Pursuing Consciousness by Studying Expertise (Invited Paper)

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***Abstract*— This paper reviews the different methods that have been employed recently to study consciousness. At least two of those methods, the neuropsychological approach and the cognitive approach, have converged on a set of characteristics that separate conscious processes from unconscious ones. These characteristics: durable, explicit representations; novel combinations of operations; and intentional behaviors intersect with the necessary requirements for the development of expertise using deliberate practice. This intersection is described in detail and its potential implications for cross-species comparisons, understanding the evolution of human consciousness, and consciousness in machines is discussed.** *Copyright © 2003-2005 Yang's Scientific Research Institute, LLC. All rights reserved.*

***Index Terms*— Consciousness, expertise, evolution, cognitive science, artificial intelligence.**

I. Introduction

SCIENCE often progresses by steadily chipping away at, and ultimately bringing down, barriers once thought impenetrable. At one time the mind was considered off limits to science since its operations were private and could not be objectively measured. Steadily though, the mind's ways have yielded to inquiry, and cognitive science has emerged and flourished. But while the secrets of memory, attention, language, problem solving, and a host of other mental processes have been coaxed from shadow to light, one process has remained meekly behind the veil – consciousness. Recently however, even this most coy of prizes has begun to reveal itself. Heedless of the naysayers, the raiders of the consciousness ark have been doggedly creeping up on their quarry, ingeniously concocting suitable methods for a science of consciousness. In this paper I shall review some of ways that consciousness researchers are plying their trade, with a special emphasis on how understanding expertise may prove to be one of the most productive weapons in the pursuit consciousness.

II. Methods for Studying Consciousness

A. Brain Chemistry

One method for studying consciousness takes advantage of our normal consciousness cycles. Daily we slide from aroused, conscious, wakefulness to relaxed, unconscious, sleep and through all the gradations in between. The physiological differences in brain chemistry associated with these states can provide valuable information about the fundamental basis of consciousness. Of specific importance are the neuromodulator systems of the brain, whose outputs appear to vary in concert with conscious states. Neuromodulators are brain chemicals transmitted from one neuron to another (neurotransmitters) whose affects tend to be longer-lived compared to other neurotransmitters (see Glynn, 1999 p.135-137 for discussion). Neuromodulators affect the way post-synaptic cells respond to inhibition or excitation. In the brain there are two general neuromodulator systems: aminergic and cholinergic. The aminergic system contains a number of subsystems delivering such chemicals as norepinephrine, serotonin, and dopamine to various parts of the cortex, while the cholinergic system delivers acetylcholine. Hobson (1999) contends that the ratio of the aminergic chemicals (especially norepinephrine and serotonin) to cholinergic are critical to conscious experience. During waking the ratio of aminergic to cholinergic is high, but during sleep it steadily declines, reaching a complete reversal during REM sleep (the stage where dreaming usually occurs). This is important because serotonin and norepinephrine appear necessary for the ongoing maintenance of a memory trace, thus helping to provide for a coherent "stream" of conscious experience. During wakefulness, owing to the abundant availability of these aminergic chemicals, the brain is able to sustain a rational ongoing sequence of consciously experienced events. During the dreaming state, however, the lack of these chemicals often results in a hodge-podge of seemingly unrelated scenes and events being rather arbitrarily fused together, helping to explain the often bizarre nature of dreams.

Along with these alternations of brain chemistry, waking and sleeping also differ (rather obviously) in their relative sensitivities to external stimuli. Of significance here is a thin collection of cells surrounding the thalamus of the brain, known as the reticular nucleus of the thalamus. The thalamus is a centrally located brain structure through which nearly all incoming sensory information must pass before being routed on to higher brain centers for further processing. Thus, for example, information striking the retina of the eye is transmitted via the optic nerve to the thalamus (the lateral geniculate nucleus to be precise), and then from the thalamus to the occipital lobe of the brain. The reticular nucleus of the thalamus, however, appears to act as something of an on/off switch either allowing sensory information to pass through or inhibiting its flow. As the reticular nucleus increasingly restricts sensory input, one's conscious awareness turns inward to introspection, contemplation, meditation, and dreaming. Normal cycles of arousal and fatigue undoubtedly trigger

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changes in reticular nucleus activity, but voluntary strategies such as closing the eyes, relaxing exercises, reciting a mantra or prayer are also likely to directly affect the reticular nucleus (Austin, 1999). Studies associating brain structures and brain chemistry with various states of consciousness are important for understanding the biology behind consciousness. They are stubbornly frustrating though, in that the leave unanswered the question of how unconscious chemicals and brain structures can produce conscious awareness, or why it might be adaptive to do so.

B. *Comparative Studies: Theory of Mind*

Another method for approaching consciousness is to compare conscious experience across different species in order to learn something about the evolution of consciousness. At first blush, this may appear to be an impossible issue to address scientifically – how does one measure an animal's conscious experience? But in the late 1960's, Gordon Gallup devised an ingenious test of chimpanzee self-awareness called the mirror test. Gallup observed the reactions of common chimpanzees and two species of monkeys when they were allowed to see their mirror reflections (Gallup, 1970). The animals were individually given access to a mirror for 8 hours per day for up to 14 days. Initially the chimps and the monkeys treated their reflections as other animals. After about 3 days of exposure, the chimp's behavior changed dramatically. Instead of continuing to exhibit socially-directed behaviors, the chimps engaged in an increasing number of self-directed behaviors such as grooming and inspecting body parts which they normally could not see. The chimps seem to recognize that the chimp in the mirror was a reflection of themselves (not another chimp) and they began to use the reflection as a means of gaining visual access to body parts normally only available through touch, (similar to a person using a mirror to inspect a fever blister or an incoming moustache). In contrast to this, the monkeys showed no marked changes in behavior over the study period. Next Gallup anesthetized the animals and placed a bright red mark on one eyebrow and one ear of each animal. The mark left no olfactory, tactile, or direct visual cues to its presence. When placed before the mirror the chimpanzees spent a considerable amount of time inspecting the marks, seemingly recognizing that the mark was a rather strange part of *their* bodies. The amount of time they spent touching and examining the mark far exceeded that of a control condition where chimps were marked but were not exposed to the mirror. Once again, the monkeys showed no particular interest in the mark.

The significance of Gallup's work was that it suggested a qualitative divergence in the self-awareness of great apes and monkeys. Apes had a concept of themselves - an internalized identity that permitted recognition of an external representation of themselves (the mirror image). They understood themselves as creatures with a distinct physical existence, one that permitted them to be both observers (as when looking in the mirror) and the observed (as when recognizing the mirror-reflected image as themselves). This apparently was a conscious capacity that had evolved after the monkey/ape phylogenetic branches had separated from each other; apes had it and monkeys didn't. While some anomalous findings have been reported (Boccia, 1994; Hauser, Kralik, Botto-Mahan, Garrett, & Oser, 1995; Suarez & Gallup, 1981; Ledbetter & Basen, 1982), most studies have confirmed the ape/monkey distinction in self-awareness (Lethmate & Dunker, 1973; Miles, 1994; Suarez & Gallup, 1981; Hyatt & Hopkins, 1994;Anderson, 1983; Lethmate & Dunker, 1973; Mitchell & Anderson, 1993; Suarez & Gallup, 1986).

The mirror test indicates that chimpanzees and other apes possess some manner of self-consciousness, but Gallup went even further and argued that self-awareness implied other-awareness as well. To some this suggested that chimpanzees might possess a "theory of mind," that is the ability to attribute mental states to others, something not seen in children until about 3 or 4 (Premack & Woodruff, 1978). Daniel Povinelli (Povinelli & Eddy, 1996) addressed this question by taking advantage of chimpanzee's natural begging gesture (holding out the hand). In the lab, he and his colleagues taught young chimpanzees to beg to the experimenter in order to receive a food treat. On test trials the chimps were allowed to beg to either an experimenter with a blindfold around the eyes or another with a blindfold around the mouth. Rather surprisingly, the chimpanzees begged randomly to either one, showing no sensitivity to the fact that only the experimenter who could *see* them could *mentally interpret* the significance of their begging gesture. In other conditions, the chimpanzees were confronted with one experimenter who could see them, and another with either a bucket on the head or hands over the eyes. Again, the chimps begged randomly completely disregarding the visual status of the experimenter. The chimps apparently did not understand the role that visual attention plays in the mental state of another.

These studies suggest that chimps do not understand what is going on inside the head of another, and thus lack a certain kind of consciousness (other-consciousness) present in humans. Another set of studies though, has provided a more ambiguous picture. Studies addressing whether chimpanzees can discriminate between the intentional versus accidental acts of another have provided contradictory results, with some concluding in the negative (Povinelli, Perilloux, Reaux, & Bierschwale, 1998; Premack, 1986), while another concluded in the affirmative (Call & Tomasello, 1998). It may be that other-awareness, like other forms of consciousness, is not an all-or-nothing phenomenon, but something that is present in degrees and may vary depending upon the ecological circumstances (Hare, Call, Agnetta, & Tomasello, 2000; Hare, Call, & Tomasello, 2001).

C. *Neural Correlates of Consciousness*

Modern brain imaging techniques such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) allow researchers to "watch" the brain at work and monitor which specific regions or structures appear to be most active for various cognitive tasks. As a subject's brain is being monitored, he/she can be required to engage in a cognitive task that either does or does not require conscious effort. This procedure then allows researchers to identify those parts of the brain that appear to be associated with conscious processing. For example, a verb generation task typically requires subjects to produce an appropriate verb when presented with a noun, such as responding “climb” when presented with the word “ladder.” Initially, the task requires conscious effort (subjects report that they have to “think about” the right word). With repetition, however, the task become automatized, such that subjects produce the verb response “without thinking.” Imaging studies indicate that two parts of the brain, the prefrontal cortex and the anterior cingulate, are active when the task requires conscious effort, but not when it has become automatic (Raichle et al., 1994). Similar studies have confirmed the apparent involvement of these same structures in conscious processing (Cohen et al., 1997; Paus, Koski, Caramanos, & Westbury, 1998).

Single cell recordings of neural activity can also be used to isolate brain regions associated with consciousness. One of the most ingenious examples of this approach has exploited the alternating perceptual awareness linked to the phenomenon of binocular rivalry. Binocular rivalry occurs when different visual images are projected onto the foveas of each eye. Typically subjects report an alternating perceptual awareness of each image (e.g. the left eye’s image may dominate momentarily, then fade as the right’s image becomes dominate, and so forth). Logothetis (Logothetis, 1998; Leopold & Logothetis, 1999) trained monkeys to respond to the different rivalrous images while recording from cells in various parts of the visual system. The studies indicated that cells in “earlier” parts of the visual system, such as in primary visual cortex, maintained a constant firing rate regardless of which image was being perceived. However, cells later in the system, such as along the inferior temporal lobe (IT), modulated their firing depending upon which image was dominate. Thus, the activity of cells in the IT appeared to be related to the conscious experience of a particular visual pattern, while cells in the primary visual cortex did not.

Another study has shown the perceptual awareness of specific patterns may be associated with different brain regions. Kanwisher (2001) presented subjects with rivalrous images of a house and face and found that when the house was dominant there was increased activity along the parahippocampus in a region referred to as the parahippocampal place area (PPA). When the face was dominant there was increased activity in a region associated with face perception called the fusiform face area (FFA). Studies such as these are valuable in that they help to establish the brain-basis of conscious experience. However, similar to the chemical basis of consciousness, the mystery remains as to why activity in one brain region leads to a conscious experience while activity in another does not.

D. Neuropsychology

Neuropsychology addresses consciousness primarily by looking at brain damaged subjects and associating deficits in consciousness to compromised brain structures. “Blindsight” patients are the classic example of this approach. Damage to the primary visual cortex of the occipital lobe can leave a person with deficits in or a complete absence of conscious visual experience (Poppel, Held, & Frost, 1973; Weiskrantz, 1986). Despite this, experimental tests reveal that visual information is being processed, albeit at a level below the patient’s awareness. For example, a patient might be presented with spots of light appearing in various locations in their visual field. Even though the patient will claim to see nothing, when asked to guess at a light’s location their performance will typically be better than chance. Since the visual cortex is only part of the brain’s visual system (which also includes the optic nerve, the superior colliculus, the thalamus, and the visual pathways of the temporal and parietal lobes), it is assumed that other, undamaged parts of the system are registering the light’s presence and directing appropriate responses to it. This would then imply that it is the compromised structure (primary visual cortex) that is a necessary element in the conscious experience of the visual stimulus.

Neuropsychological studies not only help to identify those brain structures essential to consciousness, but also to isolate the potential function of consciousness. More than one researcher has commented on the fact that blindsight patients will not respond to visual stimuli unless forced to do so by persistent experimenters (Dennett, 1992; Weiskrantz, 1997). Though they are capable of unconsciously registering the locations and shapes of visual objects, blindsight patients do not initiate voluntary responses to them. Even a thirsty blindsight patient will not reach for a glass of water in their “blind” field (Marcel, 1986). Furthermore, consciousness may be important when computations must be made extending across time and space. For instance, while blindsight patients can often identify the presence of movement within their blind field they have considerable difficulty identifying the direction of movement (Cowey & Azzopardi, 2001). Similarly, patients with cortical achromatopsia have no conscious experience of color resulting from damage to the visual cortex and possibly the ventral visual pathway (Heywood, Kentridge, & Cowey, 2001). These patients can often succeed on tests of color constancy when only local patches must be compared, but falter when more global judgements across the entire visual scene must be made. (D’Zmura, Knoblauch, Henaff, & Michel, 1998; Hurlbert, Bramwell, Heywood, & Cowey, 1998). Note how these “failures” of unconscious processing involve more demanding pattern discriminations across time and space, suggesting that when such processing is required, consciousness is necessary. A similar effect may be at work in neglect syndrome where damage to the right parietal lobe can leave a patient entirely oblivious to objects in the left visual field (Driver & Vuilleumier, 2001). Driver and Vuilleumier (2001) review a series of studies showing that neglect syndrome is most likely due to an attention deficit the leaves the subject unable to distribute cognitive resources to the left visual scene when objects are present on the right.

Neuropsychological studies present us with something of a paradox in that they show us the many powerful and adaptive cognitive functions that can operate unconsciously. At the same time, however, they also provide an outline of the limits of unconscious processing, which more clearly defines for us the functional role of consciousness. Initiating intentional acts and cognitive computations that extend across time and space appear to be two processes which lie outside the bounds of the unconscious and therefore require conscious processing.

III. Cognitive Approach to Consciousness

The cognitive approach tackles consciousness by contrasting those mental operations that appear to require conscious effort from those that can be done automatically. These operations come in many forms and can be tested in a variety of ways. One of the first issues that arose along these lines was that of implicit learning.

A. Implicit Learning

Long before consciousness became an issue of legitimate scientific interest, memory researchers were intrigued by the phenomenon of implicit learning. Implicit learning refers to the capacity of humans and other animals to acquire abstract rules and associations without any awareness of the acquisition process. The classic demonstration of implicit learning comes from Reber's studies on artificial grammar learning (Reber, 1967; 1976; 1989; 1993). Subjects were required to memorize letter strings that were constructed according to a simple set of rules (an artificial grammar). Some of the rules, for instance, stipulated that all strings must begin with either a P or T, that a P could not immediately follow another P, and that a PS combination could only occur at the end of a string. After their initial exposure to letter strings, subjects were told that the strings were constructed according to a "grammar" and that they were now going to see more strings that they would have to classify as either grammatically correct or incorrect. The interesting finding was that while subjects could not verbalize any of the rules of the grammar, they could with remarkable accuracy, correctly classify new letter strings as being either grammatical or not. In other words, they learned the rules without being aware that they were learning them, and without being aware of their content. Similar findings have been demonstrated in the learning of variables that control complex systems (see Barry & Broadbent, 1984 for details) and in sequence learning or the serial reaction time task (SRT) where subjects learn to predict where visual stimuli will occur without understanding the rules that determine locations (Nissen & Bullenmer, 1989; Reed & Johnson, 1994).

Other recent demonstrations of implicit learning are also worthy of note. Watanabe, Nanez, and Sasaki (2001) demonstrated that coherent object motion could be detected even when subjects were unaware of its presence. Subjects were given a letter identification task against a background of randomly moving dots. Five percent of the dots, however, were moving in a consistent direction. Previous testing had confirmed that this proportion of coherently moving dots was too small to be consciously detected (in other words the dots all appeared to be moving randomly). In tests given a day later or more, subjects were found to have a heightened sensitivity to motion in the same direction as the coherent motion to which they were previously exposed. A similar effect was found by Moore and Egeth (1997) using background dots that unconsciously induced the Muller-Lyer illusion in subjects. Li, VanRullen, Koch, and Perona (2002) showed that subjects could categorize background scenes as containing either an animal or vehicle, even in the absence or near absence of attention to those scenes.

While implicit learning reveals much about the sophistication of the unconscious processes, it, rather paradoxically, also highlights the importance of consciousness. It is crucial to recognize that studies of implicit learning do not involve the presentation of unconscious or subliminal percepts. What is "unconscious" about implicit learning are the associative processes that go on inside the subject's head. The input on which those associative processes operate is conscious. For example, studies on artificial grammar explicitly require subjects to attend to and often memorize the letter strings embodying the implicitly learned grammar. As of yet there have been no studies presenting masked letter strings based on an artificial grammar to see if subjects could extract the grammar from subliminal presentation. Likewise, studies involving the control of complex systems and sequence learning all require subjects to attend to the perceptual stimuli on which the learning is based.

Thus consciousness plays an important role in implicit learning. Subjects are consciously aware of the stimuli on which the implicit learning is based. They are not, however, aware of all the properties inherent to those stimuli. For example, in the Watanbe et al., (2001) study subjects were aware of the background dots, and the movement of those dots. They were unaware of the *coherent movement* of a small subset of those dots. Similarly, in the Li, et al., (2002) subjects were aware of the background scenes and the presence or absence of animals in those scenes (personal communication). In artificial grammar learning subjects are aware of the letter strings, but they are unaware of the rule-based structure of the strings.

Why would consciousness be necessary for implicit learning? Implicit learning typically involves extracting the covariant relationships among stimuli. Extracting these structural relations requires that stimulus features be temporally and spatially "bound" in one's experience. Unconscious processes appear to be inadequate for binding perceptual experience to their spatial and temporal context. This suggest that consciousness may provide enhanced discriminative powers that are essential for the contextual binding of experience. Consider for a moment the implicit learning of an artificial grammar. Extracting the "rules" of the grammar requires that rather sophisticated spatial/temporal discriminations be made. One must recognize that a lawful pattern requires a T or P at the beginning; that a P followed immediately by another P is unlawful; and that the pattern PS is only acceptable when located at the end of a string. Recognizing these properties in the letter strings as they are initially being presented necessarily means that the elements of the strings (the Ps and Ss and features therein) be located spatially and temporally in one's experience and not free-floating, as occurs pre-attentively (Treisman & Gelade, 1980). The spatial/temporal associations required for the implicit construction of the grammar would not even be available for learning (implicit or otherwise) unless first attended to and therefore consciously experienced. It may be that it is consciousness that makes these properties available for associative learning and some of that learning appears to occur unconsciously. Further studies have confirmed this.

B. Contextual Binding: Durable and Explicit Representations

For a perceptual experience to be contextually bound in time and space, it must posses two important qualities: durability and explicitness. A number of cognitive studies have demonstrated that unconscious processes fail to produce durable and explicit representations (see Dahaene & Naccache, 2001 for review). Durability (of lack thereof) refers to the fact that implicit and unconscious effects are typically short-lived. Studies of unconscious priming offer a good example of the short-lived nature of unconscious effects. Priming occurs when the processing of a current stimulus is facilitated by the presentation of an earlier, often related stimulus. For example, numerous experiments have demonstrated that the reaction time for determining if a visual stimulus is a word or a non-word letter combination (nurse vs. ydxug, for example) can be affected by a previously presented stimulus. A subject will render the response "word" to the stimulus "nurse" significantly faster if the stimulus presented just before nurse was semantically related, such as "doctor," as opposed to being semantically unrelated such as "lumber" (Meyer & Schvaneveldt, 1976). Importantly, these same priming effects can be found even when the first word of the pair (doctor in this instance) is masked such that the subject is not consciously aware of its presence (Marcel, 1983). Studies of this type, though, have generally used very brief delays between word pairs, generally ranging from 50-150ms. Unconscious priming effects dissipate very quickly when delays longer than 150ms are employed, in other words, consciousness is required for more temporally extended effects. (Greenwald, 1996).

Explicitness (or lack thereof) refers to the fact that unconscious events or percepts are spatially and temporally unbounded. Treisman and Gelede (1980) demonstrated how certain features of visual scenes such as color, orientation, or shape could exist in a free-floating state in the initial, pre-attentive stages of processing. It is not until attention is focused on aspects of the visual scene that features become unified and "bound" to specific locations in space, leading to the episodic experience of a particular object with certain qualities in a certain location. Prior to this, sensory experience is illusory and its source, as being either externally or internally generated, easily confusable (Kanwisher, 1987; Treisman & Schmidt, 1982).

An experiment by Jacoby, Woloshyn, and Kelly (1989) nicely demonstrates the source confusion produced by the nonexplicit nature of unconscious sensory inputs. Two groups of subjects read a list of names of nonfamous people. One group gave the list their full attention. The second group, however, read the list in conjunction with a secondary task that prevented them from focusing full attention on the list. In the test phase, both groups were presented with a list that contained: (a) nonfamous names from the first list (old nonfamous names), (b) nonfamous names not from the first list (new nonfamous names), and (c) names of famous people. The task for the subjects was to decide if each name was of a famous or nonfamous person. The results showed that subjects in the divided attention condition were significantly more likely to call an old nonfamous name "famous" than subjects in the full attention condition. This is exactly what would be expected if subjects in the divided attention condition suffered from a source confusion regarding the names on the first list. Why so? Both old nonfamous names and famous names should produce a sense of familiarity in subjects. However, if an old nonfamous name can be "placed" in its proper episodic context (i.e. as having been seen on the previous list) then even though it is familiar it can be rejected as famous (since all the names on the previous list were nonfamous). Subjects who were prevented from giving the first list their full attention had a much more difficult time firmly placing old nonfamous names in their proper context and thus made more errors.

The durability and explicitness lacking in unconscious experience indicates that if a representation is to be held in memory for any extended period of time such that its featural properties can be processed and its experience can be contextually bound, then consciousness is typically required. This line of research offers further confirmation for the conclusions of the neuropsychological studies discussed earlier, which had suggested that unconscious processing falters when perceptual judgements spanning across time and space are required.

Other cognitive studies have revealed two additional important limitations of unconscious processing: the inability to create novel combinations of operations and inability to guide intentional behaviors (Dehaene & Naccache, 2001).

C. Novel Combinations of Operations

Unconscious processes are generally rigid in their operational constraints and cannot accommodate novel or innovative combinations of operations. A number of studies, for example, have shown the necessity of consciousness in situations where an automated response must be inhibited so that a novel one can be executed. Debner and Jacoby (1994) used a stem completion task where subjects were presented with either heavily (50ms delay) or lightly (150ms delay) masked priming words. Immediately after the prime word, the first three letters of the word were presented and subjects were instructed to complete the word with the first word that came to mind *other than* the prime word (called an exclusion task). Thus, suppose the word "button" was the prime word which was shown with a mask occurring either 50 or 150 ms immediately after its onset. Next the subject would be shown the letters "but…" and asked to complete the word. Given typical priming effects one would expect subjects to respond with "button" at levels well above chance. However, to follow the instructions the subject should complete the word as "butler" or "butter" or even "butane, " but not "button." The results showed that the two masking conditions had opposite effects on the subject's ability to follow the instructions. When words were lightly masked (150ms delay) compliance was significantly better relative to a baseline comparison. When words were heavily masked (50ms delay) compliance was significantly worse relative to a baseline comparison. Thus, some degree of conscious awareness of the word was necessary in order to inhibit or "override" the priming effect of the word and execute a novel response.

In a similar vein, the classic Stroop effect can be reversed but only under conditions where a prime is presented consciously. Merikle, Joordens, and Stolz (1995) had subjects classify red and green colored patches. Prior to the presentation of the patch, the word red or green was presented either consciously or unconsciously. In either case, when the prime matched the subsequent color (e.g. word "red" followed by a red patch) the classic Stroop effect was obtained – subjects' ability to name the color was enhanced. However, at one point the experimenters dropped the probability of a match between the prime word and the subsequent color to 25%. This meant that most of the time the prime word "red" actually predicted the occurrence of a green patch and vice-versa. When primes were presented consciously subjects adjusted their behavior and actually became faster when primes did not match colors (effectively reversing the Stroop effect). This reversal, however, did not occur when primes were presented unconsciously. Studies by Cheesman and Merikle (1986) confirmed that only when primes were presented consciously could subjects deploy various response strategies based on the probability of a prime matching or not matching a subsequent stimulus. Strategic behaviors that override automatic ones were not possible when primes were present unconsciously. (see also Smith & Merikle, 1999 discussed in Merikle, Smilek, & Eastwood, 2001 p.127-128).

The ability to inhibit an automatic response and substitute it with a strategically more adaptive one has an important evolutionary implication. Recent studies have shown how difficult it is for apes and monkeys to inhibit automatic responses and substitute them with novel ones (even in situations where information is presented consciously). Boysen and Berntson (1995) used a reverse-contingency paradigm where chimpanzees were allowed to chose between two food rewards of different quantities. Picking the smaller quantity meant that the ape received the larger and vice-versa. Even symbol and language trained apes failed to pick the smaller quantity. Under some circumstances apes and some monkeys can pass the reverse-contingency test and children over 4 years also reliably succeed (Boysen, Mukobi, & Berntson, 1999; Kalik, Hauser, & Zimlicki, 2002; Silberberg & Fujita, 1996). Other studies involving reaching behavior, however, continue to show how difficult it is for non-human primates to inhibit automatic responses (Diamond, 1988; Santos, Ericson, & Hauser, 1999). This suggests that a potentially important conscious processing ability may have evolved along the hominin branch after it split from the that which produced our closest primate relative, chimpanzees.

D. Intentional Behaviors

The neuropsychological studies reviewed earlier had hinted at the idea that unconscious mind was incapable of directed intentional behaviors. Cognitive studies have provided further support for and shed new light on this potentially critical limitation. A potential reason why unconscious inputs may be incapable of mediating intentional acts is that they lack the necessary constraints for selecting among a range of potential responses. A classic experiment in conscious vs. unconscious priming by Marcel (1980) demonstrates what this means. In this experiment words with multiple possible meanings were used as primes in situations where they were either masked or unmasked. The context in which a prime word was presented determined which meaning was intended. For example the prime word "palm" might be presented along with "hand" in which case it would be expected to facilitate the processing of "wrist," but not "tree." However, this effect was found only when the prime was unmasked, and therefore available to consciousness. When the prime word was masked, both contextually relevant meanings (e.g. "wrist") and irrelevant meanings (e.g. "tree") were primed. Marcel (1980) concluded that one of the important functions of consciousness is selectivity. Unconsciously processed words activate all possible meanings, but consciously processed words are constrained in meaning by context. Consciousness then, is necessary in order to understand what a word is about, given its context. We cannot select an effective response to the word until its meaning is appropriately constrained. Intentional responses to objects and events may be similarly designed such that these acts are withheld until we understand what the object is about and how to best react to it – something that apparently requires conscious awareness.

IV. Expertise and Consciousness

The myriad approaches to studying consciousness have pushed forward our understanding of this important issue in a variety of ways. Steadily the biological and biochemical basis of consciousness is being uncovered. Advances in understanding the evolutionary and phylogenetic origins of consciousness as well as its potential adaptive functions are also being made. Finally, both the neuropsychological and the cognitive approaches have made great progress in delimitating the borders between conscious and unconscious processing. These approaches have converged on a set of characteristics that appear to differentiate conscious from unconscious processing: durable, explicit information representation, novel combinations of operations, and intentional behaviors. These characteristics are present when conscious processes are engaged, but absent for unconscious processes. Importantly, these characteristics also play a pivotal role in the acquisition of expertise in humans. This leads to a fairly straightforward proposition: that expertise requires consciousness. The next section will further explore this connection and its implications.

V. Acquiring Expertise

In any given domain of human activity, be it in sports, medicine, computer programming, music, etc., a very few individuals distinguish themselves as extraordinary performers. Their proficiency wins them the acclaim and admiration of others as well as the research attention of those interested in understanding expertise. Over the decades one firmly established conclusion about the acquisition of expertise is that it requires something called "deliberate practice" (Abernethy, 1987; Ericsson, 2002; Ericsson & Lehmann, 1996). Deliberate practice, as shall be seen, requires consciousness.

A. Deliberate Practice

Deliberate practice is a unique form of activity, distinguishable from both work and play, where goal-directed, concentrated effort is expended in order to hone and improve specific mental and physical skills. An example will help to elucidate its important characteristics: In their analysis of chess expertise, Charness, Krampe, and Mayr (1996) found that becoming a chess grand master involved more than just frequent chess-playing. In their formative years, future chess grand masters improved their skills by spending countless hours studying the games of past grand masters. While studying a game, they would predict the grand master's moves in various situations. When their predictions differed from that of the master, they would go back and re-analyzed the chessboard in order to uncover what the master had seen that had eluded them. In this way, they trained themselves to "see" and "think" as a grand master player.

This example highlights one of the central features of deliberate practice, which is *the constant evaluation of one's current skill state against that of a more skilled model*. Specific discrepancies between the model and one's current state are often identified and used as goal conditions for assessing progress. Constant self-monitoring and self-evaluation are necessary (often with the aid of a teacher or coach) in order to assess progress toward achieving goals. In the early stages of skill acquisition one typically focuses on emulating the model and on the process of properly executing the mental and physical strategies necessary for competent performance. In later stages, focus shifts from process monitoring to outcome monitoring, in other words, as mental and physical skills become more efficient and automatic, one concentrates on producing desired results (Schunk & Zimmerman, 1997; Zimmerman, 2002). Thus a tennis novice may closely watch a model's backhand movements, then concentrate on executing the movement. In time as the movement becomes more natural, the novice's concentration shifts to placing the ball in desired locations

A second important characteristic of deliberate practice is the *constant focus on the elevation, not maintenance, of skill*. Elevating skill often involves repetitious exercises, however, as Ericsson (2002, p.29) stresses, deliberate practice is the very opposite of mindless repetition. Once a skill has been acquired and an adequate level of competence achieved, there is a natural tendency for it to become automated (Anderson, 1982; 1987; Fitts & Posner, 1967). At this point, repetitious, less rigorous practice is usually enough to maintain one's skill. This is why simply engaging in an activity, even regularly and vigorously, will not necessarily lead to an individual becoming an elite performer. There are many, many people who play basketball, golf, chess, or their favorite musical instrument on a regular basis, but only a very few elite performers. When engaging in a desired activity, the average person is usually just running off already established, highly automated responses. Deliberate practice, however, requires that the individual resists total skill automation, and constantly challenges himself or herself with new goals and more effective behaviors. Expert pianists, for example, will often purposely rehearse an already learned piece at an excruciatingly slow tempo in order to force themselves to concentrate on the individual notes and the relationships among the notes.

This leads to a third, related feature of deliberate practice: *it requires that a certain level of conscious, voluntary control must be maintained* in order to move beyond one's current ability level to a higher one. Experts need to retain some degree of conscious control over processes in their domain in order to deal with unexpected circumstances or (in the case of sports) the responses of competitors. This "retention of control" has been experimentally demonstrated by Lehmann and Ericsson (1997) who had expert pianists memorize a short musical piece. Afterward, they were unexpectedly required to play the piece again at the same tempo; however, they were required to skip every other measure, or to play with only one hand, or even to transpose the piece into another key. Despite these unexpected changes the accuracy of their performance remained uniformly high. Since the changes required subjects to engage in novel motor movements, Lehmann and Ericsson argued that their pianists were not simply running off an automated motor routine but were using flexibly stored knowledge in an innovative way to meet task demands.

Along with the characteristics just discussed (performance evaluation against a more proficient model, constant elevation of skill, and retention of voluntary control), Ericsson (1996) has identified some other important characteristics of deliberate practice. (A) It involves activity which is at a difficulty level appropriate to but challenging of the individual's current skills, (b) it provides informative feedback concerning the individual's success in attaining new skill levels, (c) it provides opportunities for repetition of new skills, and (d) for the correction of errors as skills are being learned. On an intuitive level it would seem that these features necessarily entail conscious processing. As will be seen shortly there is a strong empirical basis bolstering this intuition.

Two important summary points emerge concerning deliberate practice and expertise. First, deliberate practice in some form is necessary if skill is to be acquired. What separates elite performers or true experts from average performers or novices is the effort and duration of deliberate practice. The average person usually drops deliberate practice for a less rigorous, more repetitious form of practice once an acceptable level of competence is achieved. Experts continue deliberate practice for a much longer time, possibly indefinitely, in order to advance skill to a superlative level (Ericsson, 2002). While there is currently disagreement over whether deliberate practice is *sufficient* for the development of expertise, its *necessity* is unquestioned (Ericsson & Charness, 1994; Sternberg, Grigorenko, & Ferrari, 2002).

Second, the general outline of what constitutes deliberate practice remains the same regardless of the skill to be mastered; and two features inherent to deliberate practice are focused attention and conscious control. Deliberate practice is by its very nature a controlled process that involves highly focussed, concentrated attention on inputs and behavioral flexibility of outputs. So demanding is this activity that only a few hours of it can be sustained in a day's time before rest is required (Ericsson, Krampe, Tesch-Romer, 1993).

B. Deliberate Practice and the Limitations of the Unconscious Mind

Certain abilities appear to fall outside the limitations of the unconscious mind. The unconscious fails to hold durable and explicit representations. It fails to combine cognitive operations in novel or innovative ways, and finally it fails to direct voluntary, intentional acts. These operations require that conscious processing be engaged. These operations intersect almost perfectly with those required for deliberate practice, which strongly suggests that one cannot engage in deliberate practice without engaging consciousness.

Durable and explicit representations. Deliberate practice requires that a model's actions be observed and held in mind as one attempts to reproduce those actions. Furthermore, the representation of the model as well as one's self-representation must be capable of providing information about discrepancies between the two so that errors can be detected and corrected. All of this strongly suggests mental representations that are relatively durable and explicit, adequate for guiding the actions of the learner. Learning a tennis backhand, for example, involves a sequence of coordinated movements extended over time and space. The learner's backhand "image" would have to be held long enough in mind, and be bound precisely enough in time and space, in order to allow the learner to evaluate his/her movements against the image, otherwise it would be useless as pedagogical tool. The lack of durability and explicitness characteristic of unconscious representations would not be capable of supporting these processes.

Novel combinations of operations. Deliberate practice involves the constant transitioning from one skill state to a higher, more proficient one. For this to occur, novel behavioral and mental skills must be acquired and integrated into one's base repertoire. The acquisition of extraordinary memory ability, for example, depends on the ability to continually organize and reorganize information into ever more sophisticated chunks. In their analysis of the expanding memory capacity of subject S.F., Ericsson, Chase, and Faloon (1980) noted how his progress depended on his ability to devise increasingly sophisticated strategies for organizing information. At first he simply associated digits into groups of four; then into supergroups of three or four, and finally into a three-level hierarchy capable of holding up to 80 digits. For S.F. to acquire greater memory skill he had to continually find new ways of organizing information. This reflects the fact that experts must continually alter and adjust their behavioral and mental strategies in order to reach more proficient levels of performance.

Intentional behaviors. As discussed earlier, conscious awareness appears to be a requirement if one is to inhibit an automated response so that a novel one can be executed. While under many circumstances it can be advantageous to automate responses, automaticity has a price that can be detrimental to the development of expertise. Sometimes signals can be misleading. Bluffs or fakes are common in many sports, such as when a tennis player "disguises" a shot or a volleyball player fakes a spike. In the medical arena, an experienced diagnostician knows that a particular symptom can be highly meaningful in conjunction with other indications, but may be irrelevant or even misleading in a different context. Thus, an expert must be ever able to inhibit initial, automatic responses to sensory data in order to retain the flexibility necessary to react effectively to changing circumstances. This is why one of the important requirements of deliberate practice is that one not allow processes to become entirely automatic. Deliberate practice is not mindless repetition. Experts always retain a certain degree of conscious, intentional control over the actions in their domain. These intentional acts though, appear to be beyond the capacity of the unconscious mind.

Thus it appears that expertise requires deliberate practice and deliberate practice requires consciousness. If this is so, then where we find evidence of expertise, we also find evidence of consciousness. This conclusion has a number of important implications.

VI. Animal Expertise

Animals display a wide variety of impressive skills. However, the preceding discussion indicates that it would only be when those skills are acquired through deliberate practice that we could consider the animal as a true "expert, " and, more importantly, that we would have definitive evidence of consciousness[1] . Whether animals engage in deliberate practice or not appears to be an open question. The term "practice" as applied to animal behavior has often encompassed a wide array of behaviors.

Goodall (1976), for example, in describing the behavior of young chimpanzees states, "Often, after watching some activity such as a male charging display or a complex tool-using performance, an infant may then try to perform the same actions. Subsequently he may *practice* the behavior time and time again" (p. 88; my italics). The description ends there so it is difficult to assess just what manner of practice this was. Ripley (1967) describes how juvenile gray langur monkeys (*Presbytis entellus thersites*) improve their jumping ability by jumping from ground to branch several times in a row or leaping over and over across a gap between two tree branches. These actions were all done in the context of play, but the question remains as to whether the animals had some "model" behavior in mind as humans do when perfecting a dive or ballet leap.

Goodall (1990) provides another interesting account of what she termed "practice" in an adolescent male chimpanzee. The chimp, Figan, had observed another chimp, Mike, incorporating empty four-gallon tin cans into his charging display. The noisy cans were hugely successful in intimidating the other males, thus permitting Mike to ascend to alpha status. "But Figan was the only one whom we saw, on two different

[1]Philosophers distinguish many different types of consciousness. Expertise may provide evidence of only a certain type of consciousness, such as access consciousness where representations are made available for various mental processes. Other types of consciousness, such as phenomenal consciousness or feeling consciousness may not be addressed by the presence or absence of expertise (see Block, 1995 or Rossano, 2003)

occasions, 'practising' with cans that had been abandoned by Mike," describes Goodall (p.44). "Characteristically – for he was a past master at keeping out of trouble – he did this only when out of sight of older males who would have been intolerant of such behavior in a mere adolescent. He would undoubtedly have become as adroit as Mike had we not removed all cans from circulation." This account suggests that Figan went off by himself with the specific intent of exploring (and perfecting?) how the cans could be used as part of one's charging display. It is also possible, however, that Figan was simply emulating behaviors he had previously observed in Mike, while being well aware of the fact that such behaviors could be dangerous under certain conditions (in the presence of older males).

Griffin (2001) uses the term "practice" to describe the behavior of African village weaver birds (*Ploceus cucullatus*) as they made their first attempts at nest building after watching older males build theirs. These initial nests were often incomplete and improperly constructed, and were therefore rejected by females. After more rounds of observing and building, eventually the bird was able to produce a competent nest. "Thus" says Griffin, "the male that builds the relatively complex structures has ordinarily had a long period of practice and has also had abundant opportunity to watch older males build more complete nests" (p.91). A similar process occurs with bowerbirds (*Ptilonorhynchus violaceus*; Diamond, 1982).

Despite the potential similarities between human and animal skill acquisition at least one researcher has argued for a critical, possibly unbridgeable difference. Donald (1999) argues that only humans can engage in deliberate practice because of what he terms the lack of "autocuing," in animals. Autocuing refers to the capacity to gain voluntary control of the contents one's own mind – to self-trigger memories (Donald, 1993). Skill development in nonhuman animals is sorely limited by the fact that the animal requires external cues in order to gain access to the stored motor responses that must be shaped and "trained-up" for greater efficacy. Donald (1999, p.143) contends:

> You cannot rehearse what you cannot recall. If an animal depends entirely upon environmental triggers to remember when and what to rehearse, skill development becomes extremely difficult, since the animal cannot self-trigger the memories supporting the skill, and effectively hangs in suspended animation until the environment provides the cues needed for retrieval of a given response-pattern. Trainers of apes have had to cope precisely with this limitation; for instance, it often takes thousands of trials to establish a reliable signing response in a chimpanzee (Greenfield & Savage-Rumbaugh, 1990).

An essential element of deliberate practice (and thus of skill acquisition) is the ability to focus awareness inward, away from the environment and onto one's own actions (Donald, 1999). It is not uncommon for a human to spend countless hours bouncing or shooting a ball, skipping rope, or hitting a tennis ball against a wall, all the while adjusting motor actions and experimenting with different combinations of movements to evaluate their efficacy. Though animals may repeat actions, they simply do not spontaneously rehearse and refine their movement patterns. As Donald succinctly puts it: "Baboons throw projectiles in a fight, but they don't systematically practice and improve their throwing skill (Donald, 1993, p.152).

Though tantalizing, the examples reviewed earlier have provided no definitive evidence that animals can or do engage in deliberate practice. If Donald is right, then any systematic studies addressing this issue should ultimately come up empty. However, the similarities documented between human and animal practice are intriguing and certainly do not preclude the possibility that animals may practice as human do (at least to some extent). If so, this would have important implications for their level of consciousness.

VII. Expertise in Hominin Evolution

A second important implication of a skills approach to consciousness is that evidence of skill can also be observed in the fossil record of human evolution. The evidence comes in the form of fossil artifacts, mostly tools, left behind by our hominin ancestors. What is interesting about these artifacts is that they do suggest evidence of skill acquisition using deliberate practice.

The earliest stone tools, called the Oldowan industry, appear about 2.5 million years ago (mya) and consist of small flakes broken from a core stone (Semaw, et al., 1997; note: both the flakes and cores may have been used as tools). Though there is no evidence that apes can create Oldowan-type tools in the wild, captive apes have created tools approaching those of the Oldowan industry (Toth, Schick, Savage-Rumbaugh, Sevcik, & Rumbaugh, 1993; Wright, 1972). Most researchers agree that the early hominins who created Oldowan tools may have possessed a degree of motor control and timing that exceeded that of apes, however, this did not represent a major intellectual advance (Toth 1985; Wynn, 1996; 2002). The same, however, cannot be said for the next major category of tools to emerge, the Acheulean industry.

The earliest Acheulean tools are about 1.5 million years old and are distinguishable from the Oldowan by their larger size and sophistication. An exemplar of the Acheulean industry is the hand axe, which was created by trimming flakes off around the sides of a core, producing a teardrop shaped, roughly symmetrical tool. Unlike Oldowan tools, hand axe construction (especially later hand axes which emerged around .6 mya) would have required considerable investment in time and energy, with the toolmaker going through a series of flaking iterations before completing the final product. Wynn (1981; 2002) has argued that the late Acheulean hand axe maker, unlike his Oldowan counterpart, could not simply have focused on the shape of the tool's edge, but instead had to understand how flakes trimmed from one part of the stone affected the tool's overall shape. He contends that to create such a tool, it would be necessary to hold in mind multiple perspectives of the tool as it was being created so that the toolmaker could appreciate how a flake removed from one side would affect the total shape of the tool. Thus, the late Acheulean hand axe may provide us with the first evidence of hominin motor behaviors guided by a durable and explicit mental image – the first step toward skill acquisition via deliberate practice.

At a number of sites where hand axes have been found, hundreds have been unearthed showing no evidence of use (Klein & Edgar, 2002 p.107; Kohn & Mithen, 1999). Kohn and Mithen (1999) contend that hand axes may have served an important function in mate selection. A male who could produce a high quality hand axe may have been signaling his industriousness, competence, and overall mate quality (good genes) to local females. Do the hundreds of unused hand axes represent evidence of hominins practicing axe-making skill? If so we might expect to find hand axes of varying quality. Toth (1985) demonstrated that the final form of an Oldowan tool depended more on the raw materials the toolmaker started with than the intentions of the toolmaker. If hominins were practicing hand axe making we might expect a similar analysis to reach the opposite conclusion for Acheulean hand axes. Furthermore, if hand axe-making skill was essential in mate selection, then we could expect the ability to acquire hand axe-making skill (i.e. the ability to practice) to be under selection pressure and therefore evolving over time.

VIII. Expertise, Consciousness, and AI

An ongoing controversy among researchers and observers of AI centers on the question of machine consciousness. Will intelligent machines become conscious? This argument has been played out in may forms on a variety of forums (e.g. Churchland & Churchland, 1989; Dennett, 1987; Searle, 1980). Approaching consciousness from the point of view of skill acquisition, however, provides something of a unique perspective on the subject.

Most AI researchers fall into the functionalist camp. That is, they believe that mental qualities such as intelligence, creativity, and even consciousness itself are a matter of the functional organization of a complex system. A crucial aspect of functionalism is that it sees nothing inherently "special" about biologically-based systems. A system is system. It's the organization of the system that matters, not whether that system is realized in biological stuff as opposed to silicon and plastic (Haugeland, 1985). Thus, intelligent machines can (in theory, according to functionalism) possess intelligence, creativity, and consciousness as soon as the right functional organization is achieved. It's possible that functionalism is all wrong, and that there *is* something unique about neurons making them the sole proprietors of consciousness. The evidence to date though favors the functionalists' camp. Machines are already doing many intelligent and creative activities, despite their lack of biology. Can consciousness be far behind?

The expertise approach to consciousness, however, suggests that there may be an aspect of consciousness, or some type of consciousness that is required if one is to deliberately practice in order to elevate skill. Therefore, assessing the consciousness of a machine should not just be a matter of how smart it is, or how complex its functional organization is, but to what extend the machine is capable of, and (dare I say it) motivated to elevate it own skill level. Furthermore, the process by which it does that would also be critical: does it do something akin to deliberate practice? Presently, it would seem that the robotic "embodied" approach to AI, exemplified by Rodney Brooks at MIT would be best poised to meet this challenge.

Brooks's approach is based on the notion that real intelligence emerges from bodily action rather than from mental representations. One of his lab's first creations, Herbert, was a robot designed to simply roam about picking up empty coke cans (Connell, 1990). Despite his impressive custodial abilities, few would attribute much conscious awareness to Herbert. However, a later project, Cog (possibly the ultimate project) is more promising. Cog is a humanoid robot complete with eyes, head, arms, etc., out of which, some have argued, consciousness itself might emerge. A key innovation of Brooks's approach to AI is something called *subsumption* architecture, where patterns in the environment are designed to automatically cue a certain programmed action. Herbert, for instance, generally just rolls along the halls using its sensing devices to avoid obstacles. However, when it detects a relatively large, horizontal flat surface (a tabletop), a new program assumes control which causes it to scan for small cylindrical objects (coke cans). Having spotted one, another program takes over which causes it to try to seize the object. The end result is intelligent looking behavior emerging from a series of simple-minded programs designed merely to react to environmental patterns.

A more conscious Herbert though would have to do more than just react to cues. It would need to self-initiate practice behaviors aimed at elevating can-collecting skill. Deliberate practice requires a number of sophisticated mental abilities: durable and explicit representations, the ability to assess one's actions against a more proficient model, resistance against automaticity and intentional control of behaviors – the subsumption approach may not be equal to these requirements. To achieve this the Brooksian approach might need to be united with work going on at the Imperial College of London, under the direction of Igor Aleksander. Alexander has been developing "virtual" robots that navigate about in cyberspace worlds. These creations have "minds" modeled on the neuronal connections of the human brain. While Brooks's robots are largely empty-headed, Alexander's virtual robots are capable of "imagination," and "contemplation" (Aleksander, 2001). Alexander's mind with Brooks's body may produce a true machine expert (at least someday).

Curiously though, the most probable arena in the near future for AI expertise is not with robots but *within* humans. The architecture capable of developing expertise is already present in humans. In the near term, AI may serve to enhance that already existing capability. Nervous system implants to aid the visually and auditorially impaired have been around for more than a decade. Increasingly these devices have become more directly wired to the brain itself. For example, some cochlear implants now bypass the auditory nerve and plug directly into the brain stem (LeVay, 2000). Berkeley engineer Boris Rubinsky (Rubinsky & Huang, 2001) has successfully constructed a "bionic" silicon/neuron chip that promises to elevate the effectiveness of future implants. Eventually implants which supplement or augment sensory functions may be adapted for cognitive functions. Our reasoning, imagination, and memories may be enhanced by neural implants connected to external computers (Warwick, 2000). NASA is also looking into using brain signals as a means of controlling external devices via implanted computer chips (Brown, 2001). Imagine being able to start your car, fire up the air-conditioning, and open the sun roof all while paying the dinner bill, just by thinking the right thoughts. Though certainly speculative, Kurzweil (1999) contends that in future decades, market forces will drive people toward increasingly greater degrees of "brain-enhancement" through implant technologies as those with silicon-enhanced mental capacities become more valued as employees and command larger and larger salaries. Certainly these enhancements will permit humans to develop even greater music, memory, chess-playing, and athletic skills. Enhanced memory and attentional powers may allow humans to engage in ever more rigorous bouts of deliberate practice without suffering the performance deteriorating effects of mental fatigue. Ever more elevated skill could be one result. Whether in the process ever "higher" realms of consciousness are achieved as well remains to be seen, but it is a distinct possibility.

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