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Review

Evidence for structural plasticity in humans: Comment on Thomas and Baker (2012)

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ABSTRACT

Thomas and Baker (2012) have provided a balanced and critical review of the scientific evidence claiming that training interventions have the capacity to alter the structural morphology of the brain. Here I provide some additional considerations when reading and interpreting both the review and the original empirical articles. Research proposing to examine the capacity for structural brain plasticity needs to contemplate methodological issues and factors that could moderate or mask potentially interesting effects. Overall, although this area of research is in need of circumspection, it also could have transformative implications if structural brain plasticity in humans is possible.

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The brain is inherently plastic. Yet, despite this well-recognized characteristic of the brain, there remains significant debate about the capability for neuroimaging techniques to detect plastic structural changes in humans. This skepticism partly stems from technical limitations of neuroimaging techniques including the relatively macroscopic spatial scale (~1 mm) of most structural imaging sequences. Is it conceivable that structural changes on the cellular level (e.g. dendritic spines) could occur to such an extent that relatively coarse structural imaging techniques could reliably detect the change? From another perspective, if changes in brain morphology can be reliably detected using structural brain imaging techniques and analyses, should these changes be considered as evidence for "plasticity" as the term is used and conceptualized in cellular and immunohistochemical studies?

These questions, and many more like them, are important to consider as the field moves forward. It is critical that scientists, students, reviewers, and others remain cautious and skeptical of studies of structural brain plasticity in humans, while also remaining enterprising and bold in experimental design and interpretations. Striking a balance between being circumspect and objective, while also progressive when interpreting results is especially challenging given the young age of the field when conceptual and methodological limitations are not always outlined. The use of neuroimaging techniques to study structural brain plasticity in humans is arguably still in its infancy, or maybe the "terrible-twos", and for the topic to mature into a respectable subfield there is a need for guidance and balanced criticism. It is this thoughtful criticism that the Thomas and Baker (2012) manuscript harmoniously navigated while maintaining a positive outlook for the evolution of the field.

It does not take much effort to perceive the larger picture with respect to structural brain plasticity. If advanced structural neuroimaging techniques and analytical methods could be leveraged to assess the effectiveness of therapeutics and training techniques on modifying the structure of the cortex, it could easily transform the way in which the effectiveness of these therapies are evaluated. There could also be an equally transformative impact on the way in which brain plasticity is conceptualized in human research studies. Because of this it is clear that the potential for measuring changes in the morphology of the cortex using structural brain imaging techniques is an exciting and potentially illuminating avenue for many fields of research from studying developmental disabilities to understanding the efficacy of rehabilitative techniques in late adulthood. Yet, again, it is important to soften this excitement and return to the cautionary tale that Thomas and Baker (2012) review. For comprehensible conclusions about the possibility of structural brain plasticity, it is necessary to conduct rigorously controlled and well-executed studies with appropriate statistical and analytical measures. This caution is perfectly justified, is not unique to this field, and should not be considered an unconventional view for any well-trained scientist. Nonetheless, Thomas and Baker (2012) describe several important limitations in

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prior studies that have attempted to interpret results as strong evidence for structural brain plasticity. Only one study in their review is recognized as providing strong evidence for plasticity (Erickson et al., 2011a). Yet, this study is also not without its limitations and criticism (Coen et al., 2011; Erickson et al., 2011b).

The most pivotal point in the Thomas and Baker (2012) review is the discussion of the fundamental scientific issues impairing progression of the field. Clearly many of the published studies on structural brain plasticity have inadequate control groups, inappropriate and weak statistical methods, and unknown reliability of the analytical methods. These fundamental design and analysis issues prevent an in depth discussion about the meaning of structural changes if any were found. However, there are other issues, inherent within this review, that warrant a few additional comments. First, there is a considerable range in the types of training paradigms employed from juggling training, working memory training, visuo-motor training, training to decipher Morse code, integrative mind–body therapy, aerobic exercise training, spatial memory training, and training to play golf. It is difficult to retrieve much homogeneity in the outcomes from such a heterogeneous set of studies and primary aims. It was not the objective of Thomas and Baker (2012) to describe the ramifications of this heterogeneity on brain plasticity, and rightly so, since trying to do so would have muddied their main points. Nonetheless, it will be important for future studies in this field to ponder the varying effect sizes and effectiveness of these therapies and interventions. In fact, neuroimaging techniques are tools that are well suited for comparing the effectiveness of different therapies and treatments if the study design is constructed appropriately.

In addition to the type of therapy being evaluated, the duration of the training or therapeutic intervention is also likely moderating the treatment effectiveness on brain plasticity. In their review, Thomas and Baker (2012) note the significant heterogeneity in the duration of the treatments reviewed ranging from 3 days to 1-year of training. Again, Thomas and Baker (2012) do not spend much time discussing this variability because it is relatively tangential to their more pressing and fundamental points related to design and methodological matters plaguing the field. Yet, the issue of sufficient treatment duration is a complex and challenging problem when designing treatment studies. Is there a treatment duration that is too short to convincingly claim as evidence for brain plasticity? Clearly expansive changes in morphology are predicated on the occurrence of earlier and subtle changes (using the term subtle rather loosely), but are subtle changes in brain morphology detectable using neuroimaging techniques? Do subtle changes accumulate to a point that could be detectable by neuroimaging methods? It is likely that widespread changes that occur over a rapid time frame and concomitantly over large sections of cortex are potentially spurious and related instead to changes in signal-to-noise or design flaws rather than meaningful shifts in volume or integrity of the underlying tissue. Yet, this is likely to depend on the type of treatment, the population studied (see below), and the resolution of the neuroimaging technique. However, if we presume that microscopic plasticity on the cellular/molecular level would take a significant amount of time to accumulate to the point of being able to be detected using structural imaging techniques, we would expect that changes in morphology would have to be rather sluggish. Yet, even if this presumption is incorrect and changes in morphology could be detected relatively rapidly, we still need to remain cautious in our interpretations of any rapid changes in brain morphology. Again, this is more than just a methodological matter, it speaks to a fundamental question of what any such structural changes could reflect on a histological level. Clearly, it will be critical for the interpretations of such results to closely consider animal models when attempting to make any cellular/molecular claims about plastic changes in humans.

Other potential moderators of structural brain plasticity are the age and diagnostic status of the sample being evaluated. That is, how much of a plastic change in gray matter volume or microstructural white matter integrity could be expected in a college-aged sample? On the other hand, how much structural brain plasticity could be expected in a sample of impaired, dysfunctional, or brain-damaged group of individuals in which significant lesions, learning impairments, or atrophy exists? The answer to these questions might depend on the brain region being examined. For example, as the hippocampus shrinks with advancing age, it might be a brain region for which changes in its size and shape are more detectable. Studies that wish to evaluate whether a particular treatment has an effect on brain plasticity need to carefully assess whether the population and brain regions of interest would demonstrate the effect sizes necessary to reliably interpret the findings.

Early studies (e.g. Draganski et al., 2004) laid the foundation for examining structural brain plasticity, despite having design and statistical limitations. It is this scientific foundation that gave rise to other studies designed to test the potential for brain plasticity using different treatments and populations. But, as Thomas and Baker (2012) describe, the discipline has matured to a point where there needs to be improvements in the design, execution, and analysis of structural brain plasticity studies in order to be taken seriously by the broader scientific community.

Thomas and Baker (2012) provide a welcome and refreshing criticism to the field, and because of this, it will be important for future authors and reviewers to closely scrutinize the interpretations of results that proclaim the presence of structural brain plasticity. However, it is important to finish on a positive note and remember the potential groundbreaking implications if structural brain plasticity can be reliably detected and interpreted in humans. Such findings could transform our conceptions of neurorehabilitation or prevention of disease, and have far-reaching implications for understanding the biological potential of the human brain.

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