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Brain-Compatible Learning: Principles and Applications in Athletic Training

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Objective: To discuss the principles of brain-compatible learning research and provide insights into how this research may be applied in athletic training education to benefit the profession.

Background: In the past decade, new brain-imaging techniques have allowed us to observe the brain while it is learning. The field of neuroscience has produced a body of empirical data that provides a new understanding of how we learn. This body of data has implications in education, although the direct study of these implications is in its infancy.

Description: An overview of how the brain learns at a cellular level is provided, followed by a discussion of the principles of brain-compatible learning. Applications of these principles and implications for the field of athletic training education are also offered.

Application: Many educational-reform fads have garnered attention in the past. Brain-compatible learning will not likely be one of those, as its origin is in neuroscience, not education. Brain-compatible learning is not an educational-reform movement. It does not prescribe how to run your classroom or offer specific techniques to use. Rather, it provides empirical data about how the brain learns and suggests guidelines to be considered while preparing lessons for your students. These guidelines may be incorporated into every educational setting, with every type of curriculum and every age group. The field of athletic training lends itself well to many of the basic principles of brain-compatible learning.

Key Words: brain-based learning, brain research, effective teaching, education

In the past 8 to 10 years, neuroscience has developed new brain-imaging techniques that allow us to explore the functional neuroanatomy of cognition and see how the brain operates when it is learning. Two of those techniques include single-photon emission-computed tomography (SPECT scan) and positron-emission tomography (PET scan). Although SPECT scans have been around for years and have now been greatly refined, PET scans are new within the past decade. Each of these tests graphically illustrates the amount of activity occurring in different areas of the brain at a given moment. The SPECT scan, although less costly, provides less detailed images than the PET scan. In combination with computed axial tomography (CAT) scans and functional magnetic resonance imaging (MRI), many different views of the brain can be obtained and cross-referenced.[1–3] The research involving these imaging techniques has produced a body of knowledge that illustrates how we learn. Educators have taken this knowledge and attempted to apply it to education, terming it brain-based learning.[4]

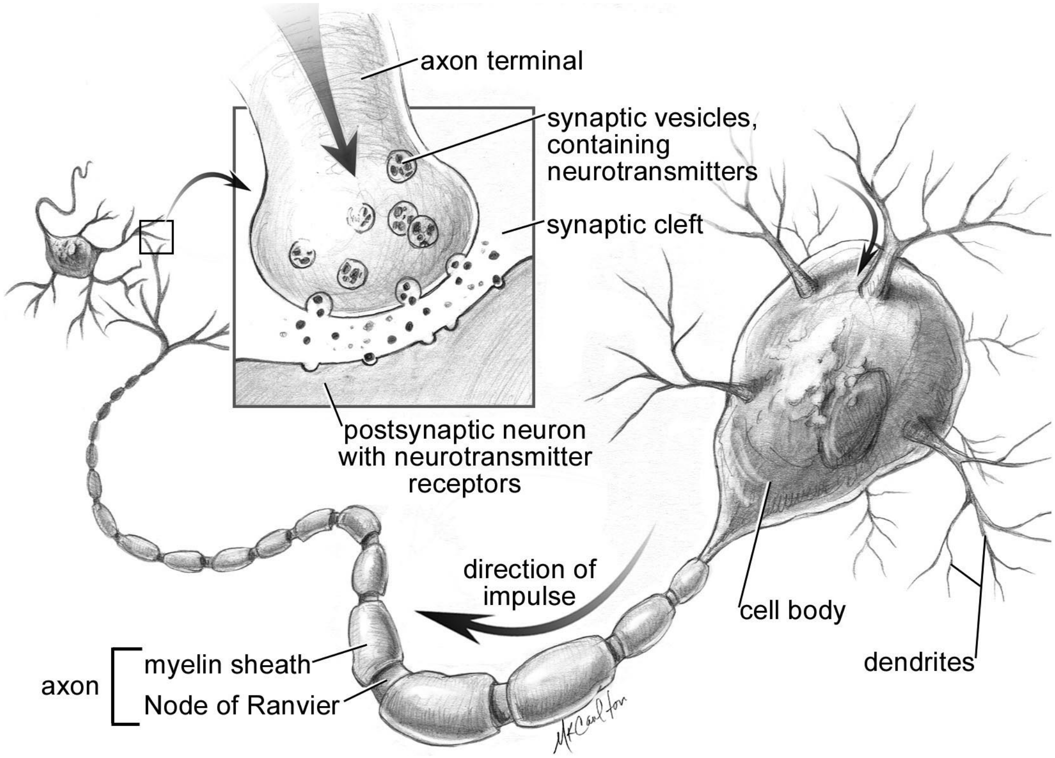
Simply stated, brain-based learning describes how the brain learns at a cellular level.[1,2,4,5] With the advent of this new body of empirical knowledge, educators have taken interest. The term *brain-compatible learning* was coined by educators to refer to the use of brain-based learning research in educational settings.[5] It is important to note that most knowledge in this field comes from neuroscience, not education. However, the implications for education are profound.

Brain-compatible learning is not a program to be installed within education. It is a set of principles that may guide our educational decisions and a field in its infancy. ''Brain-based learning is neither a panacea nor a magic bullet that will solve education's problems. It is not yet a program, a model, or a package for schools to follow.''[6] My purpose is to present the basic science of brain-compatible learning and suggest how it might be applied in athletic training education. What follows is a detailed description of how the brain functions during learning, how our brains develop, the nature versus nurture concept, principles and applications of brain-compatible learning, and implications for athletic training education.

Brain Physiology of Learning

A brief review of the physiology of how our brains learn is necessary to understand the principles of brain-compatible learning. The learning unit in the brain is the neuron. Each neuron is composed of a cell body, an axon, and dendrites (Figure). The axon transmits outgoing messages from the cell body, and the dendrites receive incoming messages from other cells' axons.[1,7,8] One axon may be as short as a millimeter or extend from the spinal cord to the big toe.[7] Each neuron has hundreds to thousands of dendrites. The dendrites extend off the cell body, resembling a tree with multiple branches.

A message is transmitted from one neuron to another through an electric-chemical process (Figure). The outgoing message travels down the axon to the end of the axon, where a synapse is located. The synapse is defined as the end of an



Neuron and synapse anatomy.

axon and the receptor on a dendrite between these 2 structures: the synaptic gap. The electric signal, or outgoing message, travels down the axon to the synapse. The signal releases a chemical message, which crosses the synaptic gap. The dendrite receives the message if the information is stimulating enough. The threshold for activation of a particular neuron is determined by a complex interplay of one's genetic code, physical condition (tired, in pain, alert), and environment (noisy, light, cold, stimulating). The chemical message now becomes an electric signal again and travels from the dendrite to the cell body, passes through that cell's axon to another cell's dendrite, and the process continues. Frequent transmissions of information between particular neurons can establish a permanent relationship between them.[1,7–10]

Each synapse has hundreds of receptors on the dendritic side waiting for the proper chemical to be exuded from its dedicated axon. Chemical transmitters, or ligands, consist of neurotransmitters, steroids, and peptides.[1,11] These chemicals travel throughout our bodies, not just in our brains. In all locations where information from the 5 senses (sight, sound, taste, smell, and touch) enters the nervous system, neuropeptide receptors are present in high concentrations. A great deal of information converges, and information is processed and prioritized. Thus, peptides filter the input of our experiences, significantly altering our perception of reality.[12]

Each synapse can contain multiple types of receptors, but each receptor can only admit its unique chemical. The types of information transmitted in one synapse can range from a dozen to a thousand. Each neuron is connected to hundreds of other neurons by anywhere from 1000 to 10 000 synapses.[1,7] Thus, it is not the number of neurons that determines our mental abilities but how they are connected.[1,7,9,10]

When we discuss learning and brain function, we must recognize 2 key structures in the brain: the synapse and the reticular activating system (RAS) of the brain stem. The RAS maintains our consciousness by regulating the modifying impulses from our sensory receptors to the brain and the brain's responses to these impulses. It acts as a screen between our brain and our communication to the outside world.[8]

The RAS also acts as a sort of toggle switch[1] in our brain stem that determines if the limbic system or the cerebral cortex is in charge of the brain. The limbic system is involved in our emotional responses to situations. With its main focus on survival, it is in charge of the brain when the fight or flight response occurs. When the RAS switches to limbic-system control, our emotions rule our responses and rationality is only minimally involved. Conversely, when the RAS switches to the control of the cerebral cortex, which is the rational and creative area of our brain, we commonly respond to a situation with due thought process.

For instance, if I am attempting parachuting from an airplane for the first time, my RAS switch has ample opportunity to go either way in midair when it is time to pull my chute cord. If my limbic system is switched on, despite several practice runs on land, I may panic and pull every cord on my parachute vest before I pull the actual chute cord. If my cerebral cortex is switched on, I will remember all of the practice runs I performed on the ground and immediately pull the correct chute cord after rationalizing where that cord is on my vest.

This model readily applies to learning in an athletic training clinical setting. Consider the first time students are asked to perform an initial injury evaluation on their own. In the classroom, they may competently be able to record the steps they would use through the entire evaluation. However, with the stress involved in actually performing those tasks for the first time on their own and in sequence, their limbic system may switch on—similar to a stage-fright response and the students may not be able to perform the evaluation.

Neural Development

Our brains are malleable. The greatest structural change occurs in our first years, although plasticity of the brain stays with us through our entire lives.[13–15] During development, each synaptic pathway represents a road an electric-chemical impulse may travel. The pathways that are used repeatedly become strengthened and more efficient. Those that are not used repeatedly are eventually physically eliminated and disappear from the brain. Thus, the use-it-or-lose-it theory applies. If these pathways are stimulated early enough, up to age 4 years, the permanent wiring of the individual brain will be affected.[7,13] From this age on, the individual operates with this base wiring, and any brain growth involves making connections between existing neurons.[16] Thus, the quality of these more complex neural networks depends on the quality of the initial base wiring and the quality and quantity of new experiences creating the new networks after the base wiring is established. The brain is estimated to increase about 30% in weight after age 4 or 5 years. The additional weight is increased weight per brain cell, due to increased dendritic growth per cell.[16] This structural change, which occurs in all animals, is based on different kinds of early life experiences.[7]

Different regions of the brain develop on different timetables. In most humans, neural circuitry is not completely developed until the early 20s.[14] Many of the nerves connecting different processing centers in the brain do not finish myelinating until the early 20s. A specific area of the cerebral cortex, the prefrontal cortex, is in charge of executive functions, or rational decision making. The prefrontal cortex handles ambiguous information and makes decisions. It moderates emotional reactions generated in the limbic system (shortening or prolonging them) by reasoning through the emotions. A high percentage of undergraduate athletic training students are teenagers, in whom the prefrontal cortex is not yet fully developed and, thus, may not be adequately moderating limbic-system responses.[14]

Nature Versus Nurture

In the past, brain-development theory fell into 2 camps. One camp, nature, believed we were born with our brains wired and our chemicals present, and the given brain structure didn't vary much through life. The other camp, nurture, believed with enough stimulation from the environment, be it positive or negative, great variation in brain development could occur throughout life. Today, with the advent of multiple brain-imaging techniques and carefully controlled experimental research studies, we know that both nature and nurture play roles in the development of our brain structure, our intelligence, and our personalities.[1,7–10,13,16] These developments have gone beyond the nature versus nurture debate to demonstrate that intellectual potential and achievement are the result of complex and poorly understood interactions between the physical body and experience.[17]

Genetics, or nature, is estimated to account for 30% to 50% of individual differences, whereas environmental factors, or nurture, serve to enhance or diminish genetic predispositions.[1,16] For example, when identical twins are reared separately from birth, they still show strong similarities—even in their religious feelings and vocational preferences.[1] Thus, we are all born with certain neural networks resulting from our genetics. Those networks, however, may be altered with life experiences.

In a series of experimental studies using brains of rats, Diamond and Hopson[7] demonstrated that environmental stimulation causes dendrites to branch and the cerebral cortex to thicken.[7] Rats raised in stimulating environments had thicker cerebral cortices than unstimulated siblings. The spines of dendrites, which are the synaptic receiving projections, grow, change shape, or shrink through experiences in the world. When a neuron develops dendrites, they increase its surface area and provide more of a landing field for incoming information transmitted through other neurons. Interestingly, the thinning of the cerebral cortex in a boring environment is more pronounced than the thickening of the cortex in an exciting environment.[7]

Generally, the thicker the cerebral cortex, the smarter the animal.[7] In the human body, of 100 billion neurons, more than one third are located in the cerebral cortex. Practically, if we as athletic training educators increase the level of environmental stimulation and challenge in our classrooms and clinics, we may influence the branching of dendrites and potentially the thickening of the cerebral cortices of our students.

How We Learn

The brain is designed to perceive and generate patterns. It also resists having meaningless patterns imposed upon it. Thus, if I attend a presentation on a new shoulder-surgery technique, my brain will perceive anatomy and previous surgery knowledge patterns and generate a new pattern to include and make sense of the new information. However, if I attend a presentation on a mathematical construct in quantum physics, my brain is less likely to perceive any pattern and may, therefore, not generate any new pattern. The information would thus be meaningless to me and would find no place or pattern in my brain in which to fit. Therefore, that information would not be retained or learned.

Learning is built on the process of detecting and making patterns.[1,9,18] It is necessary to link new knowledge to existing patterns in our brains. New learning (new brain structures in the form of increased dendrites) must be connected to what the learner already knows (existing brain structures). As teachers, we help students to identify ways to fit new information into their existing knowledge patterns, which will aid in building dendrites and synaptic connections.

Learning is the establishment of new neural networks composed of synaptic connections. New synapses appear after learning. In essence, dendrite growth is learning. The density of the brain, measured by the number of synapses, distinguishes greater from lesser mental capacity.[1,7,18] If we think in terms of connections, a piece of knowledge is represented by a pattern of connectivity between neurons. Learning occurs when modifications to this pattern occur (such as strengthening of the pattern by repetition or weakening by nonuse).

To learn, we first need a stimulus to the brain. This stimulus is then sorted and processed at several levels. The formation of a memory potential is created—knowledge pieces are in place, so memory can be activated. Neural connections are made, but they may fade quickly and disappear if not activated again. Once reactivated, the connection pattern becomes stronger. Each repetition, or recall of that knowledge, not only strengthens the pattern but makes it more efficient.

To investigate the hypothesis that practice should reduce the recruitment of executive brain mechanisms, Weissman et al[19] used functional MRI scans to study 15 participants while they performed both global and local attention tasks.[19] Practice strengthened new patterns, and fewer stimuli were required during each successive practice to engage associated processes and responses. Further, when tasks were introduced that challenged previously established patterns, brain activity increased. A shape was shown to the participants and then labeled as a specific but inaccurate color. The participants were asked to memorize the shape with the label given. Even with practice, brain activity increased, as a pattern was already established for the identification of colors. Both of the findings supported the initial hypothesis.

Learning occurs when a cell requires less input from another cell the next time it is activated.[10] Thus, novices may use more of their brain to draw on previous knowledge from different areas, but they are less efficient in how they use it. Experts performing skills within their areas of expertise demonstrate dramatically less activity on brain imaging than novices performing the same skills.[1,10,19] For instance, in a beginning violinist, the area of the brain responsible for modulating musical talents may be profusely active, whereas an expert musician performing a difficult piece of music may show minimal activity. An athletic training student learning how to tape an ankle has a very active brain, whereas a fourth-year student may show little brain activity while performing the same task.

Structural change in our brains occurs naturally, and we learn through individualized, active practice at higher and higher levels of critical and creative thinking.[7,18] The brain's natural way of learning is through problem solving. It learns best with repetition.[20,21] Along with this, ''only 4 to 8 minutes of pure factual lecture can be tolerated before the brain seeks other stimuli—whether that be daydreaming or watching others walk past in the hallway.''[22] Thus, traditional lectures may run counter to how the brain naturally learns, as there is no problem solving and no repetition and the lecture may run 30 to 60 minutes. One should use caution, however, with repetition. As Wolfe stated, ''Practice doesn't make perfect; it makes permanent.''[23] Thus, if students are repeating wrong information, that wrong information becomes permanent in their memories.

This cognitive system is directly and physiologically influenced by our emotional state.[24] The cognition and emotion systems are so interconnected that chemicals of emotion are released virtually simultaneously with cognition.[25,26] Learning is, therefore, tied to the state of mind experienced at the moment of learning,[1,2,4,9,10,21] and emotion and cognition cannot be separated. The emotionality of a learning experience directly influences retention. A bored or disengaged student will likely learn and retain less knowledge. A student who learns a construct with an emotion tied to it (be it positive or negative) will learn and retain the knowledge at a much higher level.

For instance, in a beginning athletic training class, emotion can even be incorporated in as dry a subject as the fitting and proper use of crutches. Students who use crutches for 24 hours and experience frustration and armpit rub may gain memorable knowledge on how important crutch fitting is for future clients. They may also be able to give more thorough directions to those clients on how to open doors and ascend stairways.

As we teach, if we purposefully ignore the emotional components of whatever subject we are teaching, we deprive students of meaningfulness. Emotions directly influence attention, meaning, and memory,[4,10,27,28] all of which are enhanced when we create lessons to engage emotions in a productive way. ''A classroom that is coldly rational and logical without room for appropriate forms of fun and feeling—while it might work for educating computers—is no place for humans.''[9] However, emotionally stressful environments are counterproductive because they can reduce the student's ability to learn.

Stress is an effective mediating component of learning. Influenced by the RAS, under perceived threat, the human brain downshifts from higher-order thinking to instinctive responses.[9] More threat means more downshifting. In this downshifted state, information stored in different areas of the brain may become unavailable. Consider students who perform poorly on tests because of test anxiety but exceptionally otherwise. ''If you have ever been insulted and could not think of a response until the next day, you've experienced downshifting. . . Anything that an individual brain perceives to be threatening can slow the creative, rational processing of information.''[23]

A stress response triggers high levels of cortisol to be released, which, if prolonged, can destroy neurons in the hippocampus and prefrontal cortex associated with learning and memory.[9,17,29,30] A brain-compatible approach to this problem would be to reduce the threat as much as possible for your students to encourage access to higher-order cognitive processing. However, eliminating challenges along with threat would not be beneficial. An optimal tension level needs to exist between the two. Jensen[6] argued that, at times, even high levels of stress are fine as long as the student has practiced performing successfully under those stress levels.

Principles of Brain-Compatible Learning

Different authors have different concepts of brain-compatible learning principles (Table). However, many of their concepts overlap.

Application

Brain-compatible learning is not limited to one approach or strategy.[32] In fact, to present all the different strategies a teacher could use to implement brain-compatible teaching and learning research would require a text in itself, as evidenced by a growing number of such books on the market today.[11,20,33,34] Rather than prescribe certain techniques or strategies, I present some important guidelines. Please remember that brain research does not prescribe the best way to teach. It describes brain function and how we learn. Educators should use this research with strategies that work best for them and their students.

Our Senses. Technically, the only way to provide information to the brain is through our senses.[11,23,34] The brain learns by sifting through massive amounts of input arriving simultaneously from all the senses and eliminates or ignores irrelevant material. Powerful learning, therefore, begins with high levels of sensory input from experiences. Cheng[35] compared learners using 2 learning approaches (diagrams and equations) and found that the group using diagrams learned more than the equation group and was better able to solve complex transfer problems involving multiple constraints. The

Brain-Compatible Learning Principles

Principle	Authors				
	Caine and Caine[4]	Liston[5]	Bimonte[31]	Howard[1]	Jensen[10]
Brain is a parallel processor (multitasking)	●				
Learning engages entire physiology	●			●	●
Search for meaning is innate; it occurs through patterning	●	●	●	●	●
Emotions are critical to patterning	●			●	●
Brain simultaneously perceives and creates parts and wholes	●	●			
Learning involves both focused attention and peripheral perception	●		●	●	●
Learning with specific context is best	●	●			●
Learning is enhanced by challenge and inhibited by stress/threat	●	●	●	●	●
Each brain is unique	●	●			●
Learning is process of forming novel neural networks or patterns		●		●	
Novel patterns can only form as extensions of existing patterns		●	●	●	
Learners need to recognize and connect patterns by themselves		●		●	●
Learners should be given choices to accommodate different learning styles			●	●	●
Learning must apply to real life of learners			●	●	●
Immediate feedback amplifies learning			●		●

diagram group acquired an organized network of concepts, learned effective problem-solving procedures, and experienced more positive learning events. Rather than just using cognitive problem-solving pathways, the diagram group used the additional visual input to aid learning.

"As the brain attempts to make sense out of the profusion of input flooding the senses, it constantly searches for patterns that can impose meaning on the input received."[11] The first stage of learning, then, is to extract from the senses relevant input that fits into existing patterns. Lessons should attempt to maximize the amount of sensory input during the learning process. Again, if the incoming information cannot fit into a related pattern in the student's brain, it will not be learned.[1,5,31] Teaching, then, should first use individual tasks to provide a personal connection to any new topic. Small-group work followed by larger group discussion and debriefing of the process is an example of a brain-compatible learning plan.[36]

Transfer. Brain research tells us that, each time we recall an event or a previous experience, we literally reconstruct it through the same circuit or circuits we used to store it.[1,9,23] Therefore, if we recall that information from a different angle, as long as we arrive at the same information, we then create more pathways to access it. Teaching for transfer is possible, but it is much more easily stated than accomplished. The ease of transfer between tasks is a function of the degree to which the tasks share cognitive elements and meaning for the individual.[2] Morgan[8] illustrated how transfer from the classroom to real life commonly does not occur, stating, "Street vendors in Brazil were able to make error-free money calculations in their curbside transactions but were unable to solve math problems of equal difficulty in classroom settings." Thus, the experience of learning is different than the content to be learned. If the teacher of the street vendors had used their jobs as an example during the mathematics lessons, the students would have been more likely to access the same information in both settings.

Transfer from classroom environments to real-life environments is one of the purposes of education. Transfer is defined as the ability to extend what has been learned in one context to new contexts.[2] All new learning involves transfer based on previous learning. Memory and transfer should not be confused; the former is recall, and the latter is recall plus application in a new context. Learning experiences that produce effective memory do not necessarily produce effective transfer of knowledge. For a concept to successfully transfer to another context, it must first be fully understood (mastered) within the initial context. Transfer is enhanced when we teach knowledge in multiple contexts or from different angles. An effective way to assess students' conceptual knowledge is to test for transfer of the knowledge or skill rather than assessments of memory of knowledge.[2,31]

For instance, I may spend 2 weeks teaching the concept of wound healing at the cellular level. My students may be able to memorize that information and repeat it back to me on a test. However, if I really want them to learn the material, I may have them recall that information to make a decision on whether to put an athlete with a fresh ankle sprain on crutches or not. They will not only have to recall the principles of wound healing but transfer that knowledge into a completely new context.

Active Learning. Common techniques for active learning include simulations, role playing, group learning, discovery learning, cognitive dissonance, and cooperative learning. Solving problems and creating projects are brain-compatible techniques that allow learners to recognize and connect patterns on their own rather than being teacher directed.[20] Active-learning strategies can engage all student learning styles. The more students interact with the teacher and other students, the more enhanced their brains are for learning.[10,11,15] Ideally, an active-learning lesson includes challenge, feedback, novelty, coherence of concepts, relevance and meaning to the students, and ample time for the lesson.[6] It is much more important to allow time for the concepts to be truly understood and learned, even if this means including less content, versus loading more content into a lesson to catch up. Allow time for repetition, as this strengthens learning. Repetition is only negative when it becomes boring or reinforces incorrect information.

Kinesthetic Learning. Kinesthetics is the study of touch, space, and motion.[1] Kinesthetic learning, then, is learning through touch, space, and motion or learning by physically doing. It differs from active learning in that active learning implies the student is in charge of, and actively involved in, the learning experience, which may be within a discussion group. Kinesthetic learning is a type of active learning that uses body movements with a hands-on approach. The cerebellum is much more active with motor movements involved in kinesthetic learning.[2,9,33]

Some students are high in kinesthetic intelligence, and others struggle a bit more to learn this way.[37] We have all seen this in our clinical students. Some beginners learn the Lachman test as if they had done it a hundred times, whereas others never really quite get the feel for it. Kinesthetic learning is very brain compatible because of the high amount of sensory input that occurs. A word of caution, however, from Kovalik and Olsen[11]: ''While using hands-on of the real thing undoubtedly elicits a range of sensory input, the lack of real-life *context* can significantly limit the richness and diversity of sensory input.'' In other words, a student performing a Lachman test on a subject with a healthy anterior cruciate ligament will learn less than a student performing the same test on a subject with a torn ligament.

Along with attempting to include kinesthetic learning within an appropriate context, we must be cognizant of the prior experiences of our students. Recall that, without existing patterns within their brains, students will not be able to retain novel information. Thus, hands-on approaches may be unsuccessful if students lack prior, real-world experience with the topic under study. If our student does not know what an anterior cruciate ligament is or how it is aligned anatomically, he or she may be successful in performing a Lachman test, but the information will not be retained or truly learned because the student does not know the structure being tested.

Gardner[38] stated,

> The brain learns best and retains most when the organism is actively involved in exploring physical sites and materials and asking questions to which it actually craves answers. Merely passive experiences tend to attenuate and have little lasting impact.

Fortunately, athletic training lends itself well to kinesthetic learning, as it is a hands-on profession. In clinical settings, most lessons provide for this. Even in the classroom, when we use demonstrations, simulations, role playing, etc, we invoke kinesthetic learning.

Recent research has shown that, if kinesthetic learning is combined with self-explaining, retention rate and depth of learning are even greater.[39] In 2 classroom experiments, students who explained their steps during problem-solving practice learned with greater understanding than students who did not explain their steps. Further, students who explained their steps were more successful in transfer problems. Thus, self-explanation appears to be an effective metacognitive (being aware of how we think) strategy. This implies that, in clinical learning situations, students should not only practice hands-on skills but verbally explain each step they take to the instructor or a peer. The act of explaining produces deeper learning, regardless of the listener.

Implications for Athletic Training

Many of the principles of brain-compatible or brain-based learning have been used in the field of athletic training education for years by intuitive teachers, although empirical research to back up what worked was lacking. Now, with the advent of new brain-imaging technologies, more and more researchers are illustrating how our brains learn. What has not been thoroughly researched is how best to apply these principles directly into classroom strategies. In fact, Wolfe[23] cautioned against this:

> Brain research is not a program to be implemented in schools. Neuroscience does not prove that any particular strategy or method works. Rather, the research is adding to our knowledge base, helping us better understand how the brain learns—or doesn't learn—and why. We are beginning to gain a scientific understanding of the learning process, and from that understanding, we can make better decisions about how to structure learning environments and instructional practices.

Therefore, it is imperative that athletic training instructors who wish to incorporate some of these principles do just that: incorporate some of the principles, rather than redesign a whole course or program. Some initial principles to consider incorporating follow:

1. Find out what patterns (knowledge) your students already have at the beginning of a course and adjust your lessons accordingly. For example, do they know the biomechanics of disc abnormalities? Have they witnessed an acute anterior cruciate ligament evaluation by a certified athletic trainer? If so, will they share their experience with the class?
2. Assist your students in connecting novel ideas into already existing patterns, perhaps patterns learned in another course or in their own personal life. Make learning personally relevant to the students. For example, instead of lecturing about pharmacology for a whole class period, have the student list the athletes (use fake names) they are working with who are on medication and describe which medications and how the medications are chemically working in their bodies to improve their conditions.
3. Incorporate a degree of emotion when teaching novel concepts or elicit emotion from your students around the novel concept. Often, connecting the concept to their personal lives accomplishes this. Laughter is great for engaging emotion and, importantly, reducing stress. For example, I often share a humorous version of how terrified I was to perform my first real ankle evaluation by myself during my first semester as an athletic training student. This is a prelude to general-evaluation procedures information, a novel skill they will be required to perform later in the semester.
4. Be conscious of your classroom or clinical environment by reducing distractions and providing enrichment where possible. Change your delivery mode by incorporating body movement periodically and involving as many senses as possible during the class period. For example, in presenting a lesson on anterior cruciate ligament evaluation, use a knee model they can touch, feel, and move. Use any of the numerous videos available. Have them perform the tests on each other. Whenever possible, allow them to perform the tests on a willing patient with an anterior cruciate ligament deficiency so they get the kinesthetic feel of a positive test.
5. Reduce as much stress as possible, while still posing challenges. Give choices on projects when feasible. For example, at the beginning of the semester for a modalities class, have them choose a topic for an end-of-the-semester class presentation. When preparing them for an examination, do not use threat or instill fear (even jokingly). Give thorough pretest reviews, and let them know how you test. Avoid creating mystery, tension, or fear about oral or written examinations.
6. Use immediate feedback to help refine their patterning. It is best to attempt to return graded materials by the next

class meeting. If you give an examination on a Tuesday, make all attempts to return it graded on Thursday.

7. Teach new concepts within context, then attempt to have them transfer that concept into new contexts. For example, teach an arch tape job, and have them practice that for the semester. The following semester, have them describe how an arch tape job may help to alleviate iliotibial band pain.
8. Allow ample time for your students to problem solve. This lets them recognize and connect patterns for themselves rather than having the teacher provide all the answers. Small-group work is excellent for this. For example, during a therapeutic-exercise course, ask groups of 3 or 4 students to decide when it would be safe to progress a patient with a shoulder reconstruction to phase II of a rehabilitation program, considering wound-healing principles taught earlier in the course. Give them 10 to 15 minutes to list the considerations and reasoning. After this time period, have each group present their reasoning and decisions to the class. After each group has presented its position, begin your lesson by noting the positive aspects presented and those that needed corrections.

Conclusions

Education is one of the slowest bureaucracies in which to pursue successful change. Given that and the fact that many of us as students were simply lectured to in class most of the time, a major paradigm shift and considerable preparation and effort are required to move to brain-compatible teaching. Fortunately, athletic training lends itself well to many of the principles. Kinesthetic learning, active learning, and the use of many of our senses are mandatory to being able to perform our jobs. Teaching for transfer is what we as educators attempt as we promote independent critical-thinking and problem-solving skills in our students. Some of the less obvious brain-based learning principles to consider are including emotion with our teaching (whether it be humor, empathy, sadness, or fear), connecting novel concepts to both a context and some bit of knowledge the students already possess, reducing as much stress for the students as possible while still challenging them, and building patterns and repeating them to strengthen neuronal connections.

Brain-based research is in its infancy. More has been learned in the past 7 years about the brain than in the entire century before.[22] Much more will continue to be learned as brain-imaging techniques are refined and research continues to illuminate how we learn best and why. It would be prudent for athletic training educators to monitor this research periodically and keep abreast of its implications for education. Stemming from neuroscience research rather than education, it is not an educational fad, as many new ideas have been in the past. At the same time, ‘‘Taking neuroscience into the classroom is challenging because we cannot rely exclusively on brain research. People are too complex, individuals too unique, and contexts too unpredictable.’’[40] Perhaps Jensen[6] provided the most concise conclusion:

> Educators should not run schools solely on the basis of the biology of the brain. However, to ignore what we do know about the brain would be irresponsible. . . Dismissing it as faddish, premature, or opportunistic is not only short-sighted, but also dangerous to our learners.

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COMMENTARY

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In this issue of the *Journal of Athletic Training,* Craig suggests that ''brain-compatible learning principles'' could be applied to the education of athletic trainers. Craig offers a chart showing 15 of these principles and the authors who have endorsed them (Table). She assumes that using brain-compatible learning principles will make teaching more effective.

The idea of using brain-compatible methods in education has appeal, and the reverse (brain incompatibility) sounds downright awful, but brain-compatible learning principles are broad statements with great leaps of faith between science and application. For example, the first principle suggested by Craig is, ''Find out what patterns (knowledge) your students already have at the beginning of a course and adjust your lesson accordingly.'' It is hard to take issue with general advice, but where is the evidence these principles lead to more effective teaching and learning?

Craig defines brain-compatible learning as a ''set of principles'' that describe ''how the brain learns at a cellular level,'' evoking a neuroscience foundation. But these principles do not come only, or even primarily, from neuroscience research; rather, they have been generated from a wide range of disciplines, including psychology, education, sociology, philosophy, and technology. Squire and Kandel,[1] themselves neuroscientists, pointed out that ''the analysis of how learning occurs and how memories are stored has been central to three intellectual disciplines: first philosophy, then psychology, and now biology. . . .'' They noted that neither psychology nor biology alone can satisfactorily address these questions, but the combined strength of both disciplines is needed. Citing developments in the interconnected nature of our brain, immune system, and endocrine gland system, Sylwester[2] cautioned that jargon that tends to confine learning to brain activity is itself suspect and suggested the term ''appropriate instruction'' in place of ''brain-compatible learning.''

The question is, ''How does one decide if a particular educational method or approach really works?'' Certainly new tools (such as the advances in brain imaging mentioned in this article) provide new ways to observe brain chemistry. But these new tools are not, in themselves, better science than the methods of psychology or education or any other discipline. Sagan[3] was fond of reminding us that science is a way of thinking much more than it is a body of facts. Attempts to distill effective educational methods directly from brain science research have frequently been problematic. Gabriel[4] reported the recollection of Dr Kurt Fischer, director of the mind, brain, and education concentration at Harvard School of Education, that in the 1970s, some biologists were advising educators that boys and girls should be educated differently because their brain growth patterns are different, but data on actual learning failed to substantiate those recommendations. Fleischman et al[5] pointed out that, although basic research methods are the same in all fields, the complexities of teaching and learning, as well as complicated ethical and practical considerations, make research in education particularly challenging.

Just as in medicine, education is now moving toward an evidence-based model. Evidence-based education methods allow us to sift through complexities.[6,7] Evidence-based education requires educators to augment their skills by beefing up their understanding of how to evaluate research, so they know how to separate evidence from conjecture. To evaluate research, educators will need to become literate in the general structure and function of the brain. But the first and most important thing educators need to learn is how to evaluate research as it relates to evidence-based education.

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AUTHOR'S RESPONSE

The comments from Blackley are well received. They point out the complexities of teaching and learning and the brain's role in each of these. When reviewing the literature involving brain-based learning, one finds a multitude of opinions and theories, both supportive and cautionary, but little in the way of evidence-based support for the principles of brain-based learning. Neuroscientists who find evidence of learning pathways in the brain commonly caution the reader against taking this information and applying it practically, such as ''how to best teach.''[1–7] Even the most decorated educators will likely disagree on ''how to best teach.'' Certainly, many disciplines need be involved in the ongoing empirical research studies concerning our learning pathways.[4,8]

Empirically based educational research is indeed challenging. This is due in part to the complexity and individuality of each learner.[8] The body of knowledge now being labeled brain-based learning will evolve as more empirical educational studies are conducted. It would be prudent for athletic training educators to continue to investigate this evolving body of knowledge as cautionary consumers. As Barrie Blackley suggests knowing, ''how to evaluate research as it relates to evidence-based education'' is critical when assessing the value of any new body of knowledge, including brain-based learning. It is the possibility of understanding the learning process more thoroughly that is both alluring and intriguing within brain-based learning.

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