Journal of Sport & Exercise Psychology, 2006, **28**, 421-433

An fMRI Analysis of Neural Activity During Perceived Zone-State Performance

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Performance at one's highest personal level is often accompanied by a palpable, yet enigmatic sensation that many athletes refer to as the *zone*. Competitive athletes regularly acknowledge that their top performances are dependent on achieving a zone state of performance. Functional magnetic resonance imaging (fMRI) technologies were used in observing differing patterns of neural activation that occur among athletes during a hypnotically recalled zone-state performance of eight accomplished, competitive right-handed archers. These data were compared to each participant's respective fMRI data of a hypnotically assisted recall of a normal performance. Analysis of composite group data revealed significant (p = 0.05) neural activation of zone performance (ZP) over normal performance (NP), suggesting that performance in a zone state involves identifiable characteristics of neural processing. Perhaps this investigation might stimulate additional, more creative research in identifying a psychophysiological indicator of the zone phenomenon that would provide adequate justification for a training regimen providing a more reliable and sustained zone performance.

Key Words: archery, brain mapping, flow, hypnosis

Athletes across all sport disciplines recognize that once all of the physical training and technical practice has been completed, yet one more element is required in order to be successful at the highest level. They believe that they must achieve a mental and physical state called the *zone*. While this is considered a critical element in the pursuit of competitive success (Cooper, 1998; Ferraro, 1999; Jackson, 1996; Murphy & White, 1995), it continues to be an enigma, as it remains largely undefined and undocumented in scientific research. World-renowned figure skater Michelle Kwan has stated (Starr, 2002), "To win, I have to be in the zone. If I knew

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how to get there—if I knew how to explain it—I'd always be there when I had to be." Similarly, tennis star Monica Seles has observed (Krug, 1999) that "when I am consistently playing my best tennis, I am also consistently in the zone." Competitive athletes regularly acknowledge that their top performances are dependent on a single prominent factor that has been consistently referred to by the rather generic term *mental*. Although this undefined term may include such elements as visual and mental rehearsal, arousal control, and internal positive reinforcement, it all tends to coalesce into a "zone" performance state (Cooper, 1998; Heathcote, 1996; Lewis, 1999; Marr, 2001; Young & Pain, 1999).

Given the highly charged atmosphere of the competitive environment, it would appear paradoxical that moments of highest levels of performance would be coincident with the reported sensations of relaxation, calm, effortless, automatic, and nonthinking of performance (Csikszentmihalyi, 1978, 1990; Jackson & Roberts, 1992; Privette, 1981, 1983; Ravizza, 1977). These sensations that differentiate zone from normal performance would seem to be more related to elements of mental processing than the physical demands of the various activities. Fortunately, there is a developing new tool that provides the opportunity for fresh insights in identifying neural activation associated with a variety of mental and physical tasks. Functional magnetic resonance imaging (fMRI) is being effectively employed to produce brain imaging data with exceptional spatial and temporal resolution (Forster et al., 1998; McCarthy, 1999; Turner et al., 1998). However, the fMRI subject's head must be held with as little motion as possible. This restriction would appear to severely limit the observation of most motor tasks. In order to overcome this limitation, hypnosis can be used to vividly recall subjects' active performances while remaining motionless in the MRI scanner. Hypnosis has been used with success in fMRI studies involving the perception of activity (Thornton et al., 2001; Williamson et al., 2002). The proposition that imagery mirrors the same cortical activity as those involved in the actual execution of the same movement is supported in a number of investigations (Calvo-Merino, et al., 2005; Clark, Tremblay, & St. Marie, 2003; Fadiga, Craughero, & Olivier, 2005; Fadiga et al., 1999).

In addition to the use of hypnosis to accommodate fMRI investigations by effectively enhancing perception with accompanying neural activity, hypnosis has become well established as a performance enhancement tool for many varied sports (Pates, Oliver, & Maynard, 2001; Pates, Cummings, & Maynard, 2002; Robazza et al., 1995). Hypnosis is usually incorporated within a battery of psychological interventions used to address anxieties, confidence levels, arousal levels, motivations, determination, and enthusiasm (Hawkins, 1980). Along with hypnosis, practitioners employ various relaxation procedures, visual imagery, mental rehearsal, and self-talk in order to allow athletes to most effectively access their highly practiced motor skills (Onestack, 1991).

A considerable amount of research literature has been produced to suggest the similarity of zonelike sensations among athletes from quite a wide variety of sports (Jackson, 1995, 1996). It has been previously suggested that flowlike or zone experiences are likely to be more prevalent among athletes of higher caliber (Privette, 1983). Consequently, high-caliber athletes are probably more likely to have more vivid recollections of zone state sensations, and a keener delineation of contrasting feelings while not in the zone.

Remarkably, scientific research into a zone state of performance is very limited. To gain insight into this pivotal performance state, our investigation sought to identify zone state patterns of neural activation employing the use of functional magnetic resonance imaging. We hypothesized that we might find neural activity during a perceived zone performance (ZP) that would differ from that of a similar normal performance (NP). It was suspected that the ZP condition would reveal enhanced activation in areas that support well-coordinated, learned motor activity, whereas neural areas responsible for planning complex motor movement would be relatively dormant. Further, we expected that we might find increased neural activity in the NP condition in areas that might be counterproductive to efficient motor performance.

Method

Participants

Adult right-handed archers (*n* = 8) were recruited from an extended geographic community by word of mouth. There were 7 males and 1 female (age = 37.63 ± 9.30). The subjects that were recruited had achieved competitive success at the state, national, and/or international level. Key to this investigation were reliably well-defined zone state performances that displayed overtly palpable sensations. All of the subjects were prescreened with a short, personal interview in order to ascertain their familiarity with a personal zone performance experience. During the prescreening interview, the subjects must have spontaneously included within a description of their zone experience comments relating to 1) a general relaxed state, 2) nonthinking of performance, 3) confidence in performance, and 4) very high performance outcome. Identified subjects then signed an informed consent form and the study was approved by the institutional review board committees of both the research university and a medical university.

Apparatus

All fMRI scans along with initial scout images and T1 weighted, high-resolution anatomical scans were completed using a Philips Intera 1.5 Tesla MRI scanner. The T1 scans were obtained using the following parameters: an inversion-recovery turbo spin echo sequence with TR = 3,200 ms, T1 = 400 ms, TE = 15 ms with an in-plane resolution of 0.78 mm × 0.78 mm. A gradient recalled echo (GRE) technique was used for the echo-planar data collection with in-plane resolution of 3.1 mm × 3.1 mm. Twenty-three axial slices were obtained at 6-mm intervals (5 mm thick + 1 mm gap) for both the high-resolution and functional scans. T-Values for each pixel in a 64 × 64 pixel matrix were calculated creating a 64 × 64 × 23 data set per volume.

The head support system was modified by the investigators to accommodate three key objectives in this investigation—movement abatement, ambient MRI noise suppression, and effective audio transmission of suggestions provided by the hypnotist. Subjects were provided standard pliable noise suppression ear inserts that were supplemented by the use of an ear-covering headset. The Philips provided headset includes a plastic tubing mechanism for sound transmission. A neurosurgerical rubberized pillow containing Styrofoam beads was modified to accommodate the headset as it fully encompassed both sides and the back of the head. After the pillow conformed to the specific contours of the subject's head, a vacuum source was used to remove the air within the pillow, which transformed the pillow into a rigid, form-fitting head restraint apparatus.

Procedure

Each subject was scheduled for a 2-hour contact session, with the first hour devoted to the hypnosis procedure and the second hour in data collection within the MRI scanner. The nationally certified hypnotist (certified hypnotherapist—CHT) and an investigator first met with the subject in order to gain key descriptive information about the subject's performance experiences. These would later be used in a perceptual reconstruction of the events with the aid of hypnosis. The process of hypnosis was thoroughly explained, after which the subject was induced into a hypnotic trance. During the second hour, MRI data was obtained.

Prescan Hypnosis

Within a relaxed and semiprivate atmosphere, the subject detailed the specific sensations that encompassed his or her performance-related experiences with regard to a zone-state performance. The subject was asked to relate the details of a foremost zone performance circumstance. During this discussion, a determination was made regarding a point in the performance at which their zone sensations were most palpable. For most of our subjects, this instance occurred at some point just after the full draw of the bow. Each subject was then asked to identify sensations that were indicative of a normal performance occasion. Notes were taken by the hypnotist to use the subject's own descriptive terms in order to recreate that subject's particular experience under hypnosis.

At this time prior to the hypnotic induction, a request was made of each subject to candidly relate their true reactions at each step of the experimental procedure, and cautioned not to try to accommodate their perception of the researchers' expectations. It was explained that only under these conditions could any data of value be obtained.

The subject then submitted to the hypnotic induction procedure, in which they were tested for the depth of hypnosis (Krasner, 1991) consistent with Stage 1 (small muscle catalepsy), Stage 2 (large muscle catalepsy), Stage 3 (selective amnesia), and Stage 4 (glove anesthesia). Small muscle catalepsy was observed by the inability of the subject to open the eyes upon request. An example of large muscle catalepsy was demonstrated by the inability to lift the hand from the lap. During the selective amnesia stage, the subject omitted a suggested number within a common counting sequence. Successful glove anesthesia was attained as the subject lost comparable tactile sensation of the suggested hand. All subjects in this study achieved Stage 3, with most subjects reaching Stage 4. A posthypnotic suggestion, agreed upon by prior consent, was implanted to regain a hypnotically inducted state quickly and easily after the subject was transferred to the MRI scanner.

During this prescan session, the subject was induced to recall zone sensations derived from their personal zone performance experience and a similar instance during their normal performance experience. This report focuses on the comparative neural activation differences between the subjects' zone performances and their more typical normal performance. Within the prescan session, the subjects also had the opportunity to practice a subtle ideomotor signal (momentary elevation of nondominant index finger) that each used to denote achievement of the requested state.

fMRI Scan Protocol

Initial scout images and T1 weighted, high-resolution anatomical scans were obtained first, allowing the subject to become acclimated to the scanner environment. A series of four repeated measures under three randomized hypnotized states was then obtained using fMRI scan protocols. The three states included zone performance (ZP), normal performance (NP), and a nonactivity resting state (RH). The hypnotized resting condition consisted of a subject-defined visualization. Additionally, two baseline scans of a nonhypnotized resting state (R) were obtained at the beginning and end of the hypnotized fMRI measurements. Each subject was directed through earphones to re-create, under hypnosis, one of the test conditions—zone performance, normal (nonzone) performance, or rest. The subject indicated achieving the desired state using the defined ideomotor signal. The echo-planar (EPI) scans for fMRI data acquisition were performed under each of these conditions in a pseudo-randomized sequential series for each subject. One complete fMRI volume, consisting of 23 axial slices of the brain, was obtained every 2.5 s. Each "scan condition" consisted of a 50-s block in time, allowing for 20 snapshots of the entire brain volume for each block. Additionally, each test condition was repeated four times in a mixed order (Figure 1). Subjects had their hypnotic induction reinforced at four regular intervals during the protocol, just prior to the resting conditions.

During a short debriefing following the fMRI session, each subject affirmed that they had been able to achieve the suggested visualizations throughout the procedure. When asked about general reactions to their participation, common responses included a pleasant and relaxing experience, with some surprise regarding how quickly the time had passed. Since these are common responses to hypnosis, this provided additional confirmation that hypnotic induction was successful.

Data Analysis

Analysis for each subject under each condition was carried out using FEAT (FMRI Expert Analysis Tool) Version 5.00, part of FSL (FMRIB's Software Library). FEAT is a software tool for high-quality model-based fMRI data analysis, with an easy-to-use graphical user interface. FEAT automates as many of the analysis decisions as possible and allows easy (though still robust, efficient, and valid) analysis of simple experiments while providing enough flexibility to also allow sophisticated analysis. The data modeling that FEAT uses is based on general linear modeling (GLM). A model is created to fit the data showing where the brain has activated

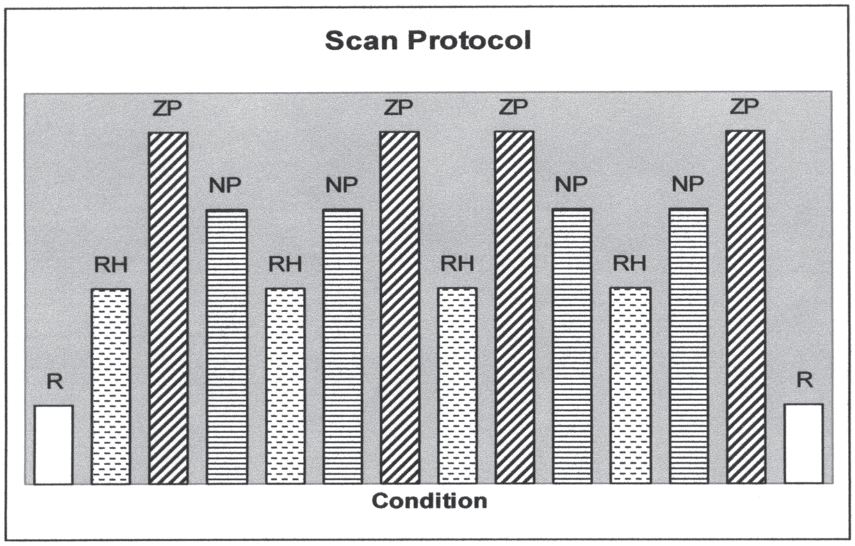

Figure 1 — Test condition order of fMRI scans. Baseline rest (R), nonactive, hypnotized rest (RH), zone performance state (ZP), and normal performance state (NP).

in response to the stimuli. If the model is derived from the stimulation that was applied to the subject in the MRI scanner, then a good fit between the model and the data means that the data were indeed caused by the stimulation.

The first two volumes of data (5 s) obtained in each block were excluded from the statistical treatment because the scanner was paused between blocks to talk to the subject and equilibrium magnetization was not present for the first two measurements. An extensive series of pre-statistics processing was applied to the raw data. Motion correction and registration was accomplished using MCFLIRT (Jenkinson 2002). MCFLIRT is the motion-corrected application of FLIRT (Jenkinson 2001, 2002), which is a robust and accurate automated linear registration tool based around a multistart, multiresolution global optimization method. It can be used for inter- and intramodal registration with 2-D or 3-D images. In addition, it can be run with a number of different transformation models (degrees of freedom) and it implements a general cost function weighting scheme for all cost functions. It is recommended for use for Talairaching with the Montreal Neurological Institute (MNI) standard brains as it has been extensively tested with these images. Talairached template images (whole head, extracted brain, brain mask, and skull) are included in FSL, courtesy of the Montreal Neurological Institute of McGill University. The MNI152 template is a standard-space average of 152 brains. Brain Extraction Tool (Smith, 2002) was used to segment the brain from nonbrain in structural and functional data. Spatial smoothing was accomplished using a Gaussian kernel of FWHM 5 mm. The raw data was subjected to a mean-based intensity normalization of all volumes by the same factor. Time-series statistical analysis was carried out using FILM (FMRIB's Improved Linear Model) (Woolrich, 2001). *Z*- (Gaussianized

T) statistical images were thresholded using clusters determined by $Z > 2.1$ and a (Bonferroni-corrected) cluster significance threshold of $p = 0.05$ (Friston, 1994; Forman, 1995; Worsley, 1992).

Each series of scans was analyzed looking for significant areas of increased neural activation, as well as significant areas of decreased activation. Results are displayed as black overlays on grayscale averaged-brain anatomical MRI images.

Results

Significant composite results were computed to depict neural areas of increased activation while comparing the hypnotized zone state (ZP) to the hypnotized normal state (NP) of performance. We also analyzed the raw data to reveal any group consistencies of neurologically localized areas of deactivation. Areas of significant ($p = 0.05$) increases of ZP when compared to the basal NP are displayed in black on a standard axial template (Figure 2). Significant areas of neural activation reflecting increased group interactions during the NP condition with respect to the RH

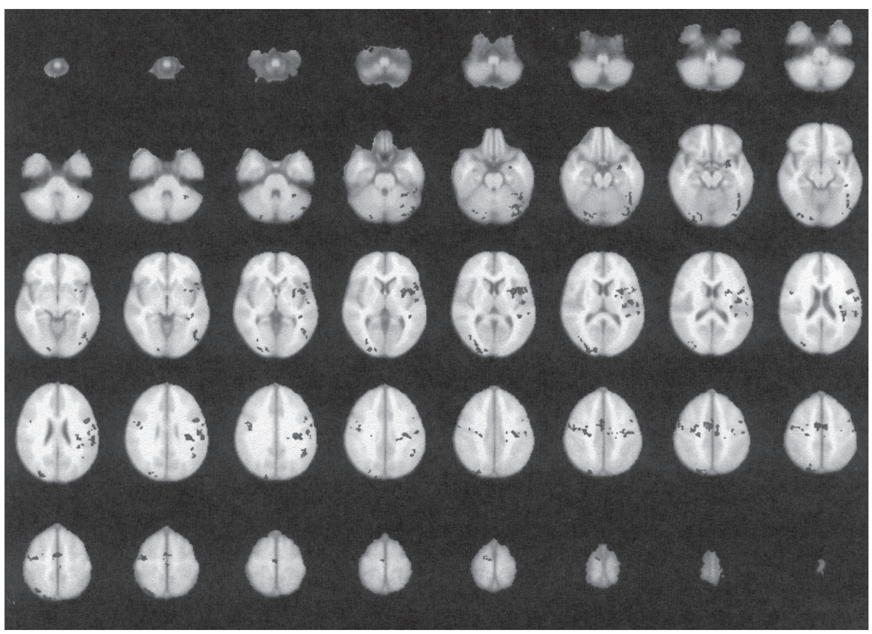

Figure 2 — Clusters in black represent a group ($N = 8$) compilation of the statistically significant ($p = .05$) areas of neural activation during hypnotically perceived zone performance (ZP) in comparison to a similar normal performance (NP). Composite representation of anatomical structures of the brain is comprised of successive 5-mm slices along the axial plane. Identification of specific axial pictures described in the text may be facilitated using letter row designation (A–E) and numerical column designation (1–8). Base of brain is represented by A1 to top of head, E8.

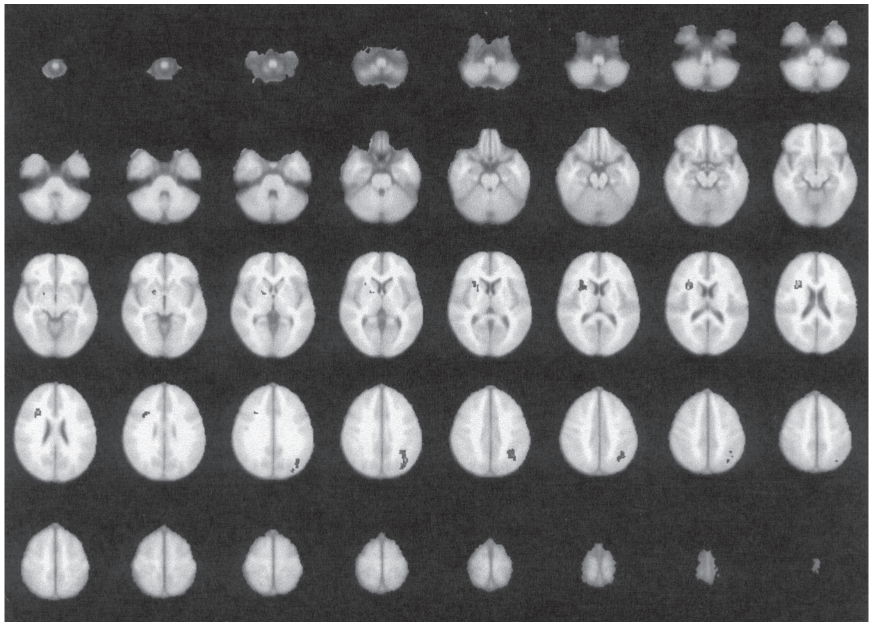

Figure 3 — Clusters in black represent a group ($N = 8$) compilation of the statistically significant ($p = .05$) areas of neural activation during hypnotically perceived normal performance (NP) in comparison to a hypnotized resting state (RH). Composite representation of anatomical structures of the brain is comprised of successive 5-mm slices along the axial plane. Identification of specific axial pictures described in the text may be facilitated using letter row designation (A–E) and numerical column designation (1–8). Base of brain is represented by A1 to top of head, E8.

condition are displayed in Figure 2. Convention dictates that the brain be viewed as if looking from the aspect of the foot toward the head; consequently, the right hemisphere appears on the left side of the image and, conversely, the left hemisphere is represented by the right side of the image. For identification in Figures 2 and 3, the horizontal rows are designated A to E (top to bottom) and the vertical columns are designated 1 to 8 (right to left).

Significant increased neural activation of ZP over NP was found in the left cerebellar region (Figure 2—B5), in the posterior-temporal region of the left (dominant) hemisphere (Figure 2—B6, 7), and the subcortical structures putamen, claustrum, and insula of the left hemisphere (Figure 2—C3-5). The data results displayed in C5–C6 reveal right occipital regional activation during ZP. Increased neural ZP activation is seen along the left hemisphere regions of the sensory motor, primary motor, and premotor areas corresponding to the right arm, right hand, neck, and face (Figure 2—D1–4). The ZP condition showed increased activation of the supplementary motor area located in the medial aspect of each hemisphere just anterior to the primary motor area (Figure 2—D7, 8), and symmetrical activation of the primary motor and premotor areas of the arms and torso (Figure 2—D5, 6) and the left trunk and leg (Figure 2—E1–3).

There were no statistically significant results when the data were treated for patterns of decreased neural activation of ZP compared to NP.

An increase in neural activity of NP over RH was found in the right inferior frontal cortical area (Figure 3—C6–D1). The other significant area of NP activity was in the posterior left parietal area, perhaps graduating to the association and somatosensory areas (Figure 3—D3–6).

Discussion

Numerous fMRI studies have identified neural responses to the acute sensations of tactile, visual, and auditory stimuli. We were interested to examine whether fMRI technology was capable of detecting the subjective subtleties that inherently defined the difference between a normally competent motor performance and an exceptional performance in the zone state. In this effort, we compared the same activity within the same subject by identifying two contrasting performance scenarios, a normal performance (NP) and a zone performance (ZP). Additionally, we collected individual and group data representing a nonactive, resting state while hypnotized (RH). Each subject's normal performance (NP) served as a control for his or her own individual zone performance (ZP) as we scanned differences in neural activation that might serve to differentiate the desired and enhanced performance state of being "in the zone." Hypnosis was also used in both performance conditions to enhance the visualization experience toward a vivid and palpable recollection of the sensations surrounding each test state. It is appropriate to recognize that the NP condition for the high caliber of athletes tested would be deemed a very good effort. The composite activation data reflect significant neural processing that our subjects ($N = 8$) associate with a zone performance over and above a normally good performance.

Previous research in the area of peak performance, including flow/zone state, has relied almost exclusively on the anecdotal accounts of many various groupings of athletes. The most obvious reason that other rigorous investigative techniques are not represented in the literature reflects the fact that the difficulties inherent in capturing the elusive zone state performance within a measurement-controlled environment are formidable. Consequently, we employed the use of hypnosis as a tool to enhance the recalled visualization of a strongly perceived zone-state performance from the subject's personal competitive experience. Hypnosis in the fMRI setting provides a tool to allow subjects to vividly access past experiences. Hypnotic suggestion has been shown to reliably elicit physiological responses to perceived motor activity (Williamson et al., 2002), an invaluable component because subjects must remain motionless as the brain is imaged. Consequently, the vivid perception of a subject's personal zone experience can be examined for neural activation.

Multiple efforts were implemented to ensure that an altered state of hypnosis was achieved and maintained throughout the multiple data collection episodes, including depth of hypnosis assessment, verbal and ideomotor subject feedback, direct rational appeal, periodic hypnosis reinforcement, and subject debriefing.

Despite these precautions, we must admit the possibility that one or more of our subjects may have constructed responses to accommodate their perception of the investigative objectives. Further research in this area utilizing hypnosis protocols might develop additional procedures to address this limitation. Only one of our eight subjects had any previous formal experience with hypnosis. His observation of that encounter was that the outcome was unsuccessful. This subject achieved a depth of hypnosis at Stage 3, but was the only one in the subject pool who did not reach Stage 4. Achievement of Stage 2 hypnotic susceptibility was defined as the acceptable level for subject participation.

It is difficult to ascertain distinctly how much primary motor activation was displayed in our data rendition owing to the close proximity of the premotor area anteriorly and the sensorimotor area posteriorly. Our data display voxel significance throughout these closely aligned cortical areas. Also, the data of eight subjects was morphed into a standardized Talairach averaged brain with somewhat indefinite anatomic landmarks. Any efferent primary motor impulses did not result in subsequent motor activity since our subjects were in a relaxed and motionless hypnotic state during the fMRI scans. It is possible that any of the observed primary motor activation did not evoke a sufficiently strong motor impulse, or that there was hypnotic inhibition of the neural signal prior to the efferent motor neurons, much as occurs in REM sleep (Chokroverty & Daroff, 1994). It is conceivable that some minimal isometric activation occurred; however, this is remote since significant isometric tension is not likely to have gone unnoticed either by the investigative team or by the subjects themselves. The initiation of isometric muscular activity invariably involves some motion as agonists and antagonists find the moment of stability about a joint. Further, our subjects were in an extremely relaxed physical state during their hypnosis. Isometric tension would be a marked departure that would have been recognized by the participants. All of our subjects remarked that they exited the hypnotic state and the fMRI test protocol in a relaxed and refreshed condition.

Areas of decreased neural activation were initially hypothesized owing to the nature of many of the anecdotal responses of athletes as they described their zone performance experiences. Specifically, the related sensations of relaxed, effortless, no thought, and automatic might suggest reduced neural activity. Those common responses were consistent with our anecdotal observations within this investigation, particularly those of automaticity (nonthinking of performance); increased confidence (decreased anxiety); and the general feelings of being calm, relaxed, and comfortable. These subject responses were consistent with the body of research on peak performance and flow (Csikszentmihalyi, 1978, 1990; Jackson & Roberts, 1992; Privette, 1981, 1983; Ravizza, 1977). Our composite data results did not support the assumption of defining neural characteristics of decreased activation. It is possible that reduced neural activity while in the zone may be somewhat subject specific.

When we observe the group interaction results of ZP in relation to NP, the neural activations occurring in the cerebellum, the subcortical structures of the putamen and claustrum, and the cortical motor and sensory areas are consistent with expectations for presenting a highly developed and coordinated motor skill (Duus, 1989; Fix, 1992; Kandel et al., 1991). Our data would suggest that these areas are relatively and specifically stimulated during the enhanced zone performance condition beyond that of a comparable normal performance. Because we would normally expect to see some similar motor skill pattern activations during NP, the general absence of significant group interaction results in the NP condition is quite possibly due to broad-spectrum competition of nonspecific neural activity. This lends further credence to the possibility that the zone state of performance is due to the focused activation of specific areas of relevance to the task performance without the excess of more diffuse neural processing. Focused neural activation as a result of a sufficiently practiced activity may provide for an efficient motor-neural pathway in the absence of extraneous mental processing. This would present an explanation for the apparent dichotomy of peak performances with concomitant sensations of ease of effort and no thinking of process.

This investigation explored the extended capabilities of fMRI technologies in identifying the subtle differences of neural activation patterns associated with an ethereal sensation experience. Perhaps this investigation might serve to stimulate additional, more creative research in identifying a psychophysiological indicator of the zone phenomenon that would provide adequate justification for the establishment of a training regimen toward more reliable and sustained zone performance. Training to achieve and sustain the zone state would have far-reaching implications not just for sport, but for many cognitive applications as well.

References

Calvo-Merino, B., Glaser, D.E., Grezes, J., Passingham, R.E., & Haggard, P. (2005). Action observation and acquired motor skills: An fMRI study with expert dancers. *Cerebral Cortex, 15*, 1243-1249 .

Chokroverty, S., & Daroff, R.B. (1994). *Sleep disorders medicine: Basic science, technical considerations, and clinical aspects*. Boston: Butterworth-Heinemann.

Clark, S., Trenblay, F., & St. Marie, D. (2003). Differential modulation of corticospinal excitability during observation, mental imagery and imitation of hand actions. *Neuropsychologia, 42*, 105-112.

Cooper, A. (1998). *Playing in the zone: Exploring the spiritual dimensions of sport*. Boston: Shambala.

Csikszentmihalyi, M. (1978). Attention and the holistic approach to behavior. In K. Pope & J. Singer (Eds.), *The stream of consciousness* (pp. 335-355). New York: Plenum Press.

Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*. New York: Harper & Row.

Duus, P. (1989). *Topical diagnosis in neurology*. New York: Thieme Medical Publishers, Inc.

Fadiga, L., Buccino, G., Craighero, L., Fogassi, L., Gallese, V., & Pavesi, G. (1999). Corticospinal excitability is specifically modulated by motor imagery: A magnetic stimulation study. *Neuropsychologia, 37*, 147-158.

Fadiga, L., Craighero, L., & Olivier, E. (2005). Human motor cortex excitability during perception of others' action. *Current Opinion in Neurobiology, 15*, 213-218.

Ferraro, T. (1999). The zone and golf. *Athletic Insight, 1*(3). Retrieved May 8, 2001, from http://www.athleticinsight.com/Vol1Iss3/Golf_Zone.htm

Fix, J.D. (1992). *Neuroanatomy*. Philadelphia: Harwal Publishing.

Forster, B.B., MacKay, A.L., Whittall, K.P., Kiehl, K.A., Smith, A.M., Hare, R.D., & Liddle, P.F. (1998). Functional magnetic resonance imaging: the basics of blood-oxygen-level dependent (BOLD) imaging. *Canadian Association of Radiologists Journal, 49*, 320-329.

Forman, S.D., Cohen, J.D., Fitzgerald, J.D., Eddy, W.F., Mintun, M.A., & Noll, D.C. (1995). Improved assessment of significant activation in functional magnetic resonance imaging (fMRI): Use of a cluster-size threshold. *Magnetic Resonance Medicine 33*, 636-647.

Friston, K.J., Worsley, K.J., Frackowiak, R.S.J., Mazziotta, J.C., & Evans, A.C. (1994). Assessing the significance of focal activations using their spatial extent. *Human Brain Mapping, 1*, 210-220.

Hawkins, R. (1980). Hypnosis and sport, In Glencross & Denis (Eds.), *Sport and the Elite Athlete—A Sports Science Review. Proceedings of the ANZAAS Congress, 50,* 63-75.

Heathcote, F. (1996). *Peak performance: Zen and the sporting zone*. Dublin, Ireland: Wolfhound.

Jackson, S. (1995). Factors influencing the occurrence of flow states in elite athletes. *Journal of Applied Sport Psychology, 7*, 138-166.

Jackson, S.A. (1996). Toward a conceptual understanding of the flow experience in elite athletes. *Research Quarterly for Exercise and Sport, 67,* 76-90.

Jackson, S.A., & Roberts, G.C. (1992). Positive performance states of athletes: Toward a conceptual understanding of peak performance. *Sport Psychologist, 6*, 156-171.

Jenkinson, M. and Smith, S. (2001). A global optimisation method for robust affine registration of brain images. *Medical Image Analysis*, *5*, 143-156.

Jenkinson, M., Bannister, P., Brady, J., and Smith, S. (2002). Improved optimisation for the robust and accurate linear registration and motion correction of brain images. *NeuroImage*, *17*(2), 825-841.

Kandel, E.R., Schwartz, J.H., & Jessell, T.M. (1991). *Principles of neuroscience* (3rd ed.) Norwalk, CT: Appleton & Lange.

Krasner, A.M. (1991). *The wizard within*. Irvine, CA: American Board of Hypnotherapy Press.

Krug, M. (1999, November). Playing tennis in the zone. *Athletic Insight*, *1*(3). Retrieved May 8, 2001, from http://www.athleticinsight.com/TennisZoneFrame1Source1.htm

Lewis, S. (1999, November). Cycling in the zone. *Athletic Insight*, *1*(3). Retrieved May 8, 2001, from http://www.athleticinsight.com/BicycleZoneFrame1Source1.htm

Marr, A.J. (2001, April). In the zone: A biobehavioral theory of the flow experience. *Athletic Insight*, *3*(1). Retrieved May 2, 2002, from http://www.athleticinsight.com/Vol3Iss1/Commentary.htm

McCarthy, G. (1999). Event-related potentials and functional MRI: A comparison of localization in sensory, perceptual and cognitive tasks. *Electroencephalography & Clinical Neurophysiology, 49*(Suppl.), 3-12.

Murphy, M., & White, R. (1995). *In the zone: Transcendent experience in sports*. New York: Penguin Books USA, Inc.

Onestak, D.M. (1991). The effects of progressive relaxation, mental practice, and hypnosis on athletic performance: A review. *Journal of Sport Behavior, 14*, 247-283.

Pates, J., Cummings, A., & Maynard, I. (2002). The effects of hypnosis on flow states and three point shooting performance. *Sport Psychologist, 16*, 34-47.

Pates, J., Oliver, R., & Maynard, I. (2001). The effects of hypnosis on flow states and golf-putting performance. *Journal of Applied Sport Psychology, 13*, 141-154.

Privette, G. (1981). Phenomenology of peak performance in sports. *International Journal of Sport Psychology, 12*, 51-58.

Privette, G. (1983). Peak experience, peak performance, and flow: A comparative analysis of positive human experiences. *Journal of Personality and Social Psychology, 45*, 1361-1368.

Ravizza, K. (1977). Peak experiences in sport. *Journal of Humanistic Psychology, 17*, 35-40.

Robazza, C., Bortoli, L., & Nougier, V. (2000). Performance emotions in an elite archer: A case study. *Journal of Sport Behavior, 23*, 144-164.

Smith, S., Zhang, Y., Jenkinson, M., Chen, J., Matthews, P., Federico, A., & DeStefano, N. (2002). Accurate, robust and automated longitudinal and cross-sectional brain change analysis. *NeuroImage*, *17*, 479-489.

Starr, Mark (2002, February 18). Kwan song. *Newsweek*, 51-53.

Thornton, J. M., Guz, A, Murphy, K., Griffith, A.R., Pedersen, D.L., Kardos, A., et al. (2001). Identification of higher brain centers that may encode the cardiorespiratory response to exercise in humans. *Journal of Physiology 533.3*, 823-836.

Turner, R., Howsemen, A., Rees, G.E., Josephs, O., & Friston, K. (1998). Functional agnetic resonance imaging of the human brain: Data acquisition and analysis. *Experimental Brain Research, 123,* 5-12.

Williamson, J.W., McColl, R., Mathews, D., Mitchell, J.H., Raven, P.B., & Morgan, W.P. (2002). Brain activation by central command during actual and imagined handgrip under hypnosis. *Journal of Applied physiology, 92*, 1317-1324.

Woolrich, M., Ripley, B., Brady, J., & Smith, S. (2001). Temporal autocorrelation in univariate linear modelling of FMRI data. *NeuroImage*, *14*, 1370-1386.

Worsley, K.J., Evans, A.C., Marrett, S., & Neelin, P. (1992). Three-dimensional statistical analysis for CBF activation studies in human brain. *Journal of Cerebral Blood Flow Metabolism 12*, 900-918.

Young, J.A., & Pain, M.D. (1999, November). The zone: Evidence of a universal phenomenon for athletes across sports. *Athletic Insight*, *1*(3). Retrieved May 8, 2001, from http://www.athleticinsight.com/EmpiricalZoneFrame1Source1.htm

Manuscript submitted: October 18, 2005

Revision accepted: June 20, 2006