Please cite this article in press as: Mudrik et al., Taking consciousness for real: Increasing the ecological validity of the study of conscious vs. unconscious processes, Neuron (2024), https://doi.org/10.1016/j.neuron.2024.03.031

Neuron

CellPress
OPEN ACCESS

Perspective

Taking consciousness for real: Increasing the ecological validity of the study of conscious vs. unconscious processes

Liad Mudrik,[1,2,*] Rony Hirschhorn,[2] and Uri Korisky[1]
[1]School of Psychological Sciences, Tel Aviv University, Tel Aviv, Israel
[2]Sagol School of Neuroscience, Tel Aviv University, Tel Aviv, Israel
*Correspondence: mudrikli@tauex.tau.ac.il
https://doi.org/10.1016/j.neuron.2024.03.031

SUMMARY

The study of consciousness has developed well-controlled, rigorous methods for manipulating and measuring consciousness. Yet, in the process, experimental paradigms grew farther away from everyday conscious and unconscious processes, which raises the concern of ecological validity. In this review, we suggest that the field can benefit from adopting a more ecological approach, akin to other fields of cognitive science. There, this approach challenged some existing hypotheses, yielded stronger effects, and enabled new research questions. We argue that such a move is critical for studying consciousness, where experimental paradigms tend to be artificial and small effect sizes are relatively prevalent. We identify three paths for doing so—changing the stimuli and experimental settings, changing the measures, and changing the research questions themselves—and review works that have already started implementing such approaches. While acknowledging the inherent challenges, we call for increasing ecological validity in consciousness studies.

> Consciousness is a fascinating but elusive phenomenon; it is impossible to specify what it is, what it does, or why it evolved.—The International Dictionary of Psychology, p. 95.

Within less than 40 years, the question of consciousness has undergone a substantial transformation: previously considered by many as non-scientific, lying well outside the scope of any empirical investigation[1] (even a taboo word[2]), it has become a legitimate field within the cognitive sciences, with dedicated conferences and journals. The modern study of consciousness encompasses different research questions (for reviews, see LeDoux et al.,[3] Seth,[4] and Zeman[5]). Here, we focus on the following key ones: first, what are the neural bases of conscious, qualitative experiences, and how they differ from the processing of information that is not accompanied by such a qualitative experience?[6–8] Second, what, if at all, are the functions of consciousness, or—complementarily—what is the scope and depth of unconscious processing?[9–11] These questions arguably touch upon the most fundamental aspects of our existence, and some even consider them to be some of the greatest challenges neuroscience and psychology are facing (e.g., Crick[12]). This remarkable transformation from a non-scientific question to an important scientific quest was facilitated by a continuous, rigorous attempt to perfect research methodologies.

A main—and still ongoing—challenge in this quest has been to operationally define consciousness. That is, to experimentally compare between conscious and unconscious processing of the very same event while controlling for possible confounds.[13,14] In the process, highly elegant and well-controlled perceptual manipulations were developed (for reviews, see Breitmeyer[15] and Kim and Blake[16]), allowing researchers to extensively expand the horizons of empirical investigation, and substantiate a feasible and reliable research program. No less challenging was the attempt to properly measure consciousness, using both subjective and objective measures.[17,18]

However, overcoming the long-lasting skepticism toward consciousness as a legitimate subject for scientific investigation came at a cost: while attempting to refine the manipulations of consciousness, these methods grew farther away from real-life instances of conscious and unconscious percepts. This raises the question of *ecological validity*[19]: do the findings obtained using these experimental manipulations generalize to everyday situations? This is a part of the experiments' *external validity*,[20] or the degree to which the findings depend on the specific context of the study. It also jeopardizes *construct validity*,[21] as these operational definitions are arguably so distant from real-life conscious and unconscious processes, that they might fall short in capturing the phenomenon of interest. Though this issue has been widely discussed in other fields,[22,23] it has by and large been overlooked by most studies in consciousness research. Here, we argue that it is high time for consciousness researchers to adopt a more ecological approach and review some experiments that have already done so as cases in point.

Before we do, an important clarification is in order: we do not advocate for abandoning classical methods in the name of ecological validity; we see great value in such methods, given their rigorousness and high controllability. Along the same lines, we do not think that the field has already surpassed the challenges of manipulating and measuring conscious and unconscious processing;

Box 1. Challenges in adopting a more ecological approach in consciousness studies

Two main concerns are commonly raised against more ecological designs: first, they are typically more complicated to conduct. Incorporating additional measurement tools (eye-tracking or motion-tracking equipment) or using virtual/augmented reality (VR/AR) environments[24] requires technological adaptations that might not be trivial. Second, a more prominent concern focuses on the trade-off between ecological validity and experimental control.[25] Both issues are not unique to consciousness science, yet there are additional challenges that are more specific to the field.

First, the richer environments that usually characterize ecological experiments also tend to be noisier, taxiing participants with a higher processing toll compared with classical designs where an isolated stimulus is presented on screen. Such competition evoked by the richer stimulation can reduce the evoked signal.[26] This, in turn, might reduce the chances of finding reliable effects. However, in some cases, adding more "noise" to one's setup (e.g., have participants walk while being presented with visual stimuli) might actually yield stronger responses.[27]

Another unique issue involves measuring awareness. This is an ongoing challenge, which continues to evoke controversy, as the field has yet to achieve consensus about the way consciousness should be measured.[17,18] Accurately measuring awareness under more ecological designs seems even more demanding, given the non-typical tasks and experimental environments. Yet, it is doable; in the multi-trial VR IB paradigm presented in the main text, trial-by-trial objective and subjective measures of awareness were taken, and IB remained effective.[28] In fact, it might be that the greater engagement entailed by this more ecological setup is the reason the attentional manipulation worked despite participants being repeatedly probed about the IB stimuli.

VR setups suffer from an additional limitation: the presentation of the visual stimulation via the VR headset substantially changes the way the eyes typically interact with the perceived environment. Specifically, there is a mismatch between the convergence of the eyes (vergence) and the focus of vision (accommodation) while viewing an object (i.e., "accommodation vergence conflict[29]"). Thus, current VR technologies do not mimic naturalistic 3D cues, which might pose a challenge when analyzing and interpreting results. While future VR technologies could possibly solve this issue, current AR setups can circumvent it to some extent by overlaying virtual content over real-world environments (though of course, that content will suffer from the same issue).

Finally, another challenge, which is relevant to all studies using virtual stimuli, concerns the contrast between the vividness and realism of virtual stimuli and participants' knowledge that they are not, in fact, real. On the one hand, convincing extended reality (XR) setups can create a significant feeling of "presence" in participants,[30] in the sense that they believe that the stimuli presented to them are a part of the same physical reality as themselves. On the other hand, participants are aware of using an XR head-mounted display, and so even if they do not know which stimuli around them are virtual (because the illusion is so convincing), they know that *some* stimuli surely are. This could create a dissonance whose implications are not yet known. In some cases, it is actually the most realistic setups that evoke such dissonances; for example, the "uncanny valley" phenomenon in face perception was found for computer-generated avatars, where a certain level of realism creates a feeling of unease in human observers.[31] Thus, by using XR to move closer to reality, one might inadvertently create a scenario in which cognition actually dissociates from everyday life—even more so than in less ecological setups, where the differentiation between the real world and the experimental stimuli is clearer. This might be especially problematic for studies of consciousness, where the content of one's experiences is being probed. It should accordingly be taken into account when designing one's experiment.

those are still withstanding and are probably harder to address in more naturalistic studies (Box 1). Yet, we suggest that such studies—challenging as they may be—can complement the classical approaches, allowing us to expand the horizons of our investigations, and test the generalizability of findings obtained with classical methods to more ecological ones.

CURRENT METHODS IN CONSCIOUSNESS STUDIES: WHAT ARE WE REALLY PROBING?

Typically, researchers either study states of consciousness (e.g., by comparing sleep stages,[32] effects of anesthesia,[33] or disorders of consciousness[34]) or focus on the content of consciousness, mostly in the visual domain[35] (Figure 1). In the latter case, some psychophysical manipulation is used to evoke different conscious percepts (i.e., manipulate the content of consciousness) while minimizing the physical differences between the experimental conditions (ideally using the exact same physical stimulus in both conditions). For example, in binocular rivalry (BR),[36,37] a different image is projected to each eye, yielding perceptual alternations between the images. Experimentally, this is one of the cleanest contrasts: the external stimulation is constant, while only the content of perception changes. Yet does it resemble any real-life instantiation of consciousness? Though unmatched monocular images frequently occur in everyday life (e.g., due to differential occlusion to the two eyes), this rarely, if ever, leads to transitions in perceptual content[38] (for a recent attempt to create BR in more naturalistic settings, see Han et al. [39]). Indeed, some suggested that the neural mechanisms underlying BR are idiosyncratic to this specific phenomenon and might reflect perceptual decision-making more than the neural correlates of consciousness.[40]

An even clearer case is continuous flash suppression (CFS[42]); in this clever method, BR is heavily biased toward the dominant eye,[43] to which flickering, often colorful, shapes ("Mondrians") are presented. This allows researchers to suppress stimuli from awareness for long durations, which can then be used to study unconscious processing, or to track the neural correlates of consciousness by comparing conscious and unconscious processes. Notwithstanding this advantage, the ecological

Please cite this article in press as: Mudrik et al., Taking consciousness for real: Increasing the ecological validity of the study of conscious vs. unconscious processes, Neuron (2024), https://doi.org/10.1016/j.neuron.2024.03.031

CellPress
OPEN ACCESS

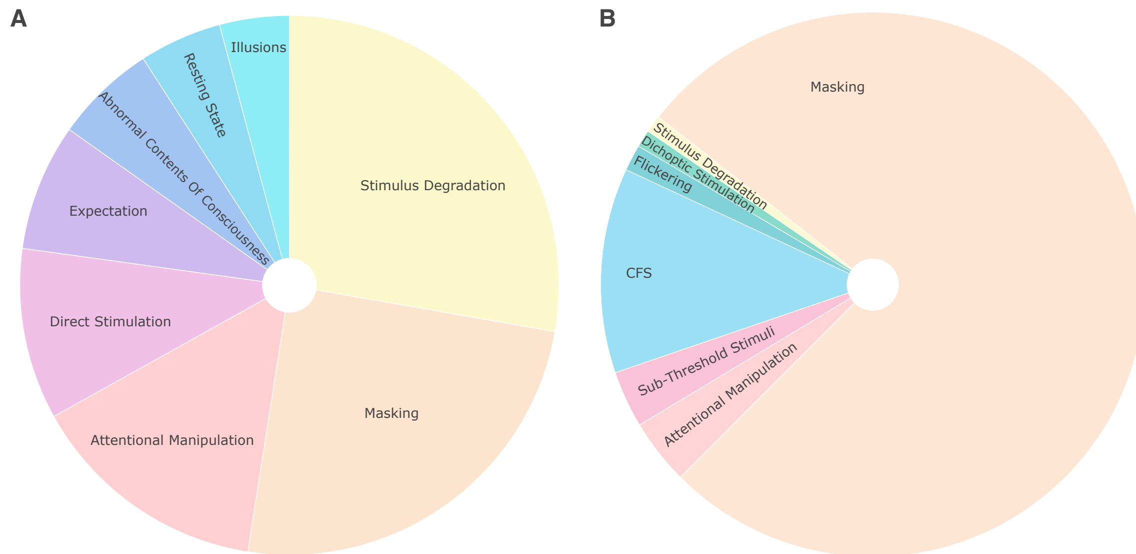

Figure 1. Surveys of current methods in the field of consciousness studies
On the left (A), a classification of methods used in 263 neuroscientific experiments manipulating the content of consciousness, whose results were interpreted in light of four theories of consciousness (taken from the ConTraSt database[41]). On the right (B), a classification of methods used in 387 behavioral experiments that examined semantic processing (*n* = 277) and attentional capture (*n* = 110) without awareness (data collected for two unpublished meta-analyses). CFS, continuous flash suppression.

validity of CFS is relatively low; it induces a highly artificial perceptual state that does not correspond to any phenomenon in the outside world. Therefore, the generalizability of its results to real-life conscious vs. unconscious processes remains open.

Similar arguments can be made about other techniques that are typically used in consciousness studies; in everyday life, we hardly ever perceive objects that appear for only a few milliseconds. No less rare are objects obscured by other inputs that immediately replace them (i.e., visual masking[44,45]). As opposed to BR or CFS, masking could potentially occur in everyday situations, but it is hardly a common phenomenon. Other methods, like stimulus degradation,[46] crowding[47] or inattentional blindness (IB),[48] are more akin to real-life occurrences of failures to consciously perceive, but the latter two are less frequently used for comparing conscious and unconscious processes (note that crowding also requires gaze contingency,[49] which again is less ecological, and IB is typically limited to a small number of trials, or even one trial only,[50] rendering it less useful for repeated measures from the same participants). Overall, one concern about many of these methods is that they might push perception to a lab-induced limit, which does not necessarily represent how these processes unfold "in the wild."[20]

Thus, participants' ability to perform various operations on stimuli suppressed using these techniques might not indicate that these abilities are indeed performed without awareness also outside the lab. For example, the ability to find edge cases where reading suppressed words is possible[51] does not necessarily mean that unconscious reading is common or that it affects behavior in everyday life (e.g., when walking or driving). To demonstrate that this is indeed the case, ecological paradigms are needed, probing real-life unconscious processes, rather than artificially induced ones. To explain why, we rely on a previously suggested analogy[52]; imagine that one studies the function of legs by temporarily paralyzing participants' legs and examining what they can do. It is plausible that participants will find a way to move in space, and we might be tempted to argue that the function of legs is not to allow locomotion in space. This would clearly be false, but this rationale is shared by many experiments: using sophisticated paradigms we can sometimes create artificial situations in which a certain function can be performed without conscious perception. However, that does not mean that this is the case also outside the lab.

Non-ecological paradigms do not only run the risk of overestimating unconscious processes by creating such artificial edge cases that do not generalize to real-life; they might also underestimate them, in the following manner: arguably, the more naturalistic the stimuli and the experimental environment, the more participants can rely on prior knowledge when processing the presented information. In that respect, classical experiments violate prior expectations: for example, by (1) presenting 2D images instead of 3D objects, with which we typically engage (though admittedly this balance is changing due to widespread usage of digital devices); (2) presenting rapidly changing stimuli that are less stable and auto-correlated than everyday experiences; or (3) simply being unimodal, as opposed to the rich, multimodal stimulation which boosts perceptual processing.[53,54] In that respect, classical experiments might fall short in capturing unconscious processes that are held by some to be less flexible[55] and hence might not easily adjust to such expectation-violating conditions.

WHY REALITY MATTERS: LESSONS LEARNED FROM OTHER FIELDS

We have argued above that the use of artificial paradigms and stimuli might jeopardize the ecological, external, and construct validity of consciousness studies. We accordingly suggest that the study of consciousness could benefit from adopting a more ecological approach. To demonstrate the potential benefits, we draw examples from similar moves in other fields.

Challenging previous claims and findings

Ecological studies sometimes yield new insights about the studied phenomenon. We demonstrate this with examples from the fields of emotion, perception, and memory. In emotion research, frontal alpha asymmetries (FAAs) are widely held to index emotional and motivational processing.[56,57] Yet, the generalizability of FAAs to real-life fear responses has recently been questioned.[58] Using virtual reality (VR), experimenters strived to create a more ecological setting that would evoke fear responses that are more natural: participants navigated inside a virtual cave, which was designed to be either frightening or neutral, using both visual and auditory stimulation. The researchers went as far as building a physical cave to provide haptic stimulation to enhance the immersion. While behavioral responses indicated highly negative emotional experiences in the negative condition, the FAA mostly failed to distinguish between the conditions (though some differences were found). The authors accordingly claimed that the FAA might not be a genuine marker of affective responses (see also Schöne et al.[59], but conversely Krogmeier et al.[60]). In the study of visual perception, a recent VR experiment presented intact, blurred, and scrambled images of people sitting on a stool, either in 2D, on a computer screen, or in 3D, in the VR environment. While the widely established face-related N170 component was found in EEG studies for the 2D stimuli, it was abolished in response to 3D ones. In this virtual condition, the researchers found only later activations that differentiated between intact faces and blurred/scrambled ones.[61] In the memory domain, new insights about the functioning of the hippocampus in memory retrieval were obtained when experimenters moved from presenting isolated, arbitrarily related items (e.g., lists of words) to more natural, richly connected stimuli (e.g., a movie).[62] While word-list studies suggested that the hippocampus is recruited for very-short-delay information retrievals, a much weaker recruitment for short delays was found compared with long delays (one day) when using a movie. Even classical textbook effects like the primacy-recency effect[63] were completely abolished when using realistic audiovisual narratives, where events are interconnected and semantically meaningful, as opposed to presenting lists of isolated words.[64] This is somewhat reminiscent of the lack of adherence to Weber's law[65] in grasping 3D, but not 2D stimuli.[66] Thus, operationalization matters, and substantially so, such that some of the most robust and widely studied effects may turn out to heavily depend on the specific experimental setting one uses, and fail to generalize to the way we process and—in this context, remember—information in real life.

Finding stronger effects

Realistic stimuli often (but not always, as demonstrated above) evoke stronger effects. Studies that compared responses to real-life, 3D objects with responses to on-screen 2D ones found that 3D objects are remembered better,[67] assigned greater value,[68,69] attract more attention,[70] and are more robust to repetition suppression[71] than 2D images. Remarkably, this higher responsiveness to 3D objects was already found in infancy.[72,73] These findings about real, tangible stimuli (for review, see Snow and Culham [23]) correspond with a long tradition of research in visual perception, emphasizing the centrality of the interaction that an organism has with its environment in shaping its perception.[74] In face processing, adding biological motion to facial stimuli yielded stronger cortical responses in face-selective areas.[75] In social neuroscience, studies showed that live interactions with another person evoke stronger neural responses than watching a video of the same interaction.[76] Taken together, these findings suggest that using more naturalistic setups can indeed evoke stronger signals and, accordingly, more robust effects.

Enabling new questions

Ecological designs can also facilitate asking new questions. For example, the study of inter-subject synchronization, which has yielded many insights about communication efficiency,[77] narrative processing,[78] and memory (especially in the context of event boundaries[79]) was driven by using more naturalistic stimuli (e.g., replacing isolated stimuli with full movie scenes,[80] narrated sections,[78] and even real-life conversations[77]). These allowed researchers to look into naturalistic responses to continuous, meaningful events, taking into account context and expectations, often also integrating across more than one modality.[80] In addition, using natural speech revealed intricate patterns of semantic mapping,[81] enabling new questions about the effect of context on semantic processing and sentence comprehension. Along the same lines, the influential idea of neural entrainment as a crucial mechanism for controlling sensory gain,[82] especially in the context of speech processing,[83] could not have been established without presenting natural speech stimuli, as opposed to isolated words or written sentences. Drawing from a closer field, the study of the concept of self has substantially benefited from introducing ecological designs. New types of illusions were found (e.g., transfer of full-body ownership[84] and body swapping[85]), highlighting the role of bottom-up sensory signals in construing a self-model and a sense of ownership, and differentiating between the contributions of first and third-person perspectives.[86] Similarly, questions about the sense of reality seem much harder to study with classical methods, as the latter are substantially less potent than VR setups in directly manipulating changes in perceived reality to test how these changes are processed.[87]

"ECOLOGIZING" THE FIELD OF CONSCIOUSNESS

Extrapolating from the above examples to the field of consciousness, we argue that introducing a more ecological, naturalistic approach holds the potential for obtaining stronger effects, widening our understanding of consciousness, and possibly revising some of the accepted views about its function and underlying neural mechanisms. Below, we propose three ways for ecologizing the study of consciousness: ecologizing the experimental materials, the measures, and even the research questions. We describe studies that have already adopted this approach and discuss the potential advantages to the field. Notably, these suggestions are orthogonal to each other, and

CellPress
OPEN ACCESS

each varies in its closeness to real-life; a study can use more ecological stimuli with a non-ecological paradigm (e.g., present real-life objects under CFS[88]), or use more ecological measures which rely on naturalistic behaviors with non-ecological stimuli (e.g., tracking 3D-motion trajectory toward 2D images[89,90]); we argue that in either case, moving up the ecological ladder introduces new opportunities and advantages in the study of consciousness.

Changing the stimuli and the experimental environment

Although still the exception rather than the rule, several lines of research have already opted for more ecological stimuli and paradigms, to different degrees. At one end of this continuum are studies that replaced isolated, artificial stimuli with more complex and natural ones; for example, studying the unconscious processing (or lack thereof) of real-life scenes (Figure 2A),[91–94] biological motion (Figure 2B),[95] movement trajectories,[96] or causal relations.[97] These studies better delineated the limits of unconscious integration of information,[98,99] which in turn bears implications for theories of consciousness that assume some relations between consciousness and integration.[100,101] Going beyond the visual modality, some studies better mimic the multifaceted (and multimodal) everyday conscious experience by using multisensory stimulation. Such studies vary in their degree of naturalness, ranging from explorations of the interplay between visual stimuli and bodily sensations or proprioception[102,103] to more natural designs, using real, full-body movement (Figure 2C).[104] In the latter case, participants were seated in a rotating chair, which provided whole body, vestibular stimulation around the yaw axis. At the same time, using VR, an optic flow stimulus was presented under CFS, whose direction was either congruent or incongruent with the vestibular stimulation. Congruent stimuli broke suppression faster than incongruent ones, suggesting that visuovestibular integration facilitates access to awareness. A somewhat different result was found in a study where participants interacted with a cog, making it rotate other, connected cogs.[105] The rotation of the rightmost cog was either controlled by the participants (by rotating the leftmost cog) or not and was either congruent with the direction of the leftmost cog or not. A virtual object was presented on the rightmost cog using augmented reality (AR) goggles and suppressed with CFS. The authors found that controllability, rather than congruency, affected suppression times. Most importantly for the present context, both of these studies demonstrate how using richer sensory stimulation allows researchers to ask new questions about consciousness, and—in these cases—its interplay with action[106,107] (for another study using VR to probe the interaction between action and conscious perception, see Vasser et al.[108]).

A promising paradigm for doing so is the recently developed "real-life" CFS paradigm (Figure 2D).[88] This paradigm also uses AR, but presents the CFS Mondrians to the dominant eye in one goggle, while the other goggle receives no stimulation. This allows the non-dominant eye to naturally view the external world, without the participant being aware of the viewed information. This method can accordingly suppress real-life, 3D objects, and even body parts or the face of an experimenter standing in front of the participant. This technique was recently used to demonstrate that real-life objects emerge into awareness faster than their 2D image representations, but—critically—only when meaningful, rather than scrambled.[114] This suggests an important role for affordances in facilitating access to consciousness and opens the gate to testing the effects of action on perception as well as the potential independence of the two.[115]

In all the above paradigms, either the stimuli or the experimental environment was naturalistic, but the method used to render these stimuli invisible was highly artificial. Another line of studies renders the manipulations of awareness more ecological, mostly relying on attentional mechanisms. Arguably, in everyday life, attention plays a crucial role in selecting which stimuli will be consciously perceived (though notably, some theories of consciousness hold attentional selection to be a post-perceptual process, such that phenomenal consciousness does not depend on attention[116]). Under this framework, all attention-based manipulations of consciousness are more ecological than other methods, which typically rest on synthetic psychophysical phenomena. Yet, even within these paradigms, some studies are more ecological than others. For example, one study showed that IB actually decreases in VR settings.[117] Others went further and demonstrated IB in the wild: participants walking down the street while talking or texting over the phone were less likely to detect money on a tree[118] or a unicycling clown[111] on their path (Figure 2E). Perhaps more worrisome and relevant to real-life situations, another study found that 33% of trained cops and 50% of police academy trainees missed a clearly visible gun placed on the dashboard in a simulated vehicle traffic stop (Figure 2E).[110] Similarly, most participants who were running after a confederate missed a fight between two other confederates.[119]

These studies reinforce the ecological validity of the IB paradigm, showing that it also occurs in everyday life (thereby also strengthening its external validity). Nevertheless, they do not reveal something new about consciousness or about the IB phenomenon. Recently, in-lab ecological versions of attentional manipulations have been utilized for that purpose; for example, a video-game variant of IB is now being used to arbitrate between theories of consciousness in an adversarial collaboration.[120] Also, recently, a multi-trial IB VR paradigm has been introduced, which potently suppresses lifelike stimuli (specifically, ads presented on billboards) from awareness over and over again, despite participants being asked to provide both objective and subjective awareness measures at the end of each trial (Figure 2F).[28]

Another striking example of a VR attentional manipulation paradigm has used change blindness. There, participants freely viewed naturalistic videos, which at some point were gradually degraded in a gaze-contingent manner such that much of the periphery of the visual field was desaturated (Figure 2G).[112] The results showed that even when only the central 10° of the stimulation remained colored, almost a third of participants failed to perceive the change and were strongly surprised to learn it occurred. Here, the free viewing of the videos, allowed by the VR environment, yielded very strong results that pushed change blindness to a new limit.

Notably, using more naturalistic stimuli and environments does not only benefit studies that focus on the content of consciousness or its characteristics, but also presents exciting opportunities for studying states of consciousness, and for testing for consciousness[121] (e.g., in non-responsive patients). The

Please cite this article in press as: Mudrik et al., Taking consciousness for real: Increasing the ecological validity of the study of conscious vs. unconscious processes, Neuron (2024), https://doi.org/10.1016/j.neuron.2024.03.031

Figure 2. Examples of ecological stimuli

(A) Natural scenes with objects substituted to create violations of semantic expectations. Adapted from Shir et al.[109]

(B) Biological motion cues presented by point-light walkers, suppressed using CFS, left: timeline of a single trial, right: illustration of male (blue) and female (red) stimuli, differing in their structural and motion properties. Adapted from Faivre and Koch. [95]

(C) Vestibular cues facilitating emergence into awareness of congruent suppressed visual motion cues, left: image of a participant sitting in a chair that rotates, right: CFS presentation of motion cues. Adapted from Salomon et al.[104]

(D) "Real-life" CFS allows to suppress real, 3D objects from awareness, left: illustration of the setup, top-right: timeline of a single trial, from the point of view of the participant, bottom-right: examples of 3D-printed stimuli depicting objects (left) and their scrambled versions (right). Adapted from Korisky et al.[88]

(E) Inattentional blindness in the real world. Left: participants failed to notice a gun in full view on a driver's dashboard. Adapted from Simons and Schlosser.[110] Right: participants failed to notice a unicycling clown despite crossing their path. Adapted from Hyman et al.[111]

(F) A multi-trial inattentional blindness VR paradigm. The participant is riding a bus through a street while following one of three moving bees (circled here for illustration purposes). Billboards in the background and on the bus stations show intact and scrambled stimuli. Adapted from Hirschhorn et al.[28]

(G) A demonstration of limited awareness of color in the periphery using immersive 360° videos. Left: visualizations of displays presented to participants in two eccentricities of color desaturation in the periphery, right: awareness to color desaturation across participants. Adapted from Cohen et al.[112]

(H) Decoding conscious perception of natural stimuli (movies) in unresponsive patients based on neural responses of healthy participants. Left: movie frames with high between-participants agreement on being suspenseful, right: visualization of selected ICA components from the healthy participants (top row), and their expression in two patients (two bottom rows), showing the degree of synchrony between neural responses of the single patient and the group. Adapted from Naci et al.[113]

underlying rationale is simple; present stimuli that humans typically encounter in everyday lives and look for a similar neural response to these stimuli, in healthy participants and clinical patients. This was done with non-responsive patients, who freely viewed (or listened to) a suspenseful movie while their brain activations were recorded using fMRI (Figure 2H). In some patients,

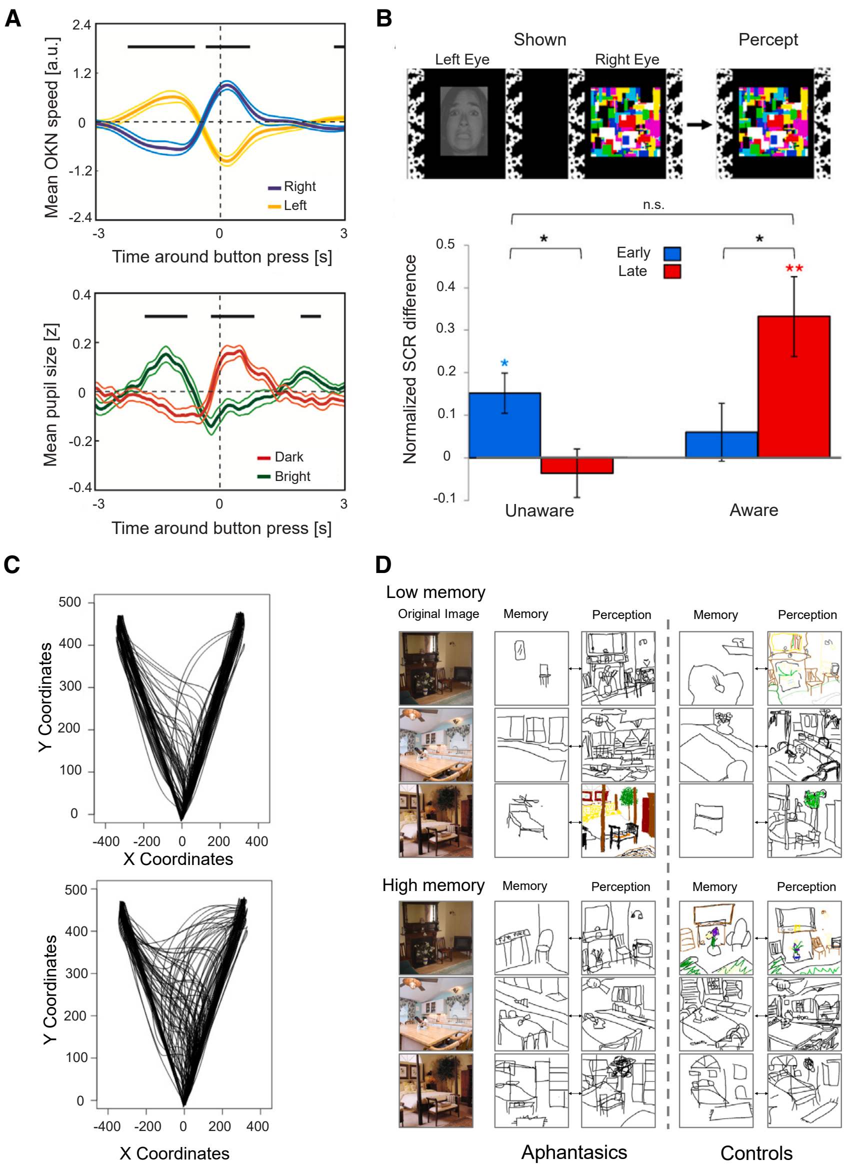

Figure 3. Examples of more ecological measures for consciousness studies

(A) Eye-tracking measures reveal the effect of binocular rivalry, both by the average OKN speed (top) and the average pupil size (bottom). Adapted from Frässle et al.[126]

(B) SCR measurements demonstrate unconscious fear conditioning. Top: experimental paradigm. Participants were presented with visible/invisible fearful faces, either coupled with a shock (CS+) or not (CS−). Bottom: a difference in SCRs between CS+ and CS− was found during unconscious processing in the early (first half, blue) part of the experiment, while for conscious processing, the effect was found during the late (second half, red) part. Adapted from Raio et al.[132]

(C) Motion tracking suggests differential reaching trajectories for a condition where the prime and target were congruent (top) as opposed to incongruent (bottom). As can be seen, trajectories in the former case are more distant and direct than in the latter condition. Adapted from Finkbeiner and Friedman.[89]

(D) Drawing as a report method reveals recall differences between aphantasic and control groups. Participants were asked to draw an image either from memory or while it was presented. In the figure are examples of drawings made by individual participants (rows) in each condition, demonstrating a differential amount of detail both between conditions and also between aphantasics and controls in the recall condition, especially for images that were more extensively described (high memory). Adapted from Bainbridge et al.[133]

the neural patterns closely resembled those of healthy participants, suggesting that they were indeed conscious of the presented content. It is precisely due to the complex nature of these narrative-bearing stimuli that these activations seem less likely to be explained simply by automated, unconscious responses.[122] Using a different modality, researchers tested for consciousness by presenting aversive (rotten fish) and pleasant (shampoo) odorants and looking for the typical sniffing response, which proved to be highly predictive of subsequent awakening.[123]

Changing the measures

Similar to most studies in cognitive sciences, the vast majority of behavioral studies of consciousness restrict participants' responses to simple selections between categories using single button presses.[124] These responses, and the metrics typically derived from them (e.g., reaction time and accuracy), limit the amount of information researchers can extract about participants' percepts, and, in the current context, they are also less natural in the sense that they require learning task-specific response associations.

Several alternatives exist, typically relying on more natural responses. Such responses also enjoy the benefits of being time-resolved and of higher dimensionality; this, in turn, can also potentially elevate their sensitivity to more subtle effects that unfold over time. Alternatively, they can eliminate confounds that stem from intentional responses. Here, we give some examples of such measures. First, eye movements have been used to replace participants' reports of their experience.[125] A seminal study used optokinetic nystagmus (OKN) to detect perceptual switches during a no-report BR (Figure 3A).[126] The results showed that the widespread frontoparietal activity found during active report almost completely vanishes in the OKN condition, in the absence of such report. Others have used gaze tracking to unravel unconscious processes in different ways[127]. Much like in other studies, the eye-tracking measures are considered indirect evidence for processing, in contrast to direct measures of awareness whereby participants report not perceiving the stimuli, and/or are unable to perform an explicit judgment about them.[128] One study presented two orthogonally drifting gratings to the two eyes in a BR paradigm, so participants only perceived one of them. They found that reflexive eye movements were influenced by the drift of the suppressed grating, a phenomenon referred to as "tracking without perceiving."[129] Another study focused on the sensitivity of eye movements to subliminal distractors, reporting small yet significant effects on saccade characteristics.[130] Finally, other studies focused on higher-level functions; in one such study, pupil dilation was used as an index of strategic processes evoked by reward cues, showing that such processes indeed take place even when the reward cues were masked, but only when the reward was given in the context of a mentally demanding task.[131]

A second alternative is skin conductance responses (SCRs),[134] a naturally occurring response that has been extensively used in psychological research and, in the current context, can also serve as indirect evidence for unconscious processes. SCR was mostly used to study unconscious emotional processing.[135–137] For example, one study used SCR to examine fear acquisition without awareness (Figure 3B).[132] The researchers used CFS to present participants with either visible or invisible faces, half of which were paired with a shock. Intriguingly, the SCR patterns suggested that the fear response was acquired faster in the invisible condition but was also faster to decline. Using such measures also allows extending the investigation toward earlier stages of the developmental axes; for example, one study presented subliminal emotional primes to 3-to 4-month-old infants and found an increased SCR to angry faces.[138]

Third, reaching responses and motion tracking provide further means to track conscious and unconscious processing as they unfold, while allowing participants to interact more naturally with the presented stimuli. Here, one may draw inspiration from the landmark works with patients,[139,140] and later with healthy participants,[141] substantiating the functional dissociation between the dorsal and the ventral visual streams.[142,143] In these cases, the reaching and grasping tasks allowed researchers to reveal the differential performance for action vs. perception (e.g., following a ventral lesion, in the case of patient D.F.[139,140]). A handful of studies also used reaching responses to probe unconscious priming[89,90] (Figure 3C). In one of them, participants were presented with supraliminal targets (images, letters, and digits) preceded by congruent/incongruent subliminal primes and were asked to classify them into categories (e.g., people/animals or letters/digits) using a reaching response. The results indicated a difference between the conditions and revealed its time course, emerging earlier for repeated as opposed to novel primes.[89] Another study directly compared reaching trajectories (though using a mouse rather than free reaching) and keyboard presses for number priming, reporting the former to yield stronger effects than the latter.[144]

Fourth, some researchers replaced traditional selection tasks with more natural forms of description:[124] free drawings have been used to characterize perceptual changes evoked by crowding[145] or to quantify aphantasia (Figure 3D).[133] Others used free reports, and first- and second-person interviewing tools, to characterize structures of experience.[146,147] A more recent formulation of that approach suggests that consciousness should be studied using micro-phenomenological interviews aimed at unraveling the pre-reflexive structures of experience.[148] Finally, metrics based on freely reported lists of words have also been suggested as means to characterize experience,[149,150] but later criticized.[151] Notably though, these alternative reporting techniques present new challenges, as the data are highly prone to subjective interpretation, and standardization and replicability are not trivial. Thus, more research is needed to develop new means of reporting that might expand our understanding of conscious experience.

Changing the research questions

Perhaps the most exciting—yet arguably most challenging—means to increase the ecological, external, and construct validity of consciousness studies is to change the research questions, pushing them closer to everyday phenomena. In some cases, old questions are simply reformulated using a more naturalistic approach. In other cases, the questions themselves are novel. For both, as we demonstrate below, mimicking everyday situations can change the findings and the ensuing conclusions. We first focus on phenomenal consciousness, then examine studies targeting the neural correlates of consciousness, and finally, we extend our scope toward the question of free will and the role of consciousness in voluntary actions. We argue that these case studies from different subfields of the study of consciousness demonstrate how the field can benefit and develop by taking a more ecological approach.

The first case study focuses on the dissociation suggested by the philosopher Ned Block, according to which the concept of consciousness conflates two different phenomena: access consciousness—our ability to report and cognitively operate on the content of our experience—and phenomenal consciousness, referring to the "what it is like" to have that experience.[152] Thus far, empirical evidence supporting this dissociation has been using paradigms that were mostly based on memory tasks, where participants failed to accurately recall all the items in a given display, yet were able to extract the information when cued (for an overview, see again Haun et al.[124]). This was taken as evidence of them experiencing more than they can report. Importantly though, these experiments only provided *indirect* evidence for a dissociation between phenomenal and access consciousness. Direct evidence seemed hard to obtain given the need to rely on access consciousness to probe phenomenal consciousness.

Yet, recently, such direct evidence has been suggested, in an experiment aimed at mimicking the everyday phenomenon of noise adaptation, when we are unaware of noises in our environment (e.g., the humming sound of a refrigerator), yet become aware of them when they stop. This example, which draws its strength from one's familiarity with this common real-life experience, is often given to motivate the claim that phenomenal consciousness can occur even without access.[152] However, it has never been systematically tested or demonstrated empirically. Thus, instead of asking if we can find evidence for the ability to retrospectively access information that participants failed to report by relying on memory processes, this study presented a different research question: can we get participants to deny having an experience in real time, while later realizing that they in fact had this experience, and even knowing how it felt. To do that, overlayed, naturalistic everyday sounds (e.g., a baby laughing and dogs barking) were presented and gradually turned off,

CellPress
OPEN ACCESS

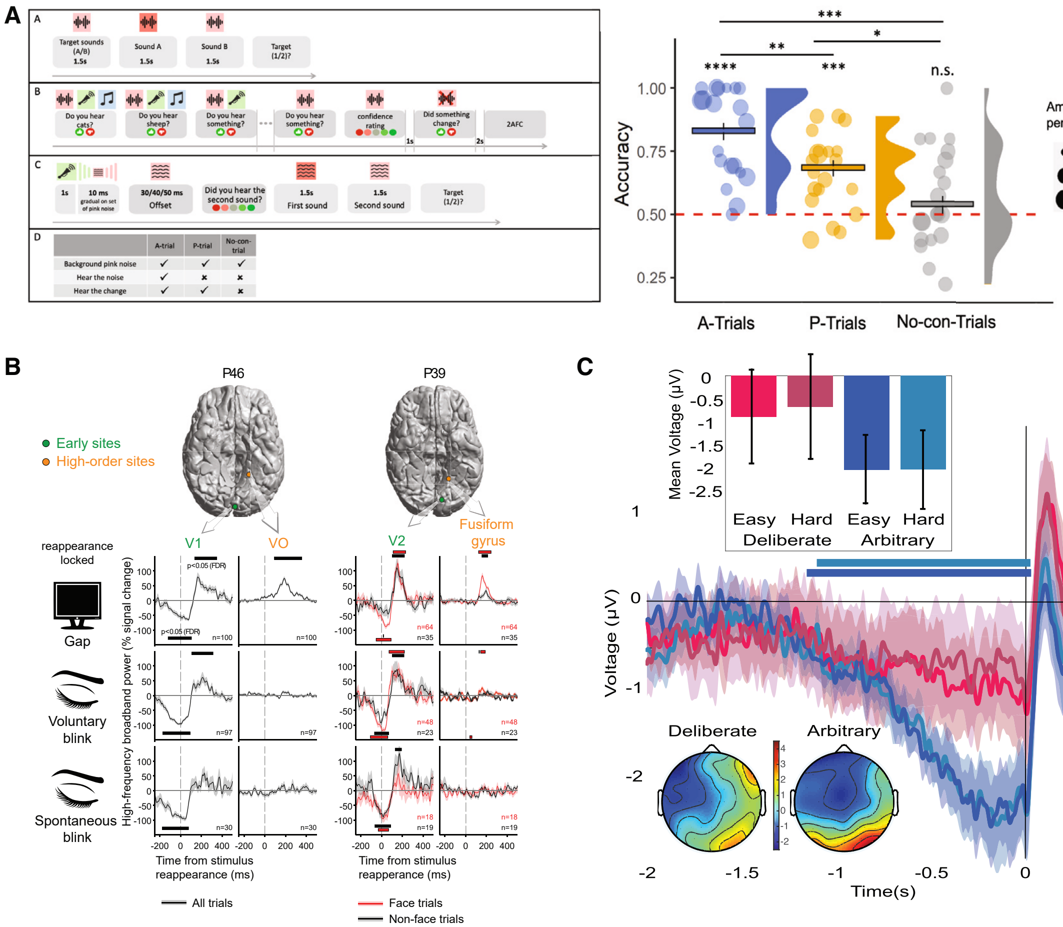

Figure 4. Ecological studies in consciousness enabling new questions

(A) Phenomenal awareness without access. Left: the experimental design in the different conditions of the study. The critical one appears in the second row: an ongoing pink noise is presented alongside multiple sounds, which gradually disappear until only the noise remains. Participants are then asked whether they hear anything. Then, the noise stops, and participants are asked whether they heard the change and are requested to detect which of two sounds were presented. The table in the bottom row shows the different types of trials, based on participants' responses. Access trials are those where participants noticed the noise when asked. Phenomenal trials are those where they denied hearing the sound in real time but noticed the change. No-consciousness trials are those where they denied hearing the stimulus and did not notice the change. Right: accuracy in retrospectively identifying the background noise for access trials (left), phenomenal trials (middle), and no consciousness (right). Adapted from Amir et al.[153]

(B) Detecting brain areas that track the physical stimulus vs. its conscious percept using blinks. Deconvolved high-frequency broadband responses from two patients with intracranial electrodes (columns). Responses shown to differentiate early sites (left sub-columns, green) from high-order sites (right sub-columns, yellow) when the content of consciousness differs from the physical stimulus (voluntary or spontaneous blinks, two bottom rows), but not when gaps are introduced to the visual stimulus itself (top row). Adapted from Golan et al.[154]

(C) The diminishing of the readiness potential (RP) for deliberate, non-arbitrary decisions. Middle: time course of deliberate (red shades) and arbitrary (blue shades) easy and hard decisions in electrode Cz; Top inset: mean voltage of the RP for the time bin [−0.5, 0] before response; Bottom inset: typical scalp distributions. Notably, the RP significantly differs from zero and displays a typical scalp distribution for arbitrary decisions only. Adapted from Maoz et al.[155]

upon recognition by the participants (Figure 4A).[153] In some trials, a constant background noise (a pink noise, mimicking the refrigerator hum) was introduced as well until it stopped. Some participants, in some trials, reported not hearing the background noise as it was playing alone but could notice when it stopped and were highly above chance at retrospectively identifying it in a two-alternatives forced choice task. Thus, by mimicking an everyday phenomenon, this study was able to directly demonstrate a retrospective phenomenal experience, to which participants had no access in real time.

The second case study where the research question was reformulated in a more ecological manner comes from the search for the neural correlates of consciousness. Typically, researchers look for these correlates by comparing brain activity evoked by a stimulus presented such that it is either consciously perceived or not. Yet here, the researchers capitalized on a phenomenon that repeatedly occurs during a typical day—blinking. In a highly elegant design, they compared naturally occurring blinks with external blanks that were added to the stimulus, matching the durations of the blinks (Figure 4B).[154] The researchers reasoned that during the blinks, the external stimulation is *de facto* blocked, as the eyes are closed, but conscious perception continues. When external blanks are introduced, on the other hand, conscious perception also halts. This contrast allowed to detect areas that track the stimulation (e.g., the primary visual area, V1) as opposed to those that track conscious experience (e.g., category-selective areas).

Similarly, the ample research conducted on sleep, and especially on dreaming, also assumes that nature provides the perfect contrast between a vivid conscious experience and an absence of external stimulation.[156] Arguably, using dreaming as a model system of consciousness circumvents the issue of distilling conscious experience from task-related processes, as no such task is involved, and from stimulus-evoked activations, as no external stimulation is presented. In one study, high-density EEG was used to monitor the brain activity of sleeping participants, who were periodically woken up and interviewed during both rapid eye movement (REM) and non-rapid eye movement (NREM) sleep epochs.[157] Specific dream contents were correlated with high-frequency EEG activity in cortical areas that are involved in the processing of similar content during wakefulness, suggesting that they are involved in conscious content irrespective of external stimulation. In addition, dream-sleep was associated with decreased low-band (1–4 Hz) activity and increased high-frequency activity in posterior areas (but see Wong et al.[158]). Sleep studies also tested for unconscious processing,[159–161] although there, the ecological approach does not quite pertain to the research question itself, but to the means by which the stimuli are presented such that they will not be consciously perceived, along the lines of the first section above.

Finally, the third example we describe here involves the debate around free will, which has evolved, to a great extent, around the seminal work by Benjamin Libet, demonstrating that the conscious urge to move is preceded by a readiness potential, held to index the unconscious decision to move.[162] Though this result has been extensively replicated,[163] it has almost exclusively been studied in the context of arbitrary, meaningless, and highly artificial decisions: participants were asked to move whenever they felt the urge to do so, with no reason to motivate them. In everyday life, we rarely make such movements or feel the urge to move for no reason (though we do make arbitrary decisions, such as picking one milk carton out of a row of identical ones, we do not wait for a conscious urge to move our hand with no reason, like in the Libet paradigm). Indeed, when a study tested the generalizability of the Libet results to meaningful, real-life decisions (a monetary donation to one of two non-profit organizations), no evidence was found for the readiness potential in such decisions, as opposed to arbitrary ones, where the classical effect was replicated (Figure 4C).[155] Here, moving one's focus to meaningful, real-life decisions substantially changed the obtained results, again demonstrating the importance of using ecological designs (or, to the very least, testing the generalizability of less ecological findings; see, for example, an attempt to do so for the Trolley dilemma, using VR[164]).

CONCLUSIONS

Consciousness is, indeed, a fascinating but elusive phenomenon. It is extremely difficult to study, yet so fundamental to our existence, that we keep looking for new ways to do so. Here, we argue that the time has come for us to look for methodologies that are not only well-controlled and experimentally elegant, but also those that aspire to mimic everyday conscious and unconscious processes. Changing the stimuli and the experimental environment, exploring more natural measures, and revising the questions we ask promise to unravel new truths about conscious and unconscious processes, and, hopefully, also yield more robust effects (which is much needed specifically when studying unconscious processes, as the effects are typically weak and short lived.[165]). Admittedly, adopting a more ecological approach is not simple and entails some challenges and methodological hurdles. Some of those are especially dire when it comes to consciousness studies (Box 1), yet they can be overcome.

Future experimentation can go beyond current efforts in many ways, and here, the sky really is the limit: drawing from clinical psychology studies, ecological momentary assessment (EMA)[166] tools might be used to track the richness and contents of perception as it unfolds in real-life, using mobile reporting applications. Utilizing new technologies, natural viewing patterns while participants are interacting with screens as part of their daily lives can be leveraged to better examine the role of attention in gating access to awareness. In addition, with current developments in artificial intelligence, being able to use neural activity to decode the content of perception, and even of naturally occurring unconscious representations,[167] paves the way for new types of no-report paradigms. These paradigms would rely on such natural responses, as opposed to task-induced ones, or incorporate technologies that allow for more naturalistic setups to begin with, such as mobile EEG, eye-tracking devices, or fMRI-compatible VR.[168] These are only a few examples of how consciousness studies can become more ecological. It is time to get real.

ACKNOWLEDGMENTS

L.M. is CIFAR Tanenbaum Fellow in the Brain, Mind, and Consciousness program. This work was supported by the European Research Council (ERC) (grant number: 101077144). Views and opinions expressed here are however those of the authors only and do not necessarily reflect those of the European Union or the ERCEA. Neither the European Union nor the ERCEA can be held responsible for them. R.H. is supported by the Milner Foundations, founded by Yuri Milner and his wife Julia. We are extremely grateful for the excellent comments we received on this manuscript from Nathan Faivre, Shai Fischer, Jason Freidman, Sofia Karageorgiou, Uri Maoz, Niccolo Negro, Maor Schreiber, Roy Salomon, Yarden Shir, François Stockart, Amir Tal, and Itay Yaron. Their input was invaluable and has substantially improved this work. We further thank the Minerva Center for Human Intelligence in immersive, augmented and mixed Realities, where many of the ideas described here were formed.

AUTHOR CONTRIBUTIONS

Conceptualization: L.M., R.H., and U.K.; writing – original draft: L.M., R.H., and U.K.; writing – review & editing: L.M., R.H., and U.K.; visualization: R.H. and U.K.; supervision: L.M.; funding acquisition: L.M.

DECLARATION OF INTERESTS

The authors declare no competing interests.

REFERENCES

1. Sutherland, N.S. (1989). The international dictionary of psychology (Continuum).

2. Tulving, E. (1997). FACT: the First Axiom of Consciousness and Thought. In Mind and Brain Sciences in the 21st Century, R.L. Solso, ed. (MIT Press), pp. 51–67. https://doi.org/10.7551/mitpress/4619.003.0007.

3. LeDoux, J.E., Michel, M., and Lau, H. (2020). A little history goes a long way toward understanding why we study consciousness the way we do today. Proc. Natl. Acad. Sci. USA *117*, 6976–6984. https://doi.org/10.1073/pnas.1921623117.

4. Seth, A.K. (2018). Consciousness: The last 50 years (and the next). Brain Neurosci. Adv. *2*, 2398212818816019. https://doi.org/10.1177/2398212818816019.

5. Zeman, A. (2002). Consciousness: a user's guide (Yale University Press).

6. Crick, F., and Koch, C. (2003). A framework for consciousness. Nat. Neurosci. *6*, 119–126. https://doi.org/10.1038/nn0203-119.

7. Koch, C., Massimini, M., Boly, M., and Tononi, G. (2016). Neural correlates of consciousness: progress and problems. Nat. Rev. Neurosci. *17*, 307–321. https://doi.org/10.1038/nrn.2016.22.

8. Dehaene, S., and Changeux, J.P. (2011). Experimental and theoretical approaches to conscious processing. Neuron *70*, 200–227. https://doi.org/10.1016/j.neuron.2011.03.018.

9. Kouider, S., and Dehaene, S. (2007). Levels of processing during non-conscious perception: a critical review of visual masking. Philos. Trans. R. Soc. Lond. B Biol. Sci. *362*, 857–875. https://doi.org/10.1098/rstb.2007.2093.

10. Mudrik, L., and Deouell, L.Y. (2022). Neuroscientific evidence for processing without awareness. Annu. Rev. Neurosci. *45*, 403–423. https://doi.org/10.1146/annurev-neuro-110920-033151.

11. van Gaal, S., and Lamme, V.A.F. (2012). Unconscious High-Level Information Processing: Implication for Neurobiological Theories of Consciousness. Neuroscientist *18*, 287–301. https://doi.org/10.1177/1073858411404079.

12. Crick, F.H.C. (1994). The astonishing hypothesis: the scientific search for the soul (C. Scribner).

13. Aru, J., Bachmann, T., Singer, W., and Melloni, L. (2012). Distilling the neural correlates of consciousness. Neurosci. Biobehav. Rev. *36*, 737–746. https://doi.org/10.1016/j.neubiorev.2011.12.003.

14. De Graaf, T.A., Hsieh, P.-J., and Sack, A.T. (2012). The 'correlates' in neural correlates of consciousness. Neurosci. Biobehav. Rev. *36*, 191–197. https://doi.org/10.1016/j.neubiorev.2011.05.012.

15. Breitmeyer, B.G. (2015). Psychophysical "blinding" methods reveal a functional hierarchy of unconscious visual processing. Conscious cogn *35*, 234–250. https://doi.org/10.1016/j.concog.2015.01.012.

16. Kim, C.-Y., and Blake, R. (2005). Psychophysical magic: rendering the visible 'invisible. Trends Cogn Sci *9*, 381–388. https://doi.org/10.1016/j.tics.2005.06.012.

17. Dienes, Z., and Seth, A.K. (2010). Measuring any conscious content versus measuring the relevant conscious content: comment on Sandberg et al. Conscious. Cogn. *19*, 1079–1083. https://doi.org/10.1016/j.concog.2010.03.009.

18. Reingold, E.M., and Merikle, P.M. (1988). Using direct and indirect measures to study perception without awareness. Percept. Psychophys. *44*, 563–575. https://doi.org/10.3758/bf03207490.

19. Schmuckler, M.A. (2001). What is ecological validity? A dimensional analysis. Infancy *2*, 419–436. https://doi.org/10.1207/S15327078IN0204_02.

20. Bracht, G.H., and Glass, G.V. (1968). The external validity of experiments. Am. Educ. Res. J. *5*, 437–474. https://doi.org/10.3102/00028312005004437.

21. Cronbach, L.J., and Meehl, P.E. (1955). Construct validity in psychological tests. Psychol. Bull. *52*, 281–302. https://doi.org/10.1037/h0040957.

22. Shamay-Tsoory, S.G., and Mendelsohn, A. (2019). Real-life neuroscience: an ecological approach to brain and behavior research. Perspect. Psychol. Sci. *14*, 841–859. https://doi.org/10.1177/1745691619856350.

23. Snow, J.C., and Culham, J.C. (2021). The treachery of images: how realism influences brain and behavior. Trends Cogn. Sci. *25*, 506–519. https://doi.org/10.1016/j.tics.2021.02.008.

24. Pan, X., and Hamilton, A.F.C. (2018). Why and how to use virtual reality to study human social interaction: The challenges of exploring a new research landscape. Br. J. Psychol. *109*, 395–417. https://doi.org/10.1111/bjop.12290.

25. Hasson, U., Nastase, S.A., and Goldstein, A. (2020). Direct fit to nature: an evolutionary perspective on biological and artificial neural networks. Neuron *105*, 416–434. https://doi.org/10.1016/j.neuron.2019.12.002.

26. Kastner, S., De Weerd, P., Desimone, R., and Ungerleider, L.G. (1998). Mechanisms of directed attention in the human extrastriate cortex as revealed by functional MRI. Science *282*, 108–111.

27. Cao, L., and Händel, B. (2019). Walking enhances peripheral visual processing in humans. PLoS Biol. *17*, e3000511. https://doi.org/10.1371/journal.pbio.3000511.

28. Hirschhorn, R., Biderman, D., Biderman, N., Yaron, I., Bennett, R., Plotnik, M., and Murdrik, L. (2024). Using virtual reality to induce multi-trial inattentional blindness despite trial-by-trial measures of awareness. Behav Res Methods. https://doi.org/10.3758/s13428-024-02401-8.

29. Cakmakci, O., and Rolland, J. (2006). Head-worn displays: a review. J. Disp. Technol. *2*, 199–216. https://doi.org/10.1109/JDT.2006.879846.

30. Suzuki, K., Mariola, A., Schwartzman, D.J., and Seth, A.K. (2023). Using extended reality to study the experience of presence. Curr Top Behav Neurosci. *65*, 255–285. https://doi.org/10.1007/7854_2022_401.

31. Mori, M., MacDorman, K.F., and Kageki, N. (2012). The uncanny valley [from the field]. IEEE Robot. Automat. Mag. *19*, 98–100. https://doi.org/10.1109/MRA.2012.2192811.

32. Nir, Y., Massimini, M., Boly, M., and Tononi, G. (2013). Sleep and consciousness. In Neuroimaging of consciousness, A. Cavanna, A. Nani, H. Blumenfeld, and S. Laureys, eds., pp. 133–182. https://doi.org/10.1007/978-3-642-37580-4_9.

33. Alkire, M.T., Hudetz, A.G., and Tononi, G. (2008). Consciousness and anesthesia. Science *322*, 876–880. https://doi.org/10.1126/science.1149213.

34. Bruno, M.A., Vanhaudenhuyse, A., Thibaut, A., Moonen, G., and Laureys, S. (2011). From unresponsive wakefulness to minimally conscious PLUS and functional locked-in syndromes: recent advances in our understanding of disorders of consciousness. J. Neurol. *258*, 1373–1384. https://doi.org/10.1007/s00415-011-6114-x.

35. Faivre, N., Arzi, A., Lunghi, C., and Salomon, R. (2017). Consciousness is more than meets the eye: a call for a multisensory study of subjective experience. Neurosci. Conscious. *2017*, nix003. https://doi.org/10.1093/nc/nix003.

36. Breese, B.B. (1909). Binocular rivalry. Psychol. Rev. *16*, 410–415. https://doi.org/10.1037/h0075805.

37. Leopold, D.A., and Logothetis, N.K. (1996). Activity changes in early visual cortex reflect monkeys' percepts during binocular rivalry. Nature *379*, 549–553. https://doi.org/10.1038/379549a0.

38. Arnold, D.H. (2011). Why is binocular rivalry uncommon? Discrepant monocular images in the real world. Front. Hum. Neurosci. *5*, 116. https://doi.org/10.3389/fnhum.2011.00116.

39. Han, S., Blake, R., Aubuchon, C., and Tadin, D. (2024). Binocular rivalry under naturalistic geometry: Evidence from worlds simulated in virtual reality. PNAS Nexus *3*, pgae054. https://doi.org/10.1093/pnasnexus/pgae054.

40. Blake, R., Brascamp, J., and Heeger, D.J. (2014). Can binocular rivalry reveal neural correlates of consciousness? Philos. Trans. R. Soc. Lond. B Biol. Sci. *369*, 20130211. https://doi.org/10.1098/rstb.2013.0211.

41. Yaron, I., Melloni, L., Pitts, M., and Mudrik, L. (2022). The ConTraSt database for analysing and comparing empirical studies of

consciousness theories. Nat. Hum. Behav. *6*, 593–604. https://doi.org/10.1038/s41562-021-01284-5.

42. Tsuchiya, N., and Koch, C. (2005). Continuous flash suppression reduces negative afterimages. Nat. Neurosci. *8*, 1096–1101. https://doi.org/10.1038/nn1500.

43. Fink, W.H. (1938). The dominant eye: its clinical significance. Arch. Ophthalmol. *19*, 555–582. https://doi.org/10.1001/archopht.1938.00850160081005.

44. Breitmeyer, B.G., and Ogmen, H. (2006). Visual Masking: Time slices through conscious and unconscious vision: Time slices through conscious and unconscious vision (Oxford University Press).

45. Bar, M., and Biederman, I. (1998). Subliminal visual priming. Psychol. Sci. *9*, 464–468. https://doi.org/10.1111/1467-9280.00086.

46. Watanabe, T., Náñez, J.E., and Sasaki, Y. (2001). Perceptual learning without perception. Nature *413*, 844–848. https://doi.org/10.1038/35101601.

47. Pelli, D.G., and Tillman, K.A. (2008). The uncrowded window of object recognition. Nat. Neurosci. *11*, 1129–1135. https://doi.org/10.1038/nn.2187.

48. Mack, A., and Rock, I. (1998). Inattentional blindness (MIT Press).

49. Faivre, N., Berthet, V., and Kouider, S. (2012). Nonconscious influences from emotional faces: a comparison of visual crowding, masking, and continuous flash suppression. Front. Psychol. *3*, 129. https://doi.org/10.3389/fpsyg.2012.00129.

50. Simons, D.J., and Chabris, C.F. (1999). Gorillas in our midst: sustained inattentional blindness for dynamic events. Perception *28*, 1059–1074. https://doi.org/10.1068/p281059.

51. Dehaene, S., Naccache, L., Le Clec'H, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., van de Moortele, P.-F., and Le Bihan, D. (1998). Imaging unconscious semantic priming. Nature *395*, 597–600.

52. Graves, T.L., Maniscalco, B., and Lau, H. (2010). Volition and the function of consciousness. In Conscious will and responsibility: A tribute to Benjamin Libet (Oxford University press), pp. 109–123. https://doi.org/10.1093/acprof:oso/9780195381641.003.0011.

53. Sonkusare, S., Breakspear, M., and Guo, C. (2019). Naturalistic stimuli in neuroscience: critically acclaimed. Trends Cogn. Sci. *23*, 699–714. https://doi.org/10.1016/j.tics.2019.05.004.

54. Stein, B.E., and Stanford, T.R. (2008). Multisensory integration: current issues from the perspective of the single neuron. Nat. Rev. Neurosci. *9*, 255–266. https://doi.org/10.1038/nrn2331.

55. Cleeremans, A. (2005). Computational correlates of consciousness. Prog. Brain Res. *150*, 81–98. https://doi.org/10.1016/S0079-6123(05)50007-4.

56. Allen, J.J.B., and Kline, J.P. (2004). Frontal EEG asymmetry, emotion, and psychopathology: the first, and the next 25 years. Biol. Psychol. *67*, 1–5. https://doi.org/10.1016/j.biopsycho.2004.03.001.

57. Coan, J.A., Allen, J.J.B., and McKnight, P.E. (2006). A capability model of individual differences in frontal EEG asymmetry. Biol. Psychol. *72*, 198–207. https://doi.org/10.1016/j.biopsycho.2005.10.003.

58. Kisker, J., Lange, L., Flinkenflügel, K., Kaup, M., Labersweiler, N., Tetenborg, F., Ott, P., Gundler, C., Gruber, T., Osinsky, R., and Schöne, B. (2021). Authentic fear responses in virtual reality: a Mobile EEG study on affective, behavioral and electrophysiological correlates of fear. Front. Virtual Real. *2*, 716318. https://doi.org/10.3389/frvir.2021.716318.

59. Schöne, B., Kisker, J., Sylvester, R.S., Radtke, E.L., and Gruber, T. (2023). Library for universal virtual reality experiments (luVRe): A standardized immersive 3D/360° picture and video database for VR based research. Curr. Psychol. *42*, 5366–5384. https://doi.org/10.1007/s12144-021-01841-1.

60. Krogmeier, C., Coventry, B.S., and Mousas, C. (2022). Affective Image Sequence Viewing in Virtual Reality Theater Environment: Frontal Alpha Asymmetry Responses From Mobile EEG. Front. Virtual Real. *3*, 895487. https://doi.org/10.3389/frvir.2022.895487.

61. Sagehorn, M., Johnsdorf, M., Kisker, J., Sylvester, S., Gruber, T., and Schöne, B. (2023). Real-life relevant face perception is not captured by the N170 but reflected in later potentials: A comparison of 2D and virtual reality stimuli. Front. Psychol. *14*, 1050892. https://doi.org/10.3389/fpsyg.2023.1050892.

62. Chen, J., Honey, C.J., Simony, E., Arcaro, M.J., Norman, K.A., and Hasson, U. (2016). Accessing real-life episodic information from minutes versus hours earlier modulates hippocampal and high-order cortical dynamics. Cereb. Cortex *26*, 3428–3441. https://doi.org/10.1093/cercor/bhv155.

63. Murdock Jr, B.B. (1962). The serial position effect of free recall. J. Exp. Psychol. *64*, 482–488. https://doi.org/10.1037/h0045106.

64. Lee, H., and Chen, J. (2022). Predicting memory from the network structure of naturalistic events. Nat. Commun. *13*, 4235. https://doi.org/10.1038/s41467-022-31965-2.

65. Fechner, G.T. (1966). Elements of psychophysics, 1860 (Rinehart and Winston).

66. Ozana, A., and Ganel, T. (2019). Weber's law in 2D and 3D grasping. Psychol. Res. *83*, 977–988. https://doi.org/10.1007/s00426-017-0913-3.

67. Snow, J.C., Skiba, R.M., Coleman, T.L., and Berryhill, M.E. (2014). Real-world objects are more memorable than photographs of objects. Front. Hum. Neurosci. *8*, 837. https://doi.org/10.3389/fnhum.2014.00837.

68. Bushong, B., King, L.M., Camerer, C.F., and Rangel, A. (2010). Pavlovian processes in consumer choice: The physical presence of a good increases willingness-to-pay. Am. Econ. Rev. *100*, 1556–1571. https://doi.org/10.1257/aer.100.4.1556.

69. Romero, C.A., Compton, M.T., Yang, Y., and Snow, J.C. (2018). The real deal: Willingness-to-pay and satiety expectations are greater for real foods versus their images. Cortex *107*, 78–91. https://doi.org/10.1016/j.cortex.2017.11.010.

70. Gomez, M.A., Skiba, R.M., and Snow, J.C. (2018). Graspable objects grab attention more than images do. Psychol. Sci. *29*, 206–218. https://doi.org/10.1177/0956797617730599.

71. Snow, J.C., Pettypiece, C.E., McAdam, T.D., McLean, A.D., Stroman, P.W., Goodale, M.A., and Culham, J.C. (2011). Bringing the real world into the fMRI scanner: Repetition effects for pictures versus real objects. Sci. Rep. *1*, 130. https://doi.org/10.1038/srep00130.

72. Gerhard, T.M., Culham, J.C., and Schwarzer, G. (2016). Distinct visual processing of real objects and pictures of those objects in 7- to 9-month-old infants. Front. Psychol. *7*, 827. https://doi.org/10.3389/fpsyg.2016.00827.

73. DeLoache, J.S., Pierroutsakos, S.L., and Uttal, D.H. (2003). The origins of pictorial competence. Curr. Dir. Psychol. Sci. *12*, 114–118. https://doi.org/10.1111/1467-8721.01244.

74. Gibson, J.J. (2014). The ecological approach to visual perception: classic edition (Psychology Press). https://doi.org/10.4324/9781315740218.

75. Schultz, J., and Pilz, K.S. (2009). Natural facial motion enhances cortical responses to faces. Exp. Brain Res. *194*, 465–475. https://doi.org/10.1007/s00221-009-1721-9.

76. Redcay, E., Dodell-Feder, D., Pearrow, M.J., Mavros, P.L., Kleiner, M., Gabrieli, J.D.E., and Saxe, R. (2010). Live face-to-face interaction during fMRI: a new tool for social cognitive neuroscience. Neuroimage *50*, 1639–1647. https://doi.org/10.1016/j.neuroimage.2010.01.052.

77. Stephens, G.J., Silbert, L.J., and Hasson, U. (2010). Speaker–listener neural coupling underlies successful communication. Proc. Natl. Acad. Sci. USA *107*, 14425–14430. https://doi.org/10.1073/pnas.1008662107.

78. Lerner, Y., Honey, C.J., Silbert, L.J., and Hasson, U. (2011). Topographic mapping of a hierarchy of temporal receptive windows using a narrated story. J. Neurosci. *31*, 2906–2915. https://doi.org/10.1523/JNEUROSCI.3684-10.2011.

79. Baldassano, C., Chen, J., Zadbood, A., Pillow, J.W., Hasson, U., and Norman, K.A. (2017). Discovering event structure in continuous narrative perception and memory. Neuron *95*, 709–721.e5. https://doi.org/10.1016/j.neuron.2017.06.041.

80. Hasson, U., Nir, Y., Levy, I., Fuhrmann, G., and Malach, R. (2004). Intersubject synchronization of cortical activity during natural vision. Science *303*, 1634–1640. https://doi.org/10.1126/science.1089506.

81. Huth, A.G., De Heer, W.A., Griffiths, T.L., Theunissen, F.E., and Gallant, J.L. (2016). Natural speech reveals the semantic maps that tile human cerebral cortex. Nature *532*, 453–458. https://doi.org/10.1038/nature17637.

82. Obleser, J., and Kayser, C. (2019). Neural entrainment and attentional selection in the listening brain. Trends Cogn. Sci. *23*, 913–926. https://doi.org/10.1016/j.tics.2019.08.004.

83. Luo, H., and Poeppel, D. (2007). Phase patterns of neuronal responses reliably discriminate speech in human auditory cortex. Neuron *54*, 1001–1010. https://doi.org/10.1016/j.neuron.2007.06.004.

84. Slater, M., Spanlang, B., Sanchez-Vives, M.V., and Blanke, O. (2010). First person experience of body transfer in virtual reality. PLoS one *5*, e10564. https://doi.org/10.1371/journal.pone.0010564.

85. Petkova, V.I., and Ehrsson, H.H. (2008). If I were you: perceptual illusion of body swapping. PLoS one *3*, e3832. https://doi.org/10.1371/journal.pone.0003832.

86. Galvan Debarba, H., Bovet, S., Salomon, R., Blanke, O., Herbelin, B., and Boulic, R. (2017). Characterizing first and third person viewpoints and their alternation for embodied interaction in virtual reality. PLoS one *12*, e0190109. https://doi.org/10.1371/journal.pone.0190109.

87. Drori, G., Bar-Tal, P., Stern, Y., Zvilichovsky, Y., and Salomon, R. (2020). UnReal? Investigating the sense of reality and psychotic symptoms with virtual reality. J. Clin. Med. *9*, 1627. https://doi.org/10.3390/jcm9061627.

88. Korisky, U., Hirschhorn, R., and Mudrik, L. (2019). "Real-life" continuous flash suppression (CFS)-CFS with real-world objects using augmented reality goggles. Behav. Res. Methods *51*, 2827–2839. https://doi.org/10.3758/s13428-018-1162-0.

89. Finkbeiner, M., and Friedman, J. (2011). The flexibility of nonconsciously deployed cognitive processes: evidence from masked congruence priming. PLoS one *6*, e17095. https://doi.org/10.1371/journal.pone.0017095.

90. Friedman, J., and Finkbeiner, M. (2010). Temporal dynamics of masked congruence priming: evidence from reaching trajectories. In Proceedings of the 9th Conference of the Australasian Society for Cognitive Science, W. Christensen, E. Schier, and J. Sutton, eds., pp. 98–105. https://doi.org/10.5096/ASCS200916.

91. Mudrik, L., Breska, A., Lamy, D., and Deouell, L.Y. (2011). Integration without awareness: expanding the limits of unconscious processing. Psychol Sci *22*, 764–770. https://doi.org/10.1177/0956797611408736.

92. Biderman, N., and Mudrik, L. (2018). Evidence for Implicit-But Not Unconscious-Processing of Object-Scene Relations *29*, 266–277. https://doi.org/10.1177/0956797617735745.

93. Faivre, N., and Koch, C. (2014). Inferring the direction of implied motion depends on visual awareness. J Vis *14*, 4. https://doi.org/10.1167/14.4.4.

94. Moors, P., Boelens, D., van Overwalle, J., and Wagemans, J. (2016). Scene Integration Without Awareness: No Conclusive Evidence for Processing Scene Congruency During Continuous Flash Suppression. Psychological Science *27*, 945–956. https://doi.org/10.1177/0956797616642525.

95. Faivre, N., and Koch, C. (2014). Temporal structure coding with and without awareness. Cognition *131*, 404–414. https://doi.org/10.1016/j.cognition.2014.02.008.

96. Goldstein, A., Rivlin, I., Goldstein, A., Pertzov, Y., and Hassin, R.R. (2020). Predictions from masked motion with and without obstacles. PLoS one *15*, e0239839. https://doi.org/10.1371/journal.pone.0239839.

97. Moors, P., Wagemans, J., and de-Wit, L. (2017). Causal events enter awareness faster than non-causal events. PeerJ *5*, e2932. https://doi.org/10.7717/peerj.2932.

98. Hirschhorn, R., Kahane, O., Gur-Arie, I., Faivre, N., and Mudrik, L. (2020). Windows of Integration Hypothesis Revisited. Front. Hum. Neurosci. *14*, 617187. https://doi.org/10.3389/fnhum.2020.617187.

99. Mudrik, L., Faivre, N., and Koch, C. (2014). Information integration without awareness. Trends Cogn. Sci. *18*, 488–496. https://doi.org/10.1016/j.tics.2014.04.009.

100. Dehaene, S., and Naccache, L. (2001). Towards a cognitive neuroscience of consciousness: basic evidence and a workspace framework. Cognition *79*, 1–37. https://doi.org/10.1016/S0010-0277(00)00123-2.

101. Lamme, V.A.F. (2020). Visual Functions Generating Conscious Seeing. Front Psychol *11*, 83. https://doi.org/10.3389/fpsyg.2020.00083.

102. Salomon, R., Lim, M., Herbelin, B., Hesselmann, G., and Blanke, O. (2013). Posing for awareness: Proprioception modulates access to visual consciousness in a continuous flash suppression task. J. Vision *13*, 2. https://doi.org/10.1167/13.7.2.

103. Salomon, R., Noel, J.P., Łukowska, M., Faivre, N., Metzinger, T., Serino, A., and Blanke, O. (2017). Unconscious integration of multisensory bodily inputs in the peripersonal space shapes bodily self-consciousness. Cognition *166*, 174–183. https://doi.org/10.1016/j.cognition.2017.05.028.

104. Salomon, R., Kaliuzhna, M., Herbelin, B., and Blanke, O. (2015). Balancing awareness: Vestibular signals modulate visual consciousness in the absence of awareness. Conscious. Cogn. *36*, 289–297. https://doi.org/10.1016/j.concog.2015.07.009.

105. Suzuki, K., Schwartzman, D.J., Augusto, R., and Seth, A.K. (2019). Sensorimotor contingency modulates breakthrough of virtual 3D objects during a breaking continuous flash suppression paradigm. Cognition *187*, 95–107. https://doi.org/10.1016/j.cognition.2019.03.003.

106. O'Regan, J.K., and Noë, A. (2001). A sensorimotor account of vision and visual consciousness. Behav. Brain Sci. *24*, 939–973. https://doi.org/10.1017/s0140525x01000115.

107. Seth, A.K. (2014). A predictive processing theory of sensorimotor contingencies: Explaining the puzzle of perceptual presence and its absence in synesthesia. Cogn. Neurosci. *5*, 97–118. https://doi.org/10.1080/17588928.2013.877880.

108. Vasser, M., Vuillaume, L., Cleeremans, A., and Aru, J. (2019). Waving goodbye to contrast: self-generated hand movements attenuate visual sensitivity. Neurosci. Conscious. *2019*, niy013. https://doi.org/10.1093/nc/niy013.

109. Shir, Y., Abudarham, N., and Mudrik, L. (2021). You won't believe what this guy is doing with the potato: The ObjAct stimulus-set depicting human actions on congruent and incongruent objects. Behav. Res. Methods *53*, 1895–1909. https://doi.org/10.3758/s13428-021-01540-6.

110. Simons, D.J., and Schlosser, M.D. (2017). Inattentional blindness for a gun during a simulated police vehicle stop. Cogn. Res.: Princ. Implic. *2*, 37. https://doi.org/10.1186/s41235-017-0074-3.

111. Hyman, I.E., Boss, S.M., Wise, B.M., McKenzie, K.E., and Caggiano, J.M. (2010). Did you see the unicycling clown? Inattentional blindness while walking and talking on a cell phone. Appl. Cogn. Psychol. *24*, 597–607. https://doi.org/10.1002/acp.1638.

112. Cohen, M.A., Botch, T.L., and Robertson, C.E. (2020). The limits of color awareness during active, real-world vision. Proc. Natl. Acad. Sci. USA *117*, 13821–13827. https://doi.org/10.1073/pnas.1922294117.

113. Naci, L., Cusack, R., Anello, M., and Owen, A.M. (2014). A common neural code for similar conscious experiences in different individuals. Proc. Natl. Acad. Sci. USA *111*, 14277–14282. https://doi.org/10.1073/pnas.1407007111.

114. Korisky, U., and Mudrik, L. (2021). Dimensions of perception: 3D real-life objects are more readily detected than their 2D images. Psychol. Sci. *32*, 1636–1648. https://doi.org/10.1177/09567976211010718.

115. Milner, A.D., and Goodale, M.A. (1995). The visual brain in action (Oxford University Press).

116. Lamme, V.A.F. (2006). Towards a true neural stance on consciousness. Trends Cogn. Sci. *10*, 494–501. https://doi.org/10.1016/j.tics.2006.09.001.

117. Schöne, B., Sylvester, R.S., Radtke, E.L., and Gruber, T. (2021). Sustained inattentional blindness in virtual reality and under conventional laboratory conditions. Virtual Real. *25*, 209–216. https://doi.org/10.1007/s10055-020-00450-w.

118. Hyman, I.E., Sarb, B.A., and Wise-Swanson, B.M. (2014). Failure to see money on a tree: inattentional blindness for objects that guided behavior. Front. Psychol. *5*, 356. https://doi.org/10.3389/fpsyg.2014.00356.

119. Chabris, C.F., Weinberger, A., Fontaine, M., and Simons, D.J. (2011). You do not talk about Fight Club if you do not notice Fight Club: Inattentional blindness for a simulated real-world assault. i-Perception *2*, 150–153. https://doi.org/10.1068/i0436.

120. Melloni, L., Mudrik, L., Pitts, M., Bendtz, K., Ferrante, O., Gorska, U., Hirschhorn, R., Khalaf, A., Kozma, C., Lepauvre, A., et al. (2023). An adversarial collaboration protocol for testing contrasting predictions of global neuronal workspace and integrated information theory. PLoS one *18*, e0268577. https://doi.org/10.1371/journal.pone.0268577.

121. Bayne, T., Seth, A.K., Massimini, M., Shepherd, J., Cleeremans, A., Fleming, S.M., Malach, R., Mattingley, J.B., Menon, D.K., Owen, A.M., et al. (2024). Tests for Consciousness in Humans and Beyond. Trends Cogn. Sci. https://doi.org/10.1016/j.tics.2024.01.010.

122. Naci, L., Sinai, L., and Owen, A.M. (2017). Detecting and interpreting conscious experiences in behaviorally non-responsive patients. Neuroimage *145*, 304–313. https://doi.org/10.1016/j.neuroimage.2015.11.059.

123. Arzi, A., Rozenkrantz, L., Gorodisky, L., Rozenkrantz, D., Holtzman, Y., Ravia, A., Bekinschtein, T.A., Galperin, T., Krimchansky, B.Z., Cohen, G., et al. (2020). Olfactory sniffing signals consciousness in unresponsive patients with brain injuries. Nature *581*, 428–433. https://doi.org/10.1038/s41586-020-2245-5.

124. Haun, A.M., Tononi, G., Koch, C., and Tsuchiya, N. (2017). Are we underestimating the richness of visual experience? Neurosci. Conscious. *2017*, niw023. https://doi.org/10.1093/nc/niw023.

125. Tsuchiya, N., Wilke, M., Frässle, S., and Lamme, V.A.F. (2015). No-report paradigms: extracting the true neural correlates of consciousness. Trends Cogn. Sci. *19*, 757–770. https://doi.org/10.1016/j.tics.2015.10.002.

126. Frässle, S., Sommer, J., Jansen, A., Naber, M., and Einhäuser, W. (2014). Binocular rivalry: frontal activity relates to introspection and action but not to perception. J. Neurosci. *34*, 1738–1747. https://doi.org/10.1523/JNEUROSCI.4403-13.2014.

127. Spering, M., and Carrasco, M. (2015). Acting without seeing: eye movements reveal visual processing without awareness. Trends Neurosci. *38*, 247–258. https://doi.org/10.1016/j.tins.2015.02.002.

128. Merikle, P.M., and Reingold, E.M. (1998). On demonstrating unconscious perception: Comment on Draine and Greenwald (1998). J. Exp. Psychol. Gen. *127*, 304–310. https://doi.org/10.1037//0096-3445.127.3.304.

129. Spering, M., Pomplun, M., and Carrasco, M. (2011). Tracking without perceiving: a dissociation between eye movements and motion perception. Psychol. Sci. *22*, 216–225. https://doi.org/10.1177/0956797610394659.

130. Van der Stigchel, S., Mulckhuyse, M., and Theeuwes, J. (2009). Eye cannot see it: the interference of subliminal distractors on saccade metrics. Vision Res. *49*, 2104–2109. https://doi.org/10.1016/j.visres.2009.05.018.

131. Bijleveld, E., Custers, R., and Aarts, H. (2009). The unconscious eye opener: Pupil dilation reveals strategic recruitment of resources upon presentation of subliminal reward cues. Psychol. Sci. *20*, 1313–1315. https://doi.org/10.1111/j.1467-9280.2009.02443.x.

132. Raio, C.M., Carmel, D., Carrasco, M., and Phelps, E.A. (2012). Nonconscious fear is quickly acquired but swiftly forgotten. Curr. Biol. *22*, R477–R479. https://doi.org/10.1016/j.cub.2012.04.023.

133. Bainbridge, W.A., Pounder, Z., Eardley, A.F., and Baker, C.I. (2021). Quantifying aphantasia through drawing: Those without visual imagery show deficits in object but not spatial memory. Cortex *135*, 159–172. https://doi.org/10.1016/j.cortex.2020.11.014.

134. Dawson, M.E., Schell, A.M., and Courtney, C.G. (2011). The skin conductance response, anticipation, and decision-making. J. Neurosci. Psychol. Econ. *4*, 111–116. https://doi.org/10.1037/a0022619.

135. Tooley, M.D., Carmel, D., Chapman, A., and Grimshaw, G.M. (2017). Dissociating the physiological components of unconscious emotional responses. Neurosci Conscious. nix021. https://doi.org/10.1093/nc/nix021.

136. Ohman, A., and Soares, J.J. (1994). Unconscious anxiety": phobic responses to masked stimuli. J Abnorm Psychol *103*, 231–240. https://doi.org/10.1037//0021-843x.103.2.231.

137. van den Hout, M.A., de Jong, P., and Kindt, M. (2003). Masked fear words produce increased SCRs: An anomaly for Öhman's theory of pre-attentive processing in anxiety. Psychophysiology *37*, 283–288. https://doi.org/10.1111/1469-8986.3730283.

138. Nava, E., Romano, D., Grassi, M., and Turati, C. (2016). Skin conductance reveals the early development of the unconscious processing of emotions. Cortex *84*, 124–131. https://doi.org/10.1016/j.cortex.2016.07.011.

139. Goodale, M.A., Milner, A.D., Jakobson, L.S., and Carey, D.P. (1991). A neurological dissociation between perceiving objects and grasping them. Nature *349*, 154–156. https://doi.org/10.1038/349154a0.

140. Goodale, M.A., Jakobson, L.S., and Keillor, J.M. (1994). Differences in the visual control of pantomimed and natural grasping movements. Neuropsychologia *32*, 1159–1178. https://doi.org/10.1016/0028-3932(94)90100-7.

141. Ganel, T., Tanzer, M., and Goodale, M.A. (2008). A double dissociation between action and perception in the context of visual illusions: opposite effects of real and illusory size. Psychol. Sci. *19*, 221–225. https://doi.org/10.1111/j.1467-9280.2008.02071.x.

142. Goodale, M.A. (2004). Perceiving the World and Grasping It: Dissociations Between Conscious and Unconscious Visual Processing. In The Cognitive Neurosciences III, M.S. Gazzaniga, ed. (MIT Press), pp. 1159–1172.

143. Goodale, M., and Milner, A.D. (1992). Separate visual pathways for perception and action. Trends in Neuroscience *15*, 20–25. https://doi.org/10.1016/0166-2236(92)90344-8.

144. Xiao, K., and Yamauchi, T. (2015). Subliminal semantic priming in near absence of attention: A cursor motion study. Conscious. Cogn. *38*, 88–98. https://doi.org/10.1016/j.concog.2015.09.013.

145. Sayim, B., and Wagemans, J. (2017). Appearance changes and error characteristics in crowding revealed by drawings. J. Vision *17*, 8. https://doi.org/10.1167/17.11.8.

146. Varela, F.J. (1996). Neurophenomenology: A methodological remedy for the hard problem. J. Conscious. Stud. *3*, 330–349.

147. Froese, T., Gould, C., and Seth, A.K. (2011). Validating and calibrating first-and second-person methods in the science of consciousness. J. Conscious. Stud. *18*, 38.

148. Petitmengin, C., Remillieux, A., and Valenzuela-Moguillansky, C. (2019). Discovering the structures of lived experience: Towards a micro-phenomenological analysis method. Phenomenol. Cogn. Sci. *18*, 691–730. https://doi.org/10.1007/s11097-018-9597-4.

149. Chuyin, Z., Koh, Z.H., Gallagher, R., Nishimoto, S., and Tsuchiya, N. (2022). What can we experience and report on a rapidly presented image? Intersubjective measures of specificity of freely reported contents of consciousness. F1000Research *11*, 69. https://doi.org/10.12688/f1000research.75364.2.

150. Fei-Fei, L., Iyer, A., Koch, C., and Perona, P. (2007). What do we perceive in a glance of a real-world scene? J. Vision *7*, 10. https://doi.org/10.1167/7.1.10.

Please cite this article in press as: Mudrik et al., Taking consciousness for real: Increasing the ecological validity of the study of conscious vs. unconscious processes, Neuron (2024), https://doi.org/10.1016/j.neuron.2024.03.031

151. Hirschhorn, R., and Mudrik, L. (2023). More than words: Can free reports adequately measure the richness of perception?. a project by OSF. https://doi.org/10.17605/OSF.IO/R73KP.

152. Block, N. (1995). On a confusion about a function of consciousness. Behav. Brain Sci. *18*, 227–247. https://doi.org/10.1017/S0140525X00038188.

153. Amir, Y.Z., Assaf, Y., Yovel, Y., and Mudrik, L. (2023). Experiencing without knowing? Empirical evidence for phenomenal consciousness without access. Cognition *238*, 105529. https://doi.org/10.1016/j.cognition.2023.105529.

154. Golan, T., Davidesco, I., Meshulam, M., Groppe, D.M., Mégevand, P., Yeagle, E.M., Goldfinger, M.S., Harel, M., Melloni, L., Schroeder, C.E., et al. (2016). Human intracranial recordings link suppressed transients rather than 'filling-in' to perceptual continuity across blinks. eLife *5*, e17243. https://doi.org/10.7554/eLife.17243.

155. Maoz, U., Yaffe, G., Koch, C., and Mudrik, L. (2019). Neural precursors of decisions that matter-an ERP study of deliberate and arbitrary choice. eLife *8*, e39787. https://doi.org/10.7554/eLife.39787.

156. Revonsuo, A., and Valli, K. (2010). Dreaming as a model system for consciousness research. In New Horizons in the Neuroscience of Consciousness, *79*, pp. 149–154. https://doi.org/10.1075/aicr.79.20rev.

157. Siclari, F., Baird, B., Perogamvros, L., Bernardi, G., LaRocque, J.J., Riedner, B., Boly, M., Postle, B.R., and Tononi, G. (2017). The neural correlates of dreaming. Nat. Neurosci. *20*, 872–878. https://doi.org/10.1038/nn.4545.

158. Wong, W., Noreika, V., Móró, L., Revonsuo, A., Windt, J.M., Valli, K., and Tsuchiya, N. (2020). The Dream Catcher experiment: blinded analyses failed to detect markers of dreaming consciousness in EEG spectral power. Neurosci. Conscious. *2020*, niaa006. https://doi.org/10.1093/nc/niaa006.

159. Makov, S., Sharon, O., Ding, N., Ben-Shachar, M., Nir, Y., and Zion Golumbic, E. (2017). Sleep disrupts high-level speech parsing despite significant basic auditory processing. J. Neurosci. *37*, 7772–7781. https://doi.org/10.1523/JNEUROSCI.0168-17.2017.

160. Arzi, A., Shedlesky, L., Ben-Shaul, M., Nasser, K., Oksenberg, A., Hairston, I.S., and Sobel, N. (2012). Humans can learn new information during sleep. Nat. Neurosci. *15*, 1460–1465. https://doi.org/10.1038/nn.3193.

161. Andrillon, T., and Kouider, S. (2020). The vigilant sleeper: neural mechanisms of sensory (de) coupling during sleep. Curr. Opin. Physiol. *15*, 47–59. https://doi.org/10.1016/j.cophys.2019.12.002.

162. Libet, B., Gleason, C.A., Wright, E.W., and Pearl, D.K. (1983). Time of conscious intention to act in relation to onset of cerebral activity (readiness-potential). The unconscious initiation of a freely voluntary act. Brain *106*, 623–642. https://doi.org/10.1093/brain/106.3.623.

163. Dominik, T., Mele, A., Schurger, A., and Maoz, U. (2024). Libet's legacy: A primer to the neuroscience of volition. Neurosci. Biobehav. Rev. *157*, 105503. https://doi.org/10.1016/j.neubiorev.2023.105503.

164. Skulmowski, A., Bunge, A., Kaspar, K., and Pipa, G. (2014). Forced-choice decision-making in modified trolley dilemma situations: a virtual reality and eye tracking study. Front. Behav. Neurosci. *8*, 426. https://doi.org/10.3389/fnbeh.2014.00426.

165. Greenwald, A.G., Draine, S.C., and Abrams, R.L. (1996). Three cognitive markers of unconscious semantic activation. Science *273*, 1699–1702. https://doi.org/10.1126/science.273.5282.1699.

166. Shiffman, S., Stone, A.A., and Hufford, M.R. (2008). Ecological momentary assessment. Annu. Rev. Clin. Psychol. *4*, 1–32. https://doi.org/10.1146/annurev.clinpsy.3.022806.091415.

167. Taschereau-Dumouchel, V., Cortese, A., Chiba, T., Knotts, J.D., Kawato, M., and Lau, H. (2018). Towards an unconscious neural reinforcement intervention for common fears. Proc. Natl. Acad. Sci. USA *115*, 3470–3475. https://doi.org/10.1073/pnas.1721572115.

168. Reggente, N., Essoe, J.K.Y., Aghajan, Z.M., Tavakoli, A.V., McGuire, J.F., Suthana, N.A., and Rissman, J. (2018). Enhancing the ecological validity of fMRI memory research using virtual reality. Front. Neurosci. *12*, 408. https://doi.org/10.3389/fnins.2018.00408.