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Vividness of mental imagery: Individual variability can be measured objectively

Xu Cui [a], Cameron B. Jeter [b], Dongni Yang [c], P. Read Montague [c], David M. Eagleman [b,d,e,*]

[a] *Program in Structural and Computational Biology and Molecular Biophysics, Baylor College of Medicine, One Baylor Plaza, Houston, TX 77030, USA*
[b] *Department of Neurobiology and Anatomy, University of Texas, Houston Medical School, 6431 Fannin St., Houston, TX 77030, USA*
[c] *Department of Neuroscience, Baylor College of Medicine, One Baylor Plaza, Houston, TX 77030, USA*
[d] *Department of Psychology, Rice University, Houston, TX 77030, USA*
[e] *Institute for Neuroscience, University of Texas, Austin, Austin, TX 78713, USA*

Abstract

When asked to imagine a visual scene, such as an ant crawling on a checkered table cloth toward a jar of jelly, individuals subjectively report different vividness in their mental visualization. We show that reported vividness can be correlated with two objective measures: the early visual cortex activity relative to the whole brain activity measured by functional magnetic resonance imaging (fMRI) and the performance on a novel psychophysical task. These results show that individual differences in the vividness of mental imagery are quantifiable even in the absence of subjective report.
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1. Introduction

Visualize the sun rising above a rocky mountain range into a bright sky. How vivid is your mental picture on a scale from 1 to 5, where 1 is akin to a photograph, and 5 is a pictureless concept? Subjective measures have found a wide distribution in the vividness of the visual images that different individuals generate (Amedi, Malach, & Pascual-Leone, 2005; Hatakeyama, 1997; Marks, 1973; McKelvie, 1994; McKelvie & Demers, 1979). We here seek to find whether this individual variability is objectively measurable—specifically, whether subjective reports are correlated with measures of blood flow (fMRI) and/or performance on a visual psychophysical task.

Accumulating evidence suggests that the neural substrates of visual imagery are similar to those of visual per-

ception (Farah, 1988; Ganis, Thompson, & Kosslyn, 2004; Ishai & Sagi, 1995; Kosslyn, Thompson, & Alpert, 1997; Kreiman, Koch, & Fried, 2000)—not surprisingly, therefore, the visual cortex is widely activated during imagery (Amedi et al., 2005; Ganis et al., 2004; Kosslyn et al., 1993; Kosslyn et al., 1997; Kosslyn, Thompson, Kim, & Alpert, 1995; Mellet, Tzourio, Denis, & Mazoyer, 1995). A previous study has suggested that visual cortex activity and vividness of visual imagery have a trend of positive correlation (Amedi et al., 2005). Thus visual cortex activity is a promising candidate for an objective index of the subjective vividness.

If visual cortex activity correlates with reported vividness of visual imagery, then it is possible that performance on a psychophysical task which utilizes the visual cortex may also differentiate visualizers (Hatakeyama, 1997). To this end, we have developed a color perception and naming task as our probe. The reason for using this task, besides its dependence on the visual cortex, was based on an observation in our laboratory that those who were more visually oriented showed a diminished ability to identify a briefly

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displayed color word when the background screen color matched the word meaning. To test that hypothesis, we sought to systematically determine whether high visualization and poor performance on our color-naming task were indeed correlated.

2. Methods

2.1. Subjects

Eight subjects (6 Males, 2 Females, ages 25–31) participated in the following three experiments: subjective vividness rating, color naming task, and visualization task while being scanned by fMRI scanner. Two additional participants were excluded from the analysis because their accuracy in the color naming task was less than 35%, where chance performance was 25%.

2.2. Subjective vividness rating

We measured participants' vividness of visual imagery (VVI) with a standardized battery of visualization questions (Marks, 1973) which are listed in the supporting online material. The average of the vividness ratings of the 16 questions was used. Note that a low VVI score means vivid imagery and a high score means vague imagery.

2.3. Color naming task

In the color naming task, we asked participants to report the identity of the words briefly flashed on a computer screen (Fig. 2a). On each trial, the background screen color turned yellow, orange, or purple, and 32 ms later the word "yellow", "orange", "purple", or no word appeared in a

central rectangle for 32 ms. The words were always in black. Participants reported on the keyboard which of the three words they saw (or no word). Each participant completed 120 trials.

2.4. Visualization task

In the fMRI scanner, the participants were blindfolded with their eyes covered by sleeping masks. Each participant completed 24 trials. In the beginning of each trial, the participants were given auditory instructions to visualize themselves or another person either bench pressing or stair climbing. The participants were asked to begin visualization upon hearing an auditory "go" signal, and continue visualization until they heard an auditory 'stop' signal. The duration between 'go' and 'stop' was set to be 10 s. The next trial started 10 s after the 'stop' signal, resulting a 10-s rest phase (Fig. 1a).

2.5. fMRI methods

Images were acquired with a 3T Siemens scanner. High-resolution T1-weighted scans were acquired using an MPRage sequence (Siemens) prior to the functional scan. Functional run details: echo-planar imaging, gradient recalled echo; repetition time (TR) = 2000 ms; echo time (TE) = 40 ms; flip angle = 90°; 64 × 64 matrix, twenty-nine 4 mm axial slices, yielding functional 3.4 × 3.4 × 4.0 mm voxels. Data analysis was performed using SPM2 (Wellcome Department of Imaging Neuroscience, University College London, United Kingdom; http://www.fil.ion.ucl.ac.uk/spm/spm2.html) and visualized using xjView (http://people.hnl.bcm.tmc.edu/cuixu/xjView). Motion correction to the first functional scan was performed using a six-parameter rigid-body transformation (Kao, Davis, & Gabrieli, 2005). The mean of the motion-corrected images was co-registered to each individual's structural image using a 12-parameter affine transformation. Slice timing artifact was corrected, after which the images were spatially normalized to the MNI template by applying a 12-parame-
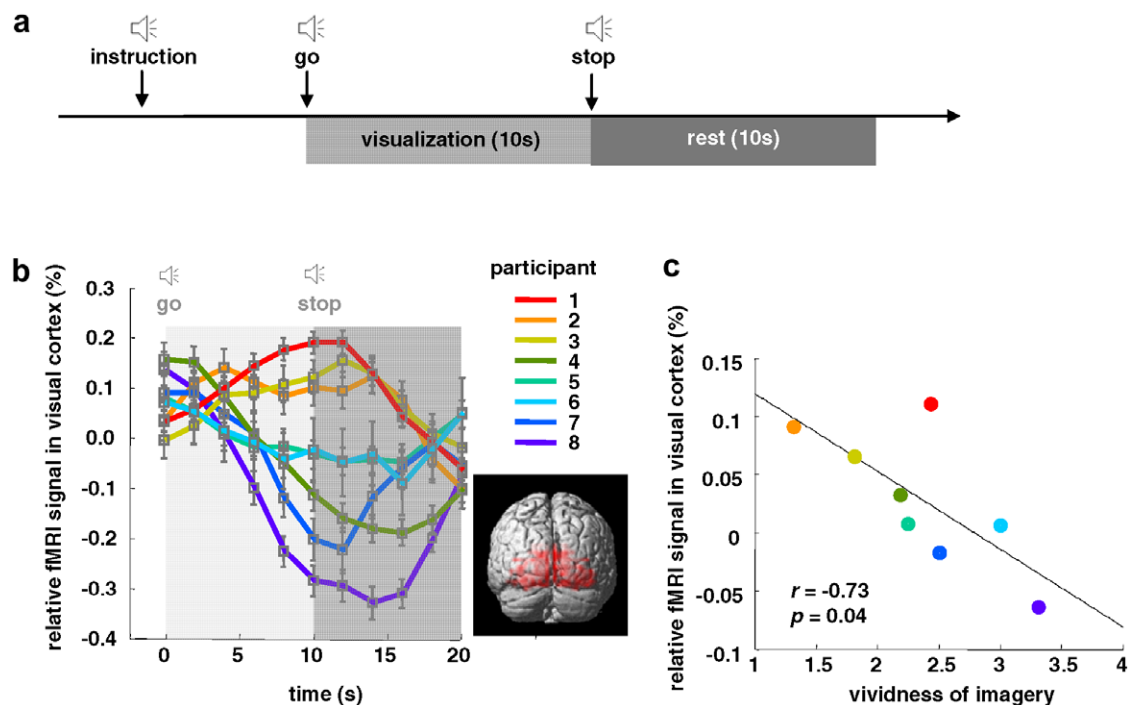

Fig. 1. Relative activity in visual cortex correlates with subjective vividness rating. (a) Timeline of the visualization task. Participants began to visualize upon hearing the 'go' signal, and stopped visualization upon hearing the 'stop' signal, resulting a 10-s visualization phase and 10-s rest phase. All instructions are auditory. (b) Time course of the relative fMRI signal in visual cortex for 8 participants. Relative fMRI is taken as the BOLD signal in early visual cortex (Brodmann's areas 17 and 18, illustrated in inset) minus the BOLD signal measured over all of gray matter. For plotting purposes, participants are ordered by their relative visual cortex activity averaged over the visualization window of 0–10 s. The negative signal for some subjects is due in part to the subtraction of the whole brain activity—i.e., other regions can increase more than the visual cortex during the time window. (c) The relative visual cortex signal averaged over the visualization window correlates significantly with the subjective rating of vividness ($p = 0.04$).

ter affine transformation, followed by a nonlinear warping using basis functions. Images were then smoothed with an 8 mm isotropic Gaussian kernel and highpass filtered in the temporal domain (filter width of 128s) (King-Casas et al., 2005).

We used as our region of interest the early visual cortex—specifically, Brodmann areas 17 and 18 (Fig. 1b, inset), as defined in the database of MNI Space Utility (http://www.ihb.spb.ru/%7Epet_lab/MSU/MSUMain.html). This area contains 526 voxels. We calculated the relative fMRI signal in visual cortex as the following: The time series of fMRI signals were averaged across the 526 voxels in the visual cortex. The baseline of the averaged signal was calculated by moving average (with window size 200s). The averaged signal was then subtracted by the baseline (detrending). The detrended signal was divided by the baseline to obtain the percentage change of fMRI signal in visual cortex. We then subtracted this signal by the percentage change of signal of the whole brain gray matter and obtained the relative fMRI signal in visual cortex. The gray matter (containing 8451 voxels) is also defined by MNI Space Utility. The resulting signal is then averaged over the 10-s imagery window to obtain Figs. 1c and 2c, d. We subtracted the visual cortex signal by the whole brain gray matter signal to determine the visual cortex activity relative to that of the whole brain. This subtraction—spatial baseline removal—can be viewed as the counterpart of the temporal baseline removal employed in most fMRI time series analysis. We felt this was important to isolate changes specific to visual cortex instead of

changes in whole brain activity. We also repeated the analysis without removing the spatial baseline.

3. Results

3.1. Vividness of visual imagery correlates with fMRI activity in early visual cortex

The relative visual cortex activity starts to differentiate for different subjects during the visualization phase and then gradually converges during the rest phase (Fig. 1b). We averaged the relative visual cortex activity over the visualization window (0–10 s) for all participants and correlated it with their subjective VVI scores. We found a strong correlation (Fig. 1c, $r = -0.73$, $p = 0.04$), demonstrating that higher relative visual cortex activity indexes more vivid imagery (a lower VVI score). This result suggests one can measure visual cortex activity to probe the vividness of a subjects' imagery, thus obtaining a more objective measure of a previously subjective rating.
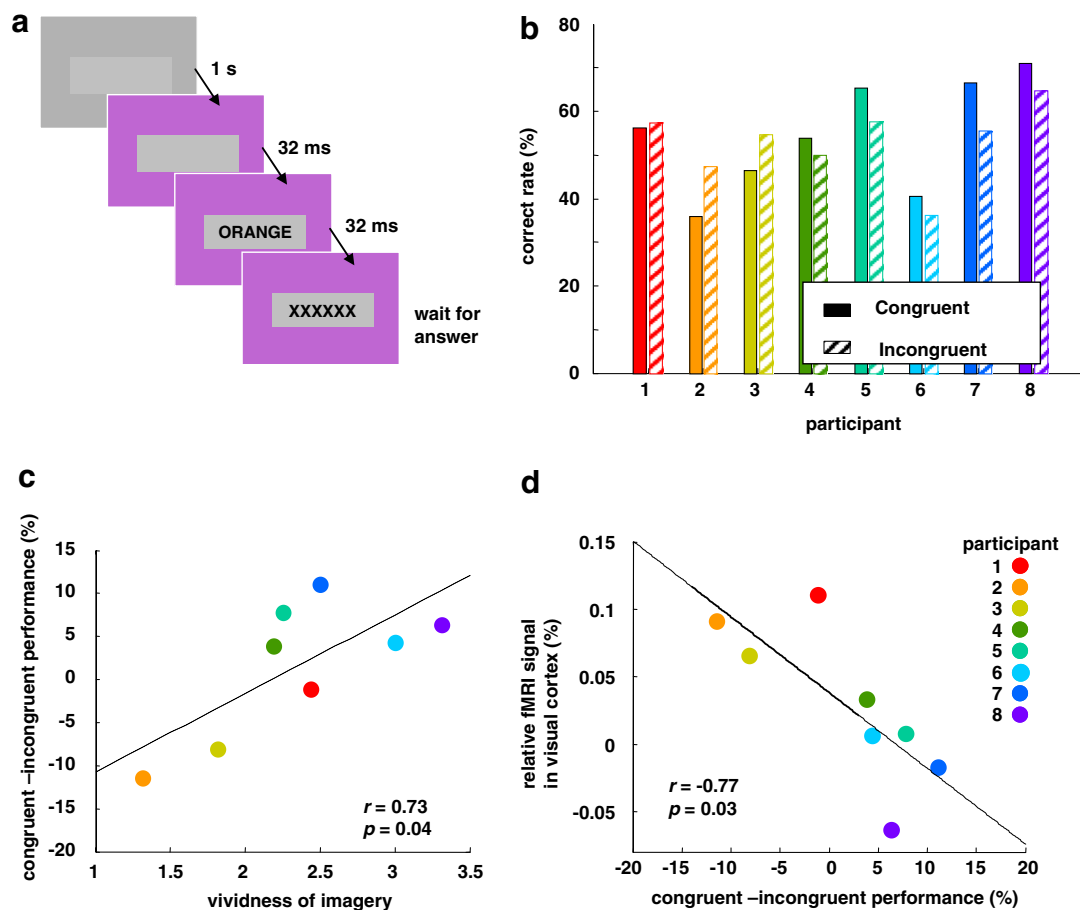

Fig. 2. Word-color interference correlates with subjective and objective measures of visual imagery. (a) Timeline of the color word identification task. On each trial, the background screen color turned from gray to yellow, orange, or purple, and 32 ms later the word "yellow", "orange", "purple", or no word flashed for 32 ms in a central rectangle. Participants reported on the keyboard which of the three words they saw (or no word). (b) The performance in congruent trials (where word and background color were the same) and incongruent trials (word and background color were different). Participants are ordered as in Fig. 1. (c) Correlation between vividness of visual imagery and the congruent–incongruent performance. The latter is defined as the difference between performances on congruent versus incongruent trials, as seen in (b). (d) Correlation between the relative visual cortex activity and congruent–incongruent performance. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this paper.)

3.2. Performance on a novel psychophysical task correlates with vividness of imagery and visual cortex activity

On average, the eight participants displayed $54 \pm 3\%$ accuracy in identifying which word was displayed, and $85 \pm 7\%$ accuracy in identifying that no word was presented. We noted a small, seemingly random *difference* in accuracy between the trials in which the displayed word matched the background color ('congruent') and when it did not match ('incongruent'): we will refer to this as the congruent–incongruent performance (Fig. 2b). This difference was often small and could easily be dismissed as noise, but observation of the participants led us to notice that those who were more visually oriented (lower VVI score) seemed more likely to suffer diminished performance in congruent trials. To test this, we correlated VVI and the congruent–incongruent performance and found a good correlation ($r = 0.73$, $p = 0.04$, Fig. 2c), indicating that subjects with stronger visual imagery are more susceptible to same-color interference. We then correlated visual cortex activity with the congruent–incongruent performance difference, and found high significance (Fig. 2d, $r = -0.77$, $p = 0.03$).

4. Discussion

These findings emphasize the importance of examining individual subject variability. For imaging data, averaging the relative visual cortex activity (Fig. 1b) across subjects would have led to the conclusion that the visual cortex did not significantly change during visualization phase. Indeed, a conventional general linear model (GLM) and random effect analysis was done using SPM2 (see Section 2) and the resulted t-values in visual cortex were not significant (data not shown). For behavior data, averaging the performance accuracy from the word-naming experiment (Fig. 2b) would have erased the individual differences between the congruent and incongruent performances of the subjects. Only upon more detailed inspection of the individual fluctuations does a pattern emerge. Specifically, these data indicate that subjects who are more visual in subjective measures (VVI) and objective measures (bloodflow in visual cortex) are more susceptible to a color-naming interference. Note that this effect is the opposite of the Stroop effect (Stroop, 1935), in which incongruence between an ink color and the color-name leads to cognitive conflict and slower reaction times. Here, for the more visual subjects, incongruent colors make it easier to see a color word. These findings imply an increased interaction between brain areas that code for color perception and color naming in highly visual individuals. Areas potentially implicated in this increased language-imagery interaction are medial occipito-temporal cortex (in particular, human area V4 or areas just anterior to it (Zeki et al., 1991), in which lesions lead to achromotopsia, a deficit in color perception (Bouvier & Engel, 2006)) and left occipital lobe (in which lesions cause color anomia, a deficit in color naming (De Vreese, 1991)).

Whether this increased interaction results from increased visualization skills, or instead explains it, remains an open question.

Our findings may have applications in legal settings. It has been reported that false memories occur more easily for high visualizers than for low visualizers (Dobson & Markham, 1993; Douglas, 1996; Wilson & Barber, 1978). If an eyewitness is a high visualizer, her accuracy of recalling the actual crime scene may be compromised, especially during a forensic investigation procedure called the cognitive interview (CI), in which she is explicitly asked to visualize scenes from the perspective of a person or an object located in another position in the room (Geiselman, Fisher, MacKinnon, & Holland, 1986). Some authors thus suggest abandoning the imagery component of the CI (Ceci & Bruck, 1995; Douglas, 1996). Our findings suggest that instead of abandoning the imagery, one might use our objective methods of evaluating imagery ability prior to the CI to flag witnesses who might be more susceptible to false recall. More broadly, and with further study, the objective methods introduced here might be used in forensic investigations to generate an index of the reliability of eyewitness recall.

Previously, the vividness of a person's imagery has been accessible only through verbal report. Our study shows that we can read out an individual's 'private' imagery vividness by measuring blood flow changes in early visual cortex. This finding is conceptually interesting because it shows that aspects of mental thought can be studied objectively with current technology (e.g., fMRI). It is also practically promising: though still more inconvenient to administer than self report, it opens the possibility that we can measure vividness by more than one method. Subjective rating is a standard method in psychology and psychophysics. However, there are few methods to check its truthfulness and validity (Prelec, 2004). In some cases people may lie if there is a conflict of interest (e.g., during forensic investigation). Thus an objective measure is at least beneficial and sometimes necessary. Finally, while it is true that the VVIQ is easier to administer than a neuroimaging experiment, in some cases (e.g., forensic investigation) objectivity may be sufficiently important that the cost of fMRI scan is trivial. In extreme cases (e.g., in studying vegetative patients), fMRI measures may be the only option (Owen et al., 2006).

These findings may also lend a new interpretation to a recent study on synesthesia (Mattingley, Rich, Yelland, & Bradshaw, 2001). In that study, a subject with synesthesia showed diminished performance in identifying a digit when the digit was presented against a background that matched her synesthetic color association. The authors of that study suggested that her 'projection' of the synesthetic color caused the digit to 'blend' into the background, making it more difficult to discern. However, an alternative hypothesis suggested by our finding is that high visualization capacity of the subject may have caused interference between the synesthetic digit and the background color.

Acknowledgments

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.visres.2006.11.013.

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