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POINT OF VIEW

Covert narrative capacity: Mental life in patients thought to lack consciousness

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Abstract

Despite the apparent absence of external signs of consciousness, a significant proportion of behaviorally nonresponsive patients can respond to commands by willfully modulating their brain activity. However, little is known about the mental life of these patients. We discuss a recent innovative approach, which sheds light on the preserved cognitive capacities of these patients, including executive function, theory of mind, and the experience of affective states. This research represents a fundamental shift in our understanding of these patients, and has important implications for both their continued treatment and care. Moreover, this research marks out avenues for future inquiry into the residual cognitive capacities of these patients.

Introduction

A proportion of patients who survive serious brain injury are behaviorally nonresponsive or exhibit very limited responsivity to commands administered at the bedside by clinical staff. Some of these patients appear to be awake, but show no signs of awareness of themselves, or of their environment, in repeated clinical examinations. Patients with this behavioral profile, specifically, signs of wakefulness – that is, periodic eye opening and closing – in the absence of signs of awareness of themselves or of the environment, are clinically diagnosed as being in the vegetative state (VS).[1] It is well established that misdiagnosis occurs frequently in this patient group, with up to 43% of patients being diagnosed as VS, when they are, in fact, at least minimally aware.[2–4]

In fact, studies using functional magnetic resonance imaging (fMRI) have demonstrated that despite the apparent absence of external signs of consciousness in repeated behavioral examinations, some behaviorally nonresponsive patients can respond to commands by willfully modulating their brain activity according to instruction.[5–14] These studies have established that a minority of behaviorally nonresponsive patients (19%) can use brain activity as a proxy for behavior to demonstrate their conscious awareness.[6,7]

Despite these advances, the mental life of behaviorally nonresponsive patients – particularly their capacity to have similar experiences to healthy individuals in response to everyday life events – has until recently remained largely unknown. In the following sections, we explore the extent to which current fMRI paradigms that probe residual cognition shed light on this question.

Consider the following (hypothetical patient) case: J is a healthy 18-year-old female who suffered a catastrophic anoxic brain injury. Upon emerging from coma several days after her accident, J lacked any signs of behavioral response to commands delivered at the bedside by the clinical staff, and on this basis, was diagnosed as being in a VS. Over several years, J showed no willful movement to command, nor any behavioral signs of functional or nonfunctional communication. She displayed no signs of localization of sound and no visual recognition or interaction with objects or people in her environment.

Twelve years after her injury, J was enrolled in a highly specialized research program, where she undertook several fMRI tests. One of these tests instructed her to perform two different mental imagery tasks. In two independent 5-min scanning sessions, J was asked either to imagine playing tennis, or to imagine navigating the rooms of her home. Depending on the task, J heard either the word "tennis" or "house"– a reminder to engage in task-appropriate brain activation, and after 30 sec, J heard the word "relax" – a reminder to stop task activity. No stimuli were presented in the 30 sec following the presentation of each command word, in order to allow J to respond exclusively to the stated command, by engaging (or ceasing to engage) in the requested mental imagery, and to rule out the possibility that any observed brain activity could be due to extraneous variables, such as external stimulation.[5]

When asked to imagine playing tennis, J's supplementary motor area – the same region activated in healthy controls during the same task[5] – became significantly active. Conversely, when asked to relax, the task-appropriate brain activity in this area ceased. Similarly, when asked to imagine navigating around the rooms of her home, J's parahippocampal place area – the same brain region activated in controls[5] – became significantly active, and when asked to relax, the task-appropriate activation in this region ceased. These results suggested that J willfully followed the commands of researchers by purposefully engaging in specific brain activity, thus, demonstrating her conscious awareness. Furthermore, these results suggested that despite the lack of behavioral response, J retained several mental faculties that underlined her successful performance of the mental imagery tasks. These included language understanding, working memory, and decision-making and execution skills.

In order to ensure that any brain activity observed in response to task commands cannot be caused by external stimuli, "command-following" paradigms, of which motor imagery is the best-established exemplar, employ a highly artificial experimental context, and as such can offer only a highly circumscribed picture of a patient's mental life.[5] By using structured instructions, such as "imagine playing tennis," "imagine navigating around your house,"[5] "imagine swimming,"[8] and "attend to the word 'yes'/'no',"[10,15] to elicit willful modulation of brain activity according to specific commands, these tasks can only probe cognition within the purview of the particular task the patient performs. However, the cognitive processes engaged by these tasks are very narrow when compared to the open-ended nature of conscious experiences in day-to-day life, wherein the brain constantly sorts through and integrates myriad inputs from multiple sensory modalities. For this reason, the mental imagery paradigm cannot address questions about the extent to which behaviorally nonresponsive patients like J may consciously process the dynamically evolving sensory environment around them.

One such question involves whether these patients can sustain attention to specific sensory inputs, while filtering out irrelevant distractors, so as to coherently process information coming from the environment. Similarly, it is not clear whether any such patient can continuously integrate the inputs of various sensory modalities into a unified whole in order to, for example, recognize the voices and faces of familiar people, or whether they can integrate knowledge stored in long-term memory with new information, so as to understand complex, real-life events unfolding over time. The answers to these questions would help to illuminate the extent to which the conscious experiences of these patients are similar to those of healthy individuals.

Covert Narrative Capacity

One recent approach[16,17] provides just this sort of insight into the mental life of behaviorally nonresponsive patients who are covertly aware. Naci and colleagues[16] investigated whether similar experiences in healthy people are supported by a common neural code, which could be used to interpret the conscious experiences of behaviorally nonresponsive patients. In order to capture the open-ended nature of consciousness, while still appealing to common cognitive processes that could be empirically measured, Naci and colleagues focused on the assessment of executive function while participants watched a highly engaging movie. Executive function – a high-order mental faculty that is integral to our conscious experience of the world – coordinates and schedules a host of other more basic cognitive operations, such as monitoring and analyzing information from the environment, and integrates it with internally generated goals.[18–20] It enables us to integrate prior knowledge with the current "state of play" in order to make predictions about likely future events. Engaging movies, which are designed to give viewers a shared conscious experience, recruit similar executive processes in different people; each viewer continuously integrates their observations, analyses, and predictions, while filtering out any distractions, leading to an ongoing involvement in the movie's plot.

Naci et al.[16] measured the brain response of healthy participants and nonresponsive patients with unknown levels of consciousness, as each individual viewed a short movie in the fMRI scanner. The movie involved a young boy who finds his uncle's revolver, loads it with bullets, and plays Russian roulette with it at home and in public, unaware of its danger. In response to the movie, healthy participants displayed highly synchronized brain activity in sensory-driven auditory and visual areas, as well as in frontal and parietal regions known to support executive function.[19,21–26] Critically, the movie's executive demands, assessed independently outside of the scanner, predicted activity in these frontal and parietal regions. To confirm the similar experience of different participants, another experiment assessed their subjective experience of the movie's suspenseful features on a moment-by-moment basis. A third and independent group of healthy participants rated how "suspenseful" the movie was, from "least" to "most suspenseful," every 2 sec. The perception of suspense was highly similar across different participants, mirroring the highly correlated brain responses of controls who saw the movie in the scanner. Together, these results suggested that executive function in response to the movie drove brain activity in frontal and parietal regions, and further, that the synchronization of this activity across individuals underpinned their similar subjective experience. Thus, the degree to which each healthy individual's frontoparietal brain activity could be predicted from the rest of the group's represented a reliable indication of how similar his or her cognitive experience was to that of others.

Naci et al.[16] applied the same approach in behaviorally nonresponsive patients with unknown levels of consciousness in order to examine and quantify their experience of the world in the absence of self-report. One patient, who had remained behaviorally nonresponsive for a 16-year period prior to the fMRI scanning, demonstrated a highly similar brain response to that of the three independent groups of controls (Fig. 1A–C). The patient's brain activity in frontal and parietal regions – areas known to support executive function[19,21–26] – was tightly synchronized with that of the healthy participants who watched the movie in the scanner. Importantly, the patient's brain response in the frontal and parietal regions was highly sensitive to the movie's executive load, as determined by the second group of controls outside of the scanner, which suggested that the patient had a similar conscious response to the movie's executive demands as the healthy participants. Moreover, the patient's brain response in the frontal and parietal regions was also highly sensitive to the healthy individuals' subjective experience of the movie's suspense, as determined by the third group of controls. This further supported the conclusion that the patient had a similar subjective experience of suspense during the movie as each and every healthy individual. Sensitivity to the executively demanding and suspenseful moments of the movie depended on covert *narrative*

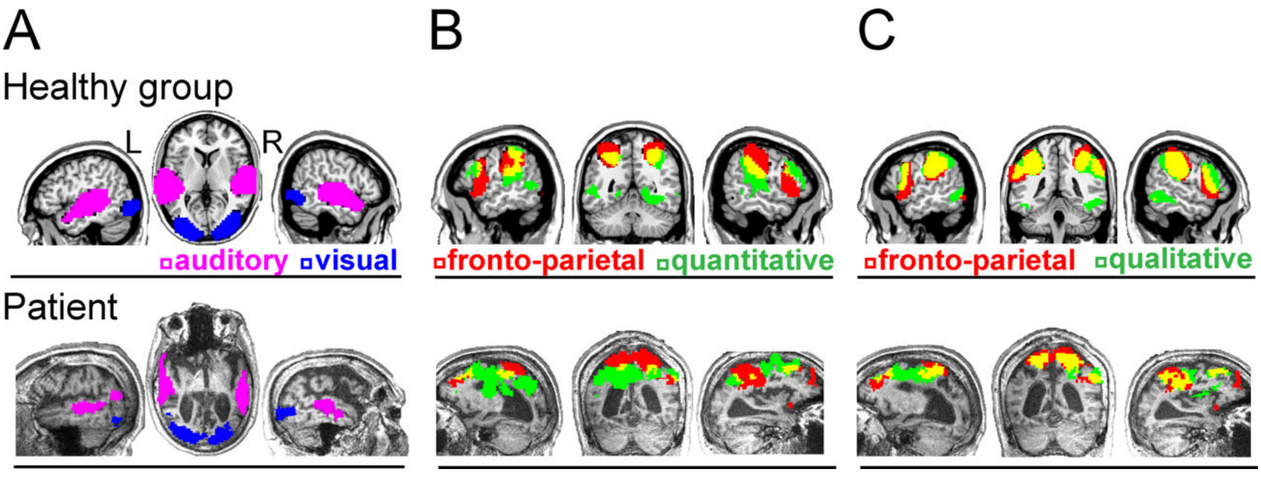

Figure 1. Decoding executive function in one behaviorally nonresponsive patient. *Healthy group*: (A) Group-level auditory (purple) and visual (blue) ICs. The healthy group's activity predicted by the quantitative (B)/qualitative (C) executive measure (green) is overlaid on the group frontoparietal IC (red); overlap areas are displayed in yellow. *Patient*: (A) The healthy group's auditory and visual ICs predicted significant activity in the patient's auditory (purple) and visual (blue) cortex, respectively. The quantitative (B) and qualitative (C) executive measures predicted activity (green) in the patient's frontal and parietal regions. Overlap with activity predicted by the healthy group's frontoparietal IC (red) is displayed in yellow. Adapted from Naci et al.[16]

capacity, or the ability to understand complex, real-world stories that evolve over time.

Here, for the first time, we unpack the sophisticated cognitive repertoire that underlies covert narrative capacity, and discuss several inferences about the preserved mental life of any patient who retains it. Some encompass mental capacities that can be inferred directly from the results of Naci et al.,[16] while others require further abstraction from the study data. Finally, we discuss the ethical implications that arise from these inferences.

Visual and Auditory Function, Including Recognition of Familiar Objects, Voices, and Faces

Probably the most basic requirement for understanding the plot of a film is the ability to hear and see what the characters onscreen are saying and doing. Naci et al.[16] found that activity in the patient's auditory and visual cortex synchronized to that of the healthy controls in these regions, suggesting intact processing of both auditory and visual information in the movie. Similarly, one must be able to employ working and long-term memory in order to identify certain characters from one scene to the next, as well as recognize familiar objects and environments critical to the plot. The fact that the patient displayed highly similar brain activity to the healthy controls in both sensory and high-order frontal and parietal regions while watching the film strongly suggests an ability to integrate auditory and visual information presented in the film across these sensory modalities. This in turn permitted an ongoing understanding of the film's linguistic content, as well as recognition of familiar objects, voices, and faces of the characters.

Executive Function

In addition to the conscious processing of visual and auditory stimuli, a critical component of following a complex narrative in a film is the ability to integrate current information with one's prior knowledge and experiences, to create a meaningful whole. This includes relating events in the film to one's experience of the real world, in order to make predictions about the plot. For example, a key aspect of the plot of the film used in Naci et al.[16] is the fact that the child points a loaded gun and threatens to shoot naïve family members and other bystanders. Understanding these scenes requires that the viewers recognize the object as a gun, draw on their prior knowledge (i.e., that guns can seriously harm or kill people when fired), and infer that *this* gun might seriously harm or kill someone if fired. Moreover, understanding the plot requires sustained attention to relevant information, while filtering out distracting elements. These types of mental capacities are collectively referred to as "executive function."[18] Evidence that the patient responded to the executive demands of the plot in a way that mirrored the response of healthy individuals, suggested that he was capable of the range of meta-cognitive mental processes that comprise executive function.

Theory of Mind

Another important part of understanding a complex narrative is the ability to make inferences about the characters' mental states, in a variety of dynamically unfolding social contexts. Because characters often do not explicitly state their beliefs, desires, and intentions, the viewer must rely on *theory of mind*, or the ability to infer the mental states of others, and differentiate them from one's own.[27,28] For example, the viewer must infer the boy's beliefs about the nature of the gun (i.e., that he falsely believes it is a toy), as well as the beliefs of other characters about the nature of the gun. Thus, the viewer's ability to comprehend the narrative depends on their capacity to correctly attribute true and false beliefs to the characters, in order to explain and predict their behavior. Similarly, the viewer will often need to infer the emotional state of a character in order to properly contextualize their language or behavior. For example, a character perceived as agitated or distressed while uttering "don't shoot" must be interpreted differently from a character perceived as cheerful or insouciant while uttering the same statement. The results from Naci et al.[16] suggest that patients who complete the movie task are capable of employing theory of mind to understand the mental states to others. However, because the movie task was not designed to assess theory of mind directly, any conclusions regarding theory of mind capabilities of patients remains tentative. Nevertheless, successful completion of this task provides compelling grounds for further, direct investigation of theory of mind capabilities in these specific patients. Such research may involve adapting classic theory of mind assessments so that they can be answered via neuroimaging-based binary communication paradigms.[6,10]

Morally Significant Distinctions

In addition to the aforementioned mental faculties, the comprehension of complex narratives frequently relies on "moral reasoning" or the process of determining whether a particular action is right or wrong.[29] Part of moral reasoning involves identifying particular features of a situation as being morally salient, so as to determine whether a certain situation is morally problematic. For example, individuals capable of making moral distinctions might recognize that it is morally bad to shoot a person with a gun, whereas it is not morally bad – or at least, much less so – to shoot a tree or a window. Consistent with this view, healthy participants in Naci et al.[16] demonstrated stronger brain responses in frontal and parietal brain regions – known to support high-level cognition[19] – when the boy pointed the loaded gun at other people (e.g., a housekeeper), as compared to morally neutral objects (e.g., a wall). Furthermore, healthy participants showed even stronger brain responses in these regions when the boy pointed the gun at his mother, as compared to the other characters.

One interpretation of this result is that it reflects the study participants' ability to distinguish between entities with and without moral status. It also suggests that participants attributed a higher moral salience to the child's mother, perhaps reflecting an appreciation of the moral significance of the familial relationship that was absent in the character's other interactions. Like those of the healthy participants, the patient's brain response was highly sensitive to the plot's moral implications, suggesting that his experience of the film may have been shaped by similar moral considerations.

Experience of Affective States

The narrative of movies by Hitchcock – the so-called "Master of Suspense" – such as the one used in Naci et al.,[16] is largely driven by suspense, a complex affective state involving excitement, tension, anxiety, fear, hope, and anticipation.[30] Conversely, the resolution of suspense may be accompanied by positive feelings of satisfaction, relief, or elation, as well as negative feelings like disappointment, sadness, or anger.[31,32] The complexity of the affective experience that comprises suspense suggests that study participants who experienced suspense are capable of experiencing a variety of the more basic affective states that underlie it. Moreover, most theorists agree that a critical component of the experience of suspense is the presence of a protagonist toward whom the viewer has either a positive or negative affective disposition.[33,34] The nature of the viewer's affective disposition toward a particular character, as well as the strength of this disposition, influences the suspense which the viewer feels about the unknown fate of the character; the viewer hopes for a good outcome – and fears for a bad outcome – for characters to which they are positively disposed.[33] This suggests that study participants who experienced suspense while watching the movie had an affective disposition toward at least one of the characters. By extension, any behaviorally nonresponsive patient, such as the one described in Naci et al.,[16] who shows a similar perception of suspense as healthy participants, may also have had a specific (positive) disposition toward at least one of the characters, as well as being capable of experiencing a similar variety of affective states.

Reflection About Future States

The experience of suspense is supported by future-directed cognitive processes, including anticipation and prediction about uncertain future outcomes.[32] Indeed, research suggests that the experience of suspense recruits brain regions involved in making strategic inferences.[35,36] In order to form predictions about future states of affairs, an individual must continually incorporate her prior knowledge and beliefs with new information as it is presented. The fact that the patient reported in Naci et al.[16] was capable of experiencing suspense throughout the movie suggests that he was capable of making inferences about possible future states of affairs based on his prior knowledge and contextual factors. This presents the possibility that such a patient would also be able to make predictions regarding his own future experiences. If a patient is capable of conceiving of a series of events as a cohesive narrative, or perceiving one event as following from another in a meaningful way, she may similarly be capable of organizing her own experiences according to a temporally coherent structure. Therefore, rather than existing merely "moment to moment," such a patient may be capable of reflecting on and interpreting the events of their own life in light of their past experiences and potential future experiences. Of course, while successfully completing the movie task strongly suggests that a patient retains awareness of him or herself as persisting through time, it does not provide conclusive evidence that this is the case. However, further testing of any such patient with neuroimaging-based binary communication paradigms[6,10] that enable direct answering of questions about himself or herself would be one way to establish the presence of self-awareness over time.

Discussion

In summary, the successful completion of the movie task can reveal a great deal about the conscious experience of any behaviorally nonresponsive patient who harbors covert awareness. We have argued that evidence for covert narrative capacity in a patient suggests preservation along several dimensions of the patient's mental life. These include preserved visual and auditory function (including recognition of familiar objects, voices and faces), executive function, theory of mind, and the ability to make morally significant distinctions, to experience emotions, and to reflect about potential future states. Some of these mental capacities can be inferred directly from successful completion of the movie task, while others require further abstraction from the study data and direct investigation in future studies.

When compared to command-following paradigms,[5–14,42–44] the movie paradigm allows for much broader and further reaching inferences regarding the mental life of behaviorally nonresponsive patients (Table 1). Furthermore, when compared to studies that probe the brain at rest[45–49] – and as such cannot shed light on cognitive operations based on sensory input – the movie task enables investigation of specific aspects of a patient's cognition that are inaccessible to resting-state studies. Moreover, the movie task is highly efficient in that it enables multidimensional assessment of cognition within a brief 8-min arc of functional neuroimaging. Brain-injured patients fatigue easily and fluctuate dramatically in arousal over time.[50] Therefore, the testing time window is highly limited and a brief multidimensional assessment is preferable to individual tasks. Additionally, by mimicking real-world experiences, this paradigm engages attention naturally and, thus, is less strenuous for brain-injured patients[51] than tasks that require compliance with arbitrary instructions.[52]

Table 1. Covert cognitive faculties of behaviorally nonresponsive patients that can be revealed by fMRI paradigms.

Paradigm	Task	Covert cognitive faculties
Command-following	*Motor imagery* instructions: Imagine playing tennis; imagine navigating; imagine swimming	Language Working memory Long-term memory Mental imagery Sustained attention to internal imagery
	Selective attention instructions: Attend to the word "yes" or "no"	Language Working memory Long-term memory Selective attention to external stimuli Sustained attention to external stimuli
Covert narrative capacity	*Movie watching* instructions: Pay attention to the movie on the screen	Language Working memory Long-term memory Selective attention to external stimuli Sustained attention to external stimuli Executive function Affective experience Theory of mind Moral discrimination Future-oriented thinking

Adoption Into Clinical Practice: Opportunities and Limitations

In this review, we present proof of concept that behaviorally nonresponsive patients may retain a highly complex mental life, even if they have been thought to lack consciousness for many years. We argue that the identification of the patient reported in Naci et al.[16] makes the case for further investigation of the preserved mental life of patients who demonstrate covert narrative capacity, and indeed, of *any* behaviorally nonresponsive patient, because such findings would have important implications for the patient's standard of care and quality of life. While many patients with disorders of consciousness may be unable to complete the movie task, it is difficult to tell, prior to scanning, which patients will provide a positive response in the MRI scanner. Therefore, a relatively simple, low-effort, and time-efficient task like the movie task is ideal for investigating both covert awareness and covert narrative capacity of patients with disorders of consciousness. Given the potential implications for patient welfare of a positive result, we suggest that the movie task be administered to any behaviorally nonresponsive patient for whom there is an opportunity to do so.

For patients who show evidence of covert awareness on the movie task, the fact that they may retain high levels of preserved consciousness should compel us to redouble our efforts to interact with them in an appropriate manner. Research has shown that strong social networks can promote psychological well-being,[36,37] while the quality of one's social relationships is also a consistent predictor of subjective well-being.[38–41] Therefore, the knowledge that patients may be aware of what occurs around them should affect the interactions the families and clinical staff have with the patient, and among themselves. Accordingly, families, caregivers, and medical professionals may be able to promote the welfare of behaviorally nonresponsive patients who harbor covert awareness by ensuring that patients are engaged in regular interaction with others, for example, by involving patients in social activities, especially in ways that can enhance their feelings of self-worth.

Furthermore, evidence of a highly preserved mental life, especially with regard to the patient's ability to anticipate possible future states of one's own life, reflect upon and interpret the events of one's past, and conceive of oneself as an entity persisting over time, has significant implications for patient welfare. First, if an individual exists only "in the moment," as soon as a particular experience ceases, it ceases to impact their welfare. Conversely, insofar as one can conceive of oneself as having a past and a future, the effects of a particular experience may extend beyond the end of the experience itself, including shaping future experiences and coloring the interpretation of past experiences. Second, the anticipation of future experiences (or reflection on past experiences) may themselves generate certain emotions, such as hopefulness at the prospect of positive future experiences, or anxiety at the prospect of negative future experiences. These may in turn contribute to or detract from an individual's welfare. Third, the ability to reflect on one's life may allow these patients to possess "higher order" interests, beyond merely pleasurable mental states. Indeed, many of the sorts of goods that contribute to individual welfare, such as, the development and achievement of goals or personal projects, and developing relationships with others, require a sense of oneself as a subject persisting through time. This is not only because the experience of these goods occurs over an extended period of time, but also because the realization of these higher order goods is not simply a series of discrete events, but an iterative process, in which past experiences and the anticipation of future outcomes interact to influence one's present experience.

If patients are capable of possessing these sorts of higher order interests, this may present new avenues for enhancing their welfare, as well as a compelling reason for working to ensure that these interests are satisfied. Of course, covert narrative capacity does not itself entail that a patient is faring well; rather, it creates the possibility of a range of interests, the satisfaction or frustration of which may promote or detract from patient welfare. It has been argued that the withdrawal of life-sustaining treatment is most consistent with the welfare of behaviorally nonresponsive with covert awareness.[53] Further discussion of the withdrawal of life-sustaining treatment would require a detailed, case by case analysis of individual welfare, as well as an exploration of the relevant regulations and policies which may vary significantly by region; such an exploration goes beyond the scope of this article. We believe that our analysis of covert narrative capacity is important precisely because it illuminates potential avenues for promoting the welfare of patients who may be experiencing a poor quality of life. Further research is required to determine the sorts of interests, including higher order interests, these patients may be capable of and how these interests may be satisfied, as well as other cognitive capacities these patients may retain. Similarly, because the ways in which we can promote patient welfare are constrained by a patient's residual cognitive capacities and the experiences they are capable of,[54] "intermediate" cases, or cases in which a patient's result shows only partial similarity to that of healthy controls would warrant further investigation, in order to best determine the treatment or care most likely to benefit that patient.

A proportion of patients with disorders of consciousness may not be able to demonstrate covert narrative capacity, and indeed, clinical prevalence is the a topic of current empirical investigation. It is likely that the determination of clinical prevalence will be susceptible to limitations in sensitivity and specificity endemic to neuroimaging-based assessment of mental content.[55] For example, of those patients who show negative results on the movie task, a proportion will be false negatives, and therefore, caution must be exercised when interpreting such results in behaviorally nonresponsive patients. A number of factors can cause a negative result on the movie task: the patient might truly lack awareness, or they might be aware but fatigued at the time of testing, and thus unable to engage with the movie. A patient may also be aware, but unable to understand the movie due to impaired visual function, or because they are lacking some other higher order faculties that prevent them from understanding the movie. Unfortunately, it is impossible to determine which of these factors caused the negative result. Therefore, a negative result on the movie task does not entail that a patient is entitled to lesser care or treatment than would be provided to a patient whose cognitive capacities remain unknown. For example, it is well established that a proportion of chronic behaviorally nonresponsive patients have absent or impaired visual function,[1] and patients in coma by definition have their eyes closed.[56] Therefore, some patients with disorders of consciousness will not be able to process the information presented in an audio–visual movie. To address this limitation, an auditory-only naturalistic paradigm that is highly similar to the movie task has been developed for the assessment of executive function and other mental faculties in these patients.[17] Providing brain-injured patients with naturalistic tasks that tap into different sensory modalities will likely increase the chances of revealing spared cognition and reduce the rate of false negative results.[52]

Caution must also be exercised when interpreting significant positive results that do align with a priori predictions in the movie task. Spurious positive results in patients can sometimes result from neuroimaging analyses, such as, for example, from the normalization of a patient's native brain space to the healthy controls'.[57,58] However, the approach discussed here did not involve normalization to a healthy template, nor did it constrain the patient's expected brain activity based on the localization of the effect in healthy controls. Instead, the time course of brain activity in healthy controls served to build a strong prediction for the temporal evolution of brain activity in the patients, should they retain covert awareness. Drawing comparisons in the temporal domain enabled direct relation of the healthy controls' activation to that of brain-injured patients, while reducing the likelihood of spurious positive results as compared to other paradigms.[17]

Multimodal assessment of patients with disorders of consciousness that combine behavioral testing with multiple neuroimaging techniques, such as F-fluorodeoxyglucose positron emission tomography (F-FDG PET) and fMRI, will likely increase the sensitivity and specificity of determining a patient's residual cognition and consciousness.[59] For example, Stender and colleagues[60] showed that F-FDG PET had high sensitivity for the identification of patients that had been diagnosed as being in a minimally conscious state (MCS)[61] according to the Coma Recovery Scare-Revised (CRS-R)[62] – the gold standard for behavioral diagnosis of disorders of consciousness – and that, indeed, F-FDG PET results were highly congruent with the CRS-R scores. Nevertheless, a patient's covert awareness may be missed by the behavioral CRS-R scale, even if careful repeated tests are conducted.[10,11] In some cases, fMRI has shown an advantage over other technologies in being able to detect signs of covert awareness that had been missed by repeated behavioral assessments with the CRS-R.[10,11]

Despite its strengths, fMRI has a number of limitations, including a high cost, lack of portability, and physical impositions on some patients, that limit its widespread adoption into clinical practice. Therefore, translation of the naturalistic approach discussed here to cheap and portable technologies, such as electroencephalography and functional near-infrared spectroscopy, would render it accessible to a broader section of patients[63] and therefore increase its future clinical utility.

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Author Contributions

L. N. designed the original research study on which this article is based; M. G. wrote original draft of manuscript; L. N. and M. G. cowrote subsequent drafts; A. M. O. and C. W. provided conceptual guidance to overall project.

Conflict of Interest

The authors declare no conflict of interest.

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