produced by the rotation of a magnet. This wave is filled with an electron-positron pair plasma, the "pulsar wind." Together, the emission of this very strong wave in combination with the acceleration of the wind particles to highly relativistic velocities occurs at the expense of the neutron star's rotational energy. This allows one to calculate the magnetic field strength from the pulse period in combination with the measured rate of increase of the pulse period of the pulsar (*8*, *9*).

With the discovery of the second pulsar in the PSR J0737-3039 system, the orbits of both stars should now be measurable with high accuracy. This in turn will allow, as Lyne *et al*. also point out (*1*), more precise tests of Einstein's general theory than were possible in the Hulse-Taylor system and other double neutron star systems. It helps that this system is much closer to Earth (only 1500 light years), which reduces the possible errors in the measured rate of orbital shrinking (caused by emission of gravitational waves) introduced by unknown galactic rotation effects. Furthermore, because the orbital plane happens to nearly coincide with our line of sight (see the figure), the radio waves of pulsar A occasionally shine through the much larger plasma-filled magnetosphere of pulsar B. This produces an "eclipse" of A's radio emission for a few tens of seconds, and it provides a unique way to probe the still largely unknown properties of pulsar magnetospheres. One complication here may be the fact that pulsar A is 3600 times as energetic as pulsar B; hence, its energetic pulsar wind may be blowing away part of the plasma-filled magnetosphere of pulsar B, causing its radio emission to be weakened. A clear sign of this energetic interaction is that during most of its orbital motion the B pulsar is hardly visible, becoming very bright only during two time intervals of about 10 min each when it is near the Earth-facing side in its orbit.

How did such a pulsar system evolve? Like other pulsars in binary systems, PSR J0737-3039A has an abnormally rapid spin and an abnormally weak magnetic field, weaker than that of "normal" single pulsars by a factor of about 200 (see above). According to the current models for the formation of these systems (*3*–*5*, *10*), the faster pulsar is the first-born neutron star, which later in life—when its companion was still an ordinary star—had matter dumped onto it by its swelling companion giant star. This accretion of matter weakened its magnetic field (*11*) and accelerated its spin (*4*). Later, the neutron star entered the envelope of the giant, and the ensuing large friction caused the orbit to become very narrow. After the giant's hydrogen envelope was expelled, a very close binary in a circular orbit was formed, consisting of the neutron star and the heavier-element core of the giant star. When this core collapsed it became the second neutron star in the system, and its remaining mass was ejected in the accompanying supernova event. Because the second-born neutron star in the system did not undergo any further evolution with mass transfer, it would be expected to be an entirely "normal" strong-field pulsar with a "normal" pulse period on the order of about 1 s, just as observed for most of the single radio pulsars in the galaxy. PSR J0737-3039B nicely fits these expectations, providing confirmation of this standard evolutionary model. The "old" neutron star in the system, which underwent a history of magnetic field decay and "spin-up" by accretion in a binary, restarted its life as a rapid pulsar and is therefore called a "recycled" pulsar (*12*). All pulsars observed in the double neutron star systems, with the exception of PSR J0737-3039B, appear to be such recycled pulsars. Their weak magnetic fields make them spin down much slower—and therefore "live" much longer as pulsars—than their newer strong-field companions, which explains why these are so rarely observed (*5*).

Much more remains to be learned about this surprising pair of stars. This binary pulsar is a rich gift of nature, holding much promise for workers in fields as diverse as general relativity and gravitational waves, pulsar emission theories, and the theory of binary stellar evolution.

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NEUROSCIENCE

The Where and When of Intention

David M. Eagleman

Intention is judge of our actions.
–Michel de Montaigne

At a moment of your own choosing, snap your fingers. Now ask yourself: "When did I first feel the urge—or intention—to make that snap? Was it a full second before my fingers moved?" Although that duration might seem counterintuitive, human brain studies using electroencephalography (EEG) have long suggested that some part of your brain was already moving toward that decision well before you were aware of it. Spontaneous, voluntary movements are preceded by a progressive rise in motor area activity known as the readiness potential (RP) (*1*–*4*) more than a second before you make your move (see the figure). Although we are subjectively unaware of this buildup of activity, does this mean that we are not aware of anything before our fingers suddenly jerk into motion? Or do we have some sense that we are about to act, some notion of intention just before our bodies begin to move?

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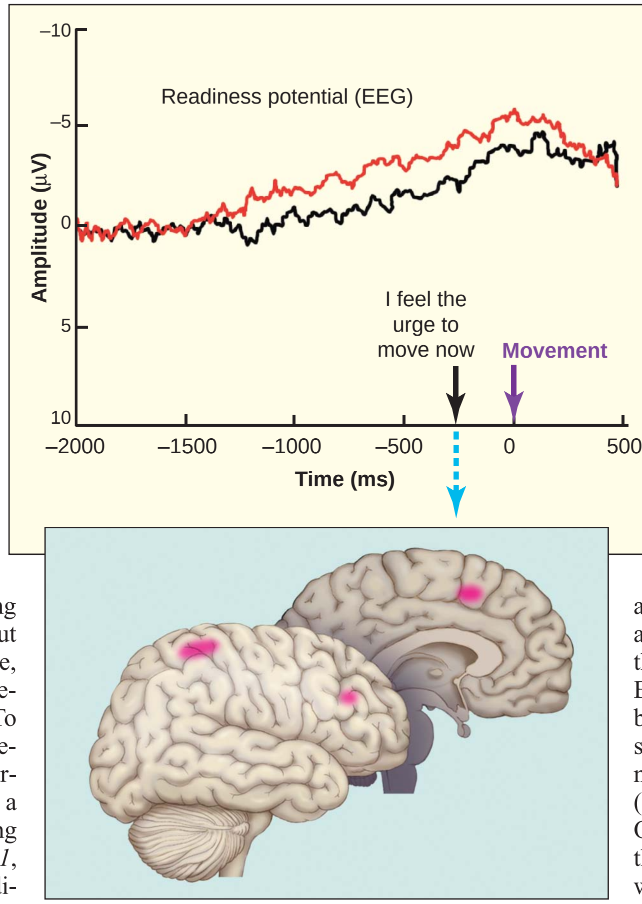
To explore this issue, one set of early experiments asked participants to make a spontaneous finger movement—at a time of their choice—while watching a spot moving around a clock face. Subjects were asked to report the time at which they first felt the urge to move. Their typical answer: ~200 to 250 ms before the time of their actual movement (*5*). This experimental design has had a long and often controversial history—after all, how do we know subjects aren't simply attending to the beginning and end of the same movement, or deciding that the time of their intention logically must precede the time of their action? Given these uncertainties, it has remained unclear whether the urge to act, and the action itself, represent actual differences in brain states. Onto this stage enter Lau *et al*. (*6*), on page 1208 of this issue, with a functional magnetic resonance imaging (fMRI) experiment that directly addresses this question.

In Lau *et al*.'s study, participants made a spontaneous finger movement and reported the time at which they first felt aware of the intention to move (I-condition) or they actually moved (M-condition). In line with previous findings, subjects reported the urge to move an average of ~200 ms before the time of the movement. In this study, however, the goal was to investigate *where*, not simply when, brain activity occurred during the I- and M-conditions. The authors used neuroimaging to achieve this goal, assuming that the two conditions represented *attending* to either the intention or the movement.

Modulating neural activity through attention is a powerful tool for neuroscientists. Many studies have shown that paying attention to a sensory stimulus increases the BOLD (blood oxygenation level–dependent) signal in the corresponding sensory part of the brain (*7*). For example, even if a retinal stimulus remains the same, attending to it will increase blood flow in the visual cortex. The attentional spotlight is a valuable tool not only for studying representations of external stimuli, but also for looking inward—for example, by attending to different internal representations in working memory (*8*). To that end, recent fMRI studies on movement have compared brain states during differing degrees of attention to a self-made motor act (*9*, *10*) or during spontaneous versus cued action (*11*, *12*). Taking the next step in this tradition, Lau *et al*. bypassed several potentially confounding factors by using a single action in both conditions: a single, voluntary lift of the finger at a time of the subject's choosing. Subjects attended to different aspects of the same act—the urge to begin, or the action itself.



Time course of a voluntary act. Subjects asked to report when they first felt the "urge" or intention to move typically report the time as ~200 ms before the actual movement. (**Top**) EEG studies have shown that a progressive rise in neural activity (the readiness potential) precedes the subjective intention by more than a second, and is larger when subjects judge the time of their urge to move (red trace), rather than the movement itself (black trace) (*16*). (**Bottom**) Bringing this tradition to neuroimaging, Lau *et al.* (*6*) found increased blood flow in the dorsal prefrontal cortex, the intraparietal sulcus, and the pre-supplementary motor area when subjects attended to the time of their urge to move, rather than the movement itself. [Graph adapted from (*16*)]

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The blood flow data showed greater activity in three brain areas during the I-condition. One of these, the pre-supplementary motor area (pre-SMA), is known to become active when subjects voluntarily generate movement (*13*), even during simulation of movement without actual execution (*14*). Furthermore, stimulation of the neighboring SMA in humans reportedly generates an "urge" or "anticipation" of movement (*15*). Lau *et al*. report that the pre-SMA BOLD signal peaks at ~3 s after the keypress, leading them to argue that neural firing preceded the motor act by some 2 to 3 s (because the hemodynamic response takes 5 to 6 s to peak). Does the pre-SMA activity reflect the readiness potential? This seems generally consistent with EEG findings suggesting that attending to intention increases the readiness potential (*16*). However, note that Lau *et al.*'s pre-SMA activity is midline, whereas the readiness potential in (*16*) is lateralized.

Next, Lau *et al.* found increased activity in the dorsal prefrontal cortex (DPFC), a key structure implicated in generating and developing plans for voluntary action (*17*, *18*). Finally, they observed that the I-condition engendered higher activation in the intraparietal sulcus (IPS), which is among the areas most consistently activated by movement preparation (*19*) as well as attention to stimulus attributes (*7*). Because patients with parietal lesions have no deficit in making a willed action (*16*, *20*), this area may be involved in self-monitoring actions rather than forming them (*21*).

When viewed in combination with other studies on attention to action, one hypothesis could be that the DPFC is involved in generating the intention to move, whereas areas in the parietal lobe, and perhaps also the pre-SMA, begin to simulate or anticipate future movement. Although Lau and co-workers suggest that the pre-SMA activity "reflects the representation of intention," the full story should include at least the parietal lobe as well. Recently, Sirigu *et al*. found that patients with parietal lesions showed no distinction between their time estimates in the I- and M-conditions, whereas normal subjects (and cerebellum-lesioned controls) consistently answered that their intention preceded their action by ~250 ms (*16*). This suggests that parietal patients have an undamaged ability to time their movement, but damaged access to an internal model that simulates future activity. One must draw parallels between studies cautiously, however, as the parietal activation reported by Lau *et al*. was anatomically much more dorsal than the lesions in the Sirigu *et al*. study. Because pre-SMA and parietal areas both seem to be important for representing intention, future research will need to clarify the relationship (causal? parallel?) between them. One way forward would be to revisit the I- and M-conditions in patients with pre-SMA lesions. Future investigations might go further by combining into one study voluntary and unpredictably forced actions, or by imaging patients with schizophrenia, which is characterized by problems with overattribution (that is, patients assume intention for actions that are not their own) (*22*).

The new study suggests a deeper question: to what, exactly, are the subjects attending in the I-condition? As mentioned, one theory postulates that the I-condition forces subjects to access an internal model of the desired movement (*16*). The idea is that during a self-generated action, copies of the commands sent to the muscles are fed into a predictive (or forward) internal model (*23*), whose job it is to simulate what is expected next. But some questions arise. First, if the readiness potential represents an internal model that begins "revving up" at least a second before the motor action, why is this model only accessible to awareness ~200 ms before the action? Does the model need to reach a certain threshold of activity to be accessible, and, if so, what is special about this threshold, neurally speaking? Second, do we consciously experience the urge to move if we are not asked the question? That is, does attending to the subjective intention generate it? Third, in the Sirigu *et al*. study, patients with lesions of the cerebellum (thought to function as an internal model) (*24*) performed like normal subjects under both the I- and M-conditions (*16*), suggesting that certain internal models may not be accessible to awareness. If there exist several internal models in the brain, what is the neural difference that makes some accessible to awareness and others not?

The finding that there are distinguishable brain states between the I- and M-conditions reinvigorates discussion about intentionality, but the final interpretation of these results lies in a thicket of further questions. Most broadly, it remains to be understood how the neural events are related to the phenomenal experience that "I" was the author of an action. The internal model hypothesis suggests this relationship may be due to matching the consequences of a movement against its internally predicted effects. But predictability cannot be the complete story, because people judge the time of their own actions and the actions of others equally well—but strangely, the "actions" of a nonbiological machine are judged quite differently, even when they are visually identical and equally predictable (*25*). This suggests that intentionality might even be judged retrospectively, an illusion arising from *watching yourself* (or another agent) make actions (*26*). This is consistent with the idea that you represent the actions of others by analogy with your own, inferring their intentions by watching their actions. Thus, in contrast to Montaigne's belief, it may be that action is the judge of intention.

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CHEMISTRY

Ions at the Air/Water Interface

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In the conventional picture of simple salt solutions, atomic ions shun the air/water interface and are more likely to be found in the bulk of the liquid. Hence, simple inorganic salts such as sodium halides should be repelled from the water surface. However, recent computational and experimental studies show that atomic ions such as halides can be present in the surface region, in some cases even at enhanced concentrations. Halide ions at the surfaces of atmospheric aerosol particles may play an important role in controlling oxidant levels in the marine boundary layer of the atmosphere.

The conventional picture of the interface of simple aqueous salt solutions is based on thermodynamic analysis of the variation of surface tension with composition of the liquid. Hu *et al.* were among the first to challenge this view (*1*). They argued that chloride and bromide ions must be present at the air/water interface to explain measurements of the uptake of Cl_2 and Br_2 gases by aqueous salt solutions. More recent studies of reactions of oxidants with concentrated aqueous NaCl solutions support this view (*2*, *3*). In these studies, surface reactions of ionic species had to be included to bring modeling and experimental results into agreement.

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Molecular simulations also support this picture. In simulations of a 6 M aqueous NaCl solution, 10 to 15% of the accessible surface area was occupied by chloride ions, whereas sodium was effectively excluded from the topmost liquid layer (*2*). In their simulations of sodium halide solutions, Jungwirth and Tobias (*4*, *5*) observed an increase in surface concentration with increasing size and polarizability of the halide ion. Thus, fluoride is depleted at the interface, whereas bromide and iodide concentrations are enhanced (see the figure). Calculations of the free energy of adsorption also predict enhanced iodide concentrations at the air/water interface (*5*, *6*).

This picture is consistent with observations of hydrogen bonding in aqueous ionic clusters. Cations form hydrated clusters in which the ion binds to water oxygen atoms. The water molecules are distributed fairly symmetrically around the ion. In contrast, anions bind to water hydrogen atoms. The water molecules are arranged asymmetrically around the ion, enabling hydrogen bonding between them. This behavior is seen for the larger anions Cl^-, Br^-, and I^- (*7*). Hence, sodium cations should prefer the homogeneous environment in the bulk liquid, whereas large anions should form asymmetric structures near the interface—as predicted by the simulations.

Molecular simulations thus present a picture of ions at the interface that is consistent with cluster studies. However, the simulations are sensitive to the description of the molecular interactions they employ (*6*). Therefore, direct experimental observations of molecular structure and energetics of ions in the interfacial region are needed to corroborate the simulations. Such experiments are difficult to perform because the liquid interface is disordered, dynamic, and small (typically only a few molecules wide) relative to the bulk.

Recent results from two laboratories shed light on this important issue (*8*–*10*). The authors have studied sodium and potassium halide solutions with nonlinear spectroscopic techniques, such as second harmonic generation (SHG) and vibrational sum-frequency spectroscopy (VSFS) (*11*). These techniques sample the surface region of the liquid where isotropic symmetry is broken. VSFS is a direct probe of the hydrogen-bonding environment in the surface region, but only an indirect probe of the halide ions. SHG provides an estimate of the free energy of adsorption.

Raymond *et al*. (*12*) have used isotopic mixtures of water in VSFS studies to separate contributions from various vibrational modes. Similar studies on sodium halide solutions (*8*) indicate that anions are present in the surface region but not at enhanced concentrations. These halide ions exhibit the same water structure-making and structure-breaking behavior in the surface region as in the bulk. However, they do not alter the hydrogen bonding of the water in the topmost surface layer, nor do they create the type of water structure indicative of a double layer formed by anion-cation separation.

Allen and co-workers (*9*) compare Raman and infrared spectra for bulk solu-