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CASE STUDY
'Without A Key': A Classroom Case Study

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This case study uses a narrative focused on locked-in syndrome to engage upper-level undergraduate students with functional neuroanatomy, clinical neuroscience, and brain computer interface technology. Students 'diagnose' the etiology of a composite patient's symptoms using behavioral, neurological, neuroimaging, and electrophysiological test results. Students work both in small groups and as a class to develop analytical and communication skills by exploring the underpinnings, symptoms, and outcomes of locked-in syndrome and how behavioral and brain computer interface techniques could be used to improve quality of life in patients. A complete, detailed description of classroom implementation and the case narratives are available from the corresponding author or from cases.at.june@gmail.com.

Key words: case study, problem-based learning, locked-in syndrome, brain computer interface; event-related potentials

BACKGROUND AND CONTEXT

Classroom case studies use realistic narratives to actively engage students with both specific course content and broader scientific skill development. They could be particularly useful in undergraduate neuroscience education (for a recent discussion, see Wiertelak et al., 2016). Although classroom case studies do not necessarily utilize a narrative based on a single patient or individual, "cases" in this classical sense of the term could be a fruitful source of material for developing novel pedagogical activities. As an example of this approach, the module described here uses a composite patient ("LW") based on several real-world individuals with locked-in syndrome (Hawkes, 1974). In addition, the case study exposes students to aspects of clinical neuroanatomy, neurological examinations, and applications of event-related potential based brain computer interface technology. More broadly, it provides students with the opportunity to work collaboratively to apply and extend their course-related skills in a novel, open-ended setting.

Locked-in syndrome is a condition that results in severe losses of voluntary motor abilities (quadriplegia), including the ability to speak (anarthria; for a clinical review, see Smith and Delargy, 2005)). It is often caused by damage to the pons, and while patients generally retain the ability to make vertical eye movements, some lack even this. A striking aspect of the disorder is that despite the near total (or in some cases, total) loss of voluntary motor function, the individual's consciousness and cognitive functioning are unaffected (Patterson and Grabois, 1986). Patients can thus literally be 'locked-in' their own minds; for an affecting memoir of an individual with the syndrome and a suggested supplemental reading offered to students in this case, see Bauby (1997).

Brain-computer interfaces (BCIs) allow individuals to control a computer or other device using neural signals. A variety of BCIs have been designed to facilitate communication and other activities for individuals living with locked-in syndrome and other motor differences (for a review, see Min et al., 2010). BCIs often employ event-related potential (ERP) techniques, which noninvasively measure cortical function. The P300 component of the ERP has been a particularly useful neuromarker in these technologies (for a review, see McFarland and Wolpaw, 2017). The P300 is a large, positive going component elicited by task- and self-relevant stimuli. Studies on the P300 (and P300-based BCIs) often use variations of the "oddball" paradigm, in which infrequent target stimuli are intermixed with frequently presented "standard" or distracter stimuli. Target stimuli, whether designated by the experimenter or selected by the participant, generate a prominent P300 response (for reviews, see Polich and Criado, 2006; Polich, 2007).

In the current case study, students must work in small groups and as a class to "diagnose" a composite patient by learning about the etiology and presentation of locked-in syndrome, and then consider ways to improve LW's life by utilizing P300-based BCI technology. The module is used in an advanced (junior/senior) level undergraduate *Cognitive Neuroscience* course (enrollment ≈ 25 students) with both lecture and laboratory components. The case is presented towards the end of the semester, when students have already been exposed to many aspects of case content (e.g., the anatomy of the brainstem, ERP techniques, neuropsychological testing) in different formats. The case is immediately preceded by a brief review lecture on the motor system and case implementation takes approximately one-and-a-half 90 minute class sessions. However, it could easily be adapted for other audiences or classroom formats. For example, it could be modified to introduce less-senior students to ERP techniques or the functional anatomy of the brainstem. Similarly, it could be modified for use in more advanced classes as either a review activity or by increasing the "diagnostic" challenges in the narratives or during the classroom implementation phases of the case.

LEARNING GOALS

Content Goals

After completing this case, students should be able to:

- understand the basic functional neuroanatomy of the brainstem
- understand and apply basic neuroanatomical information/terminology
- understand the symptoms and presentation of locked-in syndrome
- understand the relationship between damage to the pons and locked-in syndrome
- understand common neurological tests of brain stem function and apply this information to interpret the significance of a fictional patient's results
- understand and apply basic clinical uses of different ERP components and testing paradigms (including the classic "oddball paradigm") in a fictional patient
- analyze the basic logic and implementation of P300-based BCIs

Process/Skills Goals

After completing this case, students should improve their:

- information literacy skills used to identify unfamiliar scientific and clinical terms
- skills in working collaboratively to consider scientific/clinical evidence and form arguments
- abilities to implement existing content knowledge in novel settings
- skills in considering the social and personal implications of neural insult on patients' lives and communicating scientific information to nontechnical audiences

OVERVIEW OF CLASSROOM IMPLEMENTATION

Prior to the case, students individually complete a preparatory narrative assignment that introduces LW's history, symptoms, and test results (without specifically revealing her diagnosis). During the first class period, they work collaboratively in small groups (and through whole class discussions) to interpret the significance of her neurological and neuroimaging/ERP test results, diagnose the primary locus of her neural damage, and consider the implications of seemingly conflicting test results (e.g., between her outward presentation and her ERP results). After a differential diagnosis process, students arrive at the conclusion that the patient is living with locked-in syndrome. During the last portions of the class session, students consider the ramifications of the disorder on the patient's daily life and on her family, and brainstorm ideas about developing communication systems based on her remaining motor abilities (vertical eye movements).

In the subsequent class session, the case study is interweaved with brief, targeted lecturing on BCI technology to facilitate "just-in-time" learning (e.g., Riel, 1998) of information that students will immediately utilize. At the start of class, students learn that following an additional neural insult, LW's condition has deteriorated and she lost her ability to control even vertical-eye movements. Students are tasked with developing an ERP-based BCI to allow her to communicate despite her totally locked-in state. Students work in both small groups and as a class to devise ways of implementing information they have learned over the course of the semester about ERP techniques (e.g., on the neurocognitive correlates of the P300 component, the use of "oddball" paradigms) to develop ideas for first a simple (yes/no responses) and then a more complex (speller) P300-based BCI. Finally, they consider other useful ways that BCI technology could be implemented (e.g., to control web browsers, remote controls, wheelchairs, etc.) and both social and scientific factors that affect the development of BCIs.

CASE ASSESSMENT

This case was first presented in 2017 and was refined and repeated in subsequent years (for a total of three iterations). Following the initial (2017) and most recent offerings (Spring 2019), students had the opportunity to provide anonymous online feedback (via SurveyMonkey) about the case. These feedback data were collected to assess the effectiveness of a standard classroom exercise (*N 2017*=18, *N 2019*=13, *Total N*=31, 68% of students had no prior knowledge of locked-in syndrome). As such, the Lewis & Clark College Human Subjects Research Committee deemed them exempt from the informed consent process and gave approval for them to be presented here in aggregate form.

Eight feedback questions assessed students' qualitative experiences (Table 1), with potential responses ranging between 1 ("Strongly Disagree") and 5 ("Strongly Agree"). The author was interested in the percentage of students who felt the exercise met the goals described above, so a mean rating of 4 ("Agree") was considered to indicate a positive result. One question (Yes/No) probed whether students had any previous knowledge of locked-in syndrome, and a final multiple-choice question specifically probed for content acquisition ("Locked-in syndrome often results from damage to the ___: Pons; Medulla; Inferior and Superior Colliculi; Cerbellum; None of the above).

Student ratings were generally positive. Importantly, 96% of respondents "agreed" or "strongly agreed" (score ≥4) that the exercise was "…engaging and enjoyable", and that it "…provided a good opportunity to work collaboratively to answer complex neuroscientific problems." The strong majority of respondents also "agreed" or "strongly agreed" that the case "…was more engaging than a traditional lecture" (83%), and that it was "…useful to work with other students to explore unfamiliar material" (96%).

Students also generally felt that the case was successful in meeting learning goals. 96% of students "agreed" or "strongly agreed" that the case "…increased my knowledge about the symptoms and causes of locked-in syndrome" and 81% "agreed" or "strongly agreed" that it "…helped me increase my knowledge [sic] event-related potentials and brain computer interfaces". No respondents "disagreed" or "strongly disagreed" with either of these questions. In the content probe, 90% (28/31) of respondents correctly identified the pons as a typical locus of damage in locked-in syndrome.

DISCUSSION

The majority of students found that the case was engaging, that it afforded them good practice exploring unfamiliar scientific content, and that it was useful to work

Item	N	Mean (SD)
The case study:		
…was engaging and enjoyable	31	4.13 (.56)
…was more engaging than traditional lectures	30	4.27 (.52)
…was a good opportunity to work collaboratively to answer complex neuroscientific problems	29	4.17 (.47)
…was useful to work with other students to explore unfamiliar material	30	4.27 (.83)
…complemented my learning/understanding of related course readings and lecture materials	30	3.83 (.79)
…provided useful practice with searching for information about unfamiliar terms/topics	30	4.00 (.83)
…increased my knowledge about the symptoms and causes of locked-in syndrome	30	4.50 (.58)
…increased my knowledge of event-related potentials and brain computer interfaces	31	4.10 (.75)

Table 1. Presents the mean (SD) response for items on the feedback questionnaire. Responses were given on a scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). A score of 4 corresponded with "Agree". Differences in *N* reflect that some respondents skipped certain questions.

collaboratively with other students. Similarly, the students felt that the case increased their knowledge of locked-in syndrome, BCI technology, and ERPs, and 90% correctly answered the multiple-choice content probe. As such, the data suggest that the case meets both its process and content goals and therefore could be a useful addition to other undergraduate neuroscience classrooms. However, it is important to note that while examples of exam questions are presented in the case implementation notes, broader assessment data (beyond the anonymous online feedback) could not be included here. As such, instructors should carefully assess learning outcomes in their students to ensure the case is meeting their needs.

The case could also easily be broadened or altered to suit the needs of a particular instructor or audience. As separate examples of extensions from my classroom, this case has been paired with additional engaging anatomy exercises (using immersive virtual reality software to view the pons and surrounding vasculature: https://www.3dorganon.com/) and with demonstrations of a simple BCI controlled grasper (https://backyardbrains.com/products/clawBundle). Indeed, given that feedback questionnaire data suggested that a weaker aspect of this case is its integration with other parts of the course, determining ways to make this exercise coalesce more smoothly with other lecture and reading assignments will be an important future direction.

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