Auditory-visual multisensory interactions within primary cortices revealed by BOLD peak facilitation

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Introduction

Evidence now demonstrates that combined sensory inputs interact, influencing perception and behavior[1]. Neurophysiological bases for multisensory interactions are increasingly investigated. Which analytical approach is the most appropriate to investigate multisensory interactions in fMRI data sets remains debated[2-4].

Methods

In this study we analyzed the dynamics of the BOLD signal in response to rudimentary stimuli. Twelve participants were scanned at 3-Telsa while performing a simple reaction time (RT) task to visual (checkerboard), auditory (noise burst), or simultaneous auditory-visual stimuli (each 150ms duration). Stimulus jittering permitted us to effectively sample BOLD responses with a temporal resolution of 200ms, as in our previous work[5].

Results

Behavioral data confirmed that multisensory interactions occurred. Mean RTs were faster for multisensory than either visual or auditory condition (mean±s.e.m. = 355±28ms, 379±25ms, and 400±30ms, respectively; $F_{(2,8)}=36.38$; $p<0.001$) in excess of probability summation[6].

Activation maps, obtained using SPM2 and following standard procedures, show that primary cortices of each sensory modality responded to both visual and auditory stimulation, indicative of multisensory convergence. In order to assess multisensory interactions (i.e. where these convergent inputs alter responses to simultaneous auditory-visual stimulation), we derived BOLD peak latencies for each brain voxel, stimulus condition, and subject, separately. To ensure that latency measures originated from active voxels, temporal analyses were spatially restricted to regions defined by overlapping multisensory and visual or auditory activation maps. Each contrast revealed significant ($p<0.05$) multisensory facilitation in terms of earlier peak BOLD response latencies principally within primary and/or near-primary visual and auditory cortices. No regions showed significantly delayed multisensory responses. To partially overcome inter-subject cortical and functional variability, we identified voxels within individual subjects that also lied within the regions defined by the aforementioned group-level analysis of BOLD peak latency shifts. This yielded a subset of four regions – primary visual and auditory cortices, bilaterally. For each region and subject, mean BOLD dynamics were estimated across the identified voxels. Peak latencies and intensities were statistically compared using experimental condition as the within-subjects factor. Each region showed a significant main effect of experimental condition on peak latencies that was explained by earlier peak latencies for the multisensory than either unisensory condition (see **Table 1**). A significant main effect of condition on intensity was also shown in each region, which was due to smaller auditory responses within visual areas and smaller visual responses within auditory cortices. Conversely, no significant differences were obtained between multisensory and either auditory intensities within auditory areas or visual intensities within visual areas.

Discussion and Conclusions

This is the first demonstration of multisensory interactions in primary visual and auditory cortices, which manifested as dynamic shifts in BOLD responses. Conjointly, we observed robust responses, in terms of BOLD amplitude, to both senses within low-level cortices. We would note that no other regions showed significant effects on peak BOLD latency. These results also represent a methodological advancement for identifying brain regions that are functionally multisensory using fMRI (discussed in refs. 2-4). Our method highlights that the full range of effects may go undetected by typical analysis approaches. Still, it will be important for future investigations to detail bases for latency shifts in the BOLD signal. Multisensory interactions within primary cortices and between rudimentary stimuli require that longstanding notions of cortical organization be revised to include multisensory interactions as a fundamental component of neural organization (see refs. 7,8). Here, we show how investigation of BOLD dynamics can address the current gap in knowledge regarding the neurophysiological bases of and brain regions contributing to multisensory interactions.

Table 1 Results of statistical analyses on peak latency and intensity

	Multivariate Test	Follow-up comparisons (paired t-test, 2-tailed) AV vs A		AV vs V		V vs A	
Peak Latency							
Left Auditory Area	$F_{(2,10)}=19.705$ $p=5.1\cdot10^{-4}$	$t_{(11)}=-5.326$	$\mathbf{2.4\cdot10^{-4}}$	$t_{(11)}=-4.199$	**0.001**	$t_{(11)}=1.443$	0.177
Right Auditory Area	$F_{(2,10)}=4.941$ $p=0.032$	$t_{(11)}=-2.512$	**0.029**	$t_{(11)}=-2.413$	**0.034**	$t_{(11)}=0.426$	0.678
Left Visual Area	$F_{(2,9)}=11.246$ $p=0.004$	$t_{(10)}=-2.476$	**0.033**	$t_{(11)}=-4.417$	**0.001**	$t_{(10)}=-0.629$	0.544
Right Visual Area	$F_{(2,9)}=4.386$ $p=0.047$	$t_{(10)}=-2.976$	**0.014**	$t_{(11)}=-2.652$	**0.023**	$t_{(10)}=-0.746$	0.473
Peak Intensity							
Left Auditory Area	$F_{(2,10)}=4.942$ $p=0.032$	$t_{(11)}=-1.962$	0.076	$t_{(11)}=2.955$	**0.013**	$t_{(11)}=-3.169$	**0.009**
Right Auditory Area	$F_{(2,10)}=7.317$ $p=0.011$	$t_{(11)}=-0.129$	0.900	$t_{(11)}=3.666$	**0.004**	$t_{(11)}=-2.212$	**0.049**
Left Visual Area	$F_{(2,9)}=18.064$ $p=0.001$	$t_{(10)}=5.490$	$\mathbf{2.7\cdot10^{-4}}$	$t_{(11)}=-0.806$	0.437	$t_{(10)}=6.172$	$\mathbf{1.1\cdot10^{-4}}$
Right Visual Area	$F_{(2,9)}=27.195$ $p=1.5\cdot10^{-4}$	$t_{(10)}=5.500$	$\mathbf{2.6\cdot10^{-4}}$	$t_{(11)}=-0.330$	0.747	$t_{(10)}=7.766$	$\mathbf{1.5\cdot10^{-5}}$

AV = auditory-visual; A = auditory; V = visual; bold typeface indicates statistically significant values ($p<0.05$)

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