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**Preoperative Evaluation of Carotid Artery  
Stenosis: Comparison of Contrast-Enhanced  
MR Angiography and Duplex  
Ultrasonography with Digital Subtraction  
Angiography**

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This information is current as  
of July 28, 2025.

*AJNR Am J Neuroradiol* 2003, 24 (6) 1034-1035  
<http://www.ajnr.org/content/24/6/1034>

## Unlocking the Mental Aspects of the Golf Swing: Can Functional MR Imaging Give Us Insights?

“Relax grip, bring club straight back, turn right hip, full shoulder turn, drop club into slot, shift weight to left side, turn left hip, keep head behind ball, swing out, and finish with hands high”: a few of the many thoughts of a golfer with a mid to high handicap.

“Hit the ball to the target”: the thoughts of a golfer with a low handicap or of a professional golfer.

Is it any wonder, then, that a study of the areas of brain activation would show remarkable differences when these two cohorts of players are examined with functional MR imaging while “imagining” their golf swings?

In this issue of the *AJNR*, Ross et al from the Cleveland Clinic Foundation provide data that show marked activation differences between these two groups by using blood oxygen level-dependent MR imaging. Although this article provides information that many golfers with mid to high handicaps have long suspected—that they have too many thoughts whistling through their minds while standing over the ball—it is clear that the concept behind this study could be applied to many other activities and disciplines, revealing heretofore unobtainable information.

Functional MR is potentially well suited to the task of imagining because it can yield the spatial information and the time resolution needed to extract useful data. As readers of this article (and the suspicion is that this will be one of the most widely read articles in the 23-year history of the *AJNR*) will note, the areas activated are widespread, particularly in less accomplished golfers. Using a resting condition (visual imagery) and a condition in which the participant imagines pushing against a wall (noncoordinated, nonsequenced motor imagery), the authors were able to subtract these activities and suggest the functional activation of the imagined golf swing.

The article has a number of limitations: 1) only six golfers were examined, and they had a limited range of handicaps (handicaps of 0–13); 2) rigorous comparison of the results by 1.5- versus 3.0-T systems is lacking (only one participant was examined with the use of both magnets, and although these yielded similar activation patterns, it is difficult to assess the value of one system versus the other); 3) participants’ ability and effectiveness in accurately imagining their own swings and then scoring that ability with a Movement Imagery Questionnaire is undoubtedly extremely variable; and 4) the test was repeated on only one golfer so the true reliability and repeatability of the technique was not analyzed over a larger cohort of participants. Although expected differences were observed in activation of the left motor and parietal sensory cortex, the supplemental motor areas (incidentally well explained by the authors), and the frontal cortex, the differences in cerebellar vermis activity

is most intriguing. Perhaps that speaks not only to the executive processes described in this article but also to imagined “effort” in balance and coordination required by the high handicapper versus the effortless truncal balance in the low handicapper. The issue of “error detection,” centered in the cerebellum, requires further evaluation because this function is usually conceived as one centered supratentorially.

For golfers, this article raises multiple intriguing questions. Would different functional MR imaging patterns be seen in association with different clubs? Would the patterns of activation change as one’s handicap increases or decreases considerably? Does the activation vary if one imagines hitting over a huge hazard versus hitting down a broad expansive fairway? The list of intriguing postulates is long. Because mental imagery is a teaching concept in golf instruction, perhaps functional MR imaging could even sort out those most likely and least likely to benefit from such mental exercises. For example, if a golfer with a handicap of 25 showed minimal activation with this imagining teaching task and showed a pattern similar to that of a scratch golfer, could he or she be considered unteachable?

As a correlate to this specific functional MR imaging work, exploratory examinations of touring professional golfers, experienced golf instructors, and golf students with low to mid handicaps showed EEG biofeedback differences between professional golfers who revealed automatic motor processes and less experienced golfers whose skills have not been encoded as overlearned. The condition for these players is that they probably are still processing verbal-motor behavior in their frontal cortex and that the skill has not been turned over to a higher brain function. Initial testing of EEG activity at the David Leadbetter World Teaching Headquarters using professionals and amateurs on a portable Peak Achievement Trainer revealed graphic visual disruptions between accomplished golfers and those who were developing specific motor competence. The initial findings revealed that when professional golfers and experienced instructors followed their pre-shot initiation or ritual (pre-shot routine) a series of electrical firings (brainwave output in microvolts versus time in seconds) were noted on the graph. However, just before initiating the golf backswing or takeaway, every experienced golfer ( $n = 6$ ) of high motor proficiency showed a reduction and low electrical activity on the EEG monitor (Peak Achievement Trainer). This reduction of electrical activity or “quiet time” lasted for only a second, but it was positively identified for every accomplished golfer, whether using a five iron, using a driver, or on a 10-foot putting task. The findings were different for students just receiving lessons and

those players ( $n = 4$ ) who were having trouble with a specific component move of their golf swing. The graph revealed that at the initiation of their swings, significant electrical activity was evident and that these amateur golfers never had a "down time" or quiet moment to initiate the swing. Brainwave output was variable and complex during the pre-swing phase, initiating the takeaway and the through-swing phase. These findings may represent a crucial element in discovering what the motor component of trust may be or how well a learned skill movement is edified by the performer.

Without realizing it, perhaps the professional golfer is often practicing what Joseph Parent, in his book *Zen Golf: Mastering the Mental Game* (Doubleday/Random House, 2002), describes as an effortless focus applied without doubt or anxiety. In a relatively short and easily digestible treatise, Parent talks of synchronization of the body and mind; this is getting to the root of functional MR in the article by Ross et al. Would those practicing Zen golf, regardless of handicap, show fewer areas of activation because of the confidence and calmness they might bring to the game? Then we come to the hypothetical of having had the late Ben Hogan studied with functional MR imaging; would it have revealed, at long last, the area of the brain activation that would have provided a clue to his "secret move"?

Clearly, the application of functional MR imaging to mental tasks has just begun, and it is fitting that one of the first articles to deal with this subject concerns the annoying task of trying to strike a golf ball consistently well.

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### EDITOR'S NOTE

David Leadbetter is widely acknowledged as the world's number one golf instructor, and his student list, which reads like a Who's Who of Golf, includes Nick Price, Nick Faldo, Greg Norman, Ernie Els, Charles Howell III (whose swing is featured on the cover of this issue of the *AJNR*), Michael Campbell, Aaron Baddeley, Justin Rose, Lee Westwood, Scott Hoch, and Ty Tryon, among others.

Originally from Worthing in Sussex, England, Leadbetter began his career in golf on the European and South African Tours. He soon learned that his real interest was in the technique, mechanics, and intricacies of the game, which, in turn, led him to spend more time teaching than playing. It was his passion for the game that led to the establishment of 27 David Leadbetter Golf Academies worldwide. By incorporating his methods and philosophy into a training program for golf instructors, golfers throughout the world have benefited from his motivation and insights into the golf swing.

It is of great interest that Robert Winters, who is part of the David Leadbetter Golf Academies, is involved in using electrophysical measurements to examine how the mind processes information related to the golf swing. The *AJNR* is pleased to have had the input of Leadbetter and Winters into this editorial.

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## Preoperative Evaluation of Carotid Artery Stenosis: Comparison of Contrast-Enhanced MR Angiography and Duplex Ultrasonography with Digital Subtraction Angiography

Treatment of atherosclerotic disease of the extracranial carotid arteries in a patient with an advanced degree of stenosis substantially reduces the risk of subsequent neurologic event. Whether surgical endarterectomy or endovascular stent placement proves to be the more effective treatment of the narrowed carotid artery has yet to be shown. In any event, accurate assessment of the degree of luminal narrowing is an important step in treatment planning.

Rapid advances in imaging hardware, in turn, permit modifications in image acquisition techniques. However, one cannot take for granted that new methods necessarily provide more accurate results, and

frequent reevaluation of which methods are most efficacious is appropriate and necessary. This is of particular relevance to the development and wide use of contrast-enhanced MR angiography methods for evaluation of the carotid arteries. In this month's issue of the *AJNR*, Borisch et al report on whether a strategy of combining the results from contrast-enhanced MR angiography with those from color-coded duplex sonography can reduce the need for digital subtraction angiography, a catheter-based diagnostic study. The authors paid particular attention to surgical candidates who had stenoses 70% based on digital subtraction angiography. Their results indicated that

none of those patients would have been assigned to a lower grade of stenosis based on the noninvasive studies if the sonography and contrast-enhanced MR angiography findings were concordant.

The analysis presented raises a number of interesting questions. Can we rely on concordant findings to accurately evaluate all cases of carotid stenosis greater than a given cutoff point? Is there an implication that the two noninvasive methods used were somehow complementary so that where one fails the other is automatically bound to be correct? Investigation of a larger series of studies with attention paid to possible reasons for the false negatives of each technique could help define the extent to which the results presented in this article reflect an underlying mechanistic reason why concordant data are more reliable than the individual tests. If no underlying physical basis is found, the result could simply reflect that for two methods with high sensitivity, the probability that both measurements from two uncorrelated measurements will provide a false negative is much smaller than the probability that either one of them will.

Any investigation involving multi-technique imaging of the arterial lumen raises the question of how meaningful are the comparisons made between modalities that are sensitive to the luminal area and those that assess the lumen diameter. MR angiography and CT angiography provide images of the lumen in cross section, and Doppler sonography provides velocity measurements that are area-dependent, whereas conventional angiography, the historic "gold-standard" technique, is generally interpreted in terms of diameter measures. Considerations of digital subtraction angiography must also take into account the evolution of that technique, with rotational digital subtraction angiography now providing a more comprehensive evaluation of the arterial lumen than was available in earlier studies of intermodality correlation. The standard of truth, therefore, continues to be a moving target, complicating the evaluation of new techniques. The question of accuracy standards becomes more pressing as there is an increasing move to replace digital subtraction angiography with noninvasive diagnostic studies. Retaining adequate control of imaging standards in the absence of digital subtraction angiography will be challenging, and reference to

independent validation data, such as the endarterectomy specimen, will be necessary to ensure that imaging methods remain reliable and provide patients with the highest quality care possible.

These concerns are perhaps greatest for MR imaging, with which image appearance can vary considerably with small alterations in the detailed implementation of a pulse sequence. We have found in our own studies that contrast-enhanced MR angiography underestimates the caliber of the residual lumen in comparison with measurements made from time-of-flight MR angiography studies. Detailed investigations using flow models have identified several factors that contribute to an underestimation of lumen size, including absence of flow compensation gradients in contrast-enhanced MR angiography; larger voxel size used in contrast-enhanced MR angiography; and, of key importance, contrast-enhanced MR angiography of the extracranial carotid arteries being invariably implemented with the frequency-encoding gradient aligned parallel to the primary flow direction, which results in flow-related signal intensity loss. Still, in several areas, contrast-enhanced MR angiography possesses powerful advantages relative to time-of-flight MR angiography, and the optimal use of these different MR angiography methods must still be defined.

The new cross-sectional capabilities of MR angiography and the ability of MR imaging to probe the composition and geometry of the vessel wall herald a new era during which the radiologist will be asked to assess the vessel wall in addition to the lumen. Those capabilities should provide new opportunities for determining those image characteristics of the advanced atherosclerotic lesion that more comprehensively capture the complex nature of disease at the bifurcation and more fully identify the true determinants of future neurologic risk. No matter how alluring the new methods might appear, they will require, as in the case of contrast-enhanced MR angiography reported herein, careful evaluation against accepted standards.

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