The ecological approach to visual perception.* Hillsdale, NJ: Erlbaum.
Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in neurosciences*, *15*(1), 20-25.
Goupil, L. & Proust, J. (2023), Curiosity as a metacognitive feeling. *Cognition, 231, 105325.*
Goupil, L., Romand-Monnier, M., & Kouider, S. (2016). Infants ask for help when they know they don't know. *Proceedings of the National Academy of Sciences of the United States of America*, *113*(13), 3492–3496.
Huber, L., & Gajdon, G. K. (2006). Technical intelligence in animals: the kea model. *Animal cognition*, *9*(4), 295-305.
Huguet, P., & Régner, I. (2009). Counter-stereotypic beliefs in math do not protect school girls from stereotype threat. *Journal of experimental social psychology*, *45*(4), 1024-1027.
Jacob, P., & Jeannerod, M. (2003). *Ways of seeing: The scope and limits of visual cognition*.Oxford: Oxford University Press.
Jeannerod, M. (1994). The representing brain: neural correlates of motor intention and imagery. *Behav. Brain Sci.* 17, 187–202.
Kenny, A. (1963). *Action, emotion and will*. London, UK: Routledge & Kegan Paul.
Kepecs, A., Uchida, N., Zariwala, H. A., & Mainen, Z. F. (2008). Neural correlates, computation and behavioural impact of decision confidence. *Nature*, *455*(7210), 227-231.
Koriat, A. (2000), The Feeling of Knowing: Some Metatheoretical Implications for Consciousness and Control, *Consciousness and Cognition* 9, 149–171.
Koriat, A., & Ackerman, R. (2010). Metacognition and mindreading: Judgments of learning for self and other during self-paced study. *Consciousness and Cognition: An International Journal, 19*(1), 251–264.
Koriat, A., & Levy-Sadot, R. (1999). Information-based and experience-based monitoring of one's own knowledge. *Dual-process theories in social psychology*, 483-502.
Krueger, J. (2014). Affordances and the musically extended mind. *Frontiers in psychology*, *4*, 1003.
Lak, A., Stauffer, W. R., & Schultz, W. (2014). Dopamine prediction error responses integrate subjective value from different reward dimensions. *Proceedings of the National Academy of Sciences*, *111*(6), 2343-2348.

Lak, A., Okun, M., Moss, M. M., Gurnani, H., Farrell, K., Wells, M. J., Kepecs, A. & Carandini, M. (2020). Dopaminergic and prefrontal basis of learning from sensory confidence and reward value. *Neuron*, *105*(4), 700-711.

Lewin, K. (1935). *A dynamic theory of personality.* New York and London: Mc Grow Hill Book Company.

Lewis, P. A., Critchley, H. D., Rotshtein, P., & Dolan, R. J. (2007). Neural correlates of processing valence and arousal in affective words. *Cerebral cortex*, *17*(3), 742-748.

Lhermitte, F. (1983). 'Utilization behaviour'and its relation to lesions of the frontal lobes. *Brain*, *106*(2), 237-255.

Logan, G. D. (1985). Executive control of thought and action. *Acta psychologica*, *60*(2-3), 193-210.

Maranesi, M., Bonini, L., & Fogassi, L. (2014). Cortical processing of object affordances for self and others' action. *Frontiers in psychology*, *5*, 538, 1-10.

Masoudi, N., Fadel, G. M., Pagano, C. C., & Elena, M. V. (2019) A review of affordances and affordance-based design to address usability. In *Proceedings of the Design Society: International Conference on Engineering Design* (Vol. 1, No. 1, pp. 1353-1362). Cambridge University Press.

McClelland, T., & Jorba, M. (2022). Perceptual Motivation for Action. *Review of Philosophy and Psychology*, 1-20.

McCurdy, L. Y., Maniscalco, B., Metcalfe, J., Liu, K. Y., De Lange, F. P., & Lau, H. (2013). Anatomical coupling between distinct metacognitive systems for memory and visual perception. *Journal of Neuroscience*, *33*(5), 1897-1906.

McClelland, T. (2020). The mental affordance hypothesis. *Mind*, *129*(514), 401-427.

Metcalfe, J. (2009). Metacognitive judgments and control of study. *Current directions in psychological science*, *18*(3), 159-163.

Michaels, C. F. (2000). Information, perception, and action: What should ecological psychologists learn from Milner and Goodale (1995)? *Ecological Psychology, 12,* 241–258.

Middlebrooks, P. G., & Sommer, M. A. (2011). Metacognition in monkeys during an oculomotor task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(2), 325-337.

Middlebrooks, P. G., & Sommer, M. A. (2012). Neuronal correlates of metacognition in primate frontal cortex. *Neuron*, *75*(3), 517-530.

Millikan, R. G. (2017). *Beyond concepts: Unicepts, language, and natural information*. Oxford University Press.

Mishkin, M., & Ungerleider, L. G. (1982). Contribution of striate inputs to the visuospatial functions of parieto-preoccipital cortex in monkeys. *Behavioural brain research*, *6*(1), 57-77.

Osiurak, F., Rossetti, Y., & Badets, A. (2017). What is an affordance? 40 years later. *Neuroscience & Biobehavioral Reviews*, *77*, 403-417.

Park, H. D., & Tallon-Baudry, C. (2014). The neural subjective frame: from bodily signals to perceptual consciousness. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1641), 20130208.

Pezzulo, G., & Cisek, P. (2016). Navigating the affordance landscape: feedback control as a process model of behavior and cognition. *Trends in cognitive sciences*, *20*(6), 414-424.

Planer, R. (2023) Metacognition and the evolution of conversation. *Evolutionary Linguistic Theory,*

Prablanc, C., & Pelisson, D. (1990, 2018). Gaze saccade orienting and hand pointing are locked to their goal by quick internal loops. In *Attention and performance XIII* (pp. 653-676). Psychology Press.

Prinz, J.J. (2004). *Gut Reactions: A Perceptual Theory of Emotion*. Oxford: Oxford University Press.
Proust, J. (2007). Metacognition and metarepresentation: is a self-directed theory of mind a precondition for metacognition?. *Synthese*, *159*(2), 271-295.
Proust, J. (2009). Is there a sense of agency for thought? In L. O'Brien and M. Soteriou (eds.), *Mental actions*, 253-279. Oxford, Oxford University Press.
Proust, J. (2013). *The Philosophy of Metacognition. Mental agency and self-awareness.*Oxford: Oxford University Press.
Proust, J. (2014) The representational structure of feelings. In *Open Mind*. Frankfurt am Main: MIND Group.
Proust, J. (2016). The evolution of communication and metacommunication in primates. *Mind and Language, 31, 2, 177-203.*
Proust, J. (2019). From comparative studies to interdisciplinary research on metacognition. *Animal Behavior and Cognition*, 6, 4, 309-328.
Proust, J. (2022). The Cultural Evolution of Information Seeking. *Journal of Cognition and Culture,* 22, 467-484.
Proust, J. (2023). Informational communication and metacognition, *Evolutionary Linguistic Theory.*
Reder, L., M. & Schunn, C. (1996). Metacognition does not imply awareness. In L.M. Reder (ed.), *Implicit Memory and Metacognition,* pp. 45-78, Mahwah, NJ: LEA.
Rietveld, E. (2013). Affordances and unreflective freedom. In *The phenomenology of embodied subjectivity* (pp. 21-42). Springer, Cham.
Rietveld, E.. & Kiverstein, J. (2014) A Rich Landscape of Affordances, *Ecological Psychology, 26:4, 325-352,*
Rosati, A. G. (2017). Foraging cognition: reviving the ecological intelligence hypothesis. *Trends in cognitive sciences*, *21*(9), 691-702.
Sander, D., Grandjean, D., & Scherer, K. R. (2005). A systems approach to appraisal mechanisms in emotion. *Neural networks*, *18*(4), 317-352.
Schwartenbeck, P., FitzGerald, T., Dolan, R., & Friston, K. (2013). Exploration, novelty, surprise, and free energy minimization. *Frontiers in psychology*, 710.
Schwarz, N., & Lee, S. W. (2018). Embodied cognition and the construction of attitudes. In D. Albarracin & B T. Johnson (Eds.), *The handbook of attitudes* (pp. 450-479). Routledge.
Seow, T. X., Rouault, M., Gillan, C. M., & Fleming, S. M. (2021). How local and global metacognition shape mental health. *Biological psychiatry*, *90*(7), 436-446.
Shea, N. (2018). Metacognition and abstract concepts. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *373*(1752), 20170133.
Shea, N. (2023). Millikan's Consistency Testers and the Cultural Evolution of Concepts. *Evolutionary Linguistic Theory*, 5-1, 79-101.
Shea, N., Boldt, A., Bang, D., Yeung, N., Heyes, C., & Frith, C. D. (2014). Supra-personal cognitive control and metacognition. *Trends in cognitive sciences*, *18*(4), 186-193.
Silberstein, M., & Chemero, A. (2012). Complexity and extended phenomenological-cognitive systems. *Topics in cognitive science*, *4*(1), 35-50.
Soto, D., Mäntylä, T., & Silvanto, J. (2011). Working memory without consciousness. *Current Biology*, *21*(22), R912-R913.
Stepper, S., & Strack, F. (1993). Proprioceptive determinants of emotional and nonemotional feelings. *Journal of personality and social psychology*, *64*(2), 211-220.
Strawson, P. (1959). *Individuals.* London: Routledge

Turvey, M. T. (1992). Affordances and prospective control: An outline of the ontology. *Ecological psychology*, *4*(3), 173-187.
Ullsperger, M., Fischer, A. G., Nigbur, R., & Endrass, T. (2014). Neural mechanisms and temporal dynamics of performance monitoring. *Trends in cognitive sciences*, *18*(5), 259-267.
Wilson-Mendenhall, C. D., Simmons, W. K., Martin, A., & Barsalou, L. W. (2013). Contextual processing of abstract concepts reveals neural representations of nonlinguistic semantic content. *Journal of cognitive neuroscience*, *25*(6), 920-935
Winkielman, P. & Cacioppo, J. T. (2001). Mind at ease puts a smile on the face: psychophysiological evidence that processing facilitation elicits positive affect. *Journal of personality and social psychology*, *81*(6), 989-1000.
Yeung, N., Botvinick, M. M., & Cohen, J. D. (2004). The neural basis of error detection: conflict monitoring and the error-related negativity. *Psychological review*, *111*(4), 931-959.
Yeung, N., & Summerfield, C. (2012). Metacognition in human decision-making: confidence and error monitoring. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *367*(1594), 1310-1321.
Zawidzki, T. W. (2021). A new perspective on the relationship between metacognition and social cognition: Metacognitive concepts as socio-cognitive tools. *Synthese*, *198*(7), 6573-6596.