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The relationship between functional magnetic resonance imaging activation, diffusion tensor imaging, and training effects

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Abstract

While the relationship between diffusion tensor imaging (DTI) measurements and training effects is explored by Voelker et al. (this issue), a cursory discussion of functional magnetic resonance imaging (fMRI) measurements categorizes increased activation with findings of greater white matter integrity. Evidence of the relationship between fMRI activation and white matter integrity is conflicting, as is the relationship between fMRI activation and training effects. An examination of the changes in fMRI activation in response to training is helpful, but the relationship between DTI and fMRI activation, particularly in the context of white matter changes, must be examined further before general conclusions can be drawn.

Keywords

Diffusion tensor imaging; functional magnetic resonance imaging; training

Discussion

Voelker et al. (this issue) cite diffusion tensor imaging (DTI) studies that illustrate post-training differences in measures of white matter integrity such as fractional anisotropy and radial diffusivity. They suggest that the increase in white matter measures correlates with training and decreases in reaction time, and that the physiological basis for this phenomenon is the increase in synaptic transmission speed that occurs with greater myelination. They also cite functional magnetic resonance imaging (fMRI) studies, both resting-state and task-based, and describe increases in blood oxygen level-dependent (BOLD) signal in these studies in support of the argument that training improves white matter integrity. This implies that the changes in DTI measures and increases in BOLD signal are related or share similar neural mechanisms. The fMRI BOLD signal is based on the increased blood flow to a brain region that correlates with increased activation of that region (Logothetis, 2002), whereas

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DTI measures rely on the anisotropy (directionally dependent diffusion) of water molecules within myelinated axons (Emsell, Van Hecke, & Tournier, 2015).

The relationship between DTI measures and fMRI BOLD signal activation is complex. BOLD signal activation has shown variability in the direction and amount of association with white matter measures, and these associations change with age (for review, see Bennett & Rypma, 2013). A theory uniting increased BOLD signal with increased white matter integrity is that increased white matter integrity will facilitate stronger, quicker signals to gray matter regions, thus leading to increased blood flow to these regions. However, an opposing theory is that increased efficiency of signal propagation through white matter tracts may lead to more efficient interactions and consequently decreased metabolic demands in gray matter regions, which would translate to lower BOLD signal measurements (Bennett & Rypma, 2013). In addition, it has been posited that diminished white matter integrity may lead to increased compensatory behavior by the gray matter, and thus an increase in BOLD signal (Park & Reuter-Lorenz, 2009).

The fMRI study cited by the authors (Buschkuehl, Hernandez-Garcia, Jaeggi, Bernard, & Jonides, 2014) that describes an increase in BOLD signal activation in a working memory task after training describes this increase only in a maximally difficult version of the task. However, fMRI activation has also been found to decrease with training for a less difficult version of the working memory task (Schneiders, Opitz, Krick, & Mecklinger, 2011), and decreased fMRI activation in select prefrontal cortical regions has been described as a measure of cognitive efficiency (Rypma et al., 2006). In addition, timing and amplitude of BOLD signal activation were found to correlate positively with reaction time (Yarkoni et al., 2009). Taken together, these results are aligned with the theory that faster reaction times lead to more efficient interactions and decreased BOLD signal activation. This suggests that the relationship between reaction time, training, and BOLD signal activation is complex and that perhaps both theories are correct during different task requirements and are based on localized interactions.

BOLD signal activation appears to relate to training as well as DTI measures, but the relationship cannot be simply described as a positive or negative correlation. fMRI is an important, noninvasive means of measuring brain activation changes over time, but the relationship of training effects and white matter integrity to the BOLD signal must be explored further before conclusions can be drawn.

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