Title
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Journal
Neurosurgery, 89(2)

ISSN
0148-396X

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Publication Date
2021-08-01

DOI
10.1093/neuros/nyaa440

Peer reviewed

Clinical Pearls and Methods for Intraoperative Awake Language Mapping

CNS Spotlight

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Received, April 27, 2020.
Accepted, July 12, 2020.
Published Online, December 8, 2020.

Intraoperative language mapping of tumor and peritumor tissue is a well-established technique for avoiding permanent neurological deficits and maximizing extent of resection. Although there are several components of language that may be tested intraoperatively (eg, naming, writing, reading, and repetition), there is a lack of consistency in how patients are tested intraoperatively as well as the techniques involved to ensure safety during an awake procedure. Here, we review appropriate patient selection, neuroanesthetic techniques, cortical and subcortical language mapping stimulation paradigms, and selection of intraoperative language tasks used during awake craniotomies. We also expand on existing language mapping reviews by considering how intensity and timing of electrical stimulation may impact interpretation of mapping results.

KEY WORDS: Awake craniotomy, Language mapping, Direct cortical stimulation

Neurosurgery 89:143–153, 2021 https://doi.org/10.1093/neuros/nyaa440 www.neurosurgery-online.com

A long-held tenet of surgery for brain tumors within eloquent cortex is that care must be taken to preserve neurological function while striving for maximal extent of resection. Permanent postoperative neurological impairments, particularly involving language and motor function, are associated with worse overall survival and lower quality of life.[1-4] Furthermore, severe neurological impairments may in fact negate the survival benefits gained from extensive tumor resection.[5-13] Intraoperative language mapping of lesional and perilesional tissue is a well-established technique for avoiding permanent neurological deficits.[14-22] This approach was introduced by Penfield and subsequently popularized by Ojemann and others with the culmination of several different techniques described in the literature for the testing, identification, and monitoring of functional sites.[23-25] Despite differing published methods, they all have in common the administration of short pulses of electrical stimulation during completion of a language task. Stimulation is thought to result in focal disruption of networks involved in speech and language processing as demonstrated by correct and incorrect patient responses.

In this review series focused on surgery for eloquent area tumors, this article will discuss commonly applied methods for awake language mapping craniotomies. Intraoperative motor mapping and the physiology of language processing has been addressed in other submissions. Building on prior published awake language reviews, we begin with patient selection, neuroanesthetic techniques, cortical and subcortical language mapping stimulation paradigms, and the selection of intraoperative language tasks (Figure 1). We then consider how the intensity and timing of electrical stimulation may impact interpretation of intraoperative language mapping results.

ABBREVIATIONS: ADP, after-discharge potential; **AF,** arcuate fasciculus; **BMI,** body mass index; **DTI,** diffusion tensor imaging; **EEG,** electroencephalography; **fMRI,** functional magnetic resonance imaging; **IFG,** inferior frontal gyrus; **IFOF,** inferior fronto-occipital fasciculus; **LMA,** laryngeal mask airway; **MEG,** magnetoencephalography; **PN,** picture naming; **SLF,** superior longitudinal fasciculus; **SMG,** supramarginal gyrus; **STG,** superior temporal gyrus; **UF,** uncinate fasciculus

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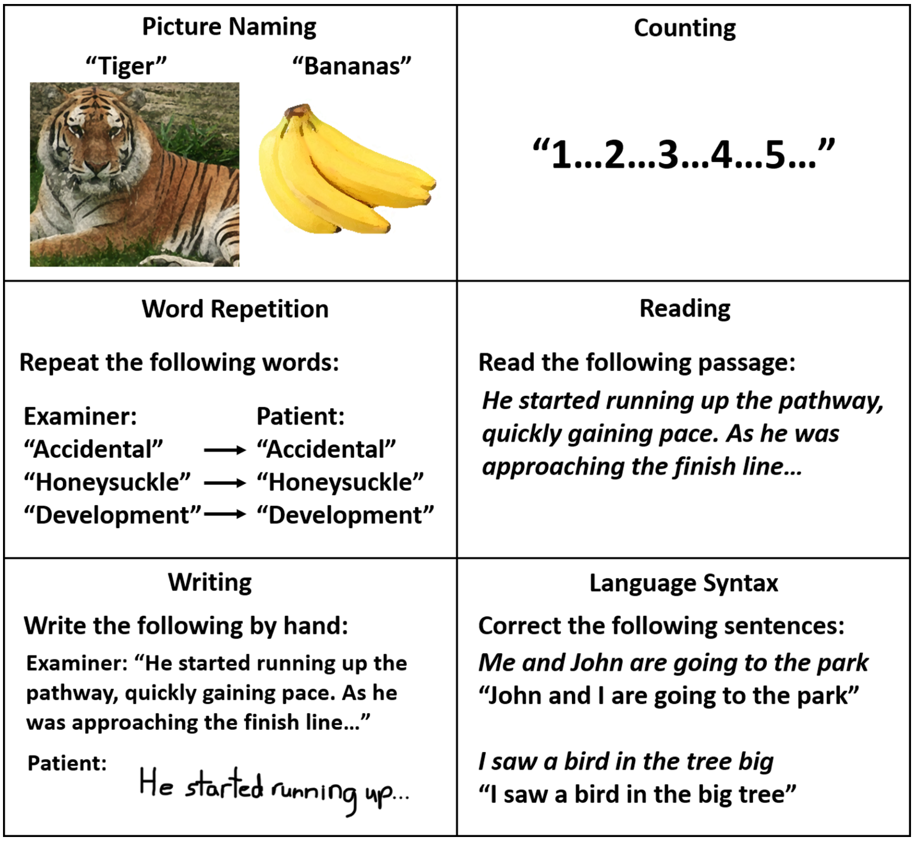

FIGURE 1. *Intraoperative language tasks. Intraoperative testing can include PN, counting, word repetition, reading, writing, and assessing language syntax.*

SELECTING PATIENTS FOR INTRAOPERATIVE LANGUAGE MAPPING

Patients with supratentorial tumors that are within or near possible eloquent language areas should be considered for awake intraoperative mapping, even when language is intact preoperatively.[14] There are several contraindications to performing awake intraoperative mapping language (Figure 2). Although there are no established guidelines, baseline language task performance must have an acceptable error rate. Patients being considered for awake language mapping must have no greater than 10% to 25% naming errors.[14] Individuals with language impairments prior to surgery may be treated with dexamethasone (2-6 mg PO q6-8 h) and/or mannitol (30-50 g intravenous q8 h) for a period of 2 to 3 d followed by language reassessment. Electroencephalography (EEG) monitoring may be considered for individuals with persistent language impairments to rule out language-related seizure activity. In addition to language-specific contraindications, patients who have significant mass effect on preoperative imaging (>1 cm of midline shift) despite steroids and diuretics are at risk of further intraoperative cerebral edema. In these cases, many will offer a staged procedure for low-grade patients with resection of a portion of the tumor presumed to be within noneloquent areas followed by a second procedure with awake mapping if language function improves.[14] For patients with significant mass effect, awake language mapping may not be safe. It is therefore reasonable that these patients undergo an asleep procedure using imaging techniques such as functional magnetic resonance imaging (fMRI), magnetoencephalography (MEG), and tractography when available.[14]

Obesity has remained a challenge when considering an awake language mapping craniotomy because of its association with obstructive sleep apnea, other medical comorbidities, and difficulties administering intravenous sedation without suppressing respiratory drive. Patients with morbid obesity (as defined by anyone with body mass index [BMI] > 40 or individuals with a BMI > 35 also experiencing obesity related health conditions such as hypertension or diabetes mellitus), an awake language mapping craniotomy may be contraindicated and should be considered on a case-by-case basis. Obese patients are prone to

Concern	**Solution**
1. Severe baseline aphasia (> 10-25% error rate)	1. IV Dexamethasone +/- IV mannitol, ? EEG
2. Significant mass effect (>1 cm of midline shift)	2. Staged resection
3. Obesity (BMI >35)	3. Nasal trumpet, LMA
4. Underlying emotional/psychiatric disorders	4. Psychiatry consult, antidepressant/ mood stabilizing medications
5. Persistent chronic cough	5. Dexamethasone, gabapentin, codeine
6. Young age (<10 years of age)	6. Subdural grid for extra operative mapping
7. Intraoperative nausea	7. IV antiemetics
8. Intraoperative seizure	8. Cold LR, Propofol

FIGURE 2. *Concerns and relative contraindications to awake language mapping and identified solutions.*

hypercapnia and intraoperative cerebral edema; however, tools such as nasal trumpets and laryngeal mask airways (LMAs) have significantly enhanced intraoperative language mapping options for these patients.

Age may be a relative contradiction for an awake procedure. For children younger than 10 yr of age, an established approach is to treat with a 2-stage approach, first placing subdural grids with extraoperative language mapping to identify cortical language sites followed by returning to the operating room for subsequent lesion resection on a separate day.[14] Many children older than 10 yr of age are able to tolerate an awake craniotomy with preoperative coaching, intermittent intravenous sedation, and the proper use of local and intravenous analgesic medications. Published reports include the safe completion of awake brain mapping craniotomies in children as young as 8 to 9 yr of age.[26,27]

The published failure rate of an awake craniotomy can be low, with 0.5% to 6.4% reported rates of aborted procedures due to intraoperative complication.[14,21,28] Intraoperative stimulation-induced seizures are the most significant predictors of failed or aborted awake language mapping craniotomies. It is therefore essential to ensure that preoperative seizure control is optimized.[14]

PREOPERATIVE ASSESSMENT

There are several imaging modalities that are instructive and may be obtained prior to an awake language mapping craniotomy. A preoperative MRI with and without gadolinium contrast should be obtained for all patients. Magnetic source imaging with MEG can provide long-range measures of functional connectivity that may predict risk of long-term postoperative neurological impairment.[29,30] Although fMRI and MEG are useful adjuncts to approximate functional intra- and peritumoral regions, they are insufficiently sensitive to exclude function and cannot be used to justify asleep surgery when language may be at risk. Diffusion tensor imaging (DTI) may be obtained as part of the preoperative scan that allows for tractography and visualization of relevant subcortical fiber tracts and their relationship to the tumor.[31,32] DTI tractography identifies dorsal and ventral subcortical tracts of importance for language processing in addition to their location relative to the tumor. Important subcortical tracts involved in language processing include the superior longitudinal fasciculus (SLF), the inferior fronto-occipital fasciculus (IFOF), the arcuate fasciculus (AF), and the uncinate fasciculus (UF). A number of language deficits can be observed with

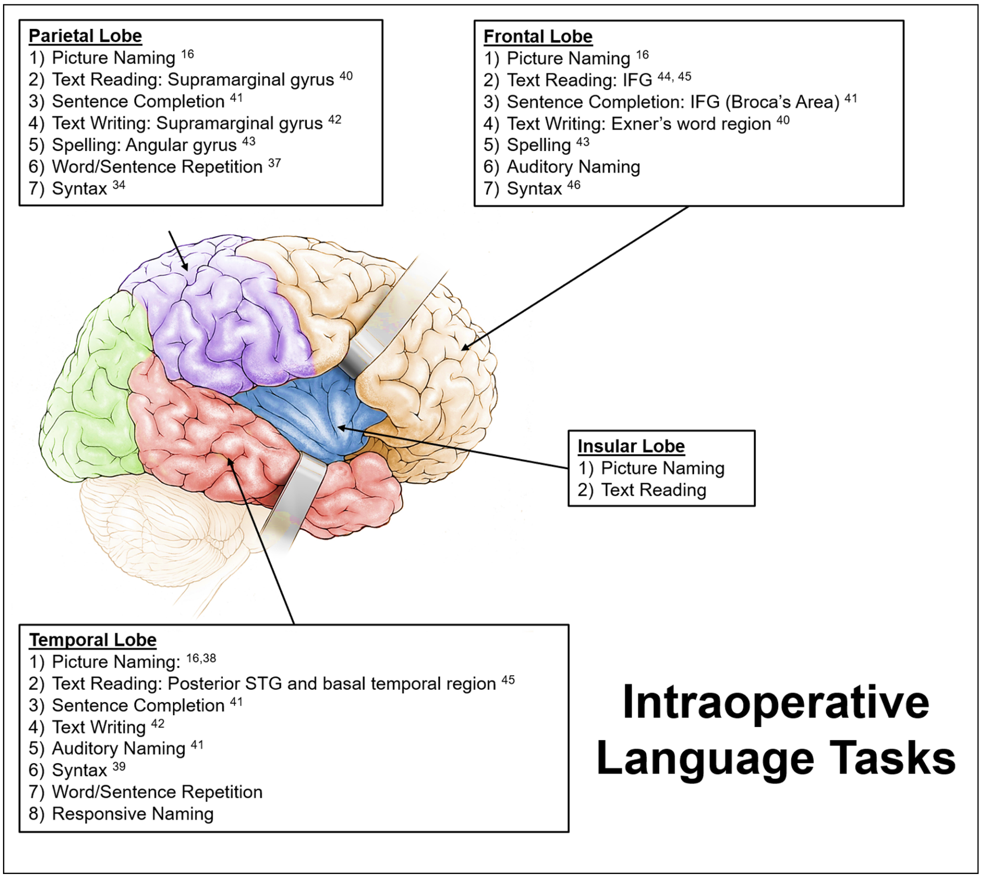

FIGURE 3. *Intraoperative language tasks based on tumor location.*

injury to specific tracts and include speech arrest and dysarthria (SLF), repetition errors and phonological paraphasias (AF, SLF), semantic paraphasias (IFOF), and syntactical errors (AF, IFOF, UF).[33]

Preoperative language assessments vary by institution. Baseline preoperative testing is performed by a surgical neuropsychology team 24 to 48 h prior to surgery. Across institutions the most commonly used baseline language assessment includes picture naming (PN) of visual stimuli, text reading, short word spelling, text writing following a visual picture stimulus, short-phrase sentence completion, syntax, auditory naming, and responsive naming.[4,14-16,18,29,34-37] Task selection varies depending on tumor location, patients baseline level of performance, and institutional protocol (Figure 3; includes references).[16,34,37-46] Visual PN remains the most commonly used language task.[25] Following completion of baseline testing the intraoperative testing battery is tailored with removal of incorrect stimuli. During the preoperative assessment of a patient, the procedural steps and expectations should be discussed thoroughly.[47]

SURGICAL TECHNIQUE AND PEARLS

Patient Positioning

As with any planned craniotomy, patient positioning is critical to the success of the awake language mapping craniotomy. The patient is placed in a semilateral position with the head turned contralateral to the side of the tumor. All extremities are padded, and if motor mapping is to be performed in addition to language mapping, the contralateral arm and leg are exposed for inspection. The operating room is preheated and a patient is covered in warm blankets and a Bair Hugger (3M Corp) in order to keep core body temperature between 36°C and 37°C. Patients are given supplemental oxygen typically by nasal cannula. Before Foley catheter placement, a low-dose propofol infusion is started to help with patient sedation and comfort. During this same infusion, the patient is given local anesthetic at the pin sites and the head is placed in a Mayfield head holder. A head position that avoids flexion is chosen that minimizes airway obstruction. If there are concerns about CO_2 retention, a nasal trumpet can be placed. After patient positioning neuronavigation can be registered, which allows for marking of a focused craniotomy over the area of interest.

Anesthesia Regimen

A neuroanesthesiology team with expertise in awake craniotomies is essential to the success of intraoperative awake language mapping. Prior to initiation of anesthesia, the patient is premedicated with an antiemetic to minimize nausea and reduce risk of intraoperative emesis. Intravenous dexamethasone (typically 2-8 mg) and mannitol (typically 30-100 g) may be administered as needed. Anticonvulsant medications are continued if started preoperatively or given at the beginning of the procedure. Levetiracetam (500-1000 mg IV) and fosphenytoin (20 mg/kg) are the most commonly used antiepileptic medications given prior to awake language mapping craniotomies.[14] Local analgesia (consisting of 1% lidocaine with 1:100 000 epinephrine and 0.5% bupivacaine) is used for application of the Mayfield head holder in addition to a field block along the entire incision with separate foci of local anesthetic to the supraorbital, supratrochlear, auriculotemporal, and lesser occipital nerves.[14] Complete scalp blocks by targeting all major scalp sensory nerves may permit patient comfort and limit the need for additional anesthetic during the procedure.

There are 2 overarching techniques for awake language mapping craniotomies including the "asleep-awake-asleep" approach and "conscious sedation" also known as the "awake-awake-awake" approach. Both techniques have been proven to be safe with low rates of aborted or failed procedures. The surgical and anesthetic team must be flexible with the regimen chosen in order to successfully complete an awake craniotomy and mapping as a transition of anesthesia protocol is required for successful completion in as many as 42% of the cases.[14] During the asleep-awake-asleep approach, the procedure begins with administration of either propofol-remifentanil, dexmedetomidine-remifentanil, or a combination of propofol-dexmedetomidine-remifentanil. This technique can allow for deeper sedation during painful portions of the procedure but may result in longer "wake up" time prior to mapping. Furthermore, the anesthesia team must remain vigilant and may experience difficulty replacing the LMA if the patient is insufficiently awake after its removal. Suero Molina et al recently showed that patients who received conscious sedation required fewer opiates, vasoactive medications, and antihypertensive drugs, which resulted in shorter postoperative lengths of stay and operative times.[48] Others have also shown that while conscious sedation is associated with higher rates of agitation and intraoperative seizures, the risk of intraoperative hypertension is greater for an asleep-awake-asleep approach.[28] In a randomized control trial comparing dexmedetomidine to propofol, the dexmedetomidine group was associated with fewer respiratory adverse events and there was no difference in the degree of sedation or the ability of patients to perform mapping tasks.[49] Prior to intraoperative language mapping, all sedation is reduced or stopped entirely. It is important to assess patient wakefulness prior to commencement of mapping as the cognitive effects of intravenous anesthesia may linger long after these medications have been stopped.[50]

Craniotomy Opening

The surgical steps in an awake craniotomy are similar to that when performed for an asleep patient. The patient is sufficiently sedated during opening for comfort, and additional lidocaine may also be used for patient comfort. The goal of the surgical exposure is to identify a safe surgical corridor to approach the tumor. Many will employ small cortical exposures with reliance on negative mapping rather than large craniotomies, which may facilitate the identification of positive cortical language sites.[15] Dural manipulation can be painful so local anesthetic may be administered through a 30-gauge needle to the dural branches of the trigeminal nerve around the middle meningeal artery.

Avoidance of Intraoperative Seizures

Intraoperative seizure control is one of the main concerns during awake craniotomies and is a contributor to a significant portion of failures.[14,21,51] The use of intraoperative electrocorticography has allowed not only the identification of afterdischarge potentials (ADP), but also identifying an appropriate stimulation current for intraoperative testing. Historically, intraoperative stimulation-induced seizures were controlled with intravenous lorazepam, but this often-necessitated cessation of intraoperative testing. More recent methods for seizure abortion include iced lactated Ringer's solution applied locally to the cortical surface with the delivery of propofol, which should be readily available during stimulation testing, as an alternative measure.

INTRAOPERATIVE LANGUAGE TESTING

Picture Naming

The most common intraoperative language mapping task employed is PN. Errors during PN have been aggregated into 6 categories: semantic paraphasias (king → "queen"), circumlocutions (pen → "thing used to write"), phonological paraphasias (deletions or substitutions of syllables), neologisms (made-up words), performance errors (slurred or stuttered responses), and no response errors (speech arrest).[52] PN is used when mapping gliomas in the frontal, parietal, temporal, or insular lobes (Figure 3). Different cortical regions may produce different errors. For example, the posterior supramarginal gyrus (SMG) has been shown to produce performance errors (eg, slurred speech, stuttering) during cortical stimulation, while the posterior middle temporal gyrus frequently generates semantic paraphasias during intraoperative stimulation. This fits with the dorsal and ventral pathways of language processing as stimulation above the superior temporal sulcus frequently impairs phonological processing while in inferior temporal sites frequently impairs semantic processing.[53] Semantic paraphasias, however, have also been identified in the frontal lobes with stimulation of the pars orbitals of the inferior frontal gyrus (IFG).[16]

Some authors have argued for the superiority of an action naming or verb generation task compared to the object naming task, but there is no consensus on the type of naming task that should be applied in the intraoperative setting. Naming may also be tested with auditory inputs rather than visual stimuli. In auditory naming tasks, participants name an object upon hearing its description (eg, "a thing that tells time" "clock"). Some studies have shown that auditory naming may be more sensitive to detecting naming impairments during intraoperative mapping, and performance on auditory naming tasks may correlate more with postoperative word-finding language impairments.[38,54,55]

Counting

Counting is another commonly used task to identify speech arrest sites. The patient is asked to slowly count to either 5 or 10 while stimulation is applied to cortical and subcortical sites. Speech arrest in this context is defined as the inability count without tongue, larynx, or pharynx movement. Alternatively, if arm movement or tongue movement also occurs, the response is more consistent with either motor arrest or dysarthria, respectively. Mandonnet et al argued for an optimized strategy where, after counting and cortical motor testing, the surgeon assesses for PN and a motor response, to distinguish between anomia and speech arrest (ie, when naming and counting are impaired).[56]

Word Repetition

Patients with conduction aphasia generally have fluent natural speech and preserved perception capabilities, but an inability to repeat words verbatim, suggesting that the perceptional, comprehension, and motor representations of the word are disconnected. To test word repetition, patients are first familiarized with a list of words usually between 2 and 4 syllables long and containing simple and difficult words (ie, words with consonant clusters and pseudowords that are derived from scrambled real words (eg, "delight" → "ledite"). Patients are then instructed to repeat individual words while direct cortical stimulation is applied to the cortex. The AF, which connects the inferior frontal cortex with the posterior superior temporal cortex, has been thought to be the primary culprit. More recent work however has suggested that verbal repetition requires coordination between multiple brain regions.[57] The posterior and middle superior temporal gyrus (STG), the anterior STG, and SMG are the most common cortical sites for stimulation induced repetition errors.[58]

Reading

Text reading has been used for intraoperative language mapping for tumors in frontal, parietal, temporal, and insular lobes (Figure 3). Reading tasks involve having the patient read short, unrelated sentences that have not been previously rehearsed. While the patient is reading, stimulation is applied to assess for interference in function. Errors in reading have been previously categorized into articulatory sites, pure reading arrest sites (patient stops reading and resumes upon cessation of stimulation, without obvious orofacial contraction), paraphasia sites (fluent speech with incomprehensible word choices), and sites that elicited ocular movements.[59]

Contemporary dual-route models separate reading into 2 distinct pathways: (1) the lexical-semantic pathway for irregularly spelled words and (2) the phonological pathway for unknown or pseudowords. The lexical-semantic pathway appears to localize to basal temporal regions, the posterior middle temporal gyrus, and pars triangularis of the IFG, whereas the phonological pathway localizes to inferior parietal and inferior frontal regions.[40,44,45]

Writing

Writing has been used as an intraoperative language mapping task for tumors in frontal, parietal, and temporal lobes (Figure 3). Patients are asked to write out dictated text using their dominant hand. Patients should be able to see what they are writing, and a writing pad is often held up to them at a visible distance by other operating room staff. While writing, direct cortical stimulation is applied, and writing deficits may include letter omissions, writing arrest, or illegible script.[60]

An impaired ability to write (ie, agraphia) can exist in multiple forms, including phonological and lexical agraphia. Patients with phonological agraphia cannot sound out words and have impairment in spelling unfamiliar or pseudowords (eg, prink). Those with lexical agraphia lose their ability to visualize words, which is a function particularly useful for words that are irregular or ambiguous (eg, friend vs frend). Historically, writing function was tied to the second frontal convolution (F2, also known as "Exner's area").[61,62] However, other groups have also identified inferior parietal sites that lead to agraphia.[63]

Language Syntax

To date, language syntax is the least commonly applied language domain during intraoperative mapping. Given the need to test more than a single word to investigate syntax, these tasks may be relatively complex, take more time, and therefore harder to perform in the operating room setting. Some studies using direct cortical and subcortical stimulation have identified the IFG, specifically the pars opercularis and triangularis as crucial hubs for language syntax networks, and the AF white matter pathway connecting the IFG to the temporal lobe being the important structures to preserve when attempting to preserve language syntax abilities.[46]

ELECTRICAL STIMULATION-TASK RESPONSE PARADIGMS

There are 2 major stimulation parameters that can be utilized during intraoperative cortical or subcortical brain mapping: bipolar and monopolar stimulation. Ojemann established the low-frequency bipolar stimulation mapping protocol to identify cortical language areas,[23,64] and recently the utility of high-frequency monopolar stimulation has been described.[18,36] Low-frequency bipolar stimulation as described by Ojemann remains the mainstay for awake language mapping. Typically, a frequency of either 50 Hz (Europe) or 60 Hz (North America) pulse trains is delivered. Early work demonstrated that an anodal current can generate a cortical stimulation effect with a lower stimulation intensity.[65] Since a biphasic pulse contains both an anodal and cathodal phase, the duration of the pulse stimulation includes both a negative and positive phase, and as a result only half of the pulse duration is effective for stimulation purposes compared to a monophasic pulse that delivers effective stimulation for the entirety of the stimulation duration.[66] Importantly, the charge delivered to the brain is dependent on the pulse duration and stimulation amplitude, meaning that biphasic stimulation pulses deliver twice the charge for the same amount of current as a monophasic pulse. Generally, the maximum intensity is limited to 20 mA.[67,68] Another important difference between bipolar and monopolar stimulators is the direction of the electric field generated. The monopolar probe creates a homogenous radiant spreading electric field, which has a lower density of current in the area of stimulation but more spacious area of stimulation. This is in comparison to the more homogenous current density created by the bipolar stimulator, where the electric field lines between the poles of the stimulator are nearly parallel.[69-71] Monopolar stimulation has been associated with decreased intraoperative seizure activity[36,72,73] although there may be local tissue damage based on animal models.[74] "Dynamic" mapping involving a specialized monopolar suction stimulator may also be used, allowing for resection and subcortical stimulation simultaneously.[75]

Electrocorticography may be used during the awake language mapping to measure stimulation-induced ADP. In many mapping protocols, ADP is also used to select the amplitude of stimulation. However, it remains unknown whether increasing stimulation amplitude correlates with a greater number of direct cortical stimulation positive cortical language sites. Initial cortical language mapping stimulation intensity is 2 mA, and if no responses are detected, the stimulation intensity is increased up to a maximum of 6 or 1 mA below than that which evokes ADP.[14] Stimulation sites are spaced over every 1 cm^2 of exposed brain surface overlying the tumor in addition to a 2 to 3 cm margin of surrounding cortex. A neuropsychologist performs intraoperative language testing in cooperation with neurosurgery. Positive language sites have been historically defined by stimulation-induced anomia, alexia, or semantic or phonological paraphasias during at least 2 of 3 stimulation trials.[14]

Subcortical mapping is also essential for avoiding postoperative language deficits. During tumor resection, bipolar or monopolar stimulation may be used to assess for eloquent language tracts including the SLF, IFOF, and AF.[33] The SLF and AF are the major fiber tracts involved in the dorsal stream language processing with injury leading to articulation and repetition errors while the IFOF is a key component of ventral stream language processing leading to semantic errors. Patients are often kept awake or intermittently awakened during subcortical mapping, and stimulation leading to specific errors (ie, semantic paraphasias as a marker for the IFOF) may help identify and protect these functional tracts.

While the majority of research has focused on which tasks are best to employ to identify critical language sites, much less attention has been given to the specific electrophysiological parameters of the stimulation itself, such as the current intensity, amplitude, duration, and volume of brain stimulated in the setting of an intrinsic brain tumor. For instance, does the cortical location (eg, frontal vs temporal cortex) influence the stimulation threshold? Does the timing of stimulation initiation or the stimulation duration impact patient performance (Figure 4)? How does cerebral edema affect stimulation sensitivity? Do distinct tasks (eg, PN vs sentence generation) have positive or negative responses at differing stimulation thresholds?

Cortical stimulation current intensity appears to impact language task performance. In a study by Roux et al, stimulation parameters were adjusted within and between patients, and current intensity was shown to affect language task performance (primarily response type).[76] The authors found the mean intensity to produce a positive naming interference site was 4.46 mA. This study also demonstrated that when stimulation current was increased, the type of naming error changed, for instance anomia transformed into speech arrest. In over 50% of positive mapping sites, percentage of positive site could be increased by increasing the stimulation threshold. They therefore concluded that in most cases, cortical language sites are represented as an "on/off" effect, and a "graded" response to increasing stimulation thresholds may be present at a minority of cortical sites.[76]

Similar to varied stimulation intensity, little research has explored the impact of electrical stimulation relative to task onset (Figure 4). Commonly, stimulation is applied during a short period immediately prior to stimulus onset (typically 1.4 s prior to a picture appearing for a PN task). This assumes that electrical cortical stimulation influences the neural processing required to produce an appropriate task response. Using this model, cortical language mapping interrogates primarily motor speech planning and production (ie, Broca's area) for short tasks such as PN. However, it is possible that some neural responses may not be completely probed by stimulating through the stimulus and not the task response. There is a potential that prolonged stimulation durations throughout both stimulus and response could impact the type of stimulus response produced or sensitivity of finding an eloquent site. Accordingly, recent work suggests that select language tasks involve neural network activity of differing spatiotemporal dynamics, with cortical activation at different time points in relation to response onset[77] (Figure 4).

OUTCOMES AFTER AWAKE LANGUAGE MAPPING

Intraoperative stimulation mapping is the gold standard for minimizing postoperative neurological deficits[78] (Table, includes

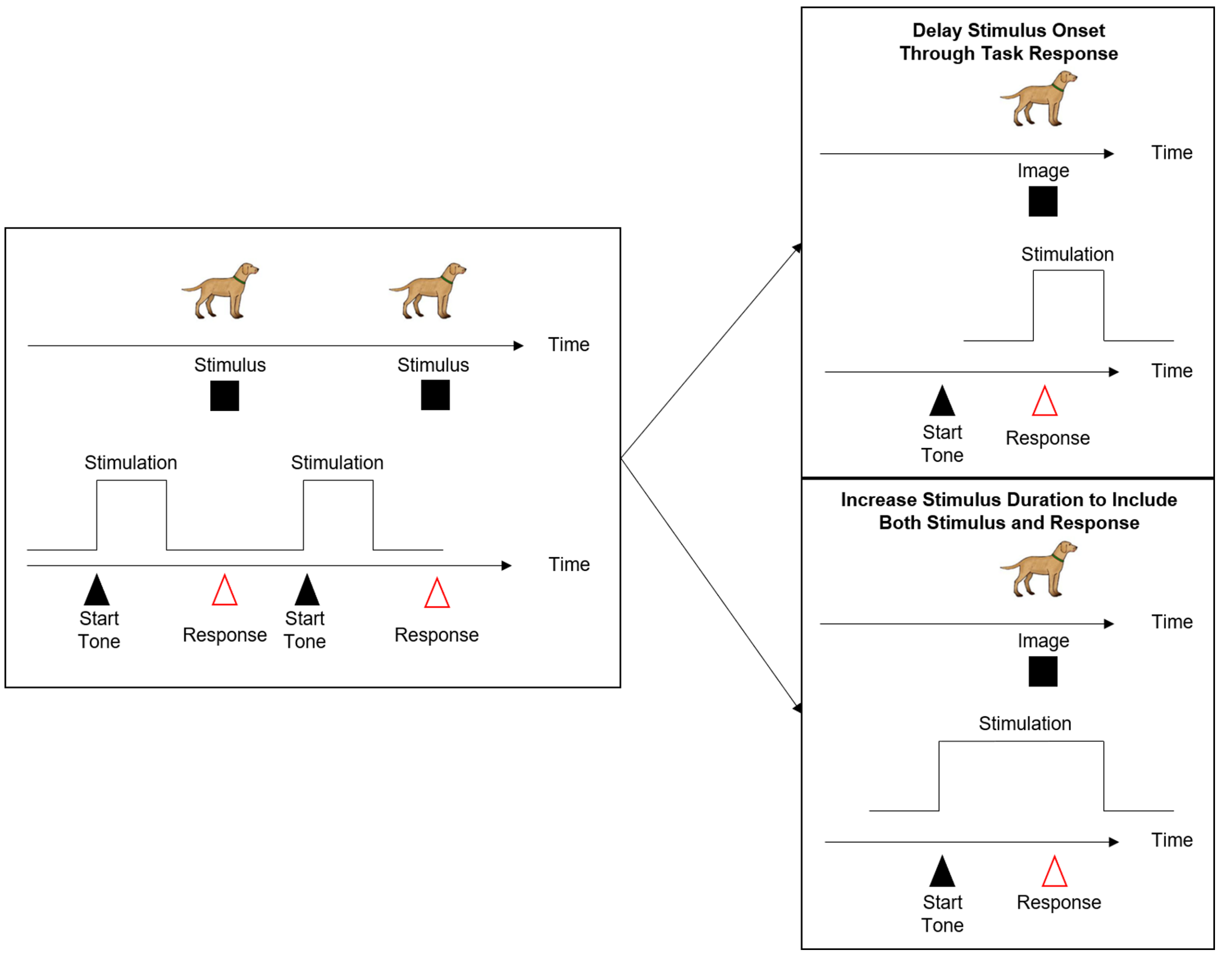

FIGURE 4. *Electrical stimulation-task response paradigms. Standard stimulation paradigms involve delivery of an electrical stimulus 1.4 s prior to a visual or auditory stimulus with the goal of focal network disruption during the motor planning phase of speech production (ie, response). Alternative stimulation paradigms may modify stimulation-response timing. Delivery of the electrical stimulus at the point of visual stimulus delivery (rather than prior) may capture speech output ie, verbal response. Additionally, lengthening the stimulus duration through both presentation of the visual stimulus and verbal response may influence different temporal-dependent cognitive networks.*

references).[15,16,18,20-22,79,80] In terms of short-term language outcomes, there is a high rate of transient aphasia (71%) with the majority of language deficits resolved by 1 mo.[81] Rates of permanent aphasia following awake language mapping range from 1.6% to 32%, but studies vary in terms of technique, lesion location, and degree of involvement of eloquent tissue.[16,17,19-22] There is also a lack of consistency in the definition of a "fixed" or "permanent" neurological deficit, with groups defining this term as a deficit persisting by anywhere from 1 to 6 mo postoperatively. In the largest series of patients undergoing an awake craniotomy for tumor resection, our group previously demonstrated an overall surgical and medical complication rate of 10%, a 30-d re-admission rate of 1%, and a intraoperative failure rate of 0.5% with all cases involving intraoperative seizures.[14] Other groups have reported slightly higher complication rates ranging from 14% to 32% and failure rates ranging from 2.3% to 6.4%.[51,80,82-84]

CONCLUSIONS

Intraoperative language mapping of tumor and peritumor tissue can provide for safe and extensive resection. Intraoperative language tasks including PN, reading, text writing, repetition, and sentence syntax can provide for more comprehensive language assessments intraoperatively but may be tailored based on preoperative symptoms and tumor location. Either bipolar or monopolar stimulation may be used for direct cortical stimulation, and stimulation of most language sites are associated

TABLE. Prior Literature Reporting Language Outcomes Following Awake Craniotomy for Language Mapping

	Number of patients	Stim-induced seizure rate	New language deficit rate	Reported EOR	Language tasks performed
Verst et al, 2019[18]	41	7%	2.4%	GTR: 48.7%	Object naming Counting Arithmetic Word formulation Sentence reading Sentence interpretation Semantic test of figure association
Southwell et al, 2017[79]	17	NR	23.5%	97.5%	Object naming Word reading Counting
Tuominen et al, 2013[20]	20 (AC)	5%	5%	GTR: 50%	Not reported
Pereira et al, 2009[21]	79 (AC)	21.5%	13.9%	100%: 31.6% >95%: 50.6% >90%: 72.1% >80%: 84.8% <80%: 15.1%	Object recall Object naming Spontaneous naming Counting
Sanai et al, 2008[15]	250 (AC)	NR	1.6%	GTR: 59.6%	Object naming Word reading Counting
Bello et al, 2007[16]	88	10.2%	2.3%	GTR: 33%	Object naming Action naming Person naming Word comprehension Sentence comprehension
Serletis and Bernstein 2007[80]	511 (AC)	4.9%	3.8%	NR	Not reported
Gupta et al, 2007[22]	26 (AC)	3.8%	25%	100%: 47.6% 90%-99%: 9.5% 80%-89%: 14.3% 70%-79%: 23.8% 60%-69%: 4.8%	Object naming Sentence reading

AC = awake craniotomy cases; EOR = extent of resection; GTR = gross total resection; NR = not reported; STR = subtotal resection.

with an "on/off" effect with a minority demonstrating a graded response to increasing stimulation thresholds.

Funding

This study did not receive any funding or financial support.

Disclosures

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article. Dr Hervey-Jumper received funding from Robert Wood Johnson Foundation, 74259, and NINDS K08 110919-01. Dr Hervey-Jumper and Dr Berger received funding from Loglio Collective.

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