Rethinking Neuroscientific Methodology: Lived Experience in Behavioral Studies

Nedah Nadia Nemati*

Introduction

Imagine you arrive home, exhausted after working a long shift. You go through a set of habits or rituals to prepare to sleep, and then perhaps drift into fantastical dreams, about which you may remember nothing. Eventually, your alarm rings and you get ready to go to work—specifically, to a behavioral neurobiology laboratory where you study sleep in fruit flies. You spend the many coming hours methodically documenting this fly behavior. Such a process—breaking down fly sleep behavior into discrete physiological steps, recording these creatures' patterned movements, dissecting their brains, mounting the tissue, using various tools for interpreting brain data, and so on—is meant to piece together a description that maps onto your sleep during the preceding night.

Philosophers of science have carefully attended to various stages of this experimental process. None, however, have systematically studied when and where neuroscientists appeal to their own experiences when studying a behavior, including what roles these experiences may play in experimentation and the construction of neuroscientific descriptions of behavior.

I argue that what has remained largely underexamined is the role of experience in behavioral refinement—how neuroscientists translate behaviors from vaguely characterized phenomena to more specific ones. The processes in the scenario depicted above, for example, often are reported in the passive tense, with the researcher removed from her experimental manipulations. Consider for a moment how strange it would seem if, while describing that researcher's methodical observations of fly behavior, I were also to mention that, as she worked, she was intermittently thinking about her partner's, sibling's, or child's sleep patterns.

* Forthcoming in *Biological Theory*.
Contact Information: Presidential Scholars in Society and Neuroscience, Columbia University, 511 Fayerweather Hall, 1180 Amsterdam Ave. New York, NY, 10027 USA.
Email: nnn2120@columbia.edu

Indeed, the best attempts at understanding how behavioral neurobiology refines behavior have been driven by the assumption that low-level behavioral neurobiology can refine behavioral concepts without concern for the positive impact of human experience.

Neuroscientists, emphasizing the importance of various tools and methodologies in research, have disallowed any appreciable role for experience in experimentation. If anything, scientific accounts have long argued that a researcher's experience is a source of bias (Rosenthal and Fode 1963; Barber 1976; Rosenthal and Rubin 1978). Some philosophers of neuroscience, closely adhering to this scientific stance, have argued that appeals to experience—such as even the use of psychological terms—can bias experimental outcomes (Bickle 2003, p. 14).

Yet, what enables behavioral refinement to occur, I argue, necessarily depends on the very features often considered to be intrusions within the refinement process. After explicating this process of refinement in neuroscience, I identify a crucial role for lived experience in the refining of behavioral concepts.

By examining the neurobiological study of sleep behavior, I will argue that experimenters' lived experiences necessarily play a role throughout experimentation and provide the conceptual glue for holding an experiment together. Beyond the individual experience, this includes the situational, social, cultural, and historical experiences that shape how one comes to understand the world. To avoid being reductive about the term experience, which would limit discussion of the researchers' engagement to the senses alone and so fail to capture that engagement's richer role in experimentation, I explicitly draw from the language of *lived experience*. Lived experience, adopted from the phenomenological rather than empiricist tradition of philosophy of science and derived from Husserl's notion of *Lebenswelt*, or "lifeworld," bypasses the distinction of subjective, first-person experience and objective, third-person experience to render experience an interaction between the human and the world. Taken for granted, cultivated by being-in-the-world, and historically informed, lived experience is alert to and shaped by environmental and contextual changes that resist the dichotomy of being either solely pregiven or strictly socially constructed. This article will show how lived experience's influence on experimentation can range from a scientist's historically imbricated ideas about sleep to more imminent, local ways of knowing—such as when one should stop looking during an experiment.[1]

The recognition that lived experience is both inherent in research and enables experimentation to generate meaningful explanations about behavior leads to a better description of neuroscientific methodology. Differences brought to bear on experimenters' practices are no longer seen as intrusions in studies, but as necessary features of neuroscientific practice.

This piece focuses its discussion of behavior on sleep for a variety of reasons. For one, sleep serves as a paradigmatic behavior to investigate: it is explicitly spelled out in so-called scientific and functional, as opposed to merely experiential, terms. Sleep has a tidy evolutionary story (Joiner 2016), is clearly tied to physiological processes such as circadian rhythms (Saper et al. 2005), sleep has neuronal and mechanistic accounts used to explain its onset and suspension (McCormick and Bal 1997), it is linked to specific genes and proteins spanning multiple types of organisms and species (Sehgal and Mignot 2011), and so on. Fine-grained accounts of our scientific knowledge about sleep notwithstanding, I show that scientific refinements and recharacterizations of sleep behavior continually rest on a shifting, coarse-grained characterization of this ubiquitous behavior. Moreover, sleep is an interesting phenomenon to examine precisely because it is not obvious how its characterization relies on human experience. Demonstrating that lived experience, including first-person experiences of sleep, are in fact involved in shaping sleep research strengthens the evidence for generalizing this claim to other, seemingly qualitatively richer behaviors.

Lastly, sleep is often seen as an inactive state and often expressed as a contrast to consciousness. By revealing how these everyday assumptions can in fact oppose neuroscientific evidence, I also show that methodological dependence on lived experience does not condemn researchers to reinforce everyday

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[1] I note that this account, by focusing on behavioral neuroscientific methodology and moving beyond subjective experience, differs from standard neurophenomenological accounts that attempt to incorporate experimental subjects' phenomenology in experimentation. Nonetheless, it shares perspective with arguments that have drawn attention to the naïve assumption that cognitive scientists can separate cognitive experience from their own first-person experience. For a detailed discussion of this debate in cognitive science, see Gallagher, 1997.

views about behavior.[2] The following sections describe the various methodological stages of refining sleep, and show how they each rely on lived experience.

In the second section, I derive a characterization of experimental refinement from behavioral neurobiological studies and further identify three relevant processes: reducibility, reversibility, and relayability. Next, I introduce *experientially derived notions* (EDNs) to designate how a scientist's lived experience plays purposeful roles in behavioral neurobiological methodology. To focus these points on behavioral neurobiological experimentation, I concentrate on studies of sleep behavior in *Drosophila melanogaster*. The third section grounds the abstract story of refinement in experimental practice by identifying various substantial, but overlooked, roles for EDNs, including the normative role of lived experience. Section four underscores the importance of EDNs by demonstrating that they are indispensable to behavioral neurobiology if empirical practices are to meaningfully reflect on and connect with behaviors experienced by humans. The fifth section engages with concerns about EDNs and the reliability of sleep data, and I conclude in the last section by calling for a more phenomenologically inspired approach to behavioral neuroscientific methodology.

A Schema of Refinement: Three Processes

Practices in behavioral neurobiology aim at capturing the behavioral features of systems in biological terms. However, methods for achieving this aim imply the replacement of initial, general behaviors under investigation with apparently more refined neural and molecular characterizations of these behaviors' constituent components. A broad compendium of behavioral neurobiology articles reveals the following steps for refining behavior (Beloate et al. 2016; Kuiper et al 2017; Zhang et al. 2018; Vaccaro et al. 2020).

First, researchers name a behavior of interest, noting that it can be observed across multiple contexts. Next, they identify a single component[3] of this general, oft-quoted as "mysterious," behavior (Bartholow 2018; Gardner 2015) that they seek to understand, such as sleep–wake states that may indicate how sleep

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[2] Note that this also distances the present account from others strictly advocating for the use of folk psychology or everyday concepts.

[3] Sometimes the study explicitly addresses a component of sleep, whereas other times it is just taken to be representative of sleep more generally.

is regulated, thereby narrowing the scope of the discussion and making the behavior more manageable for study. For example, rather than studying sleep behaviors writ large, scientists may focus on specific neural components thought to be involved in arousal. With background research at the ready, researchers proceed with using the specific descriptions that are now associated with the behavior more generally.

To assure that their findings yield meaningful information about sleep, researchers will manipulate the newly identified components and compare an organism's sleep behavior with that of a control group. Results from these practices may show a difference in behavior. If so, researchers will characterize this difference as having captured the object-of-interest. For example, if researchers discover a circuit that induces sleep when activated, arousal when inhibited, and sleep–wake irregularities when eliminated, then that circuit may be termed a "circuit for sleep generation" or "circuit for sleep-wake control" (Xu et al. 2015; Ma et al. 2019).

Finally, researchers reference other sleep studies to garner support for their interpretation of outcomes, and new descriptions of sleep might be supported by similar findings in other organisms, or by other, redescribed mechanisms that tender further insights into their discovery (Franken et al. 2009; Palma et al. 2013). The new description may be contrasted with earlier findings conducted with tools or methods laudable in some respects but shown to be insufficient for capturing the behavior at-large. In these reports, the process of refinement commonly includes three principal steps, summarized in Table 1 and described below in greater detail.

Table 1 Three steps of refinement

Redescription	Behaviors are re-presented as a set of neural circuits, mechanisms, or, at the very least, a basic molecularized story without losing major content
Reversibility	Claims are made to and from a general behavior to its neural or molecular characterization, and vice versa
Relayability	Re-presented behaviors are communicated across and transferred to different research practices

Redescribing the behavior of interest entails representing the behavior of interest in a more specific, formal, and scientific way. Here, behaviors are translated from familiar, everyday units to descriptions that capture the behavior without its seeming ill-characterization. In cognitive or behavioral neurobiology, this often entails redescribing the behavior of interest in terms of biological mechanisms, neuronal circuits, molecular descriptions, or genes.

Refinements are also typically *reversible*. Researchers attempt to demonstrate that a behavior can be convincingly redescribed in the newly provided terms by showing that no substantial information is lost: just as one can make inferences from sleep to a circuit or mechanism X, this circuit or mechanism X ought to be able to take the researcher back to the original behavior, sleep[4]. A common technique to demonstrate that a newly designated mechanism is involved in the shift from sleep to wakefulness (i.e., sleep arousal) consists of describing an activity, without which, sleep arousal cannot occur.

Finally, refinements demonstrate *relayability*. To show that sleep has, in fact, been refined, researchers must show that the new descriptions can meaningfully communicate across different studies of the same behavior that use other refined units. For example, if researchers identify a set of genes as playing a role in sleep arousal in the fly, the same genes are expected to play a similar, if not identical, role in sleep arousal in a mammal. In other cases of relayability, researchers might want to derive biological or mathematical models that capture a behavior and that can be applied to similar systems.

Rather than list all details of neurobiological experimentation, this sketch of refinement aims to capture a general trend in behavioral neurobiological studies: a behavior of interest is operationalized, and experiments are conducted to redescribe that behavior. The strengths of the resulting redescription are verified by its reversibility and relayability (see Table 1). Of note, once the behavior-of-interest is operationalized, one would think that the so-called mysterious, or what I here call *fuzzy* behavior, should

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[4] Note that this characterization of reversibility says nothing about causality. Whether or not one achieves such tight redescription is a separate issue from establishing causal claims, as there are many challenges even when the conditions for reversibility are thought to be highly characterized and reliable. For example, see the discussion on challenges to causal claims in optogenetics by *Jazayeri & Afraz, 2017.*

disappear. In the next section, however, I show, instead, that experimenters in the later stages of refinement continue to invoke phenomenal features of the behavior *in order to* refine it.

The next section turns to actual neurobiological experimentation to identify when lived experience gets employed in scientific practice, as well as its role.

Refining Sleep

Redescribing Sleep: Operationalizing by Experience

I begin my analysis of how a scientist's lived experience plays purposeful roles throughout sleep research with the process of redescription. However, rather than constantly use the broad term lived experience, I identify specific ways researchers draw from their experience to refine sleep behavior—what I call *experientially derived notions*, or EDNs—to provide a taxonomy of the different roles of lived experience in *Drosophila* sleep studies.

Refinement involves redescribing the behavioral phenomenon of interest, often by operationalizing a behavior. Here, researchers often have no choice but to start with what they know from firsthand experience. We not only have experiences of sleep (Thompson 2015; Windt et al. 2016) but can also discern when someone or something else is asleep. To be a human among other humans and nonhuman animals, we must know when another person or animal is asleep and be able to distinguish this behavior from other states, such as unconsciousness or death. Thus, EDNs play a role in characterizing sleep as a behavior early on in research because, importantly, one cannot begin to test a behavioral construct without turning to some familiar notion of that behavior.

In 1984, scientists Scott Campbell and Irene Tobler reviewed over one hundred studies on over one hundred and fifty species and settled on the following behavioral criteria for a sleep state: absence of voluntary movement, reversibility, increased arousal threshold, homeostatic regulation—or the ability for an animal to maintain an internal state—and state-regulated changes in neural function, such as decreased sensory input to the central nervous system (Campbell and Tobler 1984, pp. 342–343). These four features became the core criteria for scientific descriptions of sleep. From hereon, I will refer to this operationalized and scientific characterization as "SLEEP," in contrast to the richer and fuzzier notion with which you and I are most familiar, "sleep." Sleep, known by lived experience, exists beyond the rules set for operationalized behavior. For example, while sleep is typically associated with inactivity, one's experience confirms the possibility that someone walking and talking might be sleepwalking. Similarly, one experientially knows that, while arousal threshold generally increases during sleep, some people may be light or heavy sleepers (i.e., people awakening at the light sound of a thump, "sleeping through an earthquake," and everything in between).

Campbell and Tobler, informed by their own experiences of sleeping and identifying sleep in others, made inferences about the experiences of other organisms or persons when asleep, for SLEEP. There are many ways to demonstrate this, but, to pay homage to a literary scholar often cited in neuroscience, I here put side-by-side the scientists' account alongside the descriptions of writer Marcel Proust. Assumptions in these researchers' operationalized account become salient when placed close to the following quotation from Proust's work, which illustrates how sleep, as both individually perceived and socially imbricated, yields a reckoning with personal experience:

> *A man who, night after night, falls like a lump of lead upon his bed, and ceases to live until the moment when he wakes and rises, will such a man ever dream of making, I do not say great discoveries, but even minute observations upon sleep? He barely knows that he does sleep. A little insomnia is not without its value in making us appreciate sleep, in throwing a ray of light upon that darkness.*
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> – Marcel Proust, *Cities of the Plain*

Proust, so often celebrated by neuroscientists for his careful descriptions of ordinary human experiences (Lehrer 2008; Kandel et al. 2014), here too describes an account of sleep that captures the scientists' experiences (Proust 2006).[5] His literary account, informed by his lived examination of sleep wherein one is like a "lump of lead," immobile and apart from daily activities, closely parallels the scientific description in Campbell and Tobler's recordings wherein "purposeful movements are evidence against a sleep state" (Campbell and Tobler 1984, p. 343).

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[5] Van Campen notes Proust's influence on neuroscience, citing Bogousslavsky's scholarship that Proust came from a family of doctors and was friends with many neurologists (van Campen 2014, p. 47).

Similar to Proust's description of sleep, the sleep scientists also observe that sleep must be reversible to be distinguished from other physiological states, such as "exhaustion, paralysis, coma, or stupor" (Campbell and Tobler 1984, p. 343). Proust, by noting how attitudes toward sleep change after sleep deprivation, suggests that sleep is both reversible and a valuable state. Juxtaposed, the researchers' and the literary author's characterizations appear to designate the same behavior. It becomes clear that the behavior of SLEEP, while operationalized, relies on these ordinary experiences of sleep, including its varied and deviant dimensions.

Put concisely, sleep scientist Joan Hendricks asks, "How can we recognize a sleep-like state without using these well-established criteria that define sleep?" (Hendricks et al. 2000, p. 342). To meaningfully operationalize and redescribe SLEEP, firsthand experience of this behavior must be involved in identifying it as a significant subject of study in the first place.

This is the first instance in which lived experience, here by way of researchers' own subjectivity, plays a role in experimentation: EDNs show that researchers must draw from a private understanding of sleep to operationalize. As I discuss below, EDNs also play an important role throughout further efforts of redescribing that behavior, and to deem it reversible and relayable.

Choosing Behavioral Models

When refining behavior during study design and review, researchers determine the use of one behavioral model over another by drawing from experience-derived features outside the core criteria used to operationalize behavior. In other words, researchers invoke experiences of sleep, and other experiences related to it, in order to study SLEEP.

Consider that after operationalizing SLEEP, researchers select a model organism for testing, driven by various, complicated motives such as practicality, economic constraints, tool availability, and ethical considerations (Ankeny 2007; Ankeny & Leonelli 2020; Dietrich et al. 2020). For instance, *Drosophila* is preferred for its convenience and well-established track record in circadian biology due to its genetic and molecular tractability (Tataroglu et al. 2014). However, to highlight the important role

EDNs can play in model choice, I focus solely on selecting an organism because of its shared behavioral features with researchers or other humans.

Despite their complexity as models, certain animals are preferentially chosen so as to filter a behavior of interest from the noise that might intrude by studying another system (Nelson 2018, p. 28). In accordance with the aforementioned picture of refinement, these models help researchers exploit an animal's natural features to arrive at the "pure, isolated phenomena" of the behavior of interest (Hacking 1983, p. 226). Neuroscientists align with this thinking, citing Krogh's principle to find the best model for their scientific question (Yartsev 2017). *Drosophila*, for instance, is selected for studying sleep behavior due to its manipulability and shared core characteristics of SLEEP with other species. Researchers, however, go beyond the four operationalized criteria for SLEEP and consider other dimensions of behavior.

For example, scientists prioritize *Drosophila* over *C. elegans* as a research model, not only for its SLEEP patterns but also for additional behavioral resemblance to human sleep. Namely, researchers explicitly cite *Drosophila*'s sleep patterns of 8 to 10 hours of uninterrupted sleep per day[6] as providing a better model than the (comparable in many respects) *C. elegans* worm model, in which circadian regulation appears so foreign that it is even denoted by periods of "lethargus" rather than *sleep* (Raizen et al. 2008; Cirelli 2009, p. 551).

Nonetheless, historical analyses reveal that the idea of an uninterrupted, several-hour sleep at night is a contemporary norm, whereas segmented sleep—sleeping for 3- to 4-hour blocks with quiet but wakeful interludes—was more common in preindustrial Europe (Ekirch 2015). A "first" and "second sleep" pattern, in fact, is well documented in older medical texts and diaries, from African and South American indigenous communities (Jackson et al. 2018), as well as 19th-century English literature (Dickens 1841).

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[6] Computer-assisted video tracking and supervised learning are changing these numbers by measuring the micromovements of flies, not just their usual walking (Geissmann et al. 2019).

The countenanced "eight hours of sleep" is thus a contemporary experience of social and economic conditions, as well as neurobiology.[7]

Drosophila sleep researchers themselves also note that researchers surpass the four operationalized criteria for SLEEP. Upon analyzing the inaugural sleep papers on the four criteria identifying SLEEP, Dissel et al. recognized that none solely relied on just those behavioral criteria. Rather, the papers "extended their analysis to other important variables that are commonly studied in connection with sleep in mammals (e.g., ontogenetic changes, pharmacological perturbations, and molecular correlates)" (Dissel et al. 2015, p. 47). Yet, what Dissel et al. fail to acknowledge is that researchers often appeal to other dimensions of behavior, including experiences that are irregular and unstable across time.

A researcher's lived experience of sleep—here represented by the social and economic conditions that shape the rhythms of one's daily and nightly activity—thus supports the model relevant to such a familiar context. Importantly, the researcher's use of his or her historical understanding to determine that *Drosophila* sleep is a better match than *C. elegans* sleep engages experience to further assert a claim about what sleep *should* look like. Hence, all else equal, a researcher ought to choose the fly over the worm.

Here, the normative role of EDNs is more explicitly illuminated. Even when baseline features observed across hundreds of species are sufficient to provide an adequate, operationalized account of SLEEP, researchers appeal to other dimensions of sleep, drawn from experiences that, seemingly private, are shaped by a longer history of labored reality. Those choices, represented by the scientists who consult their lived experience, are thought to exist outside of the process of refinement and perceived to muddy neuroscientific studies. However, using EDNs to set normative constraints not only reveals that lived experience is necessary to motivate the scientists' work, but that it is also needed to actively draw research closer to an experiential understanding of the behavior under investigation.

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[7] I note how this notion of experience captures the more complex relationship between the empirical and normative as well: eight hours/night might be a prescription cultivated by social, labor practices, but human experience that one needs this amount to function well can also arise from a belief about what science has told us about sleep. For more, see Gavriloff et al. (2018).

Behavioral Testing 1: Standardizing Sleep Time

SLEEP criteria are alone insufficient to inform researchers of when a fly is asleep. Researchers draw from the fuzzier characterization of sleep (which informs the operationalized version of SLEEP) to satisfactorily measure what appears to be sleep.

From the view of behavioral refinement furthered by scientific reports, one might think that testing just one or all of the core features of SLEEP should be sufficient to determine when a fly is asleep. For example, researchers can determine fly immobility through observation, or they can comprehensively test inactivity, increased arousal threshold, homeostatic regulation, and reversibility together. In fact, in practice, neither of these approaches to testing is used. Scientists often consider the observation of voluntary movement—the simplest way to determine if a fly is asleep—too subjective. Instead, they have greater confidence that flies show genuine sleep by testing selected behavioral criteria against one another. Specifically, they measure the correspondence between the fly’s periods of quiescence (or dormancy) and homeostatic regulation (Liu et al. 2016, pp. 1–2). That is, by checking relationships between distinct components of sleep researchers can appear to objectively know a fly is asleep. In doing so, they rely on their experiences of what seems like sleep to designate a standardized period of quiescence as sleep time. Two examples clarify this point.

Consider the ease with which we can imagine sleeping longer one night following sleep deprivation earlier that week. From this experience alone, one might infer that some internal regulatory mechanism is at play. With an experientially derived notion of what is going on during sleep, one would expect the duration of rest rebound to be proportional to the degree of sleep deprivation. This is precisely what gets measured in a behavioral test run by Hendricks et al. (2000, p. 133). In it, flies are subjected to sleep deprivation through a rest-depriving stimulus administered at random intervals by an automated program. As a first pass, this stimulus often entails an automatic shaking of the tubes in which the flies rest in because, again, as experience dictates, a good way to stay awake is to move or, alternatively, to be shaken awake.

A second way of knowing whether researchers are truly testing sleep requires testing this state of immobility against an arousal threshold. Shaw et al. sought to determine how long it takes for a fly's immobility to be considered sleep by subjecting flies to a vibratory stimulus of increasing intensity. They recorded differences in this stimulus's effect on flies that were behaviorally awake as compared to those that were immobile for five minutes or longer. Shaw et al. determined that awake flies exhibited behavioral responses to the stimuli, whereas those that were behaviorally quiescent for five minutes or longer rarely showed a response (Shaw et al. 2000, p. 1834).

In both examples, EDNs play a crucial role in deciding when to stop testing. To illustrate, imagine how you determine if someone, lying still with eyes closed, is asleep. You might check their breathing; you might poke them or say their name. If they show no sign of response, you might think they are either asleep or feigning sleep. In short, you cross-check these methods because relying on any single one will be prone to error. For your ostensibly sleeping friend, you might try some sensory tests, such as light tickling, playing music, or making noise to provoke telling movement if they are not actually asleep. Importantly, you will not use every test at your disposal, but rather draw from your lived experience about context, body positioning, and so on to know when to stop or continue.

This same method is used in the lab. Objective, standardized tests—those used to determine when the fly is displaying sleep—are derived from researchers' experiences of sleep and of watching others sleep. Among these approaches, scientists incorporate checks to help recognize when they might judge incorrectly and to avoid over-testing. In the case of Shaw et al., the researchers' determination that sleep occurs after five minutes of inactivity is no less subjective than relying on sight alone to determine when a fly is asleep; despite this, such a test is neither arbitrary nor suggestive that anything goes with respect to what counts as sleep.

Shaw et al.'s five-minute rule can be deemed more objective because it withstands the cross tests of two other subjectively measured features—homeostatic regulation and arousal threshold. Importantly, those cross tests attempt to correct for the errors in judgment that might result if relying excessively on one, or even too many, measures of sleep. Therefore, while the five-minute rule is not a globally objective measure of how long it takes for a fly to fall asleep, it serves as a locally objective test for minimizing error, after one acknowledges that what counts as being asleep is tied to phenomenal experiences.

The role played by ENDs in minimizing error is a "measure of satisfaction," through which experimenters can check that they are really testing the specific sleep known from being in the world. Importantly, the process of knowing when enough inactivity tracks SLEEP is not reducible to any single set of criteria, whether a formally determined time period, some arbitrary quantitative artifact, or the quirks inherent in a lab's cultural norms. Knowing when inactivity is deemed SLEEP is a process individually, collectively, historically, and contextually negotiated that reaches a point of general satisfaction. As an example, sleep times are adjusted on the basis of a shifting context, as when recognizing when sleep may be disrupted.[8] Here, the lived experience of the researcher, arrived at through a collective and negotiated sense of knowing, re-enters experimentation long after operationalizing the behavior of interest.

Moreover, without such experience, it would become unclear how scientists should proceed. In theory, the researcher would consult the operationalized tenets of SLEEP through a standardized procedure instead of drawing from historically embedded knowledge to establish reliability. But provided that what is so essential to a more collectively known experience of sleep is precisely the element of inactivity and lack of awareness associated with sleep, the scientist's practices ought to generate data that account for this exact fact. Any attempt at doing things otherwise would provide data, but such data would not speak to what the scientist considers important in the first place: sleep, not SLEEP.

The next section discusses the downstream consequences of these EDN-influenced behavioral tests. Specifically, I will show that EDNs also trace the boundaries of what is deemed genetically relevant to sleep.

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[8] Consider this passage, that mutant *Drosophila* sleep metrics, "should also consider ongoing changes in behavioral responsiveness and sleep intensity, in order to fully capture sleep functions in different strains. For example, a long-sleeping fly may be sleeping lightly, or a short sleeping fly might be sleeping deeply; activity monitors and simple webcam interfaces cannot distinguish between these possibilities" (Faville et al. 2015, p. 1).

Behavioral Testing 2: Identifying Relevant Molecular Entities

It is common practice in *Drosophila* sleep labs to use infrared activity monitors to detect a fly's general locomotion (Shaw et al. 2000). If a fly fails to cross the midline of a tube in five minutes, the researcher can infer from the recording program that the fly is asleep. The now-standardized five-minute rule masks, but in no way eliminates, the role of EDNs in neuroscientific refinement. I now demonstrate one downstream consequence of standardizing the measure of sleep in this way.

Afonso et al. used a forward genetic screen—a procedure considered one of the least biased strategies since it rests on uncharacterized mutations—to identify a novel sleep regulatory gene, *tara*, that encodes for the protein TARA in *Drosophila*. In a forward genetic screen, *tara* was associated with a noticeable reduction in *Drosophila* sleep amount. Later testing suggested that the TARA protein regulates CyclinA (CycA), a protein previously shown to regulate SLEEP in the fly brain, and inhibiting Cdk1, a well-established interactor of CycA.

Ascertaining that *tara* is responsible for the behavioral phenotype of SLEEP led to a refined view of sleep through its redescription in more molecular terms. To arrive at this molecular redescription, however, researchers used monitors standardized to the five-minute rule. Such reliance on standardized tests, themselves informed by EDNs, shows that the human experience of sleep influenced how boundaries were drawn around entities deemed relevant even for the molecularized story of SLEEP. That is, mutating *tara* caused behavioral changes drastic enough to engender suspicion that this gene could play a meaningful role in regulating SLEEP. However, if knocking down the *tara* gene had not produced a significant phenotypic change—one recognizable through the researchers' experience—it would have been dismissed as a potential candidate for SLEEP regulation, even if it *were* involved in sleep regulation.

This strategy may seem obvious to experimentalists running a forward genetic screen, or a test that randomly induces mutations and screens for phenotypic changes in flies; one might consider the role of lived experience here to be trivial. After all, *how else* can researchers recognize which genes are relevant to the behavior of interest without observing phenotypic effects? In fact, noting this rather obvious way of linking genes to phenotypes *is* the point: without an alternative experimental method to conceive of what is behaviorally relevant, neuroscience overlooks that our designation of molecular relevance can only be tied to our lived experience.

Lived experience plays a role in many components of running a genetic screen such as determining, among flies with random mutations, candidate lists relevant to a scientist's observations of fly behavior, as well as the many aesthetic choices factoring into that evaluation. With no hard and fast rule for what a good positive candidate hit rate of random mutations should be, a neuroscientist is less likely to investigate a screen yielding a 1% positive hit rate, as that would be seen as too unlikely and too physiologically inclusive for the mechanisms of sleep.

Rather, a scientist would more likely return to the testing criteria and, even among screens promising to capture a strong phenotypic effect, reject those appearing to reflect effects arising from systemic dysregulation, rather than sleep. Where these lines get drawn, whether to set a cutoff for a substantive positive hit rate, or, how to determine that a mutation has in fact disrupted something related to sleep—these degrees of freedom are neither arbitrary nor subjective. These choices are not arbitrary because they derive from a lived experience of the researcher about sleep itself.[9]

Experimenters not only determine the relevance of molecular units—such as those marking the meaningful stability of *tara* to SLEEP maintenance—but also close doors to other possible molecular descriptions, such as speculation that some other relevant relationship may exist at a different biological level. Although prima facie insignificant, the lived experience of sleep helps guide the limning of boundaries around what is neuroscientifically relevant to it and closes doors to other conceptualizations, whether interactional or structural relationships, that may contribute to characterizing sleep.

To provide better empirical support for the sleep-regulating molecules currently invoked to refine SLEEP, Afonso et al. also sought to show reversibility, i.e., another crucial step in refinement, whereby one goes from the molecular redescription back to the behavior of interest.

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[9] Consider our knowledge of the difference between a bout of insomnia and being endlessly stimulated. The consequent lack of sleep could be measurable and identical by duration; the experiences would not be. But it is our own lived experience that guides the criteria we set to distinguish the two.

To support that TARA regulates CycA and Cdk1, these researchers focused on the antagonism between Cdk1 and CycA. Demonstrating this antagonism rested on conclusions that Cdk1 had a previously unrecognized wake-promoting role, one determined only after comparing the sleep behavior of Cdk1 mutants with *tara* mutant flies, wild-type control flies, and finally, flies with a heterozygous Cdk1 mutation introduced into a *tara* mutant background. By conducting behavioral tests for each type of fly and testing their sleep patterns against one another, the researchers were able to infer that Cdk1 mutation in fact restores SLEEP in *tara* mutants. In simpler terms, the Cdk1 *tara* double-mutant flies demonstrated a greater number of bouts of five minutes of inactivity than the *tara* mutant flies alone. The study's sleep analysis shows that a standardized account of sleep—one deriving from human experiences of sleep—is required to transition from the behavior's molecular description back to its operationalized version. This way researchers are able to meaningfully tie their results to behaviors with which people are familiar.

To summarize, EDNs play an expansive role in this research by influencing the behavioral tasks used for measuring *Drosophila* SLEEP. Moreover, EDNs help discern a stopping point for behavioral test design, later standardization, and for setting boundaries around criteria—here, the molecular criteria—for SLEEP. They determine and provide the scope of these entities and activities, as well as what is deemed relevant for scientific study, e.g., one protein over a protein complex or a network over a single cell.[10] These practices show that, in the context of testing a behavioral construct, lived experience is employed at the outset of experimental design, exerting significant effects on what is deemed standard in standardization, and continues to inform key aspects of experimentation, such as what constitutes the boundaries for behavioral redescription.

Relaying Information Across Contexts

To complete the process of refinement, researchers must corroborate their findings. At this step especially, relayability draws on EDNs and a fuzzy notion of sleep.

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[10] In the Afonso et al. study, referring to sleep that is seen to be in tune with human sleep actively plays a role in the conclusions researchers draw about the roles of TARA and CycA, which later allows them to claim that there is a "network of cell-cycle genes in sleep regulation" (Afonso et al. 2015, p. 1724).

Several studies highlight how *Drosophila* SLEEP results can generalize to other organisms (Ly et al. 2018, p. 72; Harbison et al. 2009). Importantly, some suggest the promise of translation to humans by citing similar experimental results in mammals and other animals (Berry et al. 2015). I argue that scientists draw on EDNs when they cross-validate and sometimes generalize that the same biological interactions involved in *Drosophila* sleep are involved in other organisms' sleep behavior. Specifically, in relaying biological redescriptions from one context to another, scientists acknowledge that features of SLEEP are necessary, but not sufficient, to characterize the sleep of different organisms. Thus, to garner support for redescribed behaviors, neuroscientists actually navigate speculated *differences* in sleep behavior amongst the animals being compared. These comparisons are only possible against a backdrop provided by EDNs.

Researchers study the operationalized SLEEP which encompasses common behavioral features across multiple organisms. Yet, while scientists might think that SLEEP is broad enough to capture the same behavior in, say, rodents and *Drosophila*, this view does not necessarily commit them to assuming that the behavior of these animals is similar in their biological realization. For instance, mice and flies may both exhibit inactivity during sleep, but their sleep durations and timing differ. While SLEEP is common to all organisms, researchers know from experience that different species sleep differently, finding it intriguing when the biological machinery regulating sleep are similar across species.

Nonetheless, researchers find support for their redescribed behaviors in one organism by appealing to different organisms. That support, however, is rooted in experientially knowing that species sleep differently. For example, if a dopaminergic pathway is found to regulate arousal in both flies and mice, it boosts the researcher's confidence in the validity of the original fly findings, affirming the robustness of sleep-related biological phenomena across species. Here, relying on interspecies differences makes relayability a useful feature of refining behavior. The experimenter draws from experiences of sleep and engages in perspective taking, imagining how a rodent's sleep and a fly's sleep differ. The existing, unreferenced dissimilarities between different organisms inform the experimenter's expectations and hypotheses. By observing similar physiological patterns in regulating sleep for both organisms, the researcher credits the suggested molecular mechanism as providing a meaningful, stable redescription of sleep, in turn reaffirming SLEEP's scientific characterization.

Still, one might wonder: *what determines the similarity of physiological patterns?* In addition to how experimenters arrive at the differences between organisms' sleep behaviors, experientially known facts about context also determine when physiological patterns are the same. For example, if environmental conditions between two organisms were radically different, similarities in the physiological patterns regulating sleep would be evaluated differently. Thus, EDNs are also involved through a sleep researcher's anticipation of dissimilarities in species' sleep experiences. This shows that researchers draw from those fuzzy, nonoperationalized features of sleep—those well outside SLEEP—that derive from lived experience to support the idea that two organisms' ways of being while asleep are sufficiently similar to count as SLEEP.

Relayability relies on EDNs, as EDNs allow the researcher to move from one context to a radically different one while maintaining the same notion of sleep. EDNs also underlie researchers' reasoning when determining when structural analogs are functional analogs. Alternatively, they help researchers determine when there are structural homologues between organisms, whereby different genetic, molecular, or cellular features are judged similar in terms of their regulatory roles and ancestry. For example, the wake-promoting neurotransmitter octopamine in *Drosophila*, structurally analogous to the mammalian neurotransmitter norepinephrine, is also seen to be functionally analogous to norepinephrine (Ly et al. 2018, p. 6). Here, the nature of relaying itself, or communicating that something from one context resembles another thing in a different context, rests at a minimum on independent criteria and outside explanations that rely as much on approachable narratives as chemical facts.

Similar regulatory elements can give rise to different developmental pathways. Thus, empirical claims rely on external inferential sources needed to make sense of why some biological thing is more or less similar to another. It is thus possible to conceptually link *Drosophila* sleep to mouse sleep, and to materially link their genealogies, not only because of some facts about their physiology but also because those facts make sense.

A single review paper on sleep provides many narratives for why sleep is even needed: sleep is evolutionarily conserved; synaptic homeostasis and plasticity occur during sleep; sleep enables metabolic regulation; or sleep allows for brain development (Ly et al. 2018). While one may mistakenly believe that these explanations derive or follow from a study's results, they also serve as the force underlying relaying. An evolutionary hypothesis, for example, does not simply follow the finding of a shared biological similarity regulating sleep between two species; rather, it is the relevant narrative required to say that similarities between fly and mouse sleep exist. Such explanations, rather than focusing solely on similar biological elements, furnish the story the neuroscientist invokes in making the leap between one organism and another. More specifically, to posit material similarity between *Drosophila* and mouse, rather than *Drosophila* and another physically similar animal, one must appeal to an evolutionary narrative that explains why sleep is necessary. Here, EDNs are required to relay information across context. An agreed-upon story accomplishes the work of filling in the gaps between what is considered relevant and what can be ignored.

Finally, contrary to what is often expressed, relayability works when a researcher has reason to suspect that sleep in different organisms is not the same. Otherwise, one might wonder what would drive the confidence of the explanations that are produced as a result. Researchers appeal to EDNs to unify research practices by knowing that sleep differs in different species and by seeking resources to find similarity between species.

Relayability shows how significant, nonbehavioral molecular research later gets applied to behavioral research; nonetheless, EDNs are required for those molecular results to meaningfully map onto behavioral research. The moment a molecular description is tied to redescribing a behavior, the territory of behavioral research is broached. A fuzzy behavioral notion—one whose possibilities are set by one's being-in-the-world—is required to link the behavioral redescription to a behavior of interest.

Refinement without Replacement: Summarizing the Roles of EDNs

The many different roles for EDNs—those ranging from first-person experience to socially-negotiated experience—document how lived experience explicitly plays a role in refining sleep. These are summarized in Table 2. By employing EDNs, neuroscientists can link scientific objects of study to the experienced behavior. Although the specific roles of EDNs identified in sleep studies are not necessarily present in every neurobiological experiment, EDNs show that fuzzy behaviors are needed for research findings to inform behavioral notions relevant to human lives.

Table 2 EDNs employed in refining sleep

EDN Role	***EDN Activity***	***Research Task***
Contextual Discrimination	Researchers draw on EDNs, both when revealing the qualities of a behavior of interest and what those qualities ought to be	*Choosing Model Organisms* *Example*: Choosing *Drosophila* to study sleep
Halting Design to Standardize ↓	(a) Researchers invoke EDNs to discern a methodological stopping point for the design of behavioral tests and their later standardization	*Behavioral Testing* *Example*: What duration of inactivity counts as a standardized bout of sleep?
Determining Boundaries	(b) Researchers use the standardized behavioral tests of sleep derived in (a) to determine the relevant scientific boundaries for their refined concepts	*Identifying Relevant Molecular or Neural Entities* *Example*: Characterizing behaviors as circuits, genes, mechanisms, pathways, etc.
Unifying Across Contexts	EDNs are invoked when researchers apply their results in different contexts and across different organisms; researchers rely on differences between organisms' sleep and their own sleep experiences	*Applying characterized behaviors across model organisms* *Example*: Integrating sleep study findings across different species

Lived experience informs the empirical process in ways that have been unappreciated. Moreover, failure to see that EDNs do not stop at operationalization can generate mistaken views about their importance throughout experimentation. For example, even Patricia Churchland, a staunch advocate of eliminative materialism, recognized the essential role of experience in the form of folk, or everyday, knowing at the start of neuroscientific experiments; and yet, that did not preclude the idea of eventually eliminating the folk term being used (Churchland 1989; Hochstein 2017).

Neuroscientific examination of behavior entails persistently negotiated decisions that happen in fly rooms,[11] in lab meetings, over coffee breaks, in seminars, during happy hours, and so on (Kohler 1994; Rheinberger 1997; Nelson 2018). However, studying behavior in order to refine one's neurobiological understanding of it also draws from a wealth of lived experiences throughout experimentation, whether by way of perspective-taking of another species, or by expressing a moment of satisfaction for testing. Even the simple and widely shared idea that it is neurobiologically meaningful to demarcate a distinction between "sleep" and "wake" reflects the fact that most scientists' lived experience suggests this distinction to be fact. Any truth about this claim derives from the researchers' lived realities, also importantly demonstrating why the guidance provided by lived experience does not render an arbitrarily constructed neurobiology: lived experience is precisely that which establishes the reasons for which such behavioral research is conducted.

As noted in Table 2, scientists' lived experience shapes research on sleep behavior throughout the empirical process of refinement in the following ways:

- Behavioral neuroscientists draw on collective and historically informed experiences to set normative constraints on what qualifies as sleep. This is done, for example, when ignoring certain models, such as *C. elegans*, and choosing others, such as *Drosophila*.
- Behavioral neuroscientists draw from their ways of historically being-in-the-world to determine the boundaries of experimentation. This includes drawing from years of experience, cultivated by both watching and engaging what has been called sleep, to decide the stopping points for the period of quiescence in fly experimentation. Alternatively, a scientist may use her lived

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[11] Examples include deciding the appropriate humidity and temperature of the fly room, when to age match flies, how to time and regulate light exposure, and so on.

experience to judge when entities are similar or different enough, the likelihood of some phenomenon occurring, or when certain pieces of information are irrelevant.

- Behavioral neuroscientists necessarily draw from their lived experience of being a human animal that sleeps in particular ways, in this way representing their own engagement with an environment, versus imagining being a different kind of entity that would engage its world differently.

EDNs do not reduce to perceptual experience alone. The way lived experience factors into experimentation also distinguishes EDNs from the theory-ladenness of observation, as well the heuristic and normative use of folk psychological concepts in experimentation (Dewhurst and Burr 2020; Hanson 1958; McGeer 2007). Empiricists who emphasize the importance of everyday experience and quality-based concepts of observability (Chang 2005) provide better resources for thinking about experience in science, yet their emphasis on sensation fails to appreciate the diversity of experience that is inextricably invoked in neuroscientific practice.[12] As demonstrated here, EDNs may or may not be localized to an individual, and the idea of experience as historically cultivated over generations of post-industrial practices may not be conceptual in nature, as in the case of the five-minute rule. Importantly, lived experience draws attention to the not—moments when certain decisions are *not* made by scientists or possibilities that are *not* considered—as a meaningful kind of experience, alongside moments of active decisions. Finally, another notable implication of EDNs centers on the unintelligibility that would emerge if one were to drop the role of lived experience throughout experimentation. As the study of sleep shows, failing to connect the neuroscientific data on sleep to some facet of lived experience—whether that be the labor-driven experience of sleep, the socially imbricated arrival of what amount of quiescence suffices for sleep, or the experience of simply knowing what kinds of things are sufficient for an explanation that is bound to those other experiences—does not generate usable information for scientists aiming to generate an explanation for sleep. In all these ways, the usage of lived experience is meant to capture the gaps that are left by thinking that further experimental processes are supposed to fill.

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[12] Paul Feyerabend also captures the failures of empiricism with respect to many ways persons can come to know science at the stages of testing, assimilating the results of a test, and understanding of theories (he mentions subliminal perception, latent learning, and posthypnotic suggestion, among others); however, he equates experience with sensory experience as opposed to working with an expanded notion as I have done here (Feyerabend 1969).

Luckily, there are philosophical resources, such as in the phenomenological tradition, that have long recognized the dilemma of trying to use science to explain experience by stripping away appeals to experience. Drawing from the work of Husserl, Heidegger, and Merleau-Ponty, Matthew Ratcliffe captures the sentiment that, “scientific accounts of the world operate with historically and culturally inherited metaphysical presuppositions which have been forgotten by scientists and philosophers” (Ratcliffe 2013, p. 70). According to Ratcliffe, it is easy for those ascribing to certain naturalistic views to obliviously “presuppose the world,” and a “sense of reality” cultivated by being-in-the-world (Ratcliffe 2013, p. 73), as is exemplified by simple acts, such as the possibility of grasping distinctions between something witnessed and something imagined as witnessed. The “sense of reality,” on which scientific practice depends, is taken for granted.

As is the case with EDNs in the study of sleep, how things matter or are significant to the researcher is intimately tied to the kinds of possibilities afforded that are not only tied to one’s phenomenology but also change with respect to interpersonal relations (Ratcliffe 2013, p. 77). These phenomenological accounts may be a more helpful resource for philosophers examining neuroscientific methodology, since thinking in terms of possibilities means recognizing alternative ways in which the researcher could move, but in fact, does not, and in many cases cannot. EDNs reveal the normative constraints set by lived experience in the study of sleep, just as lived histories orient researchers toward using specific animals as research models.

Why EDNs do not Undercut the Reliability of Sleep Data

Shifting to the language of lived experience may positively refigure discussions concerning the philosophy of neuroscience. Importantly, acknowledging the possibilities that *could* be engaged, but are instead ignored by researchers, relieves both philosophers and scientists of the worry that lived experience simply reduces to subjective experience. Recognizing that scientists invoke their embodiment and being-in-the-world when doing experimentation strengthens confidence that one’s systematically generated results are an explanation of the phenomenon relevant to the kind of being that is studying it, as opposed to fueling concerns related to bias. In other words, while a researcher can robustly draw from their subjective experiences, lived experience often minimally guides the sleep researcher by reducing what would otherwise be an infinite space of options requiring decision-making toward satisfactorily describing and predicting sleep. This point certainly merits longer discussion than what this article can allow, but what can be said here is that any concern about human bias or anthropomorphizing immediately directed at invoking such shared EDNs is one that readily devolves to a more substantial skepticism about scientific knowledge.

The talk of lived experience may also address specific impasses generated from philosophers of neuroscience finding recourse in the causal connections between scientific facts and the behavior-of-interest when those facts are, by themselves, explanatorily insufficient. For example, a recent paper by Francken et al. discusses attempts to map neural mechanisms to cognitive capacities throughout experimentation, noting that simply relying on the unfiltered, causal structure of the world for designating entities and activities is insufficient for knowing when one should split a functional kind (Francken et al. 2022, p. 9). Issues of operationalization, as well as abstracting and determining the boundaries of mechanisms, all give rise to circularities when carving up kinds (2022, p. 10).[13] Recognizing that cognitive ontologies are inevitably iterative and cyclic, these researchers echo neuroscientists' avowal that "neuroscience needs behavior" (Krakauer et al. 2017) to set the right constraints for enabling the cycles of kind-identification (2022, p. 15). Always, their solution is therefore to turn to more experiments.

The present article supports Ratcliffe's point by noting that endless circularity will be generated until such researchers recognize that the issue of kind-carving, or determining what cognitive capacities to pick out, cannot be ignored or solved with more data alone. Invoking lived experience can here make sense of the capacity later operationalized and studied. It may also provide further conceptual resources for views that have already noticed that more empirical facts are not always sufficient to explain when and why certain mechanisms are used to explain behavior (Hochstein 2019).

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[13] For example, imagine deciding when two tasks measure the same capacity: "we appeal to the sameness of underlying mechanisms, but sameness of underlying mechanisms depends on sameness of capacity, and judgments of the latter depend, as we have argued, upon how capacities are operationalized in tasks" (Francken et al 2022, p. 10).

Conclusion: Adopting a Phenomenologically Inspired Philosophy of Neuroscience

Philosophers of neuroscience and psychology have long attended to the process of experimentation and how behavioral phenomena are refined under investigation. Examples of this work include documenting the debates and efforts around operationalizing behavioral phenomena (Feest 2005), highlighting the importance of experimental tools used to theoretically advance neuroscientific study (Bickle 2016), considering how theory informs the uptake of such tools (Colaço and Robins 2023), interrogating the use of animal models or behavioral assays (Sullivan 2010; Atanasova 2014), and more.

By examining the neurobiological study of sleep, I call attention to what underwrites these processes of refining behavior and what is further needed to better explain experimentation: the lived experience of the researchers doing the research. This experience is cultivated both by researchers' engagement with science, such as one's time in the lab or time spent studying a particular model, as well as by their being-in-the-world.

The neglect of EDNs *throughout* experimentation is unlikely to have resulted from some lack of philosophical attention to neuroscientific practice or inattention to the details of experimentation. Rather, as the present article suggests and as future work should explore, the overlooking of EDNs may have been driven by adopting a misguided picture of naturalism, one that deems any appeals to lived experience as threatening the reliability of knowledge gained through neuroscientific practices. The worries flagged by Ratcliffe and insights from the present exploration of EDNs in sleep studies together invite longer conversations about the role of experience in science and persisting assumptions about scientific naturalism.

The study of sleep suggests revising some of our assumptions about experience that, in many cases, have been unwittingly onboarded by philosophers of neuroscience. Such a revision in thinking may be required to avoid missing the many aspects of lived experience that both shape experimental practice and make it the kind of data that can be acted on and applied to humans.

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