Seed-based functional connectivity (FC) of resting-state functional MRI data is a widely used methodology, enabling the identification of functional brain networks in health and disease. Based on signal correlations across the brain, FC measures are highly sensitive to noise. A somewhat neglected source of noise is the fMRI signal attenuation found in cortical regions in close vicinity to sinuses and air cavities, mainly in the orbitofrontal, anterior frontal and inferior temporal cortices. BOLD signal recorded at these regions suffers from dropout due to susceptibility artifacts, resulting in an attenuated signal with reduced signal-to-noise ratio in as many as 10% of cortical voxels. Nevertheless, signal attenuation is largely overlooked during FC analysis. Here we first demonstrate that signal attenuation can significantly influence FC measures by introducing false functional correlations and diminishing existing correlations between brain regions. We then propose a method for the detection and removal of the attenuated signal (“intensity-based masking”) by fitting a Gaussian-based model to the signal intensity distribution and calculating an intensity threshold tailored per subject. Finally, we apply our method on real-world data, showing that it diminishes false correlations caused by signal dropout, and significantly improves the ability to detect functional networks in single subjects. Furthermore, we show that our method increases inter-subject similarity in FC, enabling reliable distinction of different functional networks. We propose to include the intensity-based masking method as a common practice in the pre-processing of seed-based functional connectivity analysis, and provide software tools for the computation of intensity-based masks on fMRI data. Hum Brain Mapp 37:2407-2418, 2016. © 2016 Wiley Periodicals, Inc.

Tal, Z, Geva R, Amedi A. 2016 The origins of metamodality in visual object area LO: Bodily topographical biases and increased functional connectivity to S1. NeuroImage. 127:363-75. Recent evidence from blind participants suggests that visual areas are task-oriented and sensory modality input independent rather than sensory-specific to vision. Specifically, visual areas are thought to retain their functional selectivity when using non-visual inputs (touch or sound) even without having any visual experience. However, this theory is still controversial since it is not clear whether this also characterizes the sighted brain, and whether the reported results in the sighted reflect basic fundamental a-modal processes or are an epiphenomenon to a large extent. In the current study, we addressed these questions using a series of fMRI experiments aimed to explore visual cortex responses to passive touch on various body parts and the coupling between the parietal and visual cortices as manifested by functional connectivity. We show that passive touch robustly activated the object selective parts of the lateral-occipital (LO) cortex while deactivating almost all other occipital-retinotopic-areas. Furthermore, passive touch responses in the visual cortex were specific to hand and upper trunk stimulations. Psychophysiological
interaction (PPI) analysis suggests that LO is functionally connected to the hand area in the primary somatosensory homunculus (S1), during hand and shoulder stimulations but not to any of the other body parts. We suggest that LO is a fundamental hub that serves as a node between visual-object selective areas and S1 hand representation, probably due to the critical evolutionary role of touch in object recognition and manipulation. These results might also point to a more general principle suggesting that recruitment or deactivation of the visual cortex by other sensory input depends on the ecological relevance of the information conveyed by this input to the task/computations carried out by each area or network. This is likely to rely on the unique and differential pattern of connectivity for each visual area with the rest of the brain.


In the congenitally blind, language processing involves visual areas. In the case of normal visual development however, it remains unclear whether later visual loss induces interactions between the language and visual areas. This study compared the resting-state functional connectivity (FC) of retinotopic and language areas in two unique groups of late visually deprived subjects: (1) blind individuals suffering from retinitis pigmentosa (RP), (2) RP subjects without a visual periphery but with preserved central “tunnel vision”, both of whom were contrasted with sighted controls. The results showed increased FC between Broca’s area and the visually deprived areas in the peripheral V1 for individuals with tunnel vision, and both the peripheral and central V1 for blind individuals. These findings suggest that FC can develop in the adult brain between the visual and language systems in the completely and partially blind. These changes start in the deprived areas and increase in size (involving both foveal and peripheral V1) and strength (from negative to positive FC) as the disease and sensory deprivation progress. These observations support the claim that functional connectivity between remote systems that perform completely different tasks can change in the adult brain in cases of total and even partial visual deprivation.


Multisensory processes are fundamental in scaffolding perception, cognition, learning, and behavior. How and when stimuli from different sensory modalities are integrated rather than treated as separate entities is poorly understood. We review how the relative reliance on stimulus characteristics versus learned associations dynamically shapes multisensory processes. We illustrate the dynamism in multisensory function across two timescales: one long term that operates across the lifespan and one short term that operates during the learning of new multisensory relations. In addition, we highlight the importance of task contingencies. We conclude that these highly dynamic multisensory processes, based on the relative weighting of stimulus characteristics and learned associations, provide both stability and flexibility to brain functions over a wide range of temporal scales.


The brain is capable of large-scale reorganization in blindness or after massive injury. Such reorganization crosses the division into separate sensory cortices (visual, somatosensory...). As its result, the visual cortex of the blind becomes active during tactile Braille reading. Although the possibility of such reorganization in the normal, adult brain has been raised, definitive evidence has been lacking. Here, we
demonstrate such extensive reorganization in normal, sighted adults who learned Braille while their brain activity was investigated with fMRI and transcranial magnetic stimulation (TMS). Subjects showed enhanced activity for tactile reading in the visual cortex, including the visual word form area (VWFA) that was modulated by their Braille reading speed and strengthened resting-state connectivity between visual and somatosensory cortices. Moreover, TMS disruption of VWFA activity decreased their tactile reading accuracy. Our results indicate that large-scale reorganization is a viable mechanism recruited when learning complex skills.


Graphical virtual environments are currently far from accessible to blind users as their content is mostly visual. This is especially unfortunate as these environments hold great potential for this population for purposes such as safe orientation, education, and entertainment. Previous tools have increased accessibility but there is still a long way to go. Visual-to-audio Sensory-Substitution-Devices (SSDs) can increase accessibility generically by sonifying on-screen content regardless of the specific environment and offer increased accessibility without the use of expensive dedicated peripherals like electrode/vibrator arrays. Using SSDs virtually utilizes similar skills as when using them in the real world, enabling both training on the device and training on environments virtually before real-world visits. This could enable more complex, standardized and autonomous SSD training and new insights into multisensory interaction and the visually-deprived brain. However, whether congenitally blind users, who have never experienced virtual environments, will be able to use this information for successful perception and interaction within them is currently unclear. We tested this using the EyeMusic SSD, which conveys whole-scene visual information, to perform virtual tasks otherwise impossible without vision. Congenitally blind users had to navigate virtual environments and find doors, differentiate between them based on their features (Experiment1:task1) and surroundings (Experiment1:task2) and walk through them; these tasks were accomplished with a 95% and 97% success rate, respectively. We further explored the reactions of congenitally blind users during their first interaction with a more complex virtual environment than in the previous tasks—walking down a virtual street, recognizing different features of houses and trees, navigating to cross-walks, etc. Users reacted enthusiastically and reported feeling immersed within the environment. They highlighted the potential usefulness of such environments for understanding what visual scenes are supposed to look like and their potential for complex training and suggested many future environments they wished to experience.

have recently demonstrated VWFA activity for letters in contrast to other visual categories when the information is provided via other senses such as touch or audition. Which of these tasks is more dominant? By which mechanism does the CB brain process reading? Using fMRI and visual-to-auditory sensory substitution which transfers the topographical features of the letters we compare reading with semantic and scrambled conditions in a group of CB. We found activation in early auditory and visual cortices during the early processing phase (letter), while the later phase (word) showed VWFA and bilateral dorsal-intraparietal activations for words. This further supports the notion that many visual regions in general, even early visual areas, also maintain a predilection for task processing even when the modality is variable and in spite of putative lifelong linguistic cross-modal plasticity. Furthermore, we find that the VWFA is recruited preferentially for letter and word form, while it was not recruited, and even exhibited deactivation, for an immediately subsequent semantic task suggesting that despite only short sensory substitution experience orthographic task processing can dominate semantic processing in the VWFA. On a wider scope, this implies that at least in some cases cross-modal plasticity which enables the recruitment of areas for new tasks may be dominated by sensory independent task specific activation.


Topographic organization is one of the main principles of organization in the human brain. Specifically, whole-brain topographic mapping using spectral analysis is responsible for one of the greatest advances in vision research. Thus, it is intriguing that although topography is a key feature also in the motor system, whole-body somatosensory-motor mapping using spectral analysis has not been conducted in humans outside M1/SMA. Here, using this method, we were able to map a homunculus in the globus pallidus, a key target area for deep brain stimulation, which has not been mapped noninvasively or in healthy subjects. The analysis clarifies contradictory and partial results regarding somatotopy in the caudal-cingulate zone and rostral-cingulate zone in the medial wall and in the putamen. Most of the results were confirmed at the single-subject level and were found to be compatible with results from animal studies. Using multivoxel pattern analysis, we could predict movements of individual body parts in these homunculi, thus confirming that they contain somatotopic information. Using functional connectivity, we demonstrate interhemispheric functional somatotopic connectivity of these homunculi, such that the somatotopy in one hemisphere could have been found given the connectivity pattern of the corresponding regions of interest in the other hemisphere. When inspecting the somatotopic and nonsomatotopic connectivity patterns, a similarity index indicated that the pattern of connected and nonconnected regions of interest across different homunculi is similar for different body parts and hemispheres. The results show that topographical gradients are even more widespread than previously assumed in the somatosensory-motor system. Spectral analysis can thus potentially serve as a gold standard for defining somatosensory-motor system areas for basic research and clinical applications.


Topographic maps and their continuity constitute a fundamental principle of brain organization. In the somatosensory system, whole-body sensory impairment may be reflected either in cortical signal reduction or disorganization of the somatotopic map, such as disturbed continuity. Here we investigated the role of continuity in pathological states. We studied whole-body cortical representations in response to continuous sensory stimulation under functional MRI (fMRI) in two unique patient populations-patients with cervical
sensory Brown-Séquard syndrome (injury to one side of the spinal cord) and patients before and after surgical repair of cervical disk protrusion-enabling us to compare whole-body representations in the same study subjects. We quantified the spatial gradient of cortical activation and evaluated the divergence from a continuous pattern. Gradient continuity was found to be disturbed at the primary somatosensory cortex (S1) and the supplementary motor area (SMA), in both patient populations: contralateral to the disturbed body side in the Brown-Séquard group and before repair in the surgical group, which was further improved after intervention. Results corresponding to the nondisturbed body side and after surgical repair were comparable with control subjects. No difference was found in the fMRI signal power between the different conditions in the two groups, as well as with respect to control subjects. These results suggest that decreased sensation in our patients is related to gradient discontinuity rather than signal reduction. Gradient continuity may be crucial for somatotopic and other topographical organization, and its disruption may characterize pathological processing.

2014


Purpose: Sensory-substitution devices (SSDs) provide auditory or tactile representations of visual information. These devices often generate unpleasant sensations and mostly lack color information. We present here a novel SSD aimed at addressing these issues. Methods: We developed the EyeMusic, a novel visual-to-auditory SSD for the blind, providing both shape and color information. Our design uses musical notes on a pentatonic scale generated by natural instruments to convey the visual information in a pleasant manner. A short behavioral protocol was utilized to train the blind to extract shape and color information, and test their acquired abilities. Finally, we conducted a survey and a comparison task to assess the pleasantness of the generated auditory stimuli. Results: We show that basic shape and color information can be decoded from the generated auditory stimuli. High performance levels were achieved by all participants following as little as 2-3 hours of training. Furthermore, we show that users indeed found the stimuli pleasant and potentially tolerable for prolonged use. Conclusions: The novel EyeMusic algorithm provides an intuitive and relatively pleasant way for the blind to extract shape and color information. We suggest that this might help facilitating visual rehabilitation because of the added functionality and enhanced pleasantness.


Sensory substitution has advanced remarkably over the past 35 years since first introduced to the scientific literature by Paul Bach-y-Rita. In this issue dedicated to his memory, we describe a collection of reviews that assess the current state of neuroscience research on sensory substitution, visual rehabilitation, and multisensory processes.

Maidenbaum, S, Abboud S, Amedi A. 2014 Sensory substitution: closing the gap between basic research and widespread practical visual rehabilitation. [82]. Neuroscience and biobehavioral reviews. 41:3-15. Abstract [83]
They have produced exciting experimental results, and have furthered our understanding of the human brain. Unfortunately, they are still not used for practical visual rehabilitation, and are currently considered as reserved primarily for experiments in controlled settings. Over the past decade, our understanding of the neural mechanisms behind visual restoration has changed as a result of converging evidence, much of which was gathered with SSDs. This evidence suggests that the brain is more than a pure sensory-machine but rather is a highly flexible task-machine, i.e., brain regions can maintain or regain their function in vision even with input from other senses. This complements a recent set of more promising behavioral achievements using SSDs and new promising technologies and tools. All these changes strongly suggest that the time has come to revive the focus on practical visual rehabilitation with SSDs and we chart several key steps in this direction such as training protocols and self-train tools.

2012


A key question in sensory perception is the role of experience in shaping the functional architecture of the sensory neural systems. Here we studied dependence on visual experience in shaping the most fundamental division of labor in vision, namely between the ventral "what" and the dorsal "where and how" processing streams. We scanned 11 fully congenitally blind (CB) and 9 sighted individuals performing location versus form identification tasks following brief training on a sensory substitution device used for artificial vision. We show that the dorsal/ventral visual pathway division of labor can be revealed in the adult CB when perceiving sounds that convey the relevant visual information. This suggests that the most important large-scale organization of the visual system into the 2 streams can develop even without any visual experience and can be attributed at least partially to innately determined constraints and later to cross-modal plasticity. These results support the view that the brain is organized into task-specific but sensory modality-independent operators.


The exciting view of our brain as highly flexible task-based and not sensory-based raises the chances for visual rehabilitation, long considered unachievable, given adequate training in teaching the brain how to see. Recent advances in rehabilitation approaches, both noninvasive, like sensory substitution devices (SSDs) which present visual information using sound or touch, and invasive, like visual prosthesis, may potentially be used to achieve this goal, each alone, and most preferably together.


Sensory Substitution Devices (SSDs) convey visual information through sounds or touch, thus theoretically enabling a form of visual rehabilitation in the blind. However, for clinical use, these devices must provide
fine-detailed visual information which was not yet shown for this or other means of visual restoration. To
test the possible functional acuity conveyed by such devices, we used the Snellen acuity test conveyed
through a high-resolution visual-to-auditory SSD (The vOICe). We show that congenitally fully blind adults
can exceed the World Health Organization (WHO) blindness acuity threshold using SSDs, reaching the
highest acuity reported yet with any visual rehabilitation approach. This demonstrates the potential
capacity of SSDs as inexpensive, non-invasive visual rehabilitation aids, alone or when supplementing
visual prostheses.

Levy-Tzedek, S, Hanassy S, Abboud S, Maidenbaum S, Amedi A. 2012 Fast, accurate reaching
movements with a visual-to-auditory sensory substitution device [116]. Restorative neurology and
neuroscience. 30:313?323. Abstract [117]

(Author2)

Purpose Visual sensory substitution devices (SSDs) use sound or touch to convey information that is
normally perceived by vision. The primary focus of prior research using {SSDs} was the perceptual
components of learning to use {SSDs} and their neural correlates. However, sensorimotor integration is
critical in the effort to make {SSDs} relevant for everyday tasks, like grabbing a cup of coffee efficiently.
The purpose of this study was to test the use of a novel visual-to-auditory {SSD} to guide a fast reaching
movement. {METHODS} Using sound, the {SSD} device relays location, shape and color information.
Participants were asked to make fast reaching movements to targets presented by the {SSD.} {RESULTS}
After only a short practice session, blindfolded sighted participants performed fast and accurate
movements to presented targets, which did not differ significantly from movements performed with visual
feedback in terms of movement time, peak speed, and path length. A small but significant difference was
found between the endpoint accuracy of movements under the two feedback conditions; remarkably, in
both cases the average error was smaller than 0.5 cm. {CONCLUSIONS} Our findings combine with
previous brain-imaging studies to support a theory of a modality-independent representation of spatial
information. Task-specificity, rather than modality-specificity, of brain functions is crucially important for the
rehabilitative use of {SSDs} in the blind and the visually impaired. We present the first direct comparison
between movement trajectories performed with an {SSD} and ones performed under visual guidance. The
accuracy level reached in this study demonstrates the potential applicability of using the visual-to-auditory
{SSD} for performance of daily tasks which require fast, accurate reaching movements, and indicates a
potential for rehabilitative use of the device.

Zeharia, N, Hertz U, Flash T, Amedi A. 2012 Negative blood oxygenation level dependent homunculus
and somatotopic information in primary motor cortex and supplementary motor area [123].
Abstract [124]

A crucial attribute in movement encoding is an adequate balance between suppression of unwanted
muscles and activation of required ones. We studied movement encoding across the primary motor cortex
{(M1)} and supplementary motor area {(SMA)} by inspecting the positive and negative blood oxygenation
level-dependent {BOLD} signals in these regions. Using periodic and event-related experiments
incorporating the bilateral/axial movements of 20 body parts, we report detailed mototopic imaging maps in
M1 and (SMA.) These maps were obtained using phase-locked analysis. In addition to the positive
{BOLD}, significant negative {BOLD} was detected in M1 but not in the {SMA.} The negative {BOLD}
spatial pattern was neither located at the ipsilateral somatotopic location nor randomly distributed. Rather,
it was organized somatotopically across the entire homunculus and inversely to the positive {BOLD},
creating a negative {BOLD} homunculus. The neuronal source of negative {BOLD} is unclear. M1 provides
a unique system to test whether the origin of negative {BOLD} is neuronal, because different arteries
supply blood to different regions in the homunculus, ruling out blood-stealing explanations. Finally, multivoxel pattern analysis showed that positive \{BOLD\} in M1 and {SMA} and negative \{BOLD\} in M1 contain somatotopic information, enabling prediction of the moving body part from inside and outside its somatotopic location. We suggest that the neuronal processes underlying negative \{BOLD\} participate in somatotopic encoding in M1 but not in the \{SMA\}. This dissociation may emerge because of differences in the activity of these motor areas associated with movement suppression.

2011

Striem-Amit, E, Hertz U, Amedi A. 2011Extensive cochleotopic mapping of human auditory cortical fields obtained with phase-encoding FMRI [130]. PloS One. 6:e17832. Abstract [131] RTF [132] Tagged [133] XML [134] BibTex [135] Google Scholar [136] The primary sensory cortices are characterized by a topographical mapping of basic sensory features which is considered to deteriorate in higher-order areas in favor of complex sensory features. Recently, however, retinotopic maps were also discovered in the higher-order visual, parietal and prefrontal cortices. The discovery of these maps enabled the distinction between visual regions, clarified their function and hierarchical processing. Could such extension of topographical mapping to high-order processing regions apply to the auditory modality as well? This question has been studied previously in animal models but only sporadically in humans, whose anatomical and functional organization may differ from that of animals (e.g. unique verbal functions and Heschl's gyrus curvature). Here we applied \{fMRI\} spectral analysis to investigate the cochleotopic organization of the human cerebral cortex. We found multiple mirror-symmetric novel cochleotopic maps covering most of the core and high-order human auditory cortex, including regions considered non-cochleotopic, stretching all the way to the superior temporal sulcus. These maps suggest that topographical mapping persists well beyond the auditory core and belt, and that the mirror-symmetry of topographical preferences may be a fundamental principle across sensory modalities.

2010

Reich, L, Szwed M, Cohen L, Amedi A. 2011A ventral visual stream reading center independent of visual experience [137]. Current Biology: \{CB\}. 21:363?368. Abstract [138] RTF [139] Tagged [140] XML [141] BibTex [142] Google Scholar [143] The visual word form area \{\{VWFA\}\} is a ventral stream visual area that develops expertise for visual reading. It is activated across writing systems and scripts and encodes letter strings irrespective of case, font, or location in the visual field with striking anatomical reproducibility across individuals. In the blind, comparable reading expertise can be achieved using Braille. This study investigated which area plays the role of the \{\{VWFA\}\} in the blind. One would expect this area to be at either parietal or bilateral occipital cortex, reflecting the tactile nature of the task and crossmodal plasticity, respectively. However, according to the metamodal theory, which suggests that brain areas are responsive to a specific representation or computation regardless of their input sensory modality, we predicted recruitment of the left-hemispheric \{\{VWFA\}\}, identically to the sighted. Using functional magnetic resonance imaging, we show that activation during Braille reading in blind individuals peaks in the \{\{VWFA\}\}, with striking anatomical consistency within and between blind and sighted. Furthermore, the \{\{VWFA\}\} is reading selective when contrasted to high-level language and low-level sensory controls. Thus, we propose that the \{\{VWFA\}\} is a metamodal reading area that develops specialization for reading regardless of visual experience.

Abstract

Events in the world are mediated through multiple sensory inputs which are processed separately in specific unisensory areas according to the division-of-labor principle, and then need to be integrated to create a unified percept. How this is done is still not clear. For instance, recent evidence showed crossmodal activation in primary areas. We developed a novel approach to study multisensory integration using multifrequency spectral analysis to investigate the processing of audio and visual streams in a multisensory context. Auditory and visual stimuli were delivered in the same experimental condition, each in different presentation frequencies, and thus could be detected by applying Fourier spectral analysis in their different presentation frequencies. The cochleotopic and retinotopic organization of primary auditory and visual areas were found to remain intact in spite of the multisensory context. Auditory responses were also found in the Precuneus, suggesting that it might be a new auditory area responsive to pure tone stimuli, and serving as one end of a novel sensory preference gradient stretching across (POG) to the calcarine sulcus. Additional audiovisual areal convergence was detected both in areas in the middle of sensory preference gradients, and in primary auditory areas. Interestingly, the in/out synchronization rate of the auditory and visual streams yielded a third interaction frequency, which could be analyzed independently to reveal higher-order audiovisual interaction responses. These results were detected in one compact and natural multisensory experimental condition, which has several advantages over previous approaches. The method can be further implemented to study any type of interaction, within and across sensory modalities.


Abstract

*PURPOSE* Recent studies show evidence of multisensory representation in the functionally normal visual cortex, but this idea remains controversial. Occipital cortex activation is often claimed to be a reflection of mental visual imagery processes triggered by other modalities. However, if the occipital cortex is genuinely active during touch, this might be the basis for the massive cross-modal plasticity observed in the congenitally blind. *METHODS* To address these issues, we used fMRI to compare patterns of activation evoked by a tactile object recognition (TOR) task (right or left hand) in 8 sighted and 8 congenitally blind subjects, with several other control tasks. *RESULTS* TOR robustly activated object selective regions in the lateral occipital complex (LOC/LOtv) in the blind (similar to the patterns of activation found in the sighted), indicating that object identification per se (i.e. in the absence of visual imagery) is sufficient to evoke responses in the LOC/LOtv. Importantly, there was negligible occipital activation for hand movements (imitating object palpations) in the occipital cortex, in both groups. Moreover, in both groups, TOR activation in the LOC/LOtv was bilateral, regardless of the palpating hand (similar to the lack of strong visual field preference in the LOC/LOtv for viewed objects). Finally, the most prominent enhancement in TOR activation in the congenitally blind (compared to their sighted peers) was found in the posterior occipital cortex. *CONCLUSIONS* These findings suggest that visual imagery is not an obligatory condition for object activation in visual cortex. It also demonstrates the massive plasticity in visual cortex of the blind for tactile object recognition that involves both the ventral and dorsal occipital areas, probably to support the high demand for this function in the blind.
People tend to close their eyes when trying to retrieve an event or a visual image from memory. However, the brain mechanisms behind this phenomenon remain poorly understood. Recently, we showed that during visual mental imagery, auditory areas show a much more robust deactivation than during visual perception. Here we ask whether this is a special case of a more general phenomenon involving retrieval of intrinsic, internally stored information, which would result in crossmodal deactivations in other sensory cortices which are irrelevant to the task at hand. To test this hypothesis, a group of 9 sighted individuals were scanned while performing a memory retrieval task for highly abstract words (i.e., with low imaginability scores). We also scanned a group of 10 congenitally blind, which by definition do not have any visual imagery per se. In sighted subjects, both auditory and visual areas were robustly deactivated during memory retrieval, whereas in the blind the auditory cortex was deactivated while visual areas, shown previously to be relevant for this task, presented a positive (BOLD) signal. These results suggest that deactivation may be most prominent in task-irrelevant sensory cortices whenever there is a need for retrieval or manipulation of internally stored representations. Thus, there is a task-dependent balance of activation and deactivation that might allow maximization of resources and filtering out of non-relevant information to enable allocation of attention to the required task. Furthermore, these results suggest that the balance between positive and negative (BOLD) might be crucial to our understanding of a large variety of intrinsic and extrinsic tasks including high-level cognitive functions, sensory processing and multisensory integration.


This review surveys the recent literature on visuo-haptic convergence in the perception of object form, with particular reference to the lateral occipital complex (LOtv) and the intraparietal sulcus (IPS) and discusses how visual imagery or multisensory representations might underlie this convergence. Drawing on a recent distinction between object- and spatially-based visual imagery, we propose a putative model in which (LOtv), a subregion of (LOC), contains a modality-independent representation of geometric shape that can be accessed either bottom-up from direct sensory inputs or top-down from frontoparietal regions. We suggest that such access is modulated by object familiarity: spatial imagery may be more important for
unfamiliar objects and involve {IPS} foci in facilitating somatosensory inputs to the {LOC;} by contrast, object imagery may be more critical for familiar objects, being reflected in prefrontal drive to the {LOC.}