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fMRI localizer technique: Efficient acquisition and functional properties of single retinotopic positions in the human visual cortex

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Current fMRI retinotopic mapping procedures often use checkerboard stimuli consisting of expanding rings and rotating wedges to measure the topography within human visual areas. Efficient procedures are well described in the literature. For many experimental paradigms, e.g., visuo-spatial attention paradigms, the identification of task-relevant positions is the only mandatory prerequisite. To define these specific "regions-of-interest" (ROIs), spatially defined localizers are used. A precise evaluation of localizer techniques in regard to efficient scanning time, optimal BOLD (blood oxygenic level dependent) response, as well as quantification of the resulting ROIs within each visual area (size, overlap, surround effects) has not been studied to date. Here, we suggest a mapping procedure designed to quantify spatial and functional properties of single positions at close proximity in multiple human visual areas. During a passive viewing task, various stimuli (e.g., checkerboards or colored objects) subtending 1.4° of visual angle were presented at one out of four positions in a randomized block design. We measured the degree of overlap between positions at different hierarchical levels of the visual system (V1–V4v) and quantified modulatory effects on a specific position by stimulation at neighboring (1.7° spacing) or distant positions (5.1° or 8.5° spacing). Within each visual area, "mexican-hat" distributions of local signal intensity changes, which describe a particular combination of facilitatory and suppressive effects, were found. Cubic fitting revealed the most localized tuning effect in V1, which gradually decreased throughout the higher visual areas. Colored objects were most efficient in localizing circumscribed retinotopic positions in both early and higher areas.

Keywords: Occipital cortex; Retinotopy; Receptive field; Negative BOLD; Mapping

Introduction

A hallmark of the functional neuroanatomy of the visual system is its hierarchical organization, in which the visual field is topographically represented in multiple visual areas. In 1974, Hubel and Wiesel showed in non-human primate striate cortex (V1) that both scatter and the size of a receptive field (RF) increases with its distance from the fovea (eccentricity). This principle has been shown to also hold true for higher levels of visual processing (e.g., V2, V3/VP, V3a/V4v); although accompanied by coarser resolution with increase in hierarchical level (V2: Gattas et al., 1981; V3/VP: Burkhalter et al., 1986; V3/V4v: Gattas et al., 1988).

In human subjects, functional magnetic resonance imaging (fMRI) is used to map these areas in regard to their individual fine-grained topographical organization (retinotopic mapping). To do so, current mapping procedures commonly use a battery of stimuli consisting of expanding rings or rotating wedges (e.g., Engel et al., 1997; Sereno et al., 1995; DeYoe et al., 1996). The spatial and functional properties of the resulting activations within the visual areas are well described (e.g., Dougherty et al., 2003). The particular mapping procedures differ with respect to their stimulus characteristics, e.g., black–white checkerboards (e.g., Sereno et al., 1995), colored checkerboards (e.g., Warnking et al., 2002; Tootell and Hadjkhani, 2001), or video stimuli (e.g., Schira et al., 2004); the flicker frequency of stimuli, e.g., 4 Hz (e.g., Sereno et al., 1995) or 8 Hz (e.g., DeYoe et al., 1996); the block length, e.g., 16–20 s (e.g., Tootell et al., 1998a; Martinez et al., 2001), 32 s (e.g., Tootell and Hadjkhani, 2001; Engel et al., 1997), 40 s (e.g., Tootell et al., 1998b; DeYoe et al., 1996); and the task, e.g., passive viewing (e.g., Sereno et al., 1995; Tootell et al., 1998b; Engel et al., 1997) versus central or peripheral task (e.g., Martinez et al., 2001; Tootell et al., 1998a; DeYoe et al., 1996). To optimize the standard mapping technique, some groups have addressed the question how data acquisition can be improved in regards to efficient scanning time and optimal BOLD vascular response (e.g., Warnking et al., 2002; Slotnick and Yantis, 2003; Hagenbeek et al., 2002).

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It must be pointed out that in many experimental paradigms, only the distinction of task-relevant positions is necessary, e.g., in visuo-spatial attention paradigms. To spatially identify these specific positions, circumscribed localizer stimuli were introduced (e.g., Rees et al., 2000; Somers et al., 1999; Slotnick et al., 2003; Müller et al., 2003; McMains and Somers, 2004). Unfortunately, little is known about the spatial and functional properties of the resulting activations (ROIs) as the extent and characteristics of local cortical activation (e.g., size, overlap, and surround effects) under specific targeting of a circumscribed position within the visual field. It would also be helpful to know which specific stimulus type produces the strongest local BOLD effect. Bearing in mind that in many studies the main paradigm (e.g., attention task) will be demanding both, with regard to the subject's performance, as well as with regard to scanning time, it would be advantageous to optimize ROI mapping procedures.

Here, we suggest an fMRI mapping procedure designed to functionally separate circumscribed retinotopic positions at close proximity in human test subjects. This technique should be able to quantify the area-dependent local spatial and functional characteristics (size, overlap, surround effects) as well as differentiate effects across visual field quadrants. Moreover, different stimuli will be tested in terms of efficiency criteria.

Materials and methods

Subjects

Eight healthy right-handed subjects (mean age 27 years, range 25–30) with normal color vision and sufficient visual acuity participated in the study, which was conducted in conformity with the Declaration of Helsinki. All subjects signed a consent form and were rewarded for their participation.

Experimental paradigm

Mapping of visual areas (meridian-mapping)

To define the borders separating early visual areas, we used a standard meridian-mapping experiment (DeYoe et al., 1996; Slotnick and Yantis, 2003; Schira et al., 2004). Checkerboard stimuli were sequentially presented at the horizontal and vertical meridians for 20 s. All participants completed two 9-min runs (12 repetitions per condition), each with five 20-s periods of fixation (see Fig. 1A). By simultaneously stimulating either both horizontal (right/left) or both vertical meridians (upper/lower), data acquisition time was reduced (Yantis and Slotnick, 2003).

Mapping of single positions (localizer-mapping) (see Figs. 1A and B)

During a passive viewing task, various stimuli encompassing 1.4° of visual angle were presented at one out of four positions in the visual field in a block design. The specific positions were carefully selected in order (i) to test whether we can identify separate regions within each visual area (V1–V4v), (ii) to measure the degree of overlap between positions at different hierarchical levels of the visual system and, (iii) to measure modulatory effects on a specific position when neighboring (1.7° spacing) or distant (5.1° or 8.5° spacing) positions were stimulated. A central fixation cross and four squares indicating the four possible stimulus positions (positions 1–4) were visible during the entire experiment and subjects were instructed to maintain central fixation. Stimuli were presented in randomized order at the four locations (positions 1–4, block length 20 s) with 8 repetitions for each position. Three "no-stimulus" periods of

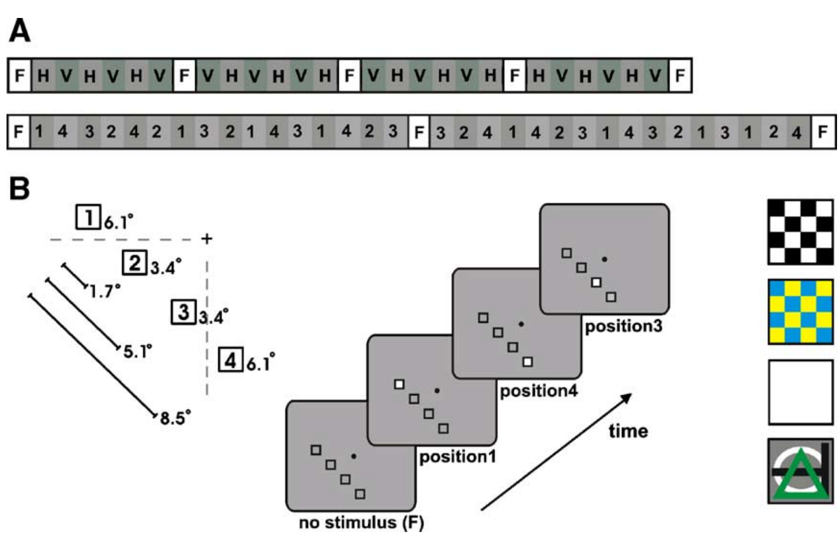

Fig. 1. Experimental design. (A) Schematic illustration of meridian- and localizer-mapping protocols. *Row 1*: One run of the meridian-mapping (F = fixation, H = checkerboards oriented along the horizontal meridian, V = checkerboards oriented along the vertical meridian). *Row 2*: One run of the localizer-mapping (F = no stimulus condition, numbers 1–4 indicate stimulus presentation at positions 1–4, respectively). (B) Illustration of stimuli. Positions 1 and 2 were 1.2° above or below the horizontal meridian and positions 3 and 4 were 1.2° right or left from the vertical meridian (dashed lines). Distance between target positions and fixation as well as spacing between stimulus positions (in degrees). Subjects passively viewed the stimuli presented randomly at each position sequentially for 8 × 20 s while maintaining central fixation. Different stimulus types (black–white/blue–yellow checkerboards, white flash stimuli, colored objects) were used in distinct experimental runs.