11 Naming: Nouns and Verbs

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11.1 Introduction

Nouns and verbs are word categories that refer to different aspects of human experience (e.g., people, places, things, states, events, actions, goals, experiences). Nouns and verbs are also categories core to the basic structure of human language (e.g., subject, predicate, argument, temporal reference). Within the scope of language mapping in a neurosurgical context, noun and verb production is typically operationalized through object and action naming tasks, respectively [1, 2]. In a typical object naming task, sometimes referred to as noun naming, participants are asked to say the name of an object by using a noun (e.g., "book"). The noun can be preceded by a lead-in sentence or preamble (e.g., "This," "This is," or "Here is"), which is arguably included to disentangle articulatory from lexical-semantic processing [3]. In some languages (e.g., French), the lead-in sentence engages the production of a determiner that agrees in number and gender with the noun (e.g., *Ceci est un livre* → *"This is a book,"* where the determiner "*un*" and "*livre*" are masculine and singular), adding a lexical-syntactic component [4]. For reviews of peri- and intraoperative tasks with nouns see [5–7].

As noted, the naming task with verbs that has been most widely adopted in an intraoperative context is action naming. In this task, participants are asked to say the

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name of an action using a nonfinite verb form (e.g., “reading,” “to read”). Alternatively, participants may be asked to produce a finite form preceded by the subject of the sentence (e.g., “she reads” or “the woman reads”), in which case the task can also be referred to as finite verb naming or naming with finite verbs. In the latter case, the task also includes a lead-in sentence, which is typically a pronoun (e.g., “he,” “she”) or a noun phrase (e.g., “the woman,” “the boy”). Action naming should be distinguished from the related task of verb generation, in which people are shown or told the name of an object and then asked to produce the first verb that comes to mind (e.g., for a picture of a book, someone may say “reading” or “to read”). Action naming should also be distinguished from verbal fluency, where participants are asked to say as many words as possible starting with a specific letter (e.g., “F”) or belonging to a specific category or nouns or actions (e.g., animals, “things you do in the kitchen”). For a broader review of tasks with verbs see [8].

Language mapping using naming tasks with nouns and verbs is often constrained by the need to elicit an overt oral response or judgment. In that sense, tasks have been emphasized that are easy to administer and score, aiding real-time decision-making in the service of supporting a maximal safe resection: maximize tumor resection and minimize postoperative deficits (e.g., [9]). By contrast, research on nouns and verbs in healthy individuals and people with chronic lesions, typically patients with post-stroke aphasia, has fewer constraints and thus a broader range of issues have been addressed over the past several decades, including theoretical work on specific characteristics of nouns and verbs and the degree to which the two word classes depend on dissociable or (partially) shared neural substrates (e.g., [10–12]).

In this chapter, we sketch a neurocognitive framework motivated by a broader range of neuropsychological, neurophysiological, and neuroimaging evidence. Our goal is to inform future investigations and clinical interventions in people undergoing awake surgery. A central theme is that in order to effectively map nouns and verbs in the brain it is important to be explicit about the (1) function(s) or nature of the computations engaged by any given task (e.g., object recognition, semantic access, lexical retrieval, articulation); (2) the cortical and subcortical representation of those functions; and on the basis of that information, to (3) chose tasks and items that are most appropriate for mapping a given brain region. For instance, to map speech motor cortex, it matters little what type of linguistic output the patient is engaged in producing (counting, picture naming, spontaneous speech); by contrast, to map regions that support word retrieval from meaning representations for instance in temporal lobe regions, tasks that emphasize fine-grained semantic processing, such as picture naming or auditory definition naming, are likely to be required.

11.2 The Neural Basis of Nouns and Verbs

Lesion studies of people with post-stroke aphasia and other neurological pathologies have shown greater involvement of left temporal lobe structures in the production and comprehension of nouns, and greater involvement of left prefrontal and inferior parietal structures in the production and comprehension of verbs (e.g., [10, 13–15]; for contrasting evidence see [16, 17]). Neuroimaging studies including positron emission tomography (PET), functional magnetic resonance imaging (fMRI), electro- and magnetoencephalography (EEG, MEG), and navigated transcranial magnetic stimulation (nTMS) have provided a more intricate picture of the neural basis of naming tasks with nouns and verbs. Studies with those methods also implicate a dominant role for perisylvian areas in the left hemisphere and an involvement of similar areas in the right hemisphere (e.g., [11, 18]). At the subcortical level, direct electrical stimulation (DES) studies in people with brain tumors have stressed the role of white-matter pathways such as the arcuate fasciculus, inferior-frontal occipital fasciculus, superior and inferior longitudinal fasciculi, uncinate fasciculus, and periventricular white matter during both object and action naming (e.g., [19–22]).

Importantly, there are aspects of the representation of nouns and verbs that have been little explored in the peri- and intraoperative literature. Here we suggest that, by examining some of these aspects carefully, future studies may enhance the sensitivity and specificity of techniques for intraoperative mapping. Such future studies will also help to build a clearer picture of perioperative language impairments—which is relevant to tailor prehabilitation regimens, intraoperative tasks, and eventual language therapy to the needs of the patient. Below, we approach this broad goal from four perspectives: (1) manipulable objects such as tools and utensils, (2) biological entities, (3) action recognition and naming, and (4) verb argument structure.

Graspable and manipulable objects Graspable and manipulable objects (hereafter "tools") such as "hammer" and "cup" are tools/utensils with strongly associated and often stereotyped actions involving one or both hands. Recognizing and naming tools engages left hemisphere regions in the posterior lateral temporal cortex, posterior parietal and premotor cortex (reviews in [23, 24], see Fig. 11.1). Those areas are automatically activated when viewing or naming tools and utensils, compared to various baseline categories that are not graspable or manipulable (e.g., faces, vehicles, houses). Furthermore, tools also activate parietal and premotor areas that are engaged by action planning and production [26–29]. This observation is supported as well by neurophysiological studies of so-called "canonical neurons" [30]. That is, neurons that are active both during first person object-directed action and during (mere) perception of the object. What is interesting about this network of regions is that it represents cortical regions where representations of objects and actions are integrated at post-perceptual and pre-linguistic levels of processing. In other words, it would not be interesting or surprising that naming tools and actions should both engage, for instance, early visual processes (to process the contrast and luminance gradients of an image) or late-stage articulatory processes (to produce speech sounds); what is interesting is the engagement of common neural mechanisms for higher-level semantic and cognitive representations, that is integrated representations of tools and the actions associated with their use. The question relevant to present

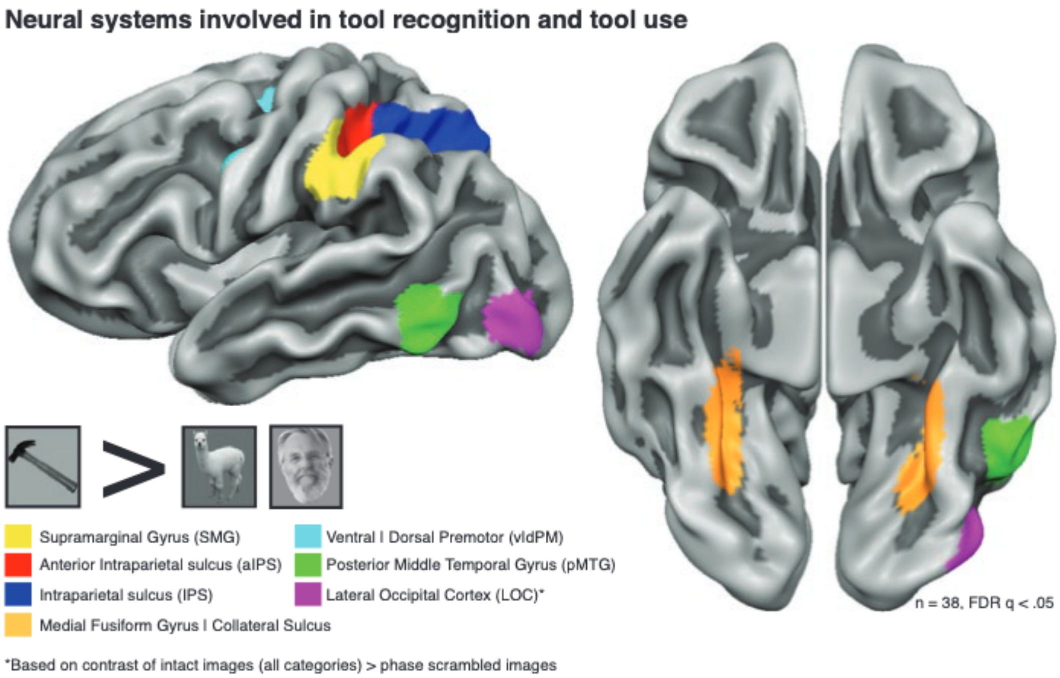

Fig. 11.1 Functional MRI has been used to delineate the neural substrates of the neural regions that support recognition and use of tools. The data shown in the figure were obtained while participants viewed tool stimuli compared to images of animals and faces. Regions are color-coded to distinguish what are functionally dissociable regions, as documented in the neuropsychological literature. (Figure reproduced, in part, from Mahon [25], with permissions)

purposes is whether (and if so, how) this broader network of action areas figures causally in visual confrontation naming of tools and other manipulable objects.

While the neuroimaging evidence is clear in that motor and motor-relevant areas in left parietal and frontal areas are automatically engaged during naming of tools, the available neuropsychological data indicate that tool naming can be preserved in the setting of damage to the same areas [31–33]. People with lesions to left parietal or premotor areas can present with limb apraxia (among other, nonaction, impairments), but can still be able to name the same objects they are unable to use correctly (provided the lesion does not involve the speech production systems) [31–33]. The dissociation between impaired action production and spared naming indicates that the ability to conceptually individuate an object does not require implicit motor simulation of the action associated with the use of the object. This frames the need for hypothesis-driven direct electrical stimulation mapping to evaluate whether transient disruption of those fronto-parietal structures specifically affects naming of graspable objects. By contrast, there is compelling evidence from both activation and lesion studies that the left posterior middle temporal gyrus plays a decisive role in supporting recognition and understanding of actions, and objects that are associated with actions [34–36]. Lesions involving the left posterior middle temporal gyrus can lead to naming impairments that are differentially profound for tools compared to other categories (e.g., animals, vehicles), and for action concepts [15, 29, 37–39].

Biological entities There is a rich neuropsychological tradition of studying dissociations by semantic category within the broad category "nouns" [40–42]. About 150 well-studied neuropsychological cases have been described with conceptual level deficits that are differential or selective for one of the categories of *fruit/vegetables, animals, nonliving things,* or *conspecifics (*i.e.*, familiar faces and people)* [43]. The evidence that the deficit in such patients is to conceptual knowledge (e.g., word and object meanings), as opposed to perceptual input (e.g., early visual/auditory processes) or linguistic output representations (e.g., word retrieval, phonological encoding), is provided by the boundaries of the impairment. Patients with category-specific *semantic* impairments have problems accessing knowledge about the impaired category independent of the format of the stimulus or the required response. For instance, such patients may be impaired at naming, but also at identification tasks that do not require a naming response, such as matching tasks like the Pyramids and Palm Trees test (see Chap. 15 and reviews in [23, 44]). Similarly, such patients can be impaired for knowledge about the impaired category regardless of whether that knowledge is cued through a picture or a spoken or written word. This is in contrast to, for example, a category-specific visual agnosia, such as prosopagnosia, for which patients have a category-specific deficit specifically for *visual* recognition but have not otherwise lost knowledge about the same category [45, 46].

While it is far from a universal generalization [47, 48], one pattern that emerges is that impairments with biological entities are often associated with damage to temporal lobe areas, in particular anterior basal and medial structures such as are affected in semantic dementia and herpes simplex encephalitis [49, 50]. This includes patients with impairments affecting animals [51], plants, and fruit/vegetables [52], as well as loss of knowledge of other people which is generally associated with right anterior temporal lobe injury [53–58]. In partial agreement with these studies, Papagno and colleagues [59] report DES positive sites in the temporal lobe and inferior frontal gyrus for naming living objects, while stimulation to other areas in the posterior third of the supramarginal gyrus and possibly the arcuate fasciculus induced more errors for nonliving things.

A related topic is the involvement of nouns referring to *names of famous people* in the anterior temporal lobe and subcortical structures, particularly, the uncinate fasciculus [59]. A topic that seems interesting to explore is whether the role of this subcortical structure is specific to names of famous people or includes other proper name categories, including individual-specific person name knowledge (e.g., surnames, first names, nicknames), geographical names (e.g., cities, countries, rivers), and names of commercial brands, books, paintings, and events (e.g., [53–57, 60]).

Action recognition and naming A critical aspect of the neural basis of action naming is the neural circuitry involved in action recognition and understanding. At the broadest level, actions are intentional movements of the body that satisfy a goal (e.g., we move the hand "to peel" a pear, or move the leg "to kick" a football). Both noninvasive and invasive neural and/or neuronal recording techniques demonstrate automatic engagement of perceptual areas, and pre- and supplemental motor areas during perception and recognition of actions [61–63]. In a similar vein, reading verbs related to different parts of the body such as the hand (e.g., "peel"), the mouth (e.g., "bite"), or the feet (e.g., "kick") drive activity in motor and motor-relevant areas [61–63]. The question is what functional role do motor production processes play in recognition and naming of actions. A currently popular interpretation of such findings [64] derives from the idea of "analysis by synthesis" [65, 66]—in order to recognize an action, the processes involved in production of the same action are internally (implicitly and automatically) simulated. For example, when naming the action "to cut," the motor areas that support the action of "cutting" at the level of the hand are active.

There has been a lot of interest in the concept of motor resonance and motor simulation, including critical discussions of the proposal [67–71]. Neuropsychological data can play a decisive role in evaluating the role(s) of action/motor processes in frontal and parietal areas in supporting action recognition and, more broadly, processing of words referring to actions. On the one hand, TMS studies [72, 73] and some patient studies [74, 75] have indicated action recognition impairments subsequent to (transient or chronic) lesions involving motor areas. On the other hand, patients can be impaired at action production but spared for action recognition. This has been observed in the setting of arm actions [32, 76, 77] and speech processing [78, 79]. Those types of patient-based findings indicate that even when motor output processes are damaged and patients are unable to produce actions in the first person, they can still recognize the same actions (for reviews, see [80–83]). In simpler terms, a person may be unable "to cut a piece of paper" but would understand the meaning of "cutting" when seeing a picture or reading a word. The implication is that while motor and motor-relevant structures are active during naming, it seems that those motor processes are not strictly necessary in order to name actions. This motivates hypothesis-driven DES studies to evaluate whether disruption of fronto-parietal structures specifically affects action naming compared to (a) nonaction events, and (b) actions outside the human action repertoire (e.g., "she jumps" vs. "the window breaks" vs. "the bug bites").

Verb argument structure Another issue to consider when assessing the integrity of verb knowledge is verb argument structure. *Transitive verbs* like "eating" take an object (e.g., Mary eats an apple, where "an apple" is the object) and are different from *intransitive verbs* such as "sleeping" which do not take such an argument (e.g., Mary sleeps). Neuroimaging studies have suggested that transitive verbs have further representation in the posterior part of the left superior temporal gyrus (e.g., [84–86]) This evidence is reinforced by lesion studies where people with post-stroke aphasia typically have more difficulties producing verbs that have more arguments (See Fig. 11.2) [87–89].

Arguments for the difference between these two types of verbs often note that transitive verbs require more complex computations than intransitive verbs in order to be expressed. Different theories emphasize different aspects of transitive and intransitive verbs. If we take a sentence with a transitive verb like "Mary eats an apple" and a sentence with an intransitive verb like "Mary sleeps," the differences

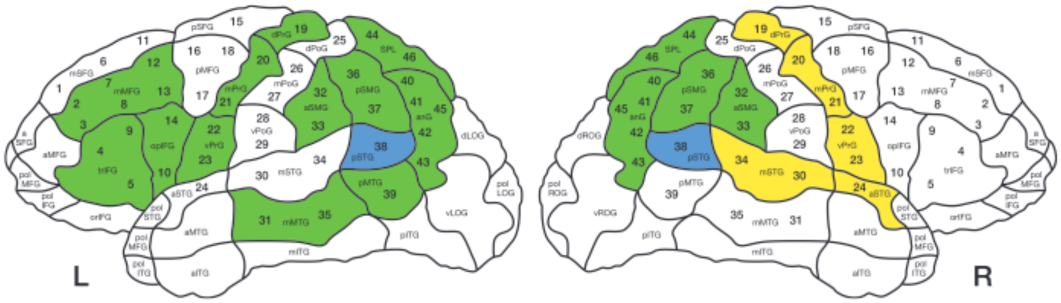

Fig. 11.2 Cortical representation of transitive and intransitive verbs in the left and right hemisphere. **Green**: Areas reported to be significantly more activated with transitive verbs. **Yellow**: Areas that have been reported to be significantly more activated with intransitive verbs. **Blue**: Areas that have been reported to be significantly more activated with both verb types

include: the amount of specified arguments (e.g., having an object like "apple" or not having an object); thematic roles (e.g., "Mary" as the agent or doer of the action of eating, and "apple" as the theme or entity that is affected by the action; compared to "Mary" as the experiencer or entity undergoing the action of sleeping); and the subcategorization frame (e.g., the lexical entry of the verb "to eat" takes two arguments with a noun phrase that functions as a subject, i.e., "Mary," and a noun phrase that functions as an object "an apple"; the lexical entry of the verb "to sleep" which can express only one event which involves one participant, namely, a noun phrase that functions as a subject, i.e., "Mary") [90, 91].

With respect to neural correlates of verb argument structure, it has been argued that there is a positive relation between the number of regions recruited and argument structure complexity. That is, further tissue is recruited to integrate the verb and its arguments into the syntactic structure of the sentence. In that sense, it may be hypothesized that transitive verbs should rely more heavily on posterior regions, as opposed to intransitive verbs [86, 92].

To summarize our arguments on the neural basis of nouns and verbs, studies indicate a general tendency for partial overlapping between cortical areas and less evidence for differentiation at the subcortical level. The partial consistency between lesion and neuroimaging studies may relate to factors such as the spatial and temporal resolution of each of the methods, the varieties of tasks/paradigms that can be used to assess object naming, and detecting areas that support and/or are essential for each of its functions (e.g., object recognition, semantic access, lexical retrieval, articulation). In this section, we argued for the use of potential differences between nouns and verbs. This emphasizes the differences within types or characteristics of nouns and verbs in order to gain new leverage on approaches for intraoperative mapping. These differences can advance understanding of how nouns and verbs are processed in the brain, while also increasing the sensitivity and specificity of language mapping, in line with the goals of the brain mapping in a neurosurgical setting.

Two of the topics we reviewed indicate that words with strong sensorimotor associations (e.g., graspable objects and actions) automatically activate sensorimotor areas during a naming task. In the same vein, a related constellation of findings points to this being a relatively broad phenomenon and not limited only to the action domain: nouns with strong gustatory ("salt"), olfactory ("jasmine"), and auditory associations ("telephone") drive activity in sensory brain regions related to taste (e.g., anterior insula, frontal operculum, lateral orbitofrontal gyrus, thalamus), smell (e.g., piriform cortex and amygdala), and audition (Heschl's gyrus) (for the original theoretical precedent, see [93]; for recent empirical studies, see [94–98]). And similarly, nouns with strong motion properties (e.g., car) differentially drive activity in the vicinity of motion sensitive area MT/V5 in posterior-lateral temporal cortex [99]. However, the available neuropsychological evidence forms a pattern in that disruption of the same structures that are automatically engaged does not necessarily disrupt naming performance—thus it remains an open question whether DES to sensory- and motor-specific structures may disrupt naming of the corresponding word types.

11.3 Evidence of Long-Term Deficits in People Who Did Not Benefit from Intraoperative Language Mapping with Naming Tasks with Nouns and/or Verbs

Here we highlight four studies in which patients were operated on with intraoperative object naming but not action naming (nonfinite forms, e.g., "jumping"), and three studies where patients were operated on with intraoperative mapping that involved both object and action naming. To the best of our knowledge, there are no studies in which only action naming, or only tasks with verbs, have been used for intraoperative mapping.

With respect to studies for which only object naming was administered, Santini and colleagues [100] studied the perioperative results of 22 people with low- and high-grade gliomas and reported a decline in naming scores immediately after surgery (within a week after surgery), with recovery at follow-up (3–6 months after surgery). The authors indicated the same pattern for other language tasks. Unfortunately, both object and action naming scores were combined as one measure of naming; hence, it is not possible to assess whether action naming was more impaired than object naming. Nonetheless, the authors showed scores below the normal level on word fluency, verbal working memory, and immediate recall of words—all of these being tasks that require language processing (along with other cognitive functions).

Satoer and colleagues [101] looked at 45 people with low- and high-grade gliomas, mostly in the perisylvian regions of the left hemisphere. The authors studied the scores of people who underwent surgery without action naming, before surgery, 3 months after surgery, and 1 year after surgery. Similar to Santini and colleagues [100], the authors reported issues in word fluency and immediate recall of words. Also, they reported problems in attention, executive functions, and object naming—the latter resolving 1 year after surgery. In this study, action naming scores were not reported. In another longitudinal study by the same group, Satoer and colleagues [102] reported spontaneous speech impairments in 18 people with low- and high-grade gliomas, also 3 months and 1 year after surgery. The majority of those patients were assessed intraoperatively with object naming and repetition, not necessarily with action naming. Interestingly, the authors reported issues with spontaneous speech that relate to lexical-semantic and morphosyntactic impairments; these aspects of linguistic computation would arguably be well mapped with action naming and, particularly, action naming with finite verbs.

Norrelgen and colleagues [103] reported findings from 27 people with a low-grade glioma or cavernoma in the left hemisphere. All patients underwent surgery with object naming but not action naming. Relative to preoperative scores, patients declined in animal and verb fluency at 3 and 12 months after surgery. Five people had impairments on object naming before surgery, but none of the patients had below-normal scores on object naming or sentence comprehension at follow-up.

With respect to studies where both object naming and action naming were used, Papagno and colleagues [104] reported preoperative data from 226 people operated on for a low- or high-grade glioma. Of those, 117 were assessed 3 months after surgery. The data are presented as percentages and participants are divided by brain area. Higher percentages of people were impaired for object naming and action naming before surgery than at follow-up. A number that is particularly striking is that 40% of people with lesions in the left parietal lobe were impaired for action naming before surgery, but only one participant presented with below-normal scores 3 months after surgery. Other than that, there is an increase of about 20% in the percentage of people with lesions in the left frontal lobe whose scores are impaired for phonemic fluency after surgery. Similar results were reported in a recent study that used a similar testing protocol and included 102 people with high-grade gliomas [105]. In contrast, Pisoni and colleagues [106] reported the perioperative results of 102 people with a high- or a low-grade glioma in either the left or right hemisphere. Interestingly, postoperative results 1–7 days after surgery revealed new action naming impairments in nearly 30% of the people, the majority of which had tumors in the left hemisphere.

In summary, while the literature remains sparse at present, postoperative testing in people with brain tumors who underwent intraoperative mapping with object naming, or with both object and action naming, do contain some language impairments, particularly, in tasks that tap into lexical-semantic and morphosyntactic processes. Fluency tasks have been shown to be impaired, along with object naming, and sometimes action naming. When both object and action naming tasks have been used intraoperatively, two studies report an increase in new impairments in action naming and a third a decrease, at least for lesions in the left parietal lobe, an area known to be involved in the processing of action verbs (see Sect. 11.1 above).

Further work is needed to understand for how long after surgery such impairments remain, if the incidence is higher when object naming alone is used during intraoperative language mapping, and how these impairments impact in quality of life. With respect to the latter point, a study examining both accuracy and response times would be valuable, similar to the report on object naming latencies and return-to-work by Moritz-Gasser and colleagues [107]. Further work on spontaneous speech could also be valuable, given the correspondence between formal testing and spontaneous speech in people with brain tumors (see Chap. 6 and [102, 108]).

11.4 Knowledge Gained from Lesion-Symptom Mapping

To our knowledge, only two studies have carried out lesion-symptom mapping with both object and action naming in people with brain tumors. Both studies included nearly one hundred Italian-speaking people with either a low- or a high-grade glioma. Pisoni and colleagues [106] looked at pre- and early postoperative results (1–7 before/days after surgery) in individuals with tumors in the left and right hemisphere, while Tomasino and colleagues [109] only considered preoperative results (1 week before surgery) and people with tumors in the left hemisphere. The results of both studies stress the role of the left hemisphere. With respect to the representation of objects, Pisoni and colleagues [106] stress the role of the anterior temporal lobe, whereas Tomasino and colleagues [109] discuss the role of basal temporo-occipital regions (see also Fig. 11.1). As discussed above (Sect. 11.1), both of these regions are known to support dissociable components of object knowledge that is accessed during naming. With respect to actions, both studies agree on a role of left parietal cortex for the production of action verbs. What is less clear is the involvement of the left frontal lobe (reported only in Tomasino et al. [109]) and the temporal cortex (only posterior aspects are reported in Pisoni and colleagues [106], while broader areas are reported in Tomasino and colleagues [109]). The involvement of subcortical pathways is also unclear, in that one study specifically reported finding no pathways [106]. However, Tomasino and colleagues reported involvement of the superior and posterior corona radiata and the inferior fronto-occipital fasciculus for actions, while the inferior longitudinal fasciculus, corpus callosum, thalamic radiation, internal capsule, and fornix were implicated in processing of objects [109].

These results for people with brain tumors are not entirely in agreement with a similarly powered study of people with left-hemisphere stroke [110]. In that study, impairment in object naming was associated with the anterior and posterior middle temporal gyrus, superior temporal gyrus, and inferior parietal cortex. Interestingly, when controlling for impairments in articulation and visual recognition, the left middle posterior temporal gyrus and underlying white matter appeared to play a critical role in object naming (see also [29]). Adding to this literature, an earlier less powered study in individuals with left-hemisphere stroke found that the inferior frontal gyrus and the anterior part of the temporal lobe were relevant for action naming [111]. In a similar study that considered different neurological populations (mostly stroke) and a variety of tasks tapping on verb processing [15], the role of the inferior frontal gyrus was also stressed. However, the anterior part of the temporal lobe was argued to not be essential for representing or processing action concepts, since a number of patients they studied who underwent anterior temporal lobe surgery for epilepsy were not impaired for tasks involving actions.

Findings with lesion-symptom mapping in people with brain tumors warrant replication in other languages, as currently available studies were conducted in Italian. For example, it would be interesting to cross-validate the results in typologically similar languages, such as French, Spanish, and Catalan, as well as to look for potential differences in languages that are rich in morphology such as Korean and Turkish, and languages with impoverished morphological markers such as English or Chinese. This is because, differences could emerge between languages that have verbs that engage more or less in morphosyntactic processes (e.g., [112]). Nonetheless, we expect action naming to be, on average, more impaired than object naming, as this is the case even in languages with poor morphological inflection (e.g., [113]). This is possibly because, even when we disregard morphological processes, verbs are key elements for structuring sentences (e.g., they specify arguments, thematic roles, have a subcategorization frame, are useful to refer to the time when the event happened), while nouns refer to concepts and are dependent on verbs to "make sense" in a sentence (e.g., "John ate pasta" vs. "John is eating/cooking pasta").

Future work could also consider running similar analyses for naming actions with finite verbs (e.g., she runs), as the use of finite verbs taps into morphosyntactic processes, which may index a broader set of linguistic computations than non-finite verbs (e.g., to run, running) or nouns [114]. Finally, the studies we reported include behavioral data at a preoperative stage or at an acute stage early after surgery (~1 week). In this sense, the performance of people at a more chronic stage such as three to six or even more months after surgery could contextualize early postoperative deficits that may not be as specifically related to the location of the surgical resection per se, but to more general consequences of neurosurgical interventions (e.g., early presence of edema, decompression of tissue around the surgical cavity [115]).

There are also important limitations associated with lesion-symptom mapping that should be considered:

First, whereas the lesion, at least defined for analytic purposes, is a static variable for any given individual, performance levels are dynamically changing along the timeline from preoperative assessment to subacute to chronic assessment; thus, for the same lesions in a group of patients, the lesion-behavioral correlates can change quite dramatically depending on when patients are tested over the trajectory of their recovery [116–118].

Second, the effect of the lesion on behavior is due not only to the tissue that is physically lost to the lesion but also to tissue that was part of a functional network with the lesioned area [119]. Lesions to one region will disrupt information processing for computations in other regions that depend(ed) on the lesioned area for inputs or outputs [120]. In a recent study of preoperative tumor patients [121], it was found that functional MRI responses in basal temporal structure (fusiform gyrus, collateral sulcus) were modulated by the presence of lesions to parietal cortex. This relation was category-specific, in that fMRI responses in the fusiform gyrus were modulated only for tools by lesions to parietal cortex, while responses to places, faces, and animals were unaffected. That finding was interpreted in terms of the need for tools (compared to places, faces, and animals) to integrate visual representations of surface structure and texture (processed by medial basal temporal lobe structures) with motor-relevant properties of the use of the objects (parietal cortex).

Third, these issues are compounded in the setting of tumor patients, as there could be reorganization of function during the period when the tumor was growing. The result is that the behavioral performance level for a given task may not be what would be predicted were an otherwise typically developed individual to have a sudden onset of a lesion in the same location as the tumor. Herbet and colleagues [122] reported a case series in which some of the patients had a low-grade glioma in the left anterior temporal lobe, while in others, this brain area was not involved with tumor. All of the patients underwent an awake craniotomy with language mapping, and specifically DES of the inferior longitudinal fasciculus (ILF) in the dominant hemisphere. The authors found that stimulation of the ILF caused anomic errors, but only in patients who did not have long-standing pathology in the anterior temporal lobe. The implications of these findings are that (1) the ILF does play a critical role in language processing, and specifically naming; and (2) if tumors have infiltrated the left anterior temporal lobe, there is reorganization of the language network (such that stimulation of the ILF no longer disrupts naming). Future systematic investigations such as reported by Herbet and colleagues will be critical for understanding plasticity, reorganization of function, and redundancy of functional pathways.

11.5 Tasks Newly Designed to Map Language

Marla Hamberger and colleagues [123–128] explored a different paradigm within noun production that does not depend on the targets being picturable—the authors refer to this paradigm as "*auditory naming*"; more generally, it is a form of *definition naming or naming to description*. For instance, the patient listens to a short description: "The yellow part of an egg" (answer: yolk) with stimulation being applied during the period that the patient is presented with the definition. Those authors found that auditory definition naming, and not visual/picture naming, identified essential language sites in the anterior temporal lobe [123]. A subsequent study by the same group investigated language outcome in people undergoing temporal lobe surgery in whom both picture naming and auditory naming were used to define essential language sites intraoperatively [126]. The key point of comparison concerned resections that avoided essential language sites identified with picture naming (i.e., the clinical standard), but did not avoid essential language sites identified with auditory naming. The authors found increased word finding difficulties in people who had auditory-naming-defined essential language sites resected, compared to people without resection of auditory naming sites. For ethical reasons, there was no comparison group where visual/picture naming-defined essential language sites were resected. Interestingly, the postoperative deficits observed in people with auditory-defined language sites resected were observed both in auditory naming and in picture naming.

The discussion about the most effective tasks for identifying essential language sites in the anterior temporal lobe continues [8, 9, 123, 126, 129–132]. Hamberger et al. [123, 126] emphasized the *auditory* nature of the stimuli and suggested an auditory representational code in the anterior temporal lobe. Subsequent research and theoretical proposals argued that the anterior temporal lobes represent amodal conceptual information [133–138]—in which case the modality of the cueing stimuli (auditory, visual) would be expected to matter less [69, 139–143].

Another important issue is that experimental paradigms in which pictures, as opposed to auditorily presented definitions, are used to cue word retrieval may allow for additional and parallel pathways to a target name from the stimulus (picture). Anatomically, such redundant pathways could be (1) right hemisphere identification processes that bypass left anterior temporal semantic representations, and access words via callosal projections (for evidence from split brain patients, see [144, 145]), and/or (2) projections that connect occipital and frontal naming sites and bypass the anterior temporal lobe (e.g., the inferior frontal occipital fasciculus [116, 146–148]).

Following the aforementioned work on naming to definition, a novel way to administer verb naming could be by providing participants a short description of the verb (e.g., what do we do with a book, "reading"). This version of the task may engage auditory processes to segment strings of sounds into words as well as understand grammatical information. This is distinct from using line drawings, as picture naming requires visual perceptual analysis and other perceptual processes (e.g., [149, 150]). To the best of our knowledge action naming to description has not been used intraoperatively.

Clinicians and researchers implement action naming and naming tasks with finite verbs with the help of line drawings, color pictures, or short vignettes [151–154]. The most common approach uses line drawings, following the tradition of intraoperative mapping with object naming [154]. The way in which the tasks are administered seems relevant, as different methods engage different language functions. For surgical mapping, it has been argued that vignettes (e.g., a person peeling a banana or cracking an egg) are more natural depictions of actions and, hence, more ecologically valid than line drawings [151]. However, this study did not compare the two types of stimuli but rather used vignettes instead of drawings.

Further inspiration for the type of stimuli that could prove useful for intraoperative mapping may be found in the psycholinguistic and post-stroke literature. For example, Salmon and colleagues [155] found that manipulable objects (e.g., "banana," "hammer") are named faster by healthy individuals when presented as photographs compared to black-and-white line drawings. Interestingly, the authors reported no difference between photographs and black-and-white drawings, when the items were non-manipulable objects (e.g., "pigeon," "staircase"). Consequently, if the amount of visual detail in photographs facilitates the retrieval of nouns that require "bodily movement," it may also be argued that action verbs (e.g., "cutting" vs. "sleeping") may be produced faster and more accurately when presented as pictures, as opposed to black-and-white drawings. The extent to which this type of work may affect peri- and intraoperative results in people with brain tumors is unknown. However, it seems relevant to consider, as it could help minimize intraoperative false positives.

A key issue, when considering how to generalize observations to broader groups of patients, is whether the group of patients in question is homogenous in terms of the neurocognitive processes affected by the lesion. For instance, the picture-naming performance of people with impairments to earlier levels of processing (e.g., picture recognition, due to posterior temporal or occipital lesions) will be affected by manipulations to the format of the visual stimuli. However, people with impairments to other levels of processing, such as peripheral phonological problems or lexical-semantic impairments, may perform the same regardless of manipulations to the input, but may be affected by output dimensions (e.g., word length). This emphasizes the need to develop explicit hypotheses, up front, about the nature of computations believed to be supported by a brain region. Therefore, it is critical to not interpret clinical categories such as "post-stroke" aphasia too seriously without further examination, as the patients subsumed under that label will be heterogenous in terms of the underlying mechanisms affected by the injury [156]. Similar arguments should also hold when considering postsurgical cases.

It should be noted that even though for action naming the final output is a verb, there exist significant differences between producing a verb in a nonfinite form (e.g., "reading," "to read") and producing a verb in its finite form (e.g., "she reads"). When producing a verb in the finite form, there is agreement over the fact that a subset of the processes necessary to produce a sentence are needed, thus engaging the retrieval of the word (lexical retrieval) as well as grammatical processing (e.g., subject-verb agreement, reference to time, use of tense). However, when producing a nonfinite form, while it is clear that lexical retrieval is involved, it is not as clear whether the same grammatical processes are obligatorily engaged [11, 157]. The engagement of those grammatical processes is consequential for the regions that will be recruited (e.g., [112, 157]), and also renders the task sensitive to processes that are involved in the use of language on an everyday basis (i.e., spontaneous speech, see Chap. 6 and [114]). A study comparing pre-, intra-, and postoperative mapping of action naming with nonfinite verbs and finite verbs, as well as more general measures of language, would shed light on these issues.

Finally, action naming tasks were discussed in early reviews of tasks to be used for intraoperative language mapping [158], and are currently included in protocols in numerous languages including English [159], German [159], Russian [160], Dutch/Flemish [159, 161], and Italian [162, 163]. Some of these versions are particularly interesting, as they include ratings for a number of word properties such as frequency, imageability, age of acquisition, and other variables [149, 150, 164]. Controlling the items for such properties may be relevant at the preoperative level, to have a better understanding of which language functions may be impaired, as well as to understand whether specific subsets within word types are differentially affected (e.g., low frequency items). All of this is also relevant to tailor the tasks to the capacities of each individual patient; for example, instead of removing single words that a person may have problems with, it may be possible to remove a whole word type (e.g., intransitive verbs). This approach could also help diminish the number of intraoperative false positives.

11.6 Functional Improvement in Patients Engaged in Intraoperative Naming Task with Nouns and/or Verbs Compared to Patients Not Studied with Those Tasks

The administration of action naming and naming finite verbs has been argued to provide intraoperative maps with more and different positive cortico-subcortical areas, particularly when compared with object naming (e.g., [19, 20, 130, 151–153]). To our knowledge, there are no studies providing evidence in favor of the unique administration of action naming or finite verbs for intraoperative language mapping. Rather, researchers and clinicians advocate for an approach with both action naming and object naming. It could be that the combination of the two tasks allows for more reliable mapping of cortico-subcortical areas and language processes that are engaged in everyday language abilities—particularly when using finite verbs [114]. However, this hypothesis has not been directly tested by prospectively manipulating the inclusion (versus not) of finite verb naming.

It is difficult to find reports stating that there is a functional improvement in patients mapped intraoperatively with action naming only, as opposed to other mapping approaches such as object naming alone. Indeed, at this stage, it seems unethical to assess patients only with action naming, particularly when many teams advocate for a combination of tasks and when the current gold standard is object naming (e.g., [130]). In this regard, if the goal is to understand functional improvement, it could be relevant to study the perioperative relation between different tasks used in awake surgery and scores on functional tasks (e.g., such as spontaneous speech, everyday communication scales, questionnaires, or quality of life measures). This is relevant to assess whether a task used during surgery engages processes required for everyday communication (e.g., [114]).

Likewise, in the domain of language, we are unaware of studies that have assessed postoperative performance when other tasks were used instead of object naming. However, it seems evident that operating on the patient awake with object naming is preferable to an asleep surgery without language testing [165].

11.7 Additional Anatomo-Functional Knowledge Gained from Intraoperative Mapping Studies

At the cortical level, intraoperative mapping studies have provided information that is not much different from lesion studies or studies with neuroimaging techniques. That is, there exist a number of brain areas in left perisylvian areas that are involved in naming tasks with objects and verbs, with substantial variability across participants (for reviews of intraoperative results, see [8, 22]). Important in this context, future intraoperative mapping studies can provide unique insight regarding the role of subcortical structures in supporting these tasks.

An example of the types of inferences about subcortical pathways that are afforded by stimulation mapping is provided by two case studies that focused on the recently described Frontal Aslant Tract, which connects the inferior frontal gyrus with pre-supplementary motor cortex [166]. One study used subcortical stimulation of the Frontal Aslant Tract while the patient was engaged in a controlled sentence production task designed to have sensitivity to subtle disruptions to sentence planning [167]. The patient was engaged in producing sentences such as “The red triangle is above the yellow circle” where the color and shapes varied from trial to trial and were cued via a visual stimulus. It was found that stimulation of the Frontal Aslant Tract disrupted sentence production specifically at the boundaries of grammatical phrases (i.e., in the example above, after the determiner phrase “the red triangle,” or before the determiner phrase “the yellow circle”). Those intraoperative findings were in agreement with a prior case report of a patient, whose left middle frontal gyrus tumor required partial resection of the Frontal Aslant Tract, and for whom postoperative spontaneous speech was marked by substantial hesitations at the boundaries of grammatical phrases [168]. The authors suggested findings from those two studies frame the hypothesis that the Frontal Aslant Tract supports mapping from the grammatical structure of sentences (inferior frontal gyrus) to linearized surface forms required for motor planning (anterior supplementary motor cortex)—referred to as the Syntagmatic Constraints on Positional Elements (SCOPE) hypothesis [167, 168]. For instance, in the sentence “The boy ate the apple,” the representations of the subject (boy) and object (apple) are processed together within the overall thematic structure of the sentence at a semantic and grammatical level; however, at the level at which the sentence is articulated, “boy” and “apple” are computationally separated in time. The idea is that the FAT maps between the structural form of the sentence and its surface form.

With respect to tasks with verbs, Lorenzo Bello’s group [19, 20] reported involvement of different portions of long association fiber pathways (e.g., arcuate fasciculus, superior longitudinal fasciculus, uncinate fasciculus, inferior fronto-occipital fasciculus) in action naming (with nonfinite verbs). Rofes and colleagues [130] also reported the involvement of subcortical pathways in action naming with finite verbs, particularly the anterior part of the arcuate fasciculus and the inferior fronto-occipital fasciculus [19, 20].

Further work is needed to understand the cortical and subcortical representation of currently used tasks via intraoperative mapping, including in patients with lesions in the right hemisphere [11]. Looking forward, there are many exciting questions to be pursued using action naming in an intraoperative context, and the clinical preparation afforded by awake language mapping holds tremendous potential to disclose new insights about the neural basis of nouns and verbs.

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