Phenomenology and the Cognitive Sciences
https://doi.org/10.1007/s11097-022-09808-8

Freediving neurophenomenology and skilled action: an investigation of brain, body, and behavior through breath

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Accepted: 11 February 2022

Abstract

In this paper I investigate the neurophenomenology of freediving (NoF) and the Skilled Intentionality Framework (SIF), using these two components to mutually inform each other in order to better understand cognition in skilled action. First, this paper provides a novel neurophenomenological exposition of the practice of freediving. It combines quantitative neurophysiological data with qualitative phenomenological reports in order to understand the neural and bodily mechanisms that correlate with the phenomenology of freediving. The NoF data suggests that freediving induces a unique neurophysiological state. This unique neurophysiological state forms the basis for a peculiar and exceptional experiential state, which is phenomenologically characterized by a heightened sense of presence, heightened perception, lack of reflective awareness, lack of anticipation in decision-making, and restricted emotional range. Second, this paper synthesizes the NoF data and the SIF conceptual framework of cognition in skilled action in order to investigate how the two can mutually inform one another. This synthesis provides 1) a unified and cohesive understanding of the NoF data; 2) elucidation and clarification of three key features generalizable to SIF's *metastable zones*; 3) refinement of the role of *anticipation* in SIF, with the focus shifting instead towards *task-specific constraint* of action-readiness; and 4) an investigation of the breath, an understudied dynamical oscillator of brain, body, and behavior, which provides an empirical mechanism to support SIF's theoretical assumption of the *dynamical self-organization* required in skilled action. Looking more broadly, this neurophenomenological investigation of freediving elucidates a novel case study which can provide rich perspectives and fertile material for further scientific, phenomenological, theoretical, and philosophical investigations in ecological psychology, expertise, reflection, enactivism, and cognition more generally.

Keywords Neurophenomenology · Freediving · Skilled action · Respiration · Breath holding · Dynamical self-organization · Apnea

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Published online: 15 March 2022

1 Introduction

The aim of this paper is twofold: understanding the neurophenomenology of freediving (NoF), and using it to investigate and refine the Skilled Intentionality Framework (SIF), which investigates cognition in skilled action (Bruineberg & Rietveld, 2014; Rietveld et al., 2018; van Dijk & Rietveld, 2018). Freediving – the practice of diving underwater on one single breath – is a highly skilled activity involving complex decision-making and actions in the face of rapidly-changing physiological, psychological, and environmental conditions. Freedivers experience exceptional physiological conditions, at the limits of gas-exchange viability; exceptional psychological conditions, in inherently life-threatening situations; and exceptional environmental conditions, through prolonged exposure to foreign underwater environments. Freediving is thus an exceptional yet non-pathological case of cognition in skilled action. Such cases are very well suited to investigation, since they allow us to "put our own normal experiences into perspective" and explore pre-existing assumptions about cognition and skilled action (Ravn & Høffding, 2017, p. 60).

First, I will investigate empirical data on NoF, discussing both quantitative neurophysiological data on freediving and respiration, and qualitative phenomenological reports from interviews conducted with freedivers. Together, these complementary datasets suggest that freediving induces a unique neurophysiological state. This unique neurophysiological state forms the basis for a peculiar and exceptional experiential state, which is phenomenologically characterized by distinctive changes to A) sense of presence, B) perception, C) reflection, D) decision-making, and E) emotions. I will discuss each of these phenomenological hallmarks in turn, along with the relevant neurophysiological data, before shifting gears to outline the main theoretical tenets of SIF. Finally, I will synthesize the NoF data and the SIF conceptual framework to investigate how these two components can mutually inform each other to better understand cognition in skilled action. This synthesis provides 1) a unified and cohesive understanding of the NoF data; 2) elucidation and clarification of three key features generalizable to SIF's *metastable zones*; 3) refinement of the role of *anticipation* in SIF, with the focus shifting instead towards *task-specific constraint* of action-readiness; and 4) an investigation of the breath, an understudied dynamical oscillator of brain, body, and behavior, which provides an empirical mechanism to support SIF's theoretical assumption of the *dynamical self-organization* required in skilled action. As such, the case study of NoF, coupled with SIF, contributes to existing literature in the fields of ecological psychology, expertise, reflection, enactivism, and cognition more generally.

2 What is freediving?

Freediving is the practice of diving underwater on one single breath. Freedivers hold their breath for the entirety of a dive, which can last anywhere from a few seconds to over 20 min, and can reach depths of over 200 m. These astonishingly prolonged breath-holds are an immense physiological and psychological feat. Physiologically, freedivers must grapple with challenging and exceptional conditions such as prolonged hypoxia (low oxygen), uncontrollable diaphragmatic spasms, and hyperbaria (high pressure). Psychologically, freedivers must grapple with challenging and exceptional conditions such as intense air deprivation and extreme anxiety of being submerged deep down in the middle of the ocean, in life-threatening situations.

To deal with these challenges, freedivers must train in specialized techniques. These techniques allow them to maintain extraordinarily tight control over their bodies and minds as they freedive (Downey, 2022). These include specialized breathing techniques, relaxation techniques, techniques to register very subtle physiological changes, techniques to decrease overall oxygen consumption, techniques to equalize the body's airspaces at extreme depths, and techniques to optimize hydrodynamic body posture and movement. To have a safe and successful dive, freedivers must deploy very specific techniques at very specific times during each dive, shifting their focus from technique to technique, depending on the status of the dive and their current psycho-physiological conditions. Fine-tuning these embodied skills takes years of experience to master.

Furthermore, freedivers must grapple with challenging and exceptional environmental conditions, due to the inherently unpredictable, ever-changing, and often dangerous conditions of their ocean environments. During each dive, freedivers must adapt their techniques to match the present ocean conditions. Big waves, for example, demand a completely different set of skills to navigate than a strong current does. The challenge of freediving is precisely this: understanding, moment to moment, the complex physiological, psychological, and environmental demands and conditions of the present situation, and acting accordingly. Complexity arises in the fact that each of these three conditions (physiological, psychological, environmental), when taken independently, is not only constantly changing, but also highly unpredictable. To make matters even more complex, all three conditions are highly interdependent, with their precise interactions dictating the success or failure of each particular action in each particular situation. Furthermore, these interdependent interactions are themselves unpredictable and ever-changing, making for an exceptionally complex task landscape.

In modern Western freediving, a typical training session involves freedivers going to the ocean, either via boat or from the shore. They will go in small groups, with other freedivers they trust. They will don their gear, which typically includes a freedive-specific wetsuit, weight belt, long fins, mask, and snorkel. They will bring a buoy, from which hangs a long weighted rope, called a dive line. The dive line is set to a specific length, signifying the depth that the diver wishes to achieve. One diver will dive at a time, aiming to push their own psycho-physiological limits and perfect their freediving techniques. A second diver is designated as the safety diver, who will keep constant watch to make sure everything is going according to plan. Any remaining divers will float on the surface, preparing to dive and waiting their turn. Figure 1 shows the set-up of a typical Western freediving training session.

Freediving, however, is not limited to training sessions. There are many different subtypes of freediving, each with their own goals and motivations: some people dive to spearfish, others to compete and set world records, others to take underwater photographs, others to perform as mermaids in underwater exhibitions, and still others to

Fig. 1 Depicts the set-up of a typical Western freediving training session. Photograph by Nicholas Kouvaras and Freedive Menorca

recreationally explore underwater creatures and landscapes. Each subtype brings with it additional task features, complexities, techniques, and challenges that must be skillfully learned. For example, spearfishers must learn to identify subtle ecological patterns that correspond to fish nests, must understand and react to the quick movements of marine life, and must operate a technical speargun. These subtype-specific tasks must be learned and executed in concert with the other more generalized freediving techniques discussed above. Together, these techniques enable freedivers to carry out their desired tasks while still safely holding their breaths, all the while submerged in a challenging underwater environment.

Further variations in the practice arise when comparing freediving across cultural contexts. Unlike modern Western forms of the practice, freediving has been a traditional livelihood and subsistence strategy for over a thousand years, and remains a traditional way of life for indigenous communities around the world, including the Ama pearl divers of Japan (Mohri et al., 1995; Schagatay et al., 2011) the Sama-Bajau 'sea nomads' of maritime Southeast Asia (Stacey et al., 2018; Ilardo et al., 2018), and the Haenyeo of Korea (Ko et al., 2010). Each culture and community has naturally adopted its own unique set of freediving tools, techniques, and adaptations, in accordance with their specific needs and environments.

What these different cultures and subtypes of freediving have in common is the fact that freedivers consistently push themselves to their absolute physiological and psychological limits, while immersed in foreign, underwater environments. Indeed they often push the bounds of what is humanly possible. Freedivers are highly skilled individuals, continually maintaining an exceptionally fine balance between rapidly-changing internal and external conditions. They must balance the unpredictable, rapidly-changing, and interdependent physiological, psychological, and environmental demands, with their own motivations for the dive. This balance is almost binary: push themselves too far, and they risk underwater blackout, drowning, and death. Don't push themselves far enough, and they are simply unable to dive, unable to carry out the underwater goals they've set for themselves. This balance is the art of freediving.

2.1 Methodology

The current study answers SIF authors' calls for investigating the phenomenology of skilled action, particularly in real life, ecologically valid settings (Bruineberg & Rietveld, 2014; Bruineberg et al., 2021). It also answers calls for incorporating more empirical data and intersubjective verification into phenomenological investigations (Gallagher, 2012; Ravn & Høffding, 2017; Schmicking, 2010). This study employs a neurophenomenological approach, based upon the notion of *mutual constraint* – in which neurophysiological data and first-person reports mutually constrain and inform one another to investigate the structure of human experience (Olivares et al., 2015; Varela, 1996). More specifically, this study combines qualitative phenomenological reports of the freediving experience with pre-existing quantitative neurophysiological data on freediving and respiration in order to understand the neural and bodily mechanisms that correlate with freediving phenomenology.[1]

I conducted semi-structured phenomenological interviews[2] with seven freediver participants for intersubjective verification. This is a typical sample size for qualitative studies using in-depth interviews (Dworkin, 2012). Participants were recruited through various international online freediving forums,[3] and were interviewed independently after giving informed consent. All participants engaged in modern Western forms of the practice,[4] yet brought a diverse range of freediving subtypes, levels of expertise, and locations of diving (Table 1). Names have been changed to maintain anonymity. A list of interview questions asked of all participants can be found in Online Resource 1. It is important to note that this is a case study aimed at elucidating perspectives, and is therefore not amenable to statistical analysis (Flyvbjerg, 2006).

[1] Ideally, a rigorous neurophenomenological approach would employ synchronous collection of qualitative and quantitative datasets, rather than relying on one or more pre-existing datasets, so as to increase the robustness of correlations discovered. However, for the case of freediving, synchronously collecting these two datasets in an ecologically valid setting is near impossible due to current technological constraints: sophisticated neuroimaging devices cannot yet be taken underwater into the freediving environment. However, a wearable, waterproof, and pressure-proof near-infrared spectroscopy device – which can collect neurophysiological measurements such as cerebral haemodynamic responses, heart rate, cerebral and arterial blood oxygen responses, and temperature – is currently under development (McKnight et al., 2021). Preliminary results show its efficacy in measuring the neurophysiology of human freedivers in an ecologically valid field setting. Future work should utilize this device, in concert with phenomenological interviews, to increase the rigor and robustness of NoF.

[2] For methodology, see Høffding (2014), Høffding and Martiny (2016), and Ravn and Høffding (2017).

[3] As participation in this study relied on voluntary response sampling, it is important to consider the effects of non-response bias and how they might affect the data collected. I cannot here discuss these considerations in due detail, but point instead to Cheung et al. (2017), where such a discussion is produced.

[4] It is important to note that all study participants engaged only in modern Western forms of freediving. While the cultural specificity of this sample allows for greater ease of comparison across participants, it is thereby not representative of other cultural variations in freediving practices. The results of the current study are thus limited in scope, and are only applicable to modern Western freediving. Future investigations should explore other freediving cultures in order to determine the extent to which the neurophysiology and phenomenology that follows obtains across different freediving cultures and contexts.

Over thirteen hours of interview material was recorded, transcribed, and phenomenologically analyzed according to the principles of Interpretative Phenomenological Analysis (Høffding & Martiny, 2016; Ravn & Høffding, 2017; Smith et al., 2009). Analysis was conducted under the assumption that commonalities in experience, reported independently by different participants, point towards generalizable qualities and structures of human subjectivity.[5] As such, the phenomenological characteristics reported with the highest degree of intersubjective verification are assumed to point towards core characteristics which unify disparate instances of the freediving experience. Importantly, these core characteristics do not preclude the possibility of further heterogeneity in freediving phenomenology. When I refer to 'the freediving experience', I thus refer not to one single experiential state but rather to a set of related and overlapping experiential states.

2.2 Essential conditions for freediving

Before delving into the core phenomenological characteristics of the freediving experience, it is important to understand the essential conditions which set the stage for this experience. The phenomenological interviews point towards two specific conditions that all seven participants independently note to be absolutely essential for eliciting the freediving experience: 1) the relaxation breathe-up, and 2) underwater conditions. These two conditions are deemed essential because together, they have the ability to induce a unique and very specific set of neurological, physiological, and psychological outcomes, which form the basis for the exceptional phenomenological experience of freediving. We will now discuss each essential condition in turn, exploring the neurological, physiological, psychological, and phenomenological outcomes of each.

2.2.1 The relaxation breathe-up

Freediving is an inherently stressful practice, due to the constant barrage of exceptional and often life-threatening physiological, psychological, and environmental stressors. However, due to the critical need to conserve oxygen during a dive, freedivers must actively overcome this stress if they wish to dive (and to survive). A relaxed psycho-physiological state is thus reported to be essential to freediving, since relaxation minimizes oxygen consumption, and minimized oxygen consumption allows freedivers to hold their breaths for longer periods of time. Physiological relaxation requirements include maximized oxygen intake, low heart rate, and relaxed muscles, since lower heart rate and lower muscle tension consume less oxygen (Casaburi et al., 1989; Radak et al., 2013; Online Resource 2.1).[6] Psychological relaxation requirements, which further

[5] I cannot defend this assumption here, but instead point to Allen-Collinson (2009) or Graneheim, Lindgren and Lundman (2017), where such a defense is produced.

[6] Online Resources 2.1 to 2.10 refer to key excerpts from the interview data, anonymized and sorted thematically.

Table 1 Anonymized Participant Information

Participant Name*	Reference Initials	Interview Duration (hr:min:sec)	Freediving Experience	Freediving Subtype	Freediving Locations
Timur Harrari	TH	1:37:34	5–7 years	Spearfishing	California
David Silverton	DS	2:06:00	25–30 years	Spearfishing Professional Competition Instructor	California Croatia
Abe de la Merre	AM	2:10:54	10 years	Recreational Professional Competition Instructor	United Kingdom Egypt Philippines Balearic Islands Indonesia
Safia Deleuze	SD	1:32:35	1 year	Recreational Mermaid Performer Academic	California
Julianna Benedict	JB	1:39:02	2 years	Recreational Competition	Oregon Norway Honduras
Nate Pendleton	NP	2:03:47	3–5 years	Recreational Competition	United Kingdom Mediterranean
Annabelle Solano	AS	1:57:21	9 years	Recreational Competition Artistic Performer	Thailand Mexico

Table 1 depicts participant information, including name (*pseudonyms have been used to protect participant anonymity), reference initials, interview duration, freediving experience, freediving subtype, and freediving location reduce oxygen consumption, include calmness, to facilitate muscle relaxation, and absence of thoughts, to reduce brain activity. Participant AS explains: "*Breath-holding depends on…stillness of the mind,"* so freedivers must train to *'let thoughts go'* (Online Resource 2.1). *"If you're thinking too much, you're burning oxygen, you're burning time…It's not very conducive to effective diving"* (TH). Negative thoughts in particular must be avoided, since they create more muscle tension, thereby burning more oxygen. If not relaxed, freedivers simply cannot dive: *"Whenever you're stressed…you're not going to be able to hold your breath, you're not going to be able to go down, that's just how it is"* (TH). Freedivers must therefore enter into a psycho-physiological state consistently described as '*calm*', '*relaxed*', '*zen*', and '*at peace,*' in order to conserve oxygen, hold their breaths, and dive down. How do they do it?

The main technique freedivers use to effect these necessary oxygen-conserving psycho-physiological changes is called the *relaxation breathe-up*. The breathe-up typically involves several minutes of slow, diaphragmatic, and exhale-biased breathing, through a snorkel, while floating facedown on the surface of the water. Simultaneously, freedivers meditatively turn their focus inward, towards the sensations of breathing, helping them get '*out of their thoughts*' and *'into their bodies*' (Online Resource 2.2). The breathe-up thus allows freedivers to enter a state of exceptional relaxation, with maximized oxygen intake and minimized oxygen consumption. They are then ready to dive.

The importance of this breathe-up cannot be overemphasized. For every freediver interviewed, the breathe-up is explicitly necessary (Online Resource 2.2). If freedivers cannot successfully breathe-up, they cannot dive: *"It's literally as simple as that. I was trying to do the breathe-up and I could not. I could not calm down, my heart rate wouldn't go down…I couldn't dive"* (TH).

Physiological evidence explains why the breathe-up is so crucial to the relaxation required for freediving. The breathe-up's diaphragmatic breathing maximizes bodily oxygen saturation (Bilo et al., 2012). Its exhalation-biased breathing lowers heart rate through a physiological phenomenon called Respiratory Sinus Arrhythmia, in which heart rate slows preferentially during exhalation (Yasuma & Hayano, 2004). Its slow breathing, through stimulating the parasympathetic nervous system, induces additional measures of psycho-physiological relaxation, such as decreased theta power in EEG, which correlates with decreased anxiety and increased relaxation and wellbeing (Zaccaro et al., 2018). The breathe-up's ability to simultaneously 1) maximize oxygen intake, 2) minimize oxygen consumption by inducing various measures of psycho-physiological relaxation, such as decreased heart rate and increased calmness, and 3) act as a focus point to let thoughts go and quiet the mind, allows freedivers to enter the relaxed psycho-physiological state that is necessary for them to hold their breaths and dive successfully.

2.2.2 Underwater Conditions

The second essential condition reported by freedivers is the underwater environment. It is of course obvious that the act of freediving cannot be done outside the water;

underwater conditions partly constitute the activity. One might object, however, that the same psycho-physiological state can be reached outside the water, for example by doing a breathe-up and breathhold in a virtual reality setting. However, physiological and phenomenological data reveals that the underwater conditions provide more than mere descriptive aspects of the ecological environment of freediving. In fact, the underwater conditions directly induce unique psycho-physiological states that are simply not possible on land, due to the combination of the following conditions specific to the underwater environment:

Challenging conditions: The inherently challenging, unpredictable, complex, stressful, uncomfortable, and rapidly-changing conditions of the underwater environment – strong currents, hypoxia, cold water, hyperbaria, poor visibility, risk of shark attacks, risk of running out of air, risk of entanglement, uncontrollable diaphragmatic spasms, shallow water blackouts, and death by drowning – impose strong demands on freedivers' focus, awareness, and actions in order to be adequately dealt with (Christensen et al., 2016). These challenging conditions require freedivers to enter states of exceptional focus and awareness which they do not experience on land (Online Resource 2.3). AM elaborates: *"Underwater, there's* no space *to get distracted. You* have *to be doing the thing that you're doing. You* can't *somehow not be there."*

No possibility to breathe: Related is the obvious fact that underwater, there is simply no option to breathe. The knowledge that breathing when submerged is not a life-sustaining action possibility psychologically helps freedivers hold their breaths for longer underwater than they are able to bear on land (Online Resource 2.3). This knowledge increases freedivers' ability to push both their psychological and physiological limits, bringing them into more exceptional psycho-physiological states than can be reached on land.

Underwater sensations: Certain sensations specific to the underwater environment also induce changes to freedivers' physiology and experience. For example, sounds of lapping water, rhythmic swaying of the body, calming visuals of deep blue and light wave patterns, and general underwater stillness all help freedivers enter states of relaxation that are not only more pronounced, but also faster and easier to achieve, than when they are on land. For these reasons, doing the relaxation breathe-up on dry land never feels the same as it does in the water, for all freedivers interviewed (Online Resource 2.3). Similarly, freedivers report that holding one's breath at depth *"is very different than just…hold[ing] your breath face down on the surface of the water. When you go down deeper…the whole experience is a lot more peaceful"* (AM). This may be because at depth, due to the increased pressure facilitating blood-oxygen uptake into the tissues, freedivers sometimes experience *elevated* oxygen levels, which can reduce the negative sensations associated with breath-holding (Bosco et al., 2018). These sensations and conditions specific to the underwater environment thus uniquely alter freedivers' psycho-physiological states, both during the breathe-up and during the breathhold.

No gravity: The fact that freedivers have a different relationship to gravity while in water uniquely shapes their experience. First, freedivers experience heightened agency underwater: *"because of buoyancy, underwater you get that added dimension of up and down exploration, which isn't possible on land"* (NP). While underwater, freedivers thus experience significantly different action possibilities when compared to land, which uniquely shapes their experience. The second way that gravity uniquely shapes freedivers' experience is through the freediving *'freefall.'* The freefall is a cherished moment of the dive in which freedivers reach depths of negative buoyancy, where their bodies become more dense than the water surrounding them. They start gliding effortlessly down into the water, which creates a sensation of *'floating'* or even *'flying.'* The experience is described as *'beautiful', 'special,' 'unique,'* and even *'transcendent.'* JB states, *"There's just no other feeling I've found like it."* AS elaborates on the peculiar ways in which gravity and the freefall uniquely affect the freediving experience:

> *"During the relaxation breathing, you're floating. So you can...just trust the water. You can lose awareness of your…proprioceptive reality, and your relationship to gravity. Your body can relinquish some responsibility in that time…You don't have to think about, like...How am I sitting? Is my leg doing this? You're just there. And the water's holding you up. And then, as you start to go down…you get to ten or twelve meters. At that point, you can just…fall. And you don't…do...anything. So all of those experiences, of being…really relaxed, having a lot of oxygen in your body, having your body have no responsibility for…its relationship to gravity…or its relationship to other objects, you sort of lose the sense of having a body. When you are…free falling in the water like that. Because…maybe there's some sense of having a body that is about…having to* do *stuff with your body. Like, I know I have a body because I have to decide about how my leg is crossed, and…how I'm expressing myself...you know, all these things. All that stuff is gone. You're just…you're not even breathing. Right. You're not even doing the most basic thing that reminds you you're alive. You're not breathing. You're not acting upon the world in any way. You're just falling, through the water. Doing nothing. And so...you lose, in a way…the idea of having a body, the idea of having a self. And when you lose the body and the self, you also lose…your own…narrative…the idea of time. Like, the idea of the past, and the future, are connected to our idea of who we are, in it. And it's just like…*all *that's gone. And you're really, really not doing anything, including breathing. And that's a really transcendent experience."*

The mammalian dive response: Finally, certain stimuli specific to the freediving environment, such as cold water on the face, hyperbaric conditions, and altered gas-exchange ratios associated with breath-holds, trigger distinct physiological changes through a phenomenon called the Mammalian Dive Response (MDR). The MDR uniquely alters physiology to prepare the body for breath-holds and hyperbaric conditions (Gooden, 1994). For example, heart rate significantly slows to conserve oxygen – freediver heart rates having been clocked at as low as 11 beats per minute (McKnight et al., 2021). Blood vessels throughout the body constrict, shifting blood, and the oxygen it carries, away from extremities to preferentially preserve the core and brain. Tiny capillaries around the lungs fill with blood to cushion hyperbaric lung compression at depth. The spleen contracts, releasing reserves of oxygen-rich red blood cells, which helps combat increasingly hypoxic conditions. Astoundingly, freedivers' arterial oxygen saturation can dip down to as low as 25% – a value not normally compatible with consciousness (McKnight et al., 2021; Schagatay, 2011). The MDR thus allows freedivers to survive these extreme conditions by inducing the above adaptive physiological changes. These changes are not known to occur in any other environment or form of activity. The MDR, triggered by the underwater environment, thus puts freedivers' bodies into a truly exceptional and unique physiological state, optimal for breath-hold diving.

We thus see that the combination and interaction of these two essential conditions – the relaxation breathe-up and underwater conditions – induces a host of intriguing neurological, physiological, psychological, and phenomenological effects which cannot realistically be reproduced otherwise. Freediving thereby induces a unique neurophysiological state. This unique neurophysiological state forms the basis for the exceptional experiential state[7] reported by freedivers, which we are now ready to investigate in more detail.

3 NoF: neurophenomenology of freediving

This section will describe the five phenomenological hallmarks of the freediving experience as they relate to A) sense of presence, B) perception, C) reflection, D) decision-making, and E) emotion. It is important to note that these categories are by no means exhaustive or mutually exclusive. As we will shortly see, they are largely overlapping, with boundaries that may be arbitrary, but are nonetheless sketched below for the sake of understanding the experience. Concurrently, we'll examine existing data on the neurophysiological mechanisms which correlate with the phenomenology, focusing specifically on how the essential conditions discussed above influence each hallmark of the freediving experience. This combination is what makes for a neurophenomenological approach.

3.1 Presence

The first phenomenological hallmark of freediving regards sense of presence. Every freediver interviewed described experiencing an unusually heightened sense of

[7] While freediving does induce a unique neurophysiological state, unable to be realistically reached otherwise, more research is needed to determine whether it also induces a unique experiential state. Current data suggests that freediving *does* induce a unique experiential state; however, similar experiential states may obtain in other practices with similar characteristics. Such practices could include intense meditative or mindfulness practices (Gamma & Metzinger, 2021; Travis & Pearson, 2000), or other extreme, water-based, and/or life-threatening practices, such as free solo climbing or big wave surfing (Ilundáin-Agurruza, 2015). More research is needed to discern whether the phenomenology that follows obtains uniquely for freediving.

presence, or situated focus and awareness of the current moment. Descriptive terminology used includes *'present,' 'centered,'* '*in the zone*,' *'clear,'* '*channeled in,*' *'focused,'* '*everything is clicking*,' '*in tune*,' and '*in the moment*' (Online Resource 2.4). For example, on a dive, AM will *"Try to get lost in that moment…I'm only thinking about what I need to be doing, in that exact moment, for me to execute the dive properly. So it's complete…present moment."* Freedivers experience a related alteration in their perception of time, with time stopping, severely slowing, or even becoming an unintelligible concept due their unusual experience of presence (Online Resource 2.5). DS describes of a freedive:

> *"I was one hundred percent in the moment…The future and the past had no relevance. Because there was only one thing that mattered, and that was* now*…There was no comprehension of anything outside of that. Yet I was one hundred percent alive, I was not asleep. I was in…this state of pure consciousness. Of pure existence…It was mindfulness at its best."*

Freedivers often compare this specific hallmark of the freediving experience to very advanced states of meditation, which are similarly described as states of *'pure presence,' 'pure consciousness,' 'pure existence,*' and *'pure awareness'* (Online Resource 2.1, 2.3, 2.9; Travis & Pearson, 2000; Gamma & Metzinger, 2021). Interestingly, a case study of an elite freediver showed that the functional cerebral changes induced by a static breath-hold on land show several similarities to the cerebral signatures of several meditation practices (Annen et al., 2021). One such similarity is increased delta power in EEG, which often correlates with altered attentional engagement. This change in brain activity may thus be involved in the altered sense of presence and in-the-moment awareness that both freedivers and meditation practitioners experience. Freedivers report, however, that the state of heightened presence they experience during freediving is significantly more intense than any states they are able to achieve through other meditative or mindfulness practices (Online Resource 2.3).[8]

The challenging, life-threatening, and rapidly-changing environmental conditions inherent to freediving play a role here, as they simply demand a heightened level of presence and situated awareness to be appropriately dealt with (Christensen et al., 2016). Furthermore, the neurophysiological changes induced by the freediving breathe-up may actively help freedivers maintain this sense of heightened presence. For example, studies show that various slow, diaphragmatic breathing techniques decrease theta power in EEG, which correlates with increased vigor and alertness (Online Resource 2.4; Zaccaro et al., 2018).

3.2 Perception

The second phenomenological hallmark of freediving regards perception. Commonly agreed upon within the relevant literature is the idea that what we perceive depends

[8] Future work should compare freediving versus advanced meditative states in more detail, in order to understand the nuanced similarities and differences in both neurophysiology and phenomenology between the two practices.

on our motivations, needs, and desires (Haugeland, 1998; Withagen et al., 2017). In freediving, we see this, for example, in how freedivers perceive fish. Spearfishers will perceive fish as objects to hunt; recreational freedivers will perceive fish as beautiful creatures to observe; competition freedivers may not perceive fish at all (Online Resource 2.6). More interesting, however, is freedivers' hallmark experience of heightened perception – both interoception and exteroception – during freediving.

3.2.1 Heightened interoception

Freedivers unanimously experience heightened interoception – the ability to sense the internal state of the body (Quadt et al., 2018). During dives, freedivers report being much more '*in tune*' with themselves and better able to '*listen to their bodies*' (Online Resource 2.6). They pick up on minute changes in their physiological conditions, including muscle tension, heart rate, lung volume, ear pressure, soft palate and glottis posture, and diaphragmatic contractions.

The challenging environment plays a role here. During a dive, a freediver's immediate physiological needs become paramount to survival. Freedivers push themselves to their absolute physiological limits in foreign underwater environments, with such a fine line between life and death. They therefore need to be acutely and accurately perceptive of very small changes in their physiological conditions in order to maintain physiological balance and survival – to push themselves far enough without pushing too far.

The breath-up also seems to play an important role. Various slow breathing techniques increase alpha power in EEG, which is implicated with increased inward-directed attention (Zaccaro et al., 2018). The freediving breathe-up, therefore, with its slow controlled breaths, may actively contribute to freedivers' heightened interoception. Furthermore, studies show that certain meditation practitioners have greater respiratory interoceptive accuracy compared to non-meditators (Daubenmeier et al., 2013). It may therefore be the case that the meditative aspect of the breathe-up, which involves actively focusing inward on the bodily sensations of breathing, increases freedivers' interoceptive abilities, which then carry over into the diving period.

3.2.2 Heightened exteroception

Freedivers also experience heightened exteroception – perception of stimuli originating outside the body. Spearfishers, for example, enter into a "*hyper-focused*" "*observation mode*" (DS), in which they are "*extremely aware of the surroundings… taking everything in, looking around…being very observant*" (TH). Similarly, recreational freedivers are able to focus on more minute details of their environment, both auditory and visual (Online Resource 2.6). One freediver even reports extra-sensory perceptual abilities during freediving, such as the ability to sense an unseen shark (Online Resource 2.6).

Assuming that heightened exteroception is objectively verifiable and not only a phenomenologically experienced illusion, the environment, again, is involved. The challenging and rapidly-changing underwater conditions demand heightened perception in order to be dealt with appropriately. The breath is also reported to play a role in perception, even when the underwater environment is held constant. When comparing perceptual abilities during scuba versus freediving, SD notes that:

> *"The ability to breathe definitely changes it...I don't notice as many small details when I'm on scuba. Being able to breathe...completely changes the experience. Your focus is different, your...awareness of the environment is different... your self-awareness is different."*

Ample evidence exists to suggest that respiration, through various mechanisms, plays a surprisingly crucial role in modulating perception. This evidence, which we will now examine, could potentially explain the altered perception reported in freediving.

3.2.3 Respiration-entrained oscillations & 'observation mode'

Respiration plays an active role in modulating brain activation and cognitive capacities, including perception. For example, recent studies show that certain perceptual and cognitive abilities are heightened during inhalation. When stimuli are presented to participants during inhalation, they perform better on subsequent visuospatial cognitive tasks, have faster reaction times, and have more accurate memory retrieval than when stimuli are presented during exhalation (Perl et al., 2019; Zelano et al., 2016). In fact, EEG data shows that the human brain processes the same stimulus differently depending on whether it was encountered during inhalation or exhalation (Perl et al., 2019). These findings suggest that certain aspects of perception and information processing are directly modulated by respiratory phase.

Perl et al. (2019) found that the mechanism of this modulation depends on nasal respiration. Nasal respiration – through rhythmic modulation of nasal mechanosensors, olfactory bulb neurons, and global temporal oscillations of neuronal activity (Grosmaitre et al., 2007; Ito et al., 2014) – drives changes in the brain's baseline functional connectivity, causing different patterns of network activity during inhalation vs. exhalation. For example, nasal inhalation leads to an increase in the strength of parietal network connectivity in the beta1 frequency range, which is consistently associated with heightened attention (Barry et al., 2003). These findings suggest that nasal inhalation – through changing the brain's baseline connectivity, architecture, and activation – heightens attention and brings the brain into an optimal information-gathering state. This optimal information-gathering state can be crudely understood as an 'observation mode,' initiated by inhalation. It is important and surprising to note that these changes to brain activation, entrained by respiration, do *not* depend on *quantitative* gas-exchange fluctuations of cerebral blood oxygenation, but rather depend on *qualitative* changes – respiration modulates the *pattern* of network activity, not just the strength of network activation (Varga & Heck, 2017). Respiration thus effects surprising, *qualitative* changes to brain activity which go far beyond respiration's traditional gas-exchange functions, therethrough altering perception, cognition, and behavior.

But can these findings explain the case of freediving, where heightened perception occurs during *breath-holds*, not during inhalation itself? While it seems likely that the final inhale of freedivers – which directly precedes the breath-hold – would alter freedivers' brain connectivity to bring them into the above-mentioned 'observation mode' for the duration of their dive, it remains unknown whether and to what extent inhalation-initiated 'observation mode' carries over into subsequent breath-holds.

A second complication arises regarding the applicability of nasal-respiration-mediated mechanisms of brain changes to the case of freediving. In freediving, the mask and snorkel prevent any form of nasal respiration, restricting freedivers to mouth-only respiration. Therefore the above-mentioned mechanisms, which depend crucially upon nasal respiration, may seem, upon first glance, inapplicable to the case of freediving. If respiration does in fact play a crucial role in freedivers' altered perception, there must be an alternate mechanism at play. A recent study suggests one such mechanism, through which the above-mentioned nasal-respiration-dependent modulations of brain activity and behavior can in fact still apply to the case of freediving:

3.2.4 Piezo2 mechanoreceptors and intracranial pressure

A 2020 preprinted study by Wang and Hamill proposes a mechanism by which respiration entrains brain activity, *independently* of nasal mechanosensation. The authors found Piezo2 mechanoreceptors,[9] which are typically found only at the periphery, in localized areas of the mammalian brain. These Piezo2 mechanoreceptors are thought to respond mechanically to oscillatory changes in intracranial pressure (ICP), which fluctuates rhythmically with respiratory and cardiac activity. As cardio-respiratory activity oscillates, ICP oscillates. Piezo2 mechanoreceptor activity subsequently oscillates, rhythmically modulating neuron membrane potentials. This subsequently modulates the timing, amplitude, and pattern of neural oscillations, not just locally but globally, throughout the entire brain. This direct, mechanical, "non-synaptic, intrinsic resonance mechanism for tracking pulsatile intracranial pressure changes would have the advantage that spatially separated brain networks could be globally synchronized effectively at the speed of sound" (Wang & Hamill, 2020, p. 3). If this mechanism is corroborated, it follows that ICP rhythms, modulated by oscillatory cardio-respiratory activity, play a critical, primary role in synchronizing neural network activity (Buzsaki, 2006; Wang & Hamill, 2020). This mechanism allows for *quantitative* changes in ICP to induce *qualitative* changes to neural network activity patterns. Through this mechanism, respiration *intrinsically* entrains neuronal temporal oscillations, producing a '*global clock mechanism*' or '*perennial oscillatory pacemaker*' in the brain,[10] *independently* of nasal respiration. Thus in the absence of nasal respiration, Piezo2 mechanoreceptors may play the same role as the nasal

[9] Low-threshold pressure sensors critical to gentle touch and proprioception.

[10] A recent study by Karalis and Sirota (2022) may provide initial corroboration of some of these findings. The study shows that breathing acts as a 'perennial oscillatory pacemaker' of the brain, entraining and synchronizing both local and global neural circuit dynamics. The breath "acts as a functional oscillatory scaffold and provides a unifying global temporal coordination of neuronal firing and network dynamics," which allows for the segregation and integration of information across distributed neuronal networks (Karalis & Sirota, 2022, p. 11). This breathing-induced oscillatory pacemaker activity may be implicated in memory consolidation, integration of exteroceptive and interoceptive inputs, fear behavior, and other cognitive processes.

mechanosensors discussed above, driving qualitative changes to behaviorally-relevant respiration-entrained neural oscillations. And in the absence of any respiration, cardiac activity may still rhythmically modulate ICP and resulting neural oscillations. This mechanism may thus allow freedivers an alternate route to the various breath-related changes in brain functioning and behavior discussed above, including heightened perception and inhalation-induced ‘observation mode.’

Further investigation shows that certain volitional breath-control practices involving diaphragmatic breathing, which is what the relaxation breathe-up employs, cause *amplified* oscillations in ICP (Aktas et al., 2019). During breath-control practices, the presence of Piezo2 mechanoreceptors in specific brain regions might thus “transduce the amplified ICP changes, thereby altering neural network activity, EEG rhythms and causing the reported changes in brain functions” (Wang & Hamill, 2020, p. 18). If ICP oscillations – modulated by respiration, and amplified by volitional breath-control practices like the freediving breathe-up – are a primary cause of altered neural network activity and subsequent behavioral changes, a lot more research needs to be done to investigate the details of this fascinating relationship.[11]

Various neurophysiological mechanisms exist by which respiration directly modulates brain activity, thereby modulating cognition, behavior, and experience. These respiration-entrained mechanisms could explain the heightened perception reported by freedivers, and provide further evidence that the freediving breathe-up specifically, and respiration in general, affects human physiology and cognition in surprising ways that go well beyond the traditional gas-exchange function of the breath. We will come back to a more detailed discussion of the importance of these neurophysiological mechanisms in Sect. 5.3. We will now explore how freediving affects the phenomenology of two related and overlapping components of higher-order cognitive processing: reflection and decision-making.

3.3 Reflection

The third phenomenological hallmark of freediving regards the capacity for reflective awareness. Phenomenologists often differentiate between *reflective* and *pre-reflective* awareness. In reflective awareness, a given aspect of experience is reflected upon

[11] The case of freediving adds further convolutions to the Piezo2/ICP mechanism which need to be investigated. For example, how does the high external pressure of deep underwater environments affect ICP? The effects of hyperbaric conditions on ICP are still unknown and require further research (Mehrpour et al., 2014). What effects do prolonged breath-holds have on ICP? Progressive increased CO_2 levels (hypercapnia), characteristic of prolonged breath-holds, can increase ICP due to cerebral vasodilation (Asgari et al., 2011). However, at depth, freedivers sometimes experience elevated O_2 levels (hyperoxia), due to the increased pressure facilitating blood-oxygen uptake into the tissues (Bosco et al., 2018) – and hyperbaric oxygen is known to decrease ICP in mammals in certain situations (Miller et al., 1970). Freedivers may thus experience amplified ICP changes due to the volitional breathe-up practice, altered ICP changes due to hyperbaric conditions, increased ICP due to hypercapnia, and decreased ICP due to hyperoxia at depth, all within a single dive. There is simply not enough information available regarding the effects of breath-holds nor hyperbaric conditions on ICP, but these are important areas for future research in order to understand the proposed respiration-entrained mechanisms that may alter freedivers’ brain activity, behavior, and experience.

and thereby *objectified* – for example, when one assesses one's actions to determine whether they are appropriate to a certain situation (Zahavi, 2008). In pre-reflective awareness, on the other hand, a given aspect of experience is "lived through as the *subject* of awareness, without any process of reflection on itself" (Colombetti, 2011 p. 303).[12] Participants unanimously report the freediving experience to be exceptionally pre-reflective in nature. Participant TH describes this differentiation – between reflective and pre-reflective awareness – as the distinction between "*creating the moment",* which is experienced *during* a freedive (pre-reflective awareness), versus "*digesting the moment",* which is experienced *after* the dive has concluded (reflective awareness).

Though participants find it difficult to describe this pre-reflective character, they report their experiences to be completely devoid of thoughts, language, concepts, and propositions – peculiar qualities which are stated to set the freediving experience significantly apart from most, if not all, other life experiences (Online Resource 2.7). AS states of her freediving experiences: "*My mind is a blank. There's nothing.*" JB elaborates further:

> *"I'm not necessarily aware of anything...but...the feeling of...just…*being. *I'm not thinking about anything else… I'm… not thinking about...bodily emotions, or sensations, or thoughts. It's just like...I don't know…I guess...if you could be speechless with your thoughts...that's what I feel like… Just* feeling *it, and* experiencing *it."*

It is important to note that this pre-reflective *'thoughtlessness'* has nothing to do with *'mindlessness'*, carelessness, or distraction. In fact freedivers experience it as quite the opposite – exceptionally mind*ful* – due to the related hallmark of intense presence, focus, and awareness (Sect. 3.1).

This pre-reflective character of experience is temporally extended – with the past, present, and future all pre-reflectively experienced. Firstly, freedivers lack reflective awareness of the past. There is no explicit invocation of learned theories, knowledge, or episodic memories, even those relevant to freediving. Instead, freedivers report relying on pre-reflective, embodied '*muscle memory*' or '*neurological programming'* to bring their past experiences to bear on the current moment. Secondly, freedivers lack reflective awareness of their current situation: they do not explicitly reflect upon themselves, on sensory information, nor on their actions. For this reason, they experience limited conceptual processing or categorization of information, no internal verbalization, and even a loss of conceptual self-awareness, unlike anything experienced in normal life (Online Resource 2.7). Finally, freedivers lack reflective awareness of the future, which affects the ways in which they plan, act, and make decisions. This will be elaborated upon in the next section.

[12] I cannot here take a particular stance on the reflection literature (eg. Dreyfus, 2014; McDowell, 2007; Toner et al., 2016; Sutton et al., 2011; Høffding, 2014), due to a lack of adequate space. While the peculiarities of the current investigation are certainly relevant to this body of literature, and should be explored in further work, the purpose of the present subsection is to explore and portray freedivers' phenomenological reports and the relevant neurophysiological data.

This pre-reflective experience of freedivers is brought about both actively through the breathe-up, and passively by the challenging underwater environment. Firstly, thoughts, which are reported to form the basis of reflective awareness, are actively let go during the relaxation breathe-up (Sect. 2.2.1). This breath-up-induced '*thoughtlessness*' or pre-reflectiveness, along with the reported lack of conceptual processing and internal verbalization, is then maintained throughout the freedive. These characteristics may be linked to the fact that voluntary breath-holds decrease fMRI connectivity in lingual areas of the brain (Annen et al., 2021). Additionally, freedivers report that this pre-reflective, thoughtless character is further maintained by the demands of the stressful and challenging underwater environment. TH states: *"Being in the water takes over your entire brain,"* leaving no space for thoughts, reflections, or distractions. Only once a diver has stepped back onto land, out of the challenging underwater environment, does the capacity for reflective awareness re-emerge (Online Resource 2.7). TH explains that immediately after stepping back to the safety of land, the *"baseline level of stress is…released, so…now your mind is like, digesting what just happened…how it went. The mind…kicks back in."*

3.4 Decision-making

The fourth phenomenological hallmark of freediving concerns decision-making – how freedivers decide which actions to take, which specific techniques to employ at which specific times during each dive. Recall from Sect. 2 the vast array of specialized freediving techniques available to a diver. Mastering these techniques, and thereby the art of freediving, takes years of practice. It requires skillfully balancing the challenging, complex, unpredictable, interdependent, and rapidly-changing conditions – physiological, psychological, and environmental – along with one's personal motivations for the dive.

Many theorists would predict that acting skillfully amidst such complex, difficult, and interdependent task conditions as those encountered in freediving would demand significant cognitive involvement, with decision-making and action execution resisting automation and involving higher-level processes such as rational deliberation (Christensen et al., 2016). However, the interviews reveal that in freediving, despite the challenging and complex conditions, decision-making and action execution are experienced as occurring with very minimal higher-level cognitive involvement. Decisions and actions are reported to occur in a *'fast,'* *'automatic,'* and *'reactionary'* manner, while still remaining flexible, adaptive, and context-sensitive. Decisions and actions occur in a *'pure'* and *'intuitive'* manner, without any experience of pre-planning, explicit reasoning, or conscious deliberation (Online Resource 2.8).[13] These characteristics align with the pre-reflective nature of experience described in the previous section. TH explains:

[13] This phenomenological description of decision-making in freediving seems, upon first glance, to be at odds with the concept of action *automaticity,* and its often inverse relationship to both the level of action flexibility and adaptability, and the level of complexity and difficulty of task conditions (see eg. Christensen et al., 2016; Ilundáin-Agurruza, 2015). Future work should explore the concept of automaticity further to determine how closely freedivers' conceptions of automaticity align with theoretical notions of automaticity, and what the implications of this phenomenology might be for the relevant theoretical frameworks.

> *"There's really no thinking. You're...very automatic. The only...mental processing is very reactionary, like...ok, the fish moved. And then you're dealing with that specific moment, that's not...been scripted...in your mind before. So it's this kind of in-the-moment thinking…very reactionary."*

In fact, decision-making during freediving, such as deciding when to go up for air, is so pre-reflective, intuitive, embodied, and unlike the way decision-making is experienced in other facets of life, that participants have a hard time describing it (Online Resource 2.8). AS elaborates:

> *"It's hard [to explain] because the training is...to empty your mind as much as possible. You're really working to be...*not *having thoughts. So for that reason, I don't really have a way to…retrospectively track my…thought-based narrative, when I'm in the water. I'm not like, 'Oh, I think this', or 'I feel this', and then I go to the surface. It's just…very…pure…intuition. And it's also very…physical. It's like…I know it's time to go up because my body goes up. It's not like...I have information, or a stimulus, and then I think 'Oh, I should go', and then I go. You're really just…*with *your body. It's...maybe not a very satisfactory answer, but I just...*feel *it, and go."*

The interviews reveal that in freediving, there is no experience of pre-planning actions, no experience of anticipation – defined here as *reflective awareness or conscious deliberation of future situations and actions* (Online Resource 2.9). Long-term anticipation – anticipation of future actions unrelated to freediving, such as what to have for dinner tonight – simply *never* arises during freediving (Online Resource 2.9). Short-term anticipation – anticipation of future actions related to freediving – are reflectively thought about *before* the dive, but not *during* the dive itself. Before the dive, motivations and objectives '*set the tone'* for the dive: am I catching fish today? Am I exploring an underwater cave? Am I attempting a world record for depth? These objectives, of course, structure the actions a diver will take during a dive (Online Resource 2.9). However, once the dive begins, anticipation of these motives and objectives needs to be actively suppressed in order to actually achieve them (Online Resource 2.9). DS states: *"What makes me a good spearfisherman is…the absence of thought of being a spearfisherman."* Such suppression of anticipation may seem peculiar and counterintuitive, but is reported to be essential for freediving.

During a dive, unwanted short-term anticipation may sometimes arise in the form of '*in-the-moment,*' '*dive-specific*' negative thoughts, which similarly need to be suppressed (Online Resource 2.9). Especially during ascent, *"It's very easy for thoughts to creep in"* (AM). Divers often struggle with thoughts like *"You're not going to make it back conscious"* (AM). When this form of anticipation arises, freedivers need to actively "*Tune out all the negative and just be very focused and centered*" (TH), in order to avoid precisely those negative situations that are being anticipated. To do so, freedivers employ various techniques, such as mantras and positive self-talk, to suppress this form of anticipation and regain their pre-reflective, anticipation-free state. For example, if negative anticipations arise, AM tries to "*get lost in that moment, in* *that action that I'm doing. Rather than what might happen, or what has happened in the past."*

Anticipation is thus not conducive to successful freediving. Before a dive, freedivers can loosely plan for *what* they are going to do. But they can never concretely plan for *how* they are going to do it, since it is such an in-the-moment activity. The rapid changes in physiology, psychology, and environment cannot be anticipated. Any anticipation or deliberate planning for what's next distracts too far outside of the current moment, leading to unsuccessful freediving. The implications of this lack of anticipation will be elaborated upon in Sect. 5.2.[14]

3.5 Emotion

The fifth phenomenological hallmark of freediving is the restricted range of emotions experienced. Freedivers describe one primary affective state that is experienced during freediving – a state of exceptional *'peace,' 'calm,'* and *'relaxation'* (Online Resource 2.10). Despite the incredibly stressful conditions inherent to freediving, this state must be maintained, due to the need to conserve oxygen, hold the breath, and dive deeper. AM explains: "*You're looking to find peace in the dive."*

Emotions that deviate from this state, such as anger or sadness, which are commonly experienced during other facets of life, simply do not arise during freediving, due to the challenging conditions. TH explains that the "*baseline stress tend[s] to suppress a lot of emotions…keeps the emotions within…a range"*. However, depending on how the dive is going, freedivers do sometimes experience certain instantaneous affective feelings – such as excitement of hitting a personal best, or frustration at missing a speargun shot – but these are described as '*dive-specific*' '*mini-emotions,'* very unlike those experienced on land (Online Resource 2.10).

To maintain this calm, peaceful, and relaxed state, freedivers actively regulate or even suppress their emotions both before and during dives (Online Resource 2.10). Breath practices with slow, diaphragmatic breaths are known to induce emotional changes, especially reduced stress, anxiety, and anger (Philippot et al., 2002; Varga & Heck, 2017; Zaccaro et al., 2018). Freedivers thus use the relaxation breathe-up to clear themselves of preexisting emotions, such as residual anger from a recent disagreement with a partner, anxiety from being in a life-threatening situation in the middle of the ocean, or apprehension over an impending work deadline (Sect. 2.2.1). Without this clearing of emotions, freedivers are unable to enter the necessary relaxed, calm, and peaceful state, and are thus unable to dive.

[14] Due to space constraints, the implications to be discussed in the present paper will focus primarily on the concept of anticipation as it is presented in the SIF literature. However, the peculiar experience (or apparent lack thereof) of anticipation in freediving should be explored further, by way of more detailed engagement with a broader literature on cognition in skilled action. Future work should apply NoF to other theoretical investigations which critically engage the concept of anticipation (eg. Christensen & Bicknell, 2019; Farrow & Abernethy, 2015).

In rarer circumstances, dangerous situations can occur during a dive that normally induce panic – things like getting swept away from the bottom of the dive line, under 80 feet of water. JB relates her experience of one such situation:

> *"I just had the thought that...I* can't *freak out right now… I* can't *hyperventilate under 80 feet of water. I just...can't. I...want to, because I'm freaked out. It's a very natural reaction when you're anxious, or stressed. Your heart rate picks up, your frequency of breaths picks up. [But]...when you're down there, you really* can't *do either of those things. Because then it's gonna limit the oxygen that you do have. So I just remembered having to be like...stop. And ok, where's the line. Ok...swim over to the line. Pull yourself up as fast as you can. Like...just having to...*do *the things. I felt like my choice was to...calm down, get back to the line, pull myself up...or, freak out. And then I wasn't gonna be coming back up."*

In these life-or-death instances, even our hard-wired primordial emotions, evolutionarily programmed to maintain survival (Denton, 2006), need to be *'counter-intuitively'* suppressed in order to survive. During freediving, any emotion deviating from a peaceful, calm, and relaxed affective state is detrimental to survival, and needs to be regulated or suppressed, providing freediving with a rather unique affective profile.

We now have a detailed neurophenomenological characterization of the practice of freediving.[15] We have explored its two essential conditions – the relaxation breathe-up and the underwater environment – and have investigated its five phenomenological hallmarks. Where available, we have investigated the relevant neurophysiological data, in an attempt to understand the neural and bodily mechanisms that correlate with the phenomenology. The next step is to use freediving as a novel case study through which to investigate cognition in skilled action. This will be done by bringing the NoF data into conversation with SIF, a theoretical framework of cognition in skilled action. While SIF is just one of many relevant theoretical frameworks,[16] it is particularly suited to the NoF case study due to its similar commitments to integrating data and perspectives from many complementary levels of analysis, including phenomenology and neurodynamics. The SIF theoretical framework and the NoF data are thus well poised to lend mutually informative insights to one other. The next section will outline the key tenets of SIF. This foregrounds the final section of this paper, in which I will synthesize the NoF data and the SIF conceptual framework to investigate how the two can mutually inform each other to lead to new understandings of cognition in skilled action.

[15] For any readers who are intrigued by the phenomenology of freediving and wish to hear more about the experience from the perspective of a world renowned freediving champion, I can recommend William Trubridge's TEDx Talk on the matter, called "This is why I freedive: A Journey into the Deep," where he beautifully and poetically describes what it feels like to freedive: https://www.youtube.com/watch?v=-MZetpFw7qY

[16] While a full review of the relevant theoretical literature in relation to the NoF data is certainly worthwhile, it is not possible in the scope of the current paper. Future work should therefore use NoF to investigate other relevant theoretical frameworks, such as Christensen et al.'s 'Mesh' framework (2016).

4 SIF: skilled intentionality framework

SIF is a recently developed conceptual framework which brings together insights from ecological psychology, emotion psychology, phenomenology, physiology, neurodynamics, and complexity sciences in order to investigate cognition in skilled action (Bruineberg & Rietveld, 2014; Rietveld et al., 2018; van Dijk & Rietveld, 2018; Bruineberg et al., 2021). *Skilled action* refers to the ability of humans and other organisms to act in such ways that they are able, amidst complex and changing environments, to produce relevant, effective, and appropriate behavior – behavior which maintains survival while simultaneously addressing desires, needs, and interests.

4.1 Affordance responsiveness & action-readiness

Crucial to SIF's understanding of skilled action is the notion of *affordances*, which are an organism's possibilities for action in a specific environment. Importantly, affordances depend not only on aspects of the current environment, such as surfaces and objects present (Gibson, 1977, 1979), but on the organism's current needs, desires, skills, and abilities (Rietveld & Kiverstein, 2014). The field of affordances, or possibilities for action, is therefore a dynamic field, constantly fluctuating due to both changes in the environment and changes within the organism. Organisms thus need to be able to respond only to those affordances which are *relevant* to any given situation – action possibilities which maintain a balance between constantly fluctuating and competing aspects of internal and external conditions. Appropriate affordance responsiveness is therefore crucial for an organism to act skillfully, to change its behaviors in line with changing conditions. SIF thus understands skilled action as "the selective engagement with multiple affordances simultaneously in a concrete situation" (Rietveld et al., 2018, p. 1).

A key component of appropriate affordance responsiveness is action-readiness. *Action-readiness*, a term borrowed from emotion psychology, refers to a bodily state of readiness for a specific action (Frijda, 1986, 2007). Every action thus has its own associated bodily action-readiness pattern. At any given moment, an organism's current concerns (eg. needs, preferences, interests), its current abilities, and the actions currently afforded by a specific environment give rise to a multiplicity of bodily action-readiness patterns, each preparing the organism for different actions. For example, if a hiker encounters a bear in the mountains, some action-readiness patterns prepare her to freeze, others to flee, others to scream, others to throw a rock, and so on. Importantly, only some of these action-readiness patterns and resultant actions are relevant to the situation, many are at odds with each other, and all lead to differential survival rates of the hiker. These competing patterns of action-readiness thus need to skillfully converge into concrete, relevant actions in a way that maintains attunement between organism and environment.

4.2 Self-organization & dynamical oscillations

How does the multiplicity of action-readiness patterns converge into a single pattern, producing relevant, concrete behavior? SIF's proposed process by which bodily action-readiness patterns converge to produce relevant action is *self-organization* (Merleau-Ponty, 2003; Frijda et al., 2014; Rietveld et al., 2018; Bruineberg & Rietveld, 2014). The multiplicity of action-readiness patterns self-organize into a single pattern of action, depending on the relative strengths of the particular action-readiness patterns involved, and the amount of equilibrium, or attunement, they bring between internal and external conditions. The proposed mechanism draws upon *dynamical systems theory* (Dotov & Chemero, 2014; Kelso, 2012; Rietveld et al., 2018; Tschacher & Haken, 2007). In a dynamical system, micro-level components (eg. action-readiness patterns) oscillate, influencing the activity of other components in the system, including other micro-level components (other action-readiness patterns) and macro-level components (eg. behavior). Importantly, the control mechanism between components is bidirectional and 'loopy': macro-level dynamics (eg. behavior) operating on longer timescales entrain and constrain the dynamics of micro-level parts (eg. action-readiness patterns) operating on much shorter timescales, while simultaneously being generated by those very same micro-level parts. Through this proposed dynamical, self-organizing process, an organism thus becomes selectively open only to those actions that bring balance to the organism-environment system. This "process of self-organization of multiple affordance-related states of action-readiness" is precisely what SIF describes as skilled action (Rietveld et al., 2018, p. 4).

To what extent this abstract theoretical description of action-readiness convergence can be empirically validated remains an open question. Empirical evidence confirms that these principles of self-organization and dynamic oscillatory activity are in fact present in various brain processes (Freeman, 1987; Friston et al., 2006; Varela et al., 2001). These principles, however, have only very minimally been documented in the convergence of multiple action-readiness patterns into concrete behaviors (Bruineberg & Rietveld, 2014). SIF authors thus call for more research "to understand better how microscopic neural activity of certain brain areas is enslaved by the dynamics of the brain as a whole, which is in turn constrained by the dynamics of the macroscopic system" (Rietveld et al., 2018, p. 22). Collecting empirical support for the existence of these proposed dynamical, oscillatory, and self-organizing mechanisms of action-readiness convergence would greatly strengthen SIF. Section 5.3 of this paper will show how NoF provides rich grounds for such empirical support.

4.3 Metastable zones

According to SIF, skilled agents are able – through self-organization of action-readiness – to maintain relative equilibrium in the individual-environment system by attuning their relevant internal conditions to the relevant external conditions. In order to do so, skilled agents must be perceptually open to changes in conditions, and must be able to act flexibly, depending on the shifting demands of each situation. SIF defines a *metastable zone* as this relative equilibrium – a state in which an organism is optimally situated to respond flexibly to changing conditions (Bruineberg & Rietveld, 2014; Rietveld et al., 2018). When an organism is in a metastable zone, it is optimally open to perceiving changes in conditions, and can flexibly and rapidly adopt a vast number of different action-readiness states and subsequent actions. Performance is thus optimal when in a metastable zone. A classic example of a metastable zone comes from research on boxing: in training, there exists an optimal distance between a boxer and a punching bag (Hristovski et al., 2009). When at this distance, a boxer is ready for multiple relevant actions at once (eg. jabs, hooks, uppercuts), and can flexibly and rapidly switch between them, depending on the rapidly-changing movements of the punching bag. Maintaining this optimal distance, or metastable zone, achieves optimal performance. On SIF, skilled agents thus tend towards metastable zones, making use of their optimal openness to changes and flexibility of actions in order to produce optimal behavior. As we will see in Sect. 5.1, freediving facilitates a more detailed investigation of the metastable zone, allowing for elaboration and clarification of its key characteristics.

4.4 Anticipation

A final tenet of skilled action on SIF is *anticipation*. Since skilled action deals with the concepts of affordances and action-readiness, which concern possibilities for actions *in the future*, it by nature implies a certain level of future-directed anticipation (Rietveld et al., 2018; van Dijk & Rietveld, 2018; van Dijk & Withagen, 2016; Bruineberg et al., 2021). Future possibilities for action can dictate current affordance responsiveness: “our current actions are often performed while reckoning with future possibilities for action that exist “on the horizon”. For example, a study in ice-climbing showed that the climbers anticipated not only the next step, but the entire route ahead (Seifert et al., 2014)” (Rietveld et al., 2018, p. 17). On SIF, this anticipation, or planning for the trajectory of future affordances, is thus necessary for skilled action, since it is required for developing appropriate action-readiness patterns demanded by subsequent actions. Section 5.2 will discuss how freediving challenges this role of anticipation in skilled action, illuminating the need for conceptual clarification and refinement.

5 NoF and SIF: synthesis and implications

Now that we have detailed characterizations of both NoF and SIF, I will synthesize the two, exploring how the SIF framework of skilled action and the NoF case study can mutually inform each other to better understand various aspects of cognition in skilled action. First, I will use SIF to push NoF forward, interpreting NoF in SIF terms to provide a unified and cohesive understanding of the neurophenomenological data. Then, I will use NoF to push SIF forward, providing 1) clarification of SIF’s *metastable zones*, 2) refinement of SIF's role of *anticipation* in skilled action, and 3) an investigation of the breath, an understudied dynamical oscillator of brain, body, and behavior, which provides an empirical mechanism to support SIF's assumption of the *dynamical self-organization* required in skilled action.

5.1 Ultra-flexibility

The interpretation of the NoF data I now propose borrows SIF terminology, understanding freediving in terms of an *ultra-flexible state*. This ultra-flexible freediving state is a pinnacle example of SIF's metastable zone, in which skilled agents are optimally prepared to both perceive and respond flexibly to changing conditions. Freediving is an interesting case of skilled action because freedivers carry out complex, challenging tasks, with many interdependent features and conditions (physiological, psychological, and environmental) that dictate the success or failure of each particular action in each particular situation. Appropriately dealing with these types of tasks is very resource intensive (Christensen et al., 2016). On top of this, freedivers are actively and continuously battling to maintain their own survival, their own fragile physiological viability conditions. Unlike most cases of skilled action discussed in the SIF literature, the stakes of freediving are therefore not just success or failure of task execution, but life or death. Moreover, this all happens amidst a foreign, challenging, and chaotic underwater environment, where conditions, both internal and external (such as quick motions of fish, shifting currents, and the fine balance of divers' psycho-physiological needs), are unpredictable, interdependent, and rapidly-changing. Freediving thus requires an optimal and truly exceptional balancing, or attunement, of crucial internal and external conditions – a feat only possible when in an ultra-flexible state. Because freediving demands such varied actions at such short timescales, and for such prolonged periods of time, it is the most amplified, prolonged, and stable case of a metastable zone currently explored in the SIF literature. This allows for a more thorough and detailed investigation of the features entailed by such zones.

An ultra-flexible state theoretically entails three key features: 1) amplified openness to change, 2) restricted temporal depth of relevance, and 3) highly unconstrained action-readiness. I will now address each of these features in turn, showing that this SIF-inspired understanding of an ultra-flexible metastable state neatly and cohesively pulls together the vast and varied effects that freediving has on neurophysiology, behavior, and experience.

5.1.1 Amplified openness to change

In order to flexibly respond to rapidly-changing conditions and maintain a dynamic balance, one needs to be able to perceive those changes. Amplified openness to changes in conditions is observed in freedivers' heightened perception (Sect. 3.2). The breathe-up both heightens interoception by increasing inward-directed attention, and heightens exteroception by neurophysiologically preparing freedivers for 'observation mode.' Simultaneously, the challenging and rapidly-changing underwater environment demands that immediate perception become more relevant, since this faculty provides the information most critical to task performance and organism survival. More attention resources are thus dedicated to immediate perception rather than to other cognitive abilities. And since attention is a limited resource that needs to be selectively allocated (Luck et al., 1996; Usrey & Kastner, 2020), resources are pulled away from less immediate concerns, like planning what to have for dinner (Sect. 3.4). This leads us to the next characteristic: restricted temporal depth of relevance.

5.1.2 Restricted temporal depth of relevance

Since maintaining an ultra-flexible state is incredibly resource-intensive, it drastically narrows the depth of temporal relevance: only affordances related to the current moment – here and now – are relevant. This restricted temporal depth is observed in freedivers' experience of intense presence: they consistently feel '*in the moment,*' and perceive time as stopped or slowed (Sect. 3.1). This restricted temporal depth is also observed in freedivers' lack of reflective awareness of both past and future: freedivers neither explicitly engage with memories of past events, nor anticipate future events, even those related to the current moment (Sects. 3.3 and 3.4). These faculties are simply too far outside the restricted here-and-now temporal depth. Any affordance that takes a freediver too far into the past or future, and thus too far outside the present moment, becomes irrelevant. Maintaining this presence, or restricted temporal depth, is crucial, since freedivers need to respond to such rapidly-changing, time-sensitive, and immediate physiological, psychological, and environmental conditions. This leads us to the third characteristic: highly unconstrained action-readiness.

5.1.3 Highly unconstrained action-readiness

An ultra-flexible state necessitates highly unconstrained action-readiness, so as to be maximally flexible to react to very rapid, unpredictable, and interdependent changes in conditions, both internal and external. This highly unconstrained action-readiness is observed in freedivers' fast, reactionary, yet context-sensitive decision-making (Sect. 3.4). Because freedivers' tasks are "complex and frequently involve situations whose fine-grained structure hasn't been previously experienced," they need to be ready to adapt to each new situation in a flexible, *non-pre-specified* manner (Christensen et al., 2016, p. 52). Freedivers therefore do not anticipate or plan their actions ahead of time – any anticipation would constrain their ultra-flexible action-readiness by gearing them towards a specific action (Bruineberg & Rietveld, 2014), taking them out of the ultra-flexible state. And they *need* to be ultra-flexible – as unconstrained as possible, ready for anything at any given moment – to be able to freedive. The next section will elaborate on this point further.

This highly unconstrained action-readiness is also observed in freedivers' restricted emotional range (Sect. 3.5). The theories of emotion compatible with SIF understand emotions as changes to (neuro)physiology which prepare the body for specific actions (Colombetti, 2014; Frijda, 1986, 2007; Scarantino & Griffiths, 2009; Shargel & Prinz, 2018). Each specific "emotional episode involves a pattern of bodily change that is conducive to specific kinds of action: fleeing, aggressing, withdrawing, and so on" (Shargel & Prinz, 2018, p. 7). Emotions thus constrain action-readiness, preparing the body for certain actions over others. In agreement with freedivers' reports, emotions are therefore not conducive to maintaining the ultra-flexible state required for freediving, since they push the body towards more constrained action-readiness patterns, restricting possibilities for action.

We thus see that understanding freediving in terms of an SIF-inspired ultra-flexible metastable state neatly and cohesively pulls together the NoF data. The five key characteristics of the freediving experience – heightened presence, heightened perception, lack of reflective awareness, lack of anticipation in decision-making, and restricted emotional range – interdependently co-emerge due to freedivers' need to maintain a prolonged ultra-flexible metastable state.

At the same time, the case of freediving has allowed for a more detailed investigation of key features of SIF's metastable zones, which were not explicitly clear before. These three key features – increased openness to changes in conditions, restricted depth of temporal relevance, and highly unconstrained action-readiness – though amplified in freediving, presumably apply to metastable zones in general. The degree to which these three features are brought about in other cases of skilled action depends on the demands of each task and the duration and stability of the metastable zones required in each case of skilled action, and will be an interesting area for further research.

5.2 Refining the role of anticipation

We now come to anticipation: a concept in which NoF and SIF seem to diverge. Recall that anticipation, such as planning for future action possibilities, is a key tenet of skilled action on SIF. And recall that freedivers experience *no* anticipation, *no* conscious deliberation, *no* planning for future action possibilities, due to the need to flexibly react, in a non-pre-specified manner, to the rapidly-changing conditions of the here-and-now. Is freediving therefore at odds with SIF?

In SIF literature, most examples of the crucial role of anticipation in skilled action define anticipation as explicitly experienced and occurring across longer timescales. This anticipation often comes in the form of planning, where anticipation of a trajectory of future action possibilities constrains one's current actions. SIF authors appeal to anticipation in order to solve a key problem in skilled action: how can a multitude of action-readiness patterns converge to produce a single concrete action? In other words, in any given situation, what is it that narrows down the vast array of action possibilities, constraining them to produce only one relevant action? SIF authors provide anticipation as the answer to this question of narrowing.[17]

In freediving, however, anticipation is actively avoided in order to maintain ultra-flexibility of action possibilities. It is important to note here that although freedivers are in an ultra-flexible state, this is not to say that their action-readiness is completely unconstrained. Firstly, freedivers' motivations for each dive constrain their action-readiness. For example, spearfishers are prepared for actions related to chasing and hunting fish, whereas recreational and competition divers are not. Secondly, the freediving breathe-up constrains action-readiness, preferentially preparing freedivers' neurophysiology for immediate perception, calm reactions, and so on. Thirdly, place affordances pre-structure the field of affordances and action-readiness (Rietveld et al., 2018; Bruineberg et al., 2021). In freediving, place affordances specific to the underwater environment, such as presence of fish, possibility of up-and-down motion, and impossibility of breathing, all pre-structure and constrain freedivers' action-readiness, preparing them to act in accordance with the vastly different action possibilities underwater versus on land. The point here is that diver motivations, the breathe-up, and underwater place affordances all constrain action-readiness *before* the dive takes place, narrowing down action possibilities at *coarser* grains and across *longer* timescales. No additional explicit constraint of action-readiness should be occurring *during* the dive itself, due to the need to be maximally open and flexibly responsive to the relevant *fine-grained* affordances at *shorter, more immediate timescales* for the duration of the dive. After these initial motivation, breathe-up, and place constraints are in place, freedivers must actively ensure that their remaining action-readiness stays as unconstrained as possible, so that they can maintain the ultra-flexible freediving state. And this is done, among other things, through avoiding anticipation. How, then, do freedivers narrow down their action possibilities to produce concrete, relevant actions?

The case of freediving shows that circumstances exist in which fine-grained constraint of action-readiness occurs due to factors other than anticipation. Emotions are one possible contender, since they constrain action-readiness patterns to produce specific actions (Shargel & Prinz, 2018). But as we have just seen, emotions, just

[17] SIF authors occasionally write that anticipation need not always be explicitly experienced. In the absence of explicit goals or plans, relevant actions arise through "the skilled animal's anticipatory dynamics, understood in terms of self-organizing states of action readiness" (Bruineberg et al., 2019, p. 5234). In these cases, anticipation takes on a different, more technical meaning, being understood as synonymous to SIF's assumed theoretical process of action-readiness self-organization. However, this second definition of anticipation, unlike the first, fails to answer the key question of narrowing. It defines the *general process* of narrowing that SIF assumes must occur in all cases of skilled action (self-organization), but does not provide an answer to the question of *what specifically* is guiding that process in any given case of skilled action. As we can see, 'anticipation' becomes a slippery term: the technical conception (which refines the *question* of narrowing through describing the presumed *general* process of self-organization) has colloquial connotations that allow for conflation with more explicit conceptions of anticipation (which provide the *answer* to what *specifically* is doing the narrowing). More precision is needed within the SIF framework to avoid conflation between these two different conceptions of anticipation. For present purposes, we focus on explicit conceptions of anticipation, since we are interested in the *answer* to what *specifically* is doing the narrowing.

like anticipation, are actively suppressed in freediving. NoF thus elucidates the need for a different explanation in SIF for fine-grained action-readiness constraint, one involving neither anticipation nor emotions.

While freedivers work hard during dives to suppress explicit, deliberate constraints of action-readiness, there are at least two important sources of implicit action-readiness constraint during freedives, the combination of which might explain how freedivers produce relevant, concrete actions. The first implicit action-readiness constraint during freediving comes from a heightened relevance, sensitivity, and responsiveness to one's viability conditions,[18] which is fundamental to the inherently life-threatening practice of freediving. In freediving, survival is not a given. Freedivers must be able to make exceptionally nuanced evaluations of threats to survival, and must allow their actions to be continuously guided by the gradients and directions that maintain their fragile physiological viability amidst the complex and challenging underwater environment. Importantly, these evaluations are reported to remain implicit, pre-reflective, and embodied, with no explicit rules, theories, or knowledge guiding freedivers' maintenance of their own survival (Sect. 3.3). In fact, expert freedivers say that learning the embodied skill of knowing one's precise physiological limits is what separates good from great freedivers. Because of this heightened relevance of survival maintenance, any action-readiness patterns, such as 'take off my fins' or 'follow that fish into the depths,' which do not support physiological viability, are overridden. Fine-grained action-readiness is thus constrained in part by the requirements implicitly established by a freedivers' own viability conditions.

But freedivers do not merely want to survive. They are driven by their dive motivations, which often compete with their viability requirements. Something is still needed to bridge the gap between these coarse-grained, temporally extended motivation constraints, and the fine-grained, immediate viability constraints just discussed. NoF data suggests that *restricted temporal depth of relevance* might play this key role. The restricted temporal depth that freedivers experience may implicitly constrain, moment-to-moment, freedivers' otherwise ultra-flexible action-readiness patterns, according to the fine-grained, immediate conditions of the here-and-now. Action-readiness patterns relevant to addressing immediate conditions, such as 'fish moved left', or 'first diaphragmatic contraction occurred,' thereby inherently outcompete action-readiness patterns not relevant to the present moment, such as 'remember my first kiss' or 'think about dinner.'

During a freedive, the combination of implicit action-readiness constraints imposed by freedivers' heightened relevance of viability conditions and their restricted temporal depth may be what produces concrete, relevant actions from the multiplicity of action possibilities. In any case, freediving shows that anticipation is only one of several drivers of the process by which the multiplicity of action-readiness patterns converges to produce single relevant actions. In most 'normal' cases of skilled action, anticipation may certainly play the role of key constrainer of action-readiness. But in certain cases of skilled action – such as freediving – while

[18] This maintenance of viability conditions relates to Di Paolo et al.'s notion of agent *normativity* (2017).

anticipation may play a crucial role in constraining action-readiness to a workable degree *before* the skilled action takes place (eg. through dive motivations), it does *not* play a role *during* the skilled action itself. In such cases, which may require a more sustained state of ultra-flexibility, the combination of viability constraints and restricted temporal depth may instead play the role of key constrainer of action-readiness, hence becoming the key producer of relevant action. The crucial concept to be explored in any case of skilled action, therefore, is not anticipation,[19] but rather *task-specific constraint* of action-readiness into concrete action. Depending on the nature of each task,[20] the key constraint of action-readiness can be performed by anticipation, emotions, viability conditions, restricted temporal depth, or any number of constrainers yet to be discovered. An interesting line of further inquiry will be to determine which task features demand which processes of action-readiness constraint.

5.3 Breath: a dynamical oscillator of affordance responsiveness

We now come to the final implication of NoF on SIF, which regards the dynamical, self-organizing process assumed to be driving skilled action. Recall that SIF understands skilled action as a process of "self-organization of multiple affordance-related states of action readiness [which] generates a macrolevel pattern of selective openness" to the dynamically changing field of affordances (Rietveld et al., 2018, p. 21). Empirical evidence for the existence of such abstract and theorized dynamical, self-organizing mechanisms in affordance-responsiveness, however, is minimal, and is explicitly called for by SIF authors. NoF provides a fertile line of inquiry for this requested empirical evidence – namely, the breath: an underexplored dynamical oscillator of the brain, body, and subsequent affordance responsiveness.

The respiration-entrained oscillations of neural activity discussed in Sect. 3.2.3 and 3.2.4 provide empirical evidence that macro-level breathing behavior dynamically oscillates micro-level brain activity, which in turn entrains macro-level affordance responsiveness. Recall that when organisms are breathing, perception, memory retrieval, information processing, and task performance are all modulated rhythmically by respiratory phase (Sect. 3.2.3 and 3.2.4). Inhalation and exhalation, through various respiration-entrained mechanisms, *qualitatively* alter micro-level brain activity and action-readiness patterns, which subsequently entrain macro-level action possibilities. In the case of freediving, for example, the slow diaphragmatic breathe-up alters the brain and body, changing not only what freedivers are able to perceive (eg. heightened perception due to inhalation-initiated 'observation mode'), but also what actions they are prepared to undertake (eg. instantaneous actions rather than reflection), and how they respond to situations

[19] On neither its explicit nor its technical conception, since 1) explicit anticipation is not necessary for skilled action, and 2) technical anticipation, while necessary due to the fact that it defines the general process which is assumed by SIF to be driving all cases of skilled action, does not address the key question of what *specifically* is driving this assumed general process.

[20] Such as task difficulty, interdependence of task features, and whether or not a task is presupposed.

(eg. calmly, without emotions). The breath, through various mechanisms, is thus a dynamical oscillator of affordance relevance and responsiveness.

But what happens when organisms are *not* breathing – when the cause of respiration-entrained oscillatory activity stops – as is the case during freediving? While the changes to brain network activity during freediving breath-holds remain yet to be discovered, phenomenological analysis reveals that the breath still plays an important role in affordance relevance and responsiveness, even throughout a breath-hold.

Throughout the course of a breath-hold dive, freedivers experience a cyclical modulation of affordance relevance: there exists a fine dynamic balance, a "*tight-rope*" (AM), between *need-to-breathe affordances* and *execute-underwater-task affordances*. Unlike when the freediver is breathing, the breath-related changes in affordance relevance during breath-holds are more dependent upon *quantitative,* gas-exchange related alterations to (neuro)physiology. Throughout the course of a breath-hold, freedivers experience decreasing O_2 and increasing CO_2 concentrations, which each implicate their own host of physiological and psychological effects. For example, increased CO_2 dilates cranial and peripheral blood vessels (Asgari et al., 2011) and increases efficiency of oxygen uptake by the tissues (Fenn, 1928), but also leads to increased negative sensations, like anxiety and the urge to breathe (Woods et al., 1988).

During a dive, affordance relevance oscillates quantitatively with the breath as follows: in the beginning and middle of a dive, when gas-exchange related physiological and psychological conditions are still optimal, only execute-underwater-task affordances are relevant. Divers do not think about need-to-breathe affordances, and instead focus on tasks such as finding fish or getting to the bottom of a dive line. At a certain point, however, involuntary diaphragmatic spasms begin, alerting the freediver that they are nearing their physiological gas-exchange limits. When these contractions start, need-to-breathe affordances become relevant. For some time after contractions start, divers are still able to maintain their focus on execute-underwater-task affordances. But then a certain point comes when, *without conscious deliberation*, the body starts ascending for air (Sect. 3.4). At this point, the freediver is momentarily brought out of their ultra-flexible zone; is no longer open to execute-underwater-task affordances. This is another prime example of how the breath entrains micro-level (neuro)physiological dynamics, giving rise to macro-level behavior: freedivers' bodily action-readiness *self*-organizes, *without* conscious deliberation. The body is now geared *only* towards resurfacing for air, due to having reached its limit of gas-exchange disequilibrium. Go-up-for-air action-readiness patterns outcompete patterns for all other actions. There is thus a constant dynamic, dictated by the breath, between the relative strengths of action-readiness patterns related to need-to-breathe versus execute-underwater-task affordances. This dynamic goes back to the ultimate challenge of freediving – maintaining an ultra-flexible state amidst rapidly-changing internal and external conditions. Give too much weight to need-to-breathe affordances, and a freediver is unable to dive, unable to execute their underwater tasks. Give too much weight to execute-underwater-task affordances, and a freediver risks blackout and death.

While the oscillations of affordance relevance during freediving breath-holds – between need-to-breathe and execute-underwater-task affordances – are related to *quantitative* gas-exchange fluctuations of breathing, *qualitative* changes to the brain and body may still occur. The Piezo2/ICP mechanism (Sect. 3.2.4) provides a way for quantitative alterations in gas concentrations to manifest into qualitative alterations in brain activity. For example, quantitative increases in CO_2 concentration during a breath-hold increase cerebral vasodilation and thus ICP, which Piezo2 mechanoreceptors in localized brain regions detect and transduce into qualitatively altered global neuronal firing patterns. Respiration-modulated neural oscillatory activity, both qualitative and quantitative, therefore exists both during breathing and breath-hold periods. The breath is thus a crucial and truly constant oscillator of affordance relevance and responsiveness. NoF thereby provides empirical support to SIF, offering the breath as a plausible mechanistic example of the abstract dynamical process that SIF assumes must occur in the generation of skilled action.

6 Conclusion

The neurophenomenology of freediving (NoF) provides a fascinating new case study through which to investigate cognition in skilled action. This paper has brought the NoF data into conversation with the Skilled Intentionality Framework (SIF), exploring how these two components can mutually inform one another. As we have just seen, this interplay of data and theory has allowed for a more unified and cohesive understanding of the NoF data, as well as investigation and refinement of SIF. More specifically, the case study of freediving has 1) elucidated three key features generalizable to SIF's metastable zones, 2) refined the role of anticipation in SIF's account of skilled action, and 3) lent empirical support to SIF's theoretical assumptions by illuminating the breath as a provocative and understudied dynamical oscillator of the brain, body, and behavior. Looking more broadly, this investigation has provided the first neurophenomenological exposition of the practice of freediving. It has revealed that freediving induces a unique neurophysiological state, which is accompanied by several peculiar and exceptional phenomenological characteristics. These include a heightened sense of presence, heightened perception, lack of reflective awareness, lack of anticipation in decision-making, and restricted emotional range. This investigation can thus provide rich perspectives and fertile material for further scientific, phenomenological, theoretical, and philosophical investigations of skilled action, ecological psychology, reflection, enactive emotions, and cognition more generally.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11097-022-09808-8.

Acknowledgements I would like to thank all the freedivers who took the time out of their busy days to share with me their unbelievably fascinating and powerful stories. Thank you to Dave Ward, Erik Rietveld, Susanne Ravn, and Andreas Roepstorff, whose feedback, insights, and revisions provided critical direction. Thank you to three anonymous reviewers for their very detailed and helpful suggestions for ways to improve the manuscript and make it more relevant and accessible to a broader audience of readers. Thank you to Simon Høffding, whose inputs, comments, and revisions provided clarity, methodology, and motivation from conceptualization to publication of this project. Thank you to my supervisor Alistair Isaac for his wonderful guidance and encouragement throughout the course of this project. A final thank you to Venita De Souza and Matthew Emslie-Smith, whose constant support was crucial to my ability to complete this project amidst a global pandemic.

Author's contributions Suraiya Luecke conceptualized the project, conducted the literature review, designed the phenomenological interview questions and structure, recruited participants, conducted the phenomenological interviews, transcribed the interviews, analyzed the data, wrote the original draft of the manuscript, and edited the final version of the manuscript.

Funding The author did not receive support from any organization for the submitted work.

Availability of data and material A list of interview questions asked of all study participants is available as Online Resource 1. An appendix of key interview excerpts, anonymized and sorted thematically, is available as Online Resource 2. Full interview transcripts are available upon request. Please send all inquiries and requests to s.luecke@berkeley.edu.

Code availability Not applicable.

Declarations

Ethics approval This study was approved on 25th June 2020 by the School of Philosophy, Psychology and Language Sciences Research Ethics Committee of The University of Edinburgh (358–1920/5).

Consent to participate All participants gave their written informed consent to participate in this study and were able to withdraw at any point during the process.

Consent for publication All participants gave their written informed consent for publication of any data corresponding to this study and were able to withdraw consent at any point during the process.

Conflicts of interest The author has no conflicts of interest to declare that are relevant to the content of this article.

References

Aktas, G., Kollmeier, J. M., Joseph, A. A., Merboldt, K.-D., Ludwig, H.-C., Gärtner, J., Frahm, J., & Dreha-Kulaczewski, S. (2019). Spinal CSF flow in response to forced thoracic and abdominal respiration. *Fluids and Barriers of the CNS, 16*(1), 10.

Allen-Collinson, J. (2009). Sporting embodiment: Sports studies and the (continuing) promise of phenomenology. *Qualitative Research in Sport and Exercise, 1*(3), 279–296.

Annen, J., Panda, R., Martial, C., Piarulli, A., Nery, G., Sanz, L. R., Valdivia-Valdivia, J. M., Ledoux, D., Gosseries, O., & Laureys, S. (2021). Mapping the functional brain state of a world champion freediver in static dry apnea. *Brain Structure and Function, 226*(8), 2675–2688.

Asgari, S., Bergsneider, M., Hamilton, R., Vespa, P., & Hu, X. (2011). Consistent changes in intracranial pressure waveform morphology induced by acute hypercapnic cerebral vasodilatation. *Neurocritical Care, 15*(1), 55–62.

Barry, R. J., Johnstone, S. J., & Clarke, A. R. (2003). A review of electrophysiology in attention-deficit/hyperactivity disorder: II. Event-related potentials. *Clinical Neurophysiology: Official Journal of the International Federation of Clinical Neurophysiology*, *114*(2), 184–198.

Bilo, G., Revera, M., Bussotti, M., Bonacina, D., Styczkiewicz, K., Caldara, G., Giglio, A., Faini, A., Giuliano, A., Lombardi, C., Kawecka-Jaszcz, K., Mancia, G., Agostoni, P., & Parati, G. (2012). Effects of slow deep breathing at high altitude on oxygen saturation, pulmonary and systemic hemodynamics. *PloS One*, *7*(11), e49074.

Bosco, G., Rizzato, A., Martani, L., Schiavo, S., Talamonti, E., Garetto, G., Paganini, M., Camporesi, E. M., & Moon, R. E. (2018). Arterial Blood Gas Analysis in Breath-Hold Divers at Depth. *Frontiers in Physiology, 9*, 1558.

Bruineberg, J., Chemero, A., & Rietveld, E. (2019). General ecological information supports engagement with affordances for "higher"cognition. *Synthese, 196*(12), 5231–5251.
Bruineberg, J., & Rietveld, E. (2014). Self-organization, free energy minimization, and optimal grip on a field of affordances. *Frontiers in Human Neuroscience, 8*, 599.
Bruineberg, J., Seifert, L., Rietveld, E., & Kiverstein, J. (2021). Metastable attunement and real-life skilled behavior. *Synthese, 199*(5), 12819–12842.
Buzsaki, G. (2006). *Rhythms of the Brain*. Oxford University Press.
Casaburi, R., Spitzer, S., Haskell, R., & Wasserman, K. (1989). Effect of altering heart rate on oxygen uptake at exercise onset. *Chest, 95*(1), 6–12.
Cheung, K. L., Peter, M., Smit, C., de Vries, H., & Pieterse, M. E. (2017). The impact of non-response bias due to sampling in public health studies: A comparison of voluntary versus mandatory recruitment in a Dutch national survey on adolescent health. *BMC Public Health, 17*(1), 1–10.
Christensen, W., Sutton, J., & McIlwain, D. J. F. (2016). Cognition in Skilled Action: Meshed Control and the Varieties of Skill Experience: Cognition in Skilled Action. *Mind & Language, 31*(1), 37–66.
Christensen, W., & Bicknell, K. (2019). Affordances and the anticipatory control of action. In *Handbook of embodied cognition and sport psychology* (pp. 601–621). MIT Press.
Colombetti, G. (2011) Varieties of Pre-Reflective Self-Awareness: Foreground and Background Bodily Feelings in Emotion Experience. *Inquiry: a journal of medical care organization, provision and financing*, *54*(3), 293–313.
Colombetti, G. (2014). *The Feeling Body: Affective Science Meets the Enactive Mind*. MIT Press.
Daubenmier, J., Sze, J., Kerr, C. E., Kemeny, M. E., & Mehling, W. (2013). Follow your breath: respiratory interoceptive accuracy in experienced meditators. *Psychophysiology, 50*(8), 777–789.
Denton, D. (2006). *The primordial emotions: The dawning of consciousness*. New York: Oxford University Press.
Di Paolo, E., Buhrmann, T., & Barandiaran, X. (2017) *Sensorimotor Life: An enactive proposal*. Oxford University Press.
Dotov, D., & Chemero, A. (2014). Breaking the Perception-Action Cycle: Experimental Phenomenology of Non-Sense and its Implications for Theories of Perception and Movement Science. In M. Cappuccio & T. Froese (Eds.), *Enactive Cognition at the Edge of Sense-Making: Making Sense of Non-Sense* (pp. 37–60). Palgrave Macmillan UK.
Downey, G. (2022). Not breathing together: The collaborative development of expert apnoea. *Collaborative Embodied Performance: Ecologies of Skill*, 93.
Dreyfus, H. L. (2014). *Skillful Coping: Essays on the phenomenology of everyday perception and action*. OUP Oxford.
Dworkin, S. L. (2012). Sample size policy for qualitative studies using in-depth interviews. *Archives of Sexual Behavior, 41*, 1319–1320.
Farrow, D., & Abernethy, B. (2015). Expert anticipation and pattern perception. *Routledge handbook of sport expertise*, 9–21.
Fenn, W. O. (1928). The carbon dioxide dissociation curve of nerve and muscle. *American Journal of Physiology-Legacy Content, 85*(2), 207–223.
Flyvbjerg, B. (2006). Five Misunderstandings About Case-Study Research. *Qualitative Inquiry: QI, 12*(2), 219–245.
Freeman, W. J. (1987). Simulation of chaotic EEG patterns with a dynamic model of the olfactory system. *Biological Cybernetics, 56*(2–3), 139–150.
Frijda, N. H. (1986). *The Emotions*. Cambridge University Press.
Frijda, N. H. (2007). What might emotions be? Comments on the Comments. *Social Sciences Information. Information Sur Les Sciences Sociales*, *46*(3), 433–443.
Frijda, N. H., Ridderinkhof, K. R., & Rietveld, E. (2014). Impulsive action: Emotional impulses and their control. *Frontiers in Psychology, 5*, 518.
Friston, K., Kilner, J., & Harrison, L. (2006). A free energy principle for the brain. *Journal of Physiology, Paris, 100*(1–3), 70–87.
Gallagher, S. (2012). What Is Phenomenology? In *Phenomenology* (pp. 7–18). Springer.
Gamma, A., & Metzinger, T. (2021). The Minimal Phenomenal Experience questionnaire (MPE-92M): Towards a phenomenological profile of "pure awareness" experiences in meditators. *Plos one*, *16*(7), e0253694.
Gibson, J. J. (1977). The theory of affordances. *Hilldale, USA*, *1*(2).
Gibson, J. J. (1979). *The ecological approach to visual perception. Boston, MA, US*. Houghton, Mifflin and Company.

Gooden, B. A. (1994). Mechanism of the human diving response. *Integrative Physiological and Behavioral Science: THe Official Journal of the Pavlovian Society, 29*(1), 6–16.
Graneheim, U. H., Lindgren, B. M., & Lundman, B. (2017). Methodological challenges in qualitative content analysis: A discussion paper. *Nurse Education Today, 56*, 29–34.
Grosmaitre, X., Santarelli, L. C., Tan, J., Luo, M., & Ma, M. (2007). Dual functions of mammalian olfactory sensory neurons as odor detectors and mechanical sensors. *Nature Neuroscience, 10*(3), 348–354.
Haugeland, J. (1998) *Mind embodied and embedded.* In: *Having thought: Essays in the metaphysics of mind*, ed. Haugeland, J., pp. 207–40. Harvard University Press.
Høffding, S. (2014). What is Skilled Coping?: Experts on Expertise. *Journal of Consciousness Studies, 21*(9–10), 49–73.
Høffding, S., & Martiny, K. (2016). Framing a phenomenological interview: What, why and how. *Phenomenology and the Cognitive Sciences, 15*(4), 539–564.
Hristovski, R., Davids, K. W., & Araujo, D. (2009). Information for regulating action in sport: Metastability and emergence of tactical solutions under ecological constraints. In M. Raab, D. Araujo, & H. Ripoll (Eds.), *Perspectives on cognition and action in sport* (pp. 43–57). Nova Science Publishers.
Ilardo, M. A., Moltke, I., Korneliussen, T. S., Cheng, J., Stern, A. J., Racimo, F., de Barros Damgaard, P., Sikora, M., Seguin-Orlando, A., Rasmussen, S., van den Munckhof, I. C. L., ter Horst, R., Joosten, L. A. B., Netea, M. G., Salingkat, S., Nielsen, R., & Willerslev, E. (2018). Physiological and genetic adaptations to diving in sea nomads. *Cell, 173*(3), 569–580.
Ilundáin-Agurruza, J. (2015). From clumsy failure to skillful fluency: A phenomenological analysis of and Eastern solution to sport's choking effect. *Phenomenology and the Cognitive Sciences, 14*(2), 397–421.
Ito, J., Roy, S., Liu, Y., Cao, Y., Fletcher, M., Lu, L., Boughter, J. D., Grün, S., & Heck, D. H. (2014). Whisker barrel cortex delta oscillations and gamma power in the awake mouse are linked to respiration. *Nature Communications, 5*, 3572.
Karalis, N., & Sirota, A. (2022). Breathing coordinates cortico-hippocampal dynamics in mice during offline states. *Nature Communications, 13*(1), 1–20.
Kelso, J. A. S. (2012). Multistability and metastability: understanding dynamic coordination in the brain. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *367*(1591), 906–918.
Ko, J. Y., Jones, G. A., Heo, M. S., Kang, Y. S., & Kang, S. H. (2010). A fifty-year production and economic assessment of common property-based management of marine living common resources: A case study for the women divers communities in Jeju, South Korea. *Marine Policy, 34*(3), 624–634.
Luck, S. J., Hillyard, S. A., Mouloua, M., & Hawkins, H. L. (1996). Mechanisms of visual–spatial attention: Resource allocation or uncertainty reduction? *Journal of Experimental Psychology Human Perception and Performance, 22*(3), 725–737.
McDowell, J. (2007). Response to Dreyfus. *Inquiry: A Journal of Medical Care Organization, Provision and Financing*, *50*(4), 366–370.
McKnight, J. C., Mulder, E., Ruesch, A., Kainerstorfer, J. M., Wu, J., Hakimi, N., Balfour, S., Bronkhorst, M., Horschig, J. M., Pernett, F., Sato, K., Hastie, G. D., Tyack, P., & Schagatay, E. (2021). When the human brain goes diving: Using near-infrared spectroscopy to measure cerebral and systemic cardiovascular responses to deep, breath-hold diving in elite freedivers. *Philosophical Transactions of the Royal Society B, 376*(1831), 20200349.
Mehrpour, M., Shams-Hosseini, N. S., & Rezaali, S. (2014). Effect of scuba-diving on optic nerve and sheath diameters. *Medical Journal of the Islamic Republic of Iran, 28*, 89.
Merleau-Ponty, M. (2003). *Nature: Course Notes from the College de France* (trans. By R. Vallier). Evanston (IL): Northwestern University Press.
Miller, J. D., Ledingham, I. M., & Jennett, W. B. (1970). Effects of hyperbaric oxygen on intracranial pressure and cerebral blood flow in experimental cerebral oedema. *Journal of Neurology, Neurosurgery, and Psychiatry, 33*(6), 745–755.
Mohri, M., Torii, R., Nagaya, K., Shiraki, K., Elsner, R., Takeuchi, H., Park, Y. S., & Hong, S. K. (1995). Diving patterns of ama divers of Hegura Island, Japan. *Undersea & Hyperbaric Medicine: Journal of the Undersea and Hyperbaric Medical Society, Inc*, *22*(2), 137–143.
Olivares, F. A., Vargas, E., Fuentes, C., Martínez-Pernía, D., & Canales-Johnson, A. (2015). Neurophenomenology revisited: Second-person methods for the study of human consciousness. *Frontiers in Psychology, 6*, 673.

Perl, O., Ravia, A., Rubinson, M., Eisen, A., Soroka, T., Mor, N., Secundo, L., & Sobel, N. (2019). Human non-olfactory cognition phase-locked with inhalation. *Nature Human Behaviour, 3*(5), 501–512.

Philippot, P., Chapelle, G., & Blairy, S. (2002). Respiratory feedback in the generation of emotion. *Cognition and Emotion, 16*(5), 605–627.

Quadt, L., Critchley, H. D., & Garfinkel, S. N. (2018). The neurobiology of interoception in health and disease. *Annals of the New York Academy of Sciences, 1428*(1), 112–128.

Ravn, S., & Høffding, S. (2017). The promise of "sporting bodies" in phenomenological thinking–how exceptional cases of practice can contribute to develop foundational phenomenological concepts. *Qualitative Research in Sport, Exercise and Health, 9*(1), 56–68.

Radak, Z., Zhao, Z., Koltai, E., Ohno, H., & Atalay, M. (2013). Oxygen Consumption and Usage During Physical Exercise: The Balance Between Oxidative Stress and ROS-Dependent Adaptive Signaling. *Antioxidants & Redox Signaling, 18*(10), 1208–1246.

Rietveld, E., Denys, D., & Van Westen, M. (2018). Ecological-Enactive Cognition as engaging with a field of relevant affordances. In *The Oxford handbook of 4E cognition* (p. 41). Oxford University Press.

Rietveld, E., & Kiverstein, J. (2014). A Rich Landscape of Affordances. *Ecological Psychology: A Publication of the International Society for Ecological Psychology, 26*(4), 325–352.

Scarantino, A., & Griffiths, P. (2009). Emotions in the wild: The situated perspective on emotion. *Cambridge Handbook Of Situated Cognition*, 347–353.

Schagatay, E. (2011). Predicting performance in competitive apnea diving. Part III: Depth. *Diving and Hyperbaric Medicine, 41*, 216–228.

Schagatay, E., Lodin-Sundström, A., & Abrahamsson, E. (2011). Underwater working times in two groups of traditional apnea divers in Asia: The Ama and the Bajau. *Diving and Hyperbaric Medicine, 41*(1), 27–30.

Schmicking, D. (2010). A Toolbox of Phenomenological Methods. In D. Schmicking & S. Gallagher (Eds.), *Handbook of Phenomenology and Cognitive Science* (pp. 35–55). Springer.

Seifert, L., Wattebled, L., Herault, R., Poizat, G., Adé, D., Gal-Petitfaux, N., & Davids, K. (2014). Neurobiological degeneracy and affordance perception support functionalintra-individual variability of inter-limb coordination during ice climbing. *PloS one, 9*(2), e89865

Shargel, D., & Prinz, J. J. (2018). An enactivist theory of emotional content. *The Ontology of Emotion*, 110–129.

Smith, J. A., Flowers, P., & Larkin, M. (2009). *Interpretative Phenomenological Analysis: Theory, Method and Research*. SAGE.

Stacey, N., Steenbergen, D. J., Clifton, J., & Acciaioli, G. (2018). Understanding social wellbeing and values of small-scale fisheries amongst the Sama-Bajau of archipelagic Southeast Asia. In *Social wellbeing and the values of small-scale fisheries* (pp. 97–123). Springer, Cham.

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*(1), 78–103.

Toner, J., Montero, B. G., & Moran, A. (2016) Reflective and prereflective bodily awareness in skilled action. *Psychology of Consciousness*.

Travis, F., & Pearson, C. (2000). Pure consciousness: Distinct phenomenological and physiological correlates of "consciousness itself." *International Journal of Neuroscience, 100*(1–4), 77–89.

Tschacher, W., & Haken, H. (2007). Intentionality in non-equilibrium systems? The functional aspects of self-organized pattern formation. *New Ideas in Psychology, 25*(1), 1–15.

Usrey, W. M., & Kastner, S. (2020). Functions of the Visual Thalamus in Selective Attention. *The Cognitive Neurosciences*, 367.

van Dijk, L., & Rietveld, E. (2018). Situated anticipation. *Synthese*.

van Dijk, L., & Withagen, R. (2016). Temporalizing agency: Moving beyond on- and offline cognition. *Theory & Psychology, 26*(1), 5–26.

Varela, F. J. (1996). Neurophenomenology: A methodological remedy for the hard problem. *Journal of Consciousness Studies, 3*(4), 330–349.

Varela, F., Lachaux, J. P., Rodriguez, E., & Martinerie, J. (2001). The brainweb: Phase synchronization and large-scale integration. *Nature Reviews. Neuroscience, 2*(4), 229–239.

Varga, S., & Heck, D. H. (2017). Rhythms of the body, rhythms of the brain: Respiration, neural oscillations, and embodied cognition. *Consciousness and Cognition, 56*, 77–90.

Wang, J., & Hamill, O. P. (2020). Piezo2, a pressure sensitive channel is expressed in select neurons of the mouse brain: a putative mechanism for synchronizing neural networks by transducing intracranial pressure pulses. In *bioRxiv* (p. 2020.03.24.006452).
Withagen, R., Araújo, D., & de Poel, H. J. (2017). Inviting affordances and agency. *New Ideas in Psychology, 45*, 11–18.
Woods, S. W., Charney, D. S., Goodman, W. K., & Heninger, G. R. (1988). Carbon Dioxide-Induced Anxiety: Behavioral, Physiologic, and Biochemical Effects of Carbon Dioxide in Patients With Panic Disorders and Healthy Subjects. *Archives of General Psychiatry, 45*(1), 43–52.
Yasuma, F., & Hayano, J.-I. (2004). Respiratory sinus arrhythmia: Why does the heartbeat synchronize with respiratory rhythm? *Chest, 125*(2), 683–690.
Zaccaro, A., Piarulli, A., Laurino, M., Garbella, E., Menicucci, D., Neri, B., & Gemignani, A. (2018). How Breath-Control Can Change Your Life: A Systematic Review on Psycho-Physiological Correlates of Slow Breathing. *Frontiers in Human Neuroscience, 12*, 353.
Zahavi, D. (2008) *Subjectivity and Selfhood: Investigating the First-Person Perspective.* MIT Press.
Zelano, C., Jiang, H., Zhou, G., Arora, N., Schuele, S., Rosenow, J., & Gottfried, J. A. (2016). Nasal Respiration Entrains Human Limbic Oscillations and Modulates Cognitive Function. *The Journal of Neuroscience: THe Official Journal of the Society for Neuroscience, 36*(49), 12448–12467.

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