# Cross modal plasticity after early blindness co-opts persisting visual architecture

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It is well established that occipital cortex shows enhanced responses to somatosensory and auditory stimuli in early blind individuals. However it is not known to whether this cross-modal plasticity arises ‘de novo’ or co-opts residual visual architecture. Here, in a sight recovery subject, we show that the directional tuning of auditory motion responses induced by early blindness in area hMT+ share common architecture with visual motion responses

Early blind subjects show enhanced tactile and auditory perceptual capacities, that seem to be at least partially mediated by novel or enhanced responses to tactile and auditory stimuli within occipital cortex. This cross-modal plasticity seems to be influenced by the normal functional role of these occipital areas: for example, in a phenomenon known as ‘metamodal plasticity’ {Pascual-Leone, 2001 #9101} or ‘functional constancy’ {Saenz, 2008 #9940}, hMT+ responds selectively to auditory motion, an auditory ‘body shape’ task preferentially activates the extrastriate body area {Striem-Amit, 2014 #10996}, and there is some evidence of preferential activation to vocalizations within the fusiform gyrus {Gougoux, 2009 #10995}.

We examined joint tuning for direction of motion across visual and auditory responses within hMT+ in a sight recovery subject, MM, who acquired vision at the age of 46 after becoming blind at age 3. When blind MM had low light perception only. At the date of testing MM’s sight had been restored (20/1000, limited by severe amblyopia rather than optics) for 14 years. Despite severe losses in acuity, MM has no known deficits in his ability to process visual motion, reports continued use of visual motion information in everyday life, and shows robust hMT+ responses to visual motion [[4](#_ENREF_4)]. However, similar to individuals who become blind before the age of 11 and remain blind, MM shows robust cross-modal responses to *auditory* motion within hMT+ {Fine, 2003 #10692}.

Using both BOLD multivoxel pattern classification and adaptation we show that in MM direction of motion tuning selectivity is shared across visual and auditory responses within hMT+ - the novel cross-modal responses induced by early blindness share common architecture with residual visual motion responses.

*Cross modal MVPA classification for direction of motion*

hMT+ was defined as a region that showed significant responses to visual motion (q(FDR)<0.05) in separate localizer sessions. The MVPA auditory motion stimulus consisted of 900ms auditory motion noise bursts containing 8 spectrally and temporally overlapping bands of noise with center frequencies evenly spaced between 1500-3500Hz. Motion was simulated using inter-aural time and level differences, and Doppler shift. Two coherence levels were included: unambiguous (50%) with 6 bands moving to the right and 2 to the left (or vice versa), and ambiguous (0%) with 4 bands moving to the right and 4 to the left. The visual stimulus consisted of 0.3◦ (dot density 1 per degree) limited lifetime (600ms) moving dots within a circular aperture (radius 8◦). Two coherence levels were used: unambiguous (35%) with 35% of dots moving either leftward or rightward, and ambiguous (0%) with the all dots moving in random directions. Each visual/auditory motion block lasted 18s, and contained 6s of baseline and 12s of auditory or visual stimulus presentation. MM reported the apparent direction of motion after each of two probe beeps that occurred ~4s and 10s after stimulus onset. A trial was included for multivoxel pattern analysis if MM reported the direction of motion *correctly* across both probe beeps (unambiguous trials) or if MM did not switch his answer during that trial (ambiguous trials). Because of the limited number of trials, we did not analyze unambiguous and ambiguous trials separately.

Figure 1a shows the ability to classify the direction of motion of an auditory motion stimulus on the basis of BOLD responses within left and right hMT+ using a classifier that was also trained on auditory motion. For comparison previously published group data are shown for MM (black large circles) and an age and gender matched sighted control subjects (empty large circles). In sighted subjects (empty symbols) the direction of motion of an auditory stimulus cannot be classified from responses in hMT+. In contrast, within early blind subjects the direction of auditory motion can be classified from responses in hMT+. A similar pattern of results are obtained for MM and his sighted control – it is possible to classify the direction of auditory motion from responses in hMT+ for MM, but not for his sighted control.

Figure 1b shows cross modal classification for direction of motion. In MM the direction of auditory motion could be successfully classified based on the pattern of BOLD responses to a visual motion stimulus, and vice versa. In contrast, in his sighted control cross-modal classification was at chance – this last result is of course entirely predictable given that the data in Panel A implies that there is no reliable pattern in the BOLD response of hMT+ that can differentiate leftward from rightward auditory motion

Figure 1. fMRI pattern classification and adaptation performance for auditory motion in hMT+. (A) MVPA classification accuracy for the direction of an unambiguous auditory motion stimulus. (B) Cross-modal classification accuracy. For SR and EB subjects large square symbols show mean MVPA classification accuracy for the direction of ambiguous motion stimulus with error bars representing the standard error of the group mean. Individual SR and EB subjects are represented with small circles. For MM and his age-matched control subject large circles represent mean accuracy across scans, with error bars calculated across separate scans. Wilcoxon signed rank tests (one-sided, uncorrected for multiple comparisons) were used to examine whether behavioral or classification performance was significantly above chance performance of .5. \*p < 0.05; \*\* p < 0.01; \*\*\* p < 0.001.

*Cross-modal adaptation for direction of motion*

Successful cross-modal classification implies a congruence in architecture between auditory and visual direction motion tuning within hMT+, but does not necessarily imply congruence on the scale of shared neuronal selectivity. To examine whether there might be shared tuning at a neuronal level in MM we carried out a cross-modal adaptation paradigm. Motion adaptation stimuli were identical to those used in the classification experiment except that both auditory and visual stimuli consisted of 100% coherent motion (auditory: 8 bands moving to the right or left; visual: all dots moving to the right or left). After an initial 2min pre-adaptation period the stimulus alternated every 8s between the adaptor (e.g. leftward auditory motion) and a stimulus in the other modality that either (pseudo-randomly) moved in the same or a different direction. If cross-classification is mediated by neurons that are tuned for visual and auditory motion in the same direction then we would predict a cross-modal adaptation effect for direction of motion.

Figure 2a shows the difference in BOLD between responses when the stimulus in the test period was in the different vs. same direction as the adaptor. There was significant adaptation effect (in both hemispheres) when using a visual adaptor – responses to auditory motion were weaker when the auditory motion was in the same direction as the visual motion adaptor, suggesting shared neuronal tuning across vision and audition. There was no discernable adaptation effect for an auditory motion adaptor. One possible reason for this is that the auditory motion stimulus produced weaker hMT+ responses than the visual stimulus, and might therefore have been an ineffective adaptor.

How might this finding of congruence between visual and auditory motion tuning have been affected by the peculiar visual history of MM? It is not surprising that MM shows a pattern of auditory cross-modal plasticity within hMT+ typical of early and congenitally blind individuals, despite having been blinded at the relatively late age of 3 and a half. Several studies now suggest that cross-modal plasticity as a result of blindness is a developmental phenomenon with a relatively long critical period that can extend to the pre-teen years.

It is less clear whether or not these findings would generalize to early blind or anophthalmic individuals who lack developmental experience of visual motion. As yet almost nothing is known as to how the development of neuronal architecture in hMT+ depends on visual experience. In the macaque, adult-like retinotopic connections between V1 and V2 are present before birth, shortly after LGN axons reach layer IV {Coogan, 1996 #10958} and are primarily driven by molecular signaling {Huberman, 2008 #10860; Cang, 2013 #10938}, though further refinement occurs with the onset of visual experience {Baldwin, 2012 #10973}. In adult humans persisting retinotopic organization can be seen within V1-V3, even within anophthalmic individuals who develop without eyes {Bock, 2015 #10982}. It is possible that MT/MST architecture is similarly robust to the absence of visual experience. Like basic acuity, motion sensitivity has a remarkably early critical period Maurer). Moreover, like V1, MT receives direct subcortical input (from the pulvinar, \Rodman, 1990 #10993}. If, like V1-V3, MT/MST has ‘visual’ architecture that persists even in the absence of visual experience, then it is possible our findings in MM might reflect a general property of cross-modal plasticity that also occurs in early blind and possibly even anophthalmic individuals. However, even if these results are unique to MM they nonetheless imply that cross-modal plasticity as a result of blindness does not necessarily arise ‘de novo’, but rather is capable of repurposing existing connectivity at the neuronal scale.

1,000-1,200 words