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Localization Patterns of Language Errors in the Brain during Direct Electrical Stimulation: A Systematic Review

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Introduction

Awake craniotomy with direct electrical stimulation (DES) is the standard treatment for patients with eloquent area gliomas. Language errors are detected with DES and indicate functional boundaries that need to be maintained during tumor resection to preserve quality of life. Traditionally, counting and object naming were used during DES. The Dutch Linguistic Intraoperative Protocol (DuLIP, De Witte et al., 2015) was the first linguistic test-battery with tasks at different linguistic modalities and levels (production, comprehension, reading, phonology, semantics, syntax) divided into cortico-subcortical areas. The DuLIP model was based on the (limited) available literature and knowledge at the time. As much has been done since, the model needs to be updated. We investigate the localization patterns of different speech/language errors during awake craniotomy.

Methods

A systematic review was conducted and 102 studies were included reporting on speech arrests and specific speech/language errors and their corresponding brain locations during awake glioma craniotomy with DES. Language errors were counted and categorized in modalities or levels: speech errors (speech arrest, dysarthria/anarthria, verbal apraxia), speech initiation difficulty, semantic errors, phonemic errors, syntactic errors, reading errors and writing errors.

Results

A wide distribution of brain locations (hemispheres combined) for all speech/language errors (n=930) was found with different patterns. Cortically, errors occurred most often in the precentral gyrus (22%), while subcortically at the inferior fronto-occipital fascicle (IFOF: 11%). Localization patterns for specific speech/language errors were also found: **speech errors** (n=388)-precentral gyrus (43%), inferior frontal gyrus (9%), postcentral gyrus (4%), frontal aslant/striatal tract (3%); **speech initiation difficulty** (n=9)-frontal aslant tract (33%), frontal striatal tract (22%); supplementary motor area (22%); **semantic errors** (n=128)-IFOF (57%), superior temporal gyrus (9%); **phonemic errors** (n=115)-arcuate fascicle (52%), superior longitudinal fascicle (10%), uncinate fascicle (3%); **syntactic errors** (n=15)-inferior frontal gyrus (27%); **reading errors** (n=25)-temporal lobe (48%), inferior longitudinal fascicle (32%) and **writing errors** (n=7)-superior parietal gyrus (71%).

Conclusions

This is the first systematic review on the localization of speech/language errors during awake craniotomy. The localization of most speech/language errors are consistent with the assumed functionality of those brain locations as presented in the DuLIP model. However, additional locations for articulation/motor speech, phonology, reading and writing were found and are added to the model, as shown in blue italic print (Table 1). Importantly, many articles exclusively administered object naming, which is not always sensitive enough to find deficits at different linguistic modalities. Subsequently, errors may have been missed. Therefore, we suggest to always use multiple language tests tapping into different modalities and/or levels. Next to DuLIP, various options are available (e.g. Dragoy et al., 2020; Ohlerth et al., 2020, Rofes et al., 2017; Sierpowska et al., 2017).

The updated DULIP model should be considered for future selection of perioperative language tasks to improve language testing/monitoring, which may pave the way to a better postoperative language outcome. The possible relation between different intraoperative speech/language errors and postoperative language outcome has yet to be determined.

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Table 1. Suggestions for modification of the Dutch Linguistic Intraoperative Protocol (DuLIP) model for cortical and subcortical brain locations and their corresponding functions and tasks.

Brain location	Function(s)	Intraoperative language tasks from DuLIP
Frontal regions		
Inferior frontal gyrus	Articulatory processing, syntax, (writing)	Verbal diadochokinesis, repetition, verb generation, action naming
Posterior midfrontal gyrus	Action naming, (writing)	Action naming
Supplementary motor area (posterior superior frontal gyrus)	Language initiation	Sentence completion (close and broad context), fluency
Precentral gyrus	Motor network	Repetition, verbal diadochokinesis
Temporal Regions		
Posterior superior temporal gyrus	Semantics, naming living objects, auditory comprehension	Semantic odd picture out, semantic judgement, object naming
Middle posterior superior temporal sulcus	Phonological network	Phonological judgement
Middle inferior temporal gyrus	Lexical interface, naming non-living objects, *reading*	Semantic judgement, object naming, *reading*
Anterior middle temporal gyrus	Famous face naming, *reading*	Naming, *reading*
Parietal Regions		
Supramarginal gyrus	Reading, naming, semantics	Reading, sentence completion, semantic association, naming
Angular gyrus (ANG)	Reading, writing	Reading, sentence completion
Postcentral gyrus	*Articulatory programming/motor speech*	*Verbal diadochokinesis*
Superior parietal gyrus	*Writing*	*Writing (e.g. Van Ierschot et al., 2018)*
Subcortical pathways		
Subcallosal fascicle *(= frontal striatal tract), frontal aslant tract*	Initiation of speech, *motor speech*	Fluency, sentence completion, *verbal diadochokinesis*
Inferior fronto-occipital fascicle	Semantics, reading, judgement	Semantic association, semantic odd word/picture out, semantic judgement
Inferior longitudinal fascicle	Reading, phonology, semantics	Reading, sentence completion, naming, *repetition*
Superior longitudinal fascicle ~~(arcuate fascicle)~~	Articulatory processing, phonology	Verbal diadochokinesis, repetition, phonological odd word out
Arcuate fascicle	Phonology	Repetition, phonological odd word out
Uncinate fascicle	Famous face naming, semantics, *phonology*	Naming, semantic odd picture out, *repetition*
Corticospinal tract	Motor speech	Verbal diadochokinesis, repetition

This table is taken and adjusted from De Witte et al. (2015). Black print is from the original model, blue italic print are additions from the authors based on the data in this review.