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Superior Temporal Sulcus

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Synonyms

STS

Definition

The superior temporal sulcus is a long furrow within the temporal lobes. It is functionally related mainly with speech and social perception. Its anterior and posterior ends are highly associative areas dealing with higher-level processes contributing to recognition, understanding, and reasoning about oneself and others.

Introduction

The superior temporal sulcus (STS) is a long surface of grey matter folded to form a trench dividing the superior and middle temporal gyri – two rounded ridges on the cortical surface. The STS is located both in right and left cerebral hemisphere, and its length corresponds to approximately half of the cerebral cortex's length. Due to its size, its bilaterality, and its multiple connectivity nodes, the STS is attributed to numerous (and partially still debated) functions. In light of this complexity, the present entry therefore focuses on the well-evidenced functions, with an emphasis on the linguistic and social aspects, as they are related to the two most established sets of functions associated with the STS. To facilitate the understanding of the functional organization of the STS, Figure 1 provides a meta-analysis of neuroimaging studies based on Neurosynth (Yarkoni et al. 2011) illustrating which topics (taken from studies' titles and abstracts) are commonly associated to six different STS sites (equally spaced vertically) in each hemisphere.

Anatomy

The STS is located on the lateral surface of the temporal lobe and follows a ventral-anterior (or dorsal-posterior) inclination. Its posterior part ends dorsally in the surrounding angular gyrus, which is a part of the temporo-parietal junction (TPJ). The TPJ refers to a loosely defined brain area neighboring the intersection of the temporal and parietal lobes, which are anteriorly the supramarginal gyrus and posteriorly the angular gyrus and a rostrocaudal part of the occipital lobe (see also entry on ► TPJ in this encyclopedia). Hence, the most posterior part of the STS (pSTS) is

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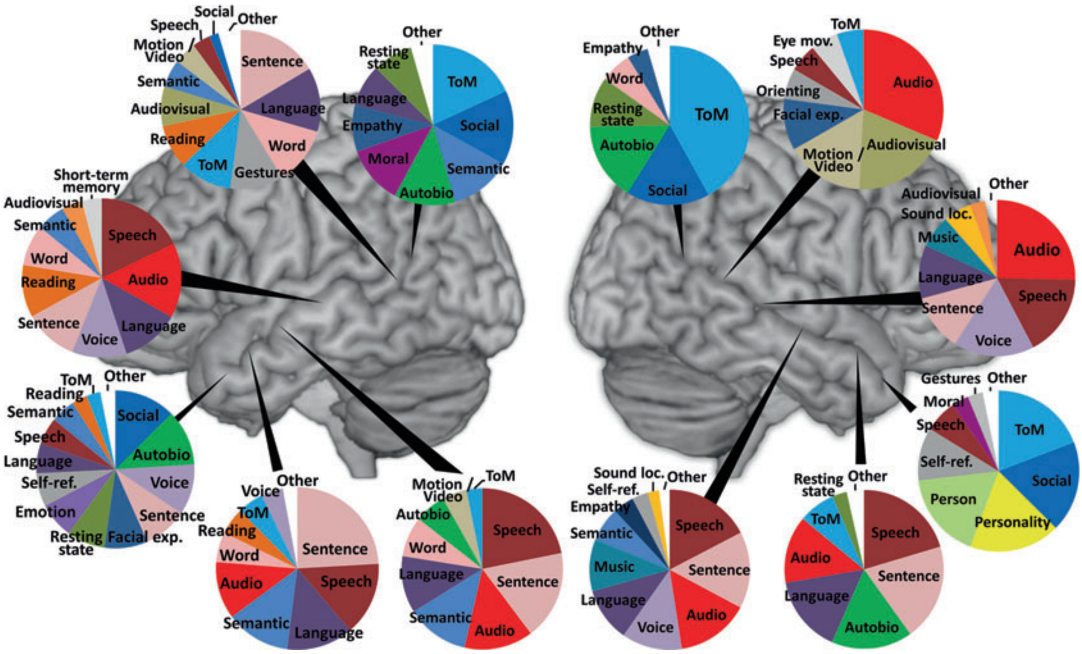

Superior Temporal Sulcus, Fig. 1 Illustrations of most common topics of neuroimaging literature (indexed from studies' title and abstract) associated with 12 different STS sites equally spaced vertically. Size of the pie slice reflects the proportional z-score (i.e., statistical support) of the site-topic association. (Data calculated from Neurosynth, an online platform allowing to perform meta-analyses on the results from 11,000 fMRI studies (Yarkoni et al. 2011))

sometimes referred to as the angular gyrus or the TPJ. As for the anterior STS (aSTS), it extends ventrally and is sometimes included in, and thus referred to as, the temporal pole (Ribas 2010). The aSTS and pSTS are connected with multiple cortical lobes and are thus heteromodal associative areas, with the aSTS being particularly connected with the orbital and ventrolateral prefrontal cortex (PFC), whereas the pSTS is particularly connected with parietal cortices and the dorsolateral PFC. In contrast, the middle STS has mainly intra-temporal connections and processes the auditory signals relayed by primary auditory cortex located in the dorsal bank of the superior temporal gyrus.

Functions

Language is a key function attributed to the whole STS bilaterally, with a left-hemispheric dominance for syntactic processes and a right-hemispheric dominance for prosodic processing. Neighboring the primary auditory cortex, the bilateral middle STS is particularly involved in phoneme-level (smallest sound units of speech) processing of speech, while the middle to posterior STS deals with semantic processing by mapping words with their widely distributed meanings, in particular in the left-hemisphere. Sentence-level semantic mapping and syntactic structure of speech processing are particularly associated with the left anterior STS; its role in semantic processing is mainly evidenced by the fact that the temporal variant of the fronto-temporal dementia (tv-FTD) causes semantic difficulties and damages first the temporal poles. More posteriorly, overlapping with TPJ, the left pSTS is also involved in sensory-motor transformation to access articulatory properties of speech and to pronounce new words (Hickok and Poeppel 2007).

Voice conveys, beyond language, meaningful information such as the gender, identity, and the emotional state of the speaker. Voice perception is found to recruit predominantly the right STS with some degree of functional specialization; the aSTS is preferentially active when the identity and emotional state are retrieved, the mSTS processes voice-specific spectral features, and the pSTS seems involved for unspecific spectro-temporal features of sounds (Kriegstein and Giraud 2004).

Music perception seems to recruit the middle-to-anterior STS, but this involvement is actually limited to the superior temporal gyrus and shows little preferential activation when compared to speech and nonlinguistic vocalizations, which suggests that STS is not functionally specialized to process music.

Face processing recruits an extended brain network that includes the aSTS and the pSTS, with a right-hemispheric dominance. The aSTS would enable access to face identities and memories, while the pSTS processes dynamic aspects such as facial expression and eye movement.

Biological motions from the eyes, mouth, hand, or the body convey important social information because they allow to track others' gaze, read their facial and postural expressions, and recognize their gestures. Biological motion processing is often found to recruit bilaterally the pSTS (ventral to the TPJ) (Pelphrey et al. 2005).

Audio-visual integration allows combining observed dynamic stimuli, such as actions (e.g., footsteps, tearing an object) and facial movements (e.g., vocalizations), with their corresponding sounds. Audio-visual integration recruits bilaterally the pSTS but at different location depending on the stimuli to be processed: speech is more left-hemisphere dominant, and anterior, nonverbal voice sounds (e.g., emotion sounds) are more right-dominant, and objects are most posterior (Stevenson and James 2009).

Reorienting attention refers to detection of unattended and unexpected stimuli toward which attention is shifted, or reflexively reoriented from a different focus of attention. This attentional mechanism is particularly implemented via the ventral attention network, which consists essentially in the ventral PFC and the TPJ extending to the pSTS, with a right-hemispheric predominance.

Autobiographical memory is a memory system allowing storing and retrieving information about oneself, which consists in both a collection of personal experiences and semantic information (i.e., facts and knowledge). The retrieval of such memories recruits a largely distributed network that encompasses bilaterally the aSTS and the most posterior part of STS, that is, the TPJ (Spreng and Grady 2010).

Self-other attribution refers to the processes leading to attributing causality of actions (i.e., agency), ownership of body parts or voices, or references of various stimuli (e.g., a name, traits, personal belongings) to the self or another person. These three processes recruit predominantly the right hemisphere at various locations within the STS depending on the actual stimulus to be attributed. Self-other attribution of agency (e.g., perceiving self/other-executed movements as externally/self-controlled due to altered visual feedbacks), however, consistently recruits the pSTS/TPJ, in particular when actions and expected outcomes do not match (Sperduti et al. 2011).

Theory of mind (ToM) and empathy are both strongly associated with the aSTS and the pSTS, with mentalizing (i.e., inferring mental states of others) being the common denominator for both regions. The recruitment of the temporal poles is believed to provide access to personal memories and general semantic social rules to understand the state of mind of others. This implies that aSTS is not always recruited for mentalizing but only for complex stimuli where social narratives need to be formed (Olson et al. 2007). Although, ToM and empathy are consistently shown to recruit bilaterally the pSTS overlapping with the TPJ, the exact function of these regions remain controversial (this issue is further addressed in entry TPJ).

Resting state activity, corresponding to the default mode network, refers to a set of brain areas preferentially active and functionally correlating when one is asked to rest in an environment with minimal external stimulation while staying awake. Mental activities typically performed during a resting state are said to be self-referential in nature and consist in mind-wandering, daydreaming, remembering and planning events, thinking about others and oneself. Within the STS, resting state activity is mainly found in aSTS and the TPJ bilaterally (Spreng and Grady 2010).

Personality differences across individuals are in several ways associated with the temporal poles, and particularly in the right hemisphere. Other parts of the STS have been associated with individual differences in personality traits but no consistent pattern has yet emerged; the importance of the temporal pole may be explained by its strong ties with the orbitofrontal cortex and the amygdala, key regions involved in socio-emotional processing. Direct involvement of right temporal pole is supported by the occurrence of the Klüver-Bucy syndrome following dysfunction of this region caused by temporal variant of fronto-temporal dementia, herpes encephalitis, or post-ictal temporal lobe epilepsy. The Klüver-Bucy syndrome is characterized by social withdrawal, poor facial expression, voice prosody recognition and production, apathy, and egocentrism due to a loss of interest in social interaction; these changes directly impact personality traits such as extraversion, social dominance, and neuroticism (Olson et al. 2007). Congruently, several recent fMRI studies showed associations between neuroticism (and emotional stability in general) and functional and structural features of the right temporal pole.

Conclusions

Many cognitive functions anatomically overlap in the STS and these functions strongly interact, where integration culminates in the aSTS and pSTS: sounds become identified speakers conveying verbal contents; images become moving agents expressing social cues; and identities, verbal contents, actions, and social cues combine to form rich understandings and predictions of others' behaviors.

The pSTS overlapping with the TPJ appears to be a nexus of information equipped with attentional and reasoning mechanisms allowing to detect and transform social cues into meaningful and predictable social agents (Lamm et al. 2016). On the other side, the right and left aSTS overlapping with the temporal poles can be viewed as a socioemotional and semantic hub, respectively. They sit at the end of the "what" streams of auditory and visual processing, where auditory and visual modalities converge, integrate, and combine with limbic areas. This integration allows highly processed audio-visual representations to be linked with their personal and semantic meaning and constitute the personal semantic memory. Put more simply, together, the aSTS and pSTS contribute to the ability to personally recognize, attach, understand, and interact with others as much as to recognize, know, and reason about oneself.

Cross-References

▶ Empathy
▶ Extraversion
▶ Lateral Prefrontal Cortex (LPFC)
▶ Medial Prefrontal Cortex (MedPFC)
▶ Neuroticism
▶ Orbitofrontal Cortex
▶ Social Dominance Orientation
▶ Temporo-Parietal Junction (TPJ)
▶ Theory of Mind

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