CHAPTER 17

# FINDING LIKENESS

## Neural Plasticity and Ritual Experience

Robert Turner

> At the still point of the turning world. Neither flesh nor fleshless;
> Neither from nor towards; at the still point, there the dance is,
> But neither arrest nor movement.
>
> —T.S. Eliot, *Burnt Norton*

### Introduction

Before elaborating my hypothesis regarding how our brains may be transformed in rites of passage, I should provide some historical and personal background for my interest in this topic. I am trained as a physicist and applied mathematician, and I pursued a career of research in solid and liquid state physics until 1975, culminating in postdoctoral research at the Cavendish Laboratory in Cambridge. At that point, needing a broader perspective on academic enquiry in order to clarify my life goals, I made an abrupt switch, enrolling in a two-year postgraduate diploma course in social anthropology offered by the Anthropology Department at University College London, then chaired by Mary Douglas. By that time (as now) under my father Victor Turner's influence, I considered social anthropology to be the most empirical of the social sciences, begging the fewest questions regarding human capacities for describing each other's actions and understandings.

Having some success in this course of study, I decided to undertake ethnographic fieldwork, on the theme of the conflict between legitimations based on traditional worldviews with competing legitimations based on conceptions of science. This research question was underpinned by Habermas's sociology of knowledge. I chose to make this study in a small Scottish seaside town with a very long history of commercial share fishing and very high church attendance, which was then dealing with the consequences of the recent installation of a huge coal-fired power station nearby. My project was funded for two years by the Social Science Research Council. The work was absorbing and rewarding. However, I found that I was continually struggling with the first rule of ethnography, which is to take nothing for granted. Although the culture (and indeed language) of the fishing families that I came to know was strikingly different from that of my own upbringing and experience, it was still far more familiar than that of a Dani tribesman (for instance), which made ethnographic objectivity a significant challenge. This experience precipitated the further reflection that without a certain bedrock of assumptions regarding the goals, intentions and ethical values of the people one met, accurate ethnography in any (perhaps more exotic) culture might be impossible. But who would be brave enough to itemize these assumptions? And in what theoretical language should these assumptions be framed?

It was at this time that I first heard about the novel technique of magnetic resonance imaging (MRI), which was starting to provide completely non-invasive images of living human brains. I also encountered the pioneering work of Nils Lassen and David Ingvar, who used injected radioactive tracers and an array of particle detectors to crudely map localized changes in blood flow in the brains of human volunteers while they performed specific tasks. It occurred to me that if MRI (an essentially non-invasive technique) could be adapted likewise to detect cerebral blood flow changes, it might be possible to compare human brain responses across cultures, and by this means to effect a kind of translation of human action, matching the meaning of actions by matching their concomitant patterns of brain activity. From such observations, I felt, some progress might be made towards creating a more objective ontology of human motives and actions, which could constitute a robust framework for cross-cultural comparisons.

Soon after this insight, I met and became friends with the great developmental psychologist Colwyn Trevarthen, then a professor at the University of Edinburgh. Having previously worked for years with Sperry in the field of human neuroscience, Trevarthen was happy to encourage me to pursue these ideas. When I discovered in 1983 that a position was advertised in the Physics Department of the University of Nottingham, with the opportunity of developing MRI with Peter Mansfield (later to be awarded the Nobel Prize), I applied for and, to my delight, got the job.

Meanwhile, in Charlottesville, Virginia, the anthropologist Victor Witter Turner was developing his own perspective on the human brain as the organ of culture. In his late paper, 'Body, Brain and Culture', published in 1985 in his post-mortem collection 'On the Edge of the Bush', he took inspiration from Laughlin and D'Aquili (Laughlin and D'Aquili 1974) and other early writers attempting to connect brain science with anthropology. In his first paragraph he wrote:

> The present essay is for me one of the most difficult I have ever attempted. This is because I am having to submit to question some of the axioms [that] anthropologists of my generation – and several subsequent generations – were taught to hallow. These axioms express the belief that all human behaviour is the result of social conditioning. Clearly a very great deal of it is, but gradually it has been borne home to me that there are inherent resistances to conditioning.

The paper went on to consider the possible relationship between the hemispheric specializations of the human brain and types of thought and action, whether ritual or instrumental. He supported these ideas by extensive neuroanatomical details. It is clear that a convergence had come about between my own concerns regarding the translation of culture, and my father's desire to ground some aspects of culture in brain activity.

This convergence, which included a growing academic link between my parents and Colwyn Trevarthen, culminated in discussions I had with Vic the night before he died, in December 1983 in his home in Charlottesville, Virginia. Still recovering from a serious heart attack that he had suffered eight weeks previously, he described his fieldwork during that spring in Israel, where he had attended the Samaritan Passover ceremony on Mount Gerizim, and told me about his ideas regarding brain laterality and social action. I described my acceptance to a faculty position enabling me to carry out MRI research at the University of Nottingham, and my ambition to make thought visible in the form of functional imaging of the human brain. The following morning, he had his final heart attack (in circumstances that I had dreamt about in considerable detail a few weeks earlier) and died, despite the best efforts of my mother Edie and myself to resuscitate him.

Two weeks later I returned to Scotland, moved house, and started my job at Nottingham University, understandably highly motivated to develop MRI to the point that it could be useful in cross-cultural comparison studies. The first goal was to determine whether MRI could capture the traces of thought, as manifested in cerebral blood flow changes. By 1991 my research had formed a vital step towards the discovery that the MRI contrast provided by the presence of deoxygenated blood could be used to track changes in brain activity, with a spatial resolution of about a millimetre and a temporal resolution of a few seconds, limited only by the slow response of blood flow to changes in neural electrical activity. By that time, working as a visiting scientist at the USA's National Institutes of Health, I performed a series of experiments using cats which led directly to the first demonstration of functional MRI (fMRI) in humans, performed by Ken Kwong and a team of physicists and radiologists at Harvard Medical School, with whom I was collaborating.

The next important challenge was to define precisely where such activity was taking place in the brain, defined in relation to our shared neuroanatomy, so that localized changes in brain activity could be compared across individual people, perhaps with different cultural or ethnic origins. By 1993 I had become aware that MRI was capable of distinguishing different areas of cerebral cortex by their internal structure – an insight shared by very few radiologists using MRI at that time, who had mostly come to regard MRI purely as a diagnostic modality, with little interest in its potential as a unique tool for neurological discovery science. The source of the visible distinction between cortical areas was their differing distributions of myelin, the lipid membrane that wraps and insulates neural pathways (axons), about which we shall hear more later.

I was soon appointed to a personal chair at the Institute of Neurology, in London, as leader in the technical development of functional MRI for the radically new approach to brain function research known as 'imaging neuroscience'. Besides directing my team of physicists, who supported five other groups – neurologists, psychologists, psychiatrists, neurolinguists and computational neuroscientists – in our new laboratory, I proceeded to educate myself about myelin and its enormous importance in brain MRI contrast, and to seek research funding for comprehensive mapping using myelin contrast of the cortical territories of living brain.

It was immediately clear that to discriminate these areas using their differential patterns of myelin – their myeloarchitecture – would require excellent spatial resolution, because the human cortex is never more than about 4 millimetres thick. To obtain a resolution of the needed half a millimetre in an acceptable scanning time would need a more powerful scanner than those available at that time, so I focused my efforts on encouraging MRI manufacturers to be ambitious in developing scanners operating at much higher magnetic field strengths.

In 2005, at a Society for Neuroscience meeting in Washington DC, I encountered by chance Douglas Fields, head of a myelin research laboratory at the National Institutes of Health in Bethesda, Maryland. He told me that his lab was working on the hypothesis that the wrapping of axons by myelin is driven by experience, such that the passage of neural impulses down an unmyelinated axon would stimulate the relevant nearby cells to perform their wrapping task. It is now well recognized that this process is fundamental to the maturation of neurons, an important component of the hypothesis of this chapter.

Using a 4.7 tesla prototype scanner funded by the Wellcome Trust, I was able to make some progress in the visualization of cortical features, specifically the identification of the human primary visual cortex at the back of the brain, but it was not until I was appointed in 2006 as director at the Max Planck Institute for Human Cognitive and Brain Sciences, in Leipzig, Germany, that I was able to bring this endeavour much further, having the immense benefit of the exclusive use of a well-engineered 7 tesla scanner, the major experimental resource of the my research department of about twenty-five staff.

I also set up a small histology laboratory there, under the care of an experienced neuroanatomist whom I had recruited, which enabled direct comparison between features of the MR image and the observable details of stained sections of cadaver brain. At 7 tesla we were quickly able to pick out striking details of myelin in the cerebral cortex of our volunteer subjects, as well as imaging their functional brain activity much more precisely. By 2011 we were able to publish a paper calling for more systematic myeloarchitectural studies of living human brain, a call soon echoed by David van Essen at Washington University in St. Louis, one of the world's leading neuroanatomists.

It was becoming increasingly apparent that human cognitive development occurs in parallel with the progressive myelination of crucially important neuronal circuits. Here was a mechanism that could account for the relative permanence of some acquired human skills and habits. But what remained lacking was an account of how transformations could take place in our behavioural repertoires, given the stability conferred by myelination. The work of my father, Vic, in appreciating the enormous power of ritual in effecting such gestalt changes in people during rites of passage, began to feel more and more relevant to this question.

## Neuroanthropology

The relatively novel disciplines of cultural neuroscience and neuroanthropology (Domínguez Duque et al. 2009) have arisen from the recognition (from slightly differing perspectives) that a dialectical relationship exists between the brain of an individual human being and the cultural milieu within which that person lives. The regularities that define culture materially shape our brains, even from before birth, whilst our activities as human agents, directed by our brains, maintain the culture that provides definition to our social experiences (Turner R. 2002; Turner R. and Whitehead 2008).

Crucial to this theme is the well-demonstrated fact that our brains themselves are highly adaptable, or plastic, with neurobiological competences that capture and maintain the fruits of experience (Karni et al. 1995). As we develop and interact with each other, this shaping continues, both through unconscious probabilistic learning and by explicit instruction, tuning our brains adaptively to the kinds of social and physical events that we are most likely to encounter, under the constraints of our own physiological limitations and our technological artefacts. In a tight feedback relationship, our cultures are also produced by our brains, extending into the future from the social rules, languages, traditions, buildings and infrastructure that our ancestors constructed. Even if we are not conscious innovators, we maintain our cultures by our collective assent to their contents.

If this simple model told the entire story, our lives as social beings might play out in a static equilibrium. However, embedded within our cultures are institutions that can transform us as social beings by physically and rapidly transforming the organization of our brains. I will focus on this process of transformation, which can aptly be compared with the transition from caterpillar to butterfly. I will provide arguments that extend this conceptualization to include our mortality: the dynamic changes in our lives, and in our cultures. I will describe a hypothetical model for material changes in our brains that can occur during the liminal period of rites of passage, which could be tested using magnetic resonance imaging.

## What Are Brains For?

To begin with, it is worth considering the special role that a brain plays in the organism in which it is located (Swanson 2011). The simplest animals, such as Hydra, possess only sensory and effector nerves. More evolved species add a layer of interneurons that mediate between these two classes, and at this point the structure that densely includes them can be called a brain. As brain research has progressed, it has become increasingly clear that the brain of even the simplest-brained animal fulfils the vital ethological needs for recording experiences, predicting future experiences on the basis of such recordings, and deciding on actions that help survival and reproduction. Neurons have the characteristic feature, conserved throughout evolution, that their structure and connections can be modified by experience, and can thereby record it. When we cooperate, we dramatically enhance our survival capabilities: we gain access to greatly improved methods for recording sharable experience, vastly more accurate capacities for predicting future events, and reliable guidelines for the formulation of productive decisions.

In the absence of external stimuli, neurons remain somewhat active, exchanging signals in the form of action potentials – and in so doing, predicting and preparing for what may probably occur next. Neurons, far more than any other type of cell, have immensely long processes, or neurites, extending many times the length of the central nuclear part (soma) of the cell, and making highly specific connections with other, more distant, neurons. Thus neurons have the capacity to pool data characterizing the present state of the organism and, collectively, to generate commands that control its actions, in relation to its sensations and desired future state.

With a simple animal it is easy to understand how its complement of neural types, its pattern of neural connections, and its ethological and environmental context, limit its action repertoire within a finite set of choices consistent with survival and reproductive success. A classic example is provided by Tinbergen (1951) in which he describes the behavioural repertoire of the stickleback fish, which has about ten million neurons. The pattern of connections, or connectome, of the brain of the larval zebrafish has recently been fully delineated (Hildebrand et al. 2017), which will enable plausible neural modelling of the action repertoires of simple fish. An intriguing reflection on the importance of such repertoires is that the animal's conspecifics need somehow to recognize its actions, in order to respond appropriately – for instance, the gravid female stickleback must know that it should follow the male into the nest tunnel, so that mating can take place. Thus evolutionary pressure can result in increasingly stereotypical repertoires.

Even though we humans have vastly larger brains than sticklebacks, the same evolutionary pressures apply. As social beings we require to be understood, in order to thrive, survive and multiply. Such tacit and explicit understandings are facilitated by the fact that almost all of our actions are governed by rules and regularities, of many of which we are happily unaware, but without which we should be unable to interpret and predict each other's actions. In general terms, this myriad of rules for action forms the basis of human knowledge. (Elements of such knowledge that are sharable by people can fairly be described as 'scientific knowledge'.)

In the research field of cognitive neuroscience, the brain activity that accompanies the formulation of the likelihood of future events is described as 'predictive coding' (Rao and Ballard 1999). In addition to receiving input from neural sensors and controlling motor outputs, any assemblage of neurons that is complex enough to be described as a brain must have the capability of predicting future events, and planning responses accordingly. For instance, identification of objects of sensory experience can be performed with high efficiency when a brain region can rapidly compare the afferent signals arriving from sensory organs (such as the eye) with a restricted set of possibilities stored in memory – Bayesian priors – and report accordingly to other brain areas, even when only a small number of discriminating signals have been received. This approach was first hinted at by Richard Gregory (1966) and has been embodied in neural network models, such as recurrent neural networks (Bitzer and Kiebel 2012; Bastos et al. 2012).

In this context, the concept of prediction error, as a brain signal of survival importance, has been explored in some depth. Friston and Stephan (2007) have formulated a global model of the relationship of a brain to its environment which gives a central place to this concept, equivalent to surprise, using the statistical mechanical metaphor of 'free energy'. He argues that many measurable characteristics of brain function can be viewed as a process of minimization of this free energy. In his sense of the term, human cultures can be seen to operate as a collective means to minimize free energy for all participants.

## What Is Culture?

The concept of 'culture' is notoriously contestable, and a wide range of definitions have been proposed and advocated across the social sciences and humanities. To be clear, I define culture as what people know, tacitly or explicitly, that enables them to pursue their lives in a way that is acceptable to those around them (Turner R. 2002). The culture of an interacting group of humans thus comprises their beliefs, rituals, myths, history, morals and language. It also includes their power relations, exchange relations and kinship system. Finally, it includes their skills, aesthetic principles and communicative genres, such as music, poetry, theatre, carnival, masque and dance. A culture is shared by a human group, and being non-instinctive and not genetically inherited, must be learned by every person in order for him or her to be accepted as a competent member. Thus, culturally informed action is inevitably a tiny proportion of all possible human action, and can be described as quite stereotyped.

As a means of classifying and identifying human experiences, culture greatly helps people to make decisions. Even our very large and complex human brains are probably incapable of the task of reinventing our lived-in worlds at every passing second. Instead of an infinite range of possibilities, possible options are narrowed down to discrete alternatives, each of which carries describable weights and consequences that can somehow be predicted. To the extent that people classify themselves and each other as occupying a particular social status, specific ranges of actions and interactions are mapped out for them. Seen as predictive coding, a brain's planning activity, forming expectations of future experience, has only to deal with a manageable number of feasible outcomes.

This much-needed simplification requires validation by some form of social consensus. By presenting a finite and therefore manageable system of meaningful options, cultures provide a framework within which cooperation is easy. This all-important cooperation entails trust, the ability to think alike, allowing the goals and methods of actions to remain largely tacit and thus avoiding repeated commands or explanations. But how do we come to think alike? I argue that we learn to usefully inhabit the same social, mental and physiological worlds when our feelings and thoughts become entrained with those of our companions. To be perceived as a viable option, a proposed action must make sense in the cultural context. One would be considered foolish to hope to be understood if speaking Swahili in a Kyoto hostess bar. Our shared background cultural knowledge protects us continually from performing such meaningless actions. The question then arises, how is such a consensus built?

## Entrainment

On a summer's afternoon in Paradise, a nature reserve on the banks of the Cam, a passer-by may often enjoy the sight of a group of nine domestic white geese, now living ferally. Without any obvious external command, all nine geese can be seen to coordinate their activities, so that at any given time they are all doing the same thing – grazing on the meadow, preening themselves, having a nap with head under wing, honking with excitement or alarm, or extending their long and graceful necks down to the river for a drink. Their actions are not usually precisely synchronized, but they stay within eyesight of each other, residing year round within a 100-metre stretch of river bank.

Such behavioural synchrony can be observed in all social animals, including us. It must therefore be inferred that this predisposition to what may be called 'social entrainment' confers evolutionary fitness, and that it is firmly encoded in specific brain circuitry. Clearly this biological predilection underlies the existence of social facts, to use Durkheim's term.

Recent neuropsychological research on music and infancy sheds further light on this phenomenon. A study by Jessica Phillips-Silver and Peter Keller published in 2012 investigated musical chorusing and turn-taking: 'When individuals join together in almost any musical behaviour, ranging from a simple tune shared between a young child and caregiver, to a rhythmically complex performance of a Cuban jazz band, their joint action is characterized by entrainment'. The authors distinguish two kinds of entrainment, temporal and affective. We often experience temporal musical entrainment in the automatic, even unconscious nodding of the head, or tapping of the hand or foot, when we hear music. Even when such overt motion is repressed or absent, activity in motor areas of the brain recorded by electroencephalography or functional magnetic resonance imaging reveals this shared entrainment (Merchant et al. 2015).

Affective entrainment, on the other hand, involves the formation of interpersonal bonds, and can emerge from many shared activities, including vicarious sharing (Konvalinka et al. 2011). Most immediately, it arises from the pleasure in moving the body to music and being in time with others. How much the precision of synchrony affects the intensity of such entrainment remains to be discovered. It is clear that early musical interactions between infants and their caregivers can provide the first experiences of affective and temporal entrainment (Malloch and Trevarthen 2009), often supported by their coordinated body motion (Phillips-Silver and Trainor 2005). Entrainment of this kind must be intrinsically rewarding. Indeed, it has been shown that the 'reward' neurotransmitter dopamine drives entrainment to the circadian cycle (Baba, DeBruyne and Tosini 2017).

Similar brain processes are likely to be involved in many human activities, ranging from dancing, choral singing, saying prayers together, marching, and forming the audience at concerts and parades. What these situations have in common is their unambiguous framing, providing a context in which identical performance becomes unproblematic, indeed desirable. Entrainment with one's fellow participants is insidiously invited, as well as superveningly compelled. A sense of affective membership with other participants, knowing that they are thinking and acting the same as oneself, is very likely to begin and grow.

## Brain Plasticity

Mammalian brains comprise grey matter, which contains the cell bodies of neurons and almost all of their points of connection, and white matter, formed by the long output fibres that join neurons. It is beyond question that repetition of neural activity results in the strengthening of neural circuits, as described by Hebb (1949), a result which is variously denoted as learning, memory, adaptation or neural plasticity. This can involve three distinct processes. The first two such processes take place where separate neurons meet, and occur within the grey matter. The output fibres of a given neuron, generally small in number, are called axons, and its profuse input fibres are called dendrites. Axons connect with dendrites at synapses, where their electrical neural signals (action potentials) are transmitted from axon to dendrite by the release of specific chemicals such as glutamate or dopamine. In the first instance, repeated synaptic activity alters the biochemistry of the synapse and results in altered synaptic performance, known as long-term potentiation or depression, which can be maintained over timescales from minutes to hours. Over a similar timescale, additional synapses may be created by the growth and extension of dendrites, and terminal branches of axons, to form new contacts with available axons.

Strikingly, these processes whereby neurons adapt their connectivity via experience are largely reversible. If potentiated synapses do not find further use, their potentiation is lost. Newly sprouted arborizations of dendrites can simply be reabsorbed, together with their new synapses (e.g. Lai, Adler and Gan 2018).

The third process that changes brain connectivity is the transformation of axons through their wrapping by myelin, a membrane structure with a highly specific composition that consists mainly of a blend of lipid molecules, importantly including cholesterol. Myelination greatly improves the efficiency of an axon, increasing by up to thirtyfold the speed with which an action potential travels, and reducing the axon's energy requirements. For a given axonal fibre bundle, myelination can take a few days to complete and is generally irreversible. The traffic of neuronal signals between different brain regions is critically determined by the myelination of their connecting axons (Chorghay et al. 2018).

The major neural pathways throughout our brains thus develop in a bootstrapping fashion, building sequentially on what has already been established (Guillery 2005). Even in our late teens, the process is not yet complete in the white matter of the frontal lobes, and increases in myelination have been observed in adult brain. Combining faster transmission with a shorter recovery time gives a three-thousand-fold increase between infancy and adulthood in the brain's computational bandwidth, thereby enabling extensive and elaborate networking among brain regions. Crucially, myelination inhibits local dendritic and axonal arborization, and prevents formation of further synapses along the length of the axon (Chiquet 1989). Thus it casts in stone the connections supplied by that axon.

The fundamental point here is that myelination is largely driven by experience (Fields 2015). It regularly proceeds when the cells responsible for myelin formation, oligodendrocytes, receive chemical signals that action potentials are passing along nearby axons. The oligodendrocyte gets busy, wrapping a sheet of myelin in several precise layers around the axon, over a period of a few hours. The resulting increase of action potential traffic encourages myelination of more axons, which in turn improves the coupling of the brain areas that the pathway connects, and thereby enables more action potentials to be transmitted. Repetition of experiences or actions further durably consolidates and structures such pathways. Myelin protects these vital circuits. Its random and encroaching loss in multiple sclerosis, devoured by the white cells that are supposed to protect us, bitterly strips a person of one faculty after another until death supervenes. During this agonizing process, oligodendrocyte precursors repeatedly but vainly attempt to remyelinate the bare axons.

In human brains, the process of systematic myelination is quite slow. At birth, only a few axons are yet myelinated, mainly in the primary visual and motor pathways (Flechsig 1920). Much of the white matter is at least partly myelinated by age four, but the white matter in the prefrontal lobes continues to increase its myelination until one's early twenties (Giedd 2015). Even in fully adult brains, it has been estimated that a reserve of perhaps 30 per cent of white matter axons remain unmyelinated. Giedd cogently argues that this particularly human characteristic – no other primates take so long for their brains to mature – gives us an evolutionary advantage in that our brains remain relatively plastic and adaptable at an age when we are able to participate in a wide range of experiences, and to form our own plans and agendas in relation to them.

However, it must be noted that in regard to social stability and trust, permanence in networks relating to social interactions is highly desirable (Olsson et al. 2018). The durability provided by myelination is a critical feature of the laboriously configured neural circuits that embody our expectations, and enable predictions and planning.

But we age. Our lives have chapters, acts in our own plays (Shakespeare, *As You Like It*, Act II). We move from role to role, and our movement is marked, in every human culture. Somehow cognitive and emotional switching must be achievable, in the whole person, or social expectations will be disappointed and we will not thrive. How can myelin-protected neural circuits be rearranged? Do our human brains have the resources to undergo the systematic and collective transformations that may result from entrainment? How do we deal with a situation that is not part of our previous personal experience?

## Ritual, Entrainment and Liminal Status

The most frequently discussed human situations in which participants find themselves in a liminal condition occur in the course of rituals, which I define as prescribed sequences or processes of collective human action, the features of which generally change only slowly over time. Not all rituals are markers of transitions of social status, though many may reinforce the sense of inclusion in a community or category initially brought about by a rite of passage. To avoid complication, I will refrain from discussing closely associated human experiences, for instance the liminoid status described by Victor Turner (1974), and focus on how the liminal period is established as a social context within ritual, which I consider to be particularly significant for driving important changes in the brain organization of the participants (Turner R. 2015).

The frame of ritual provides an additional, or indeed alternative, set of norms for actions, including relaxation of normal restrictions, and presumes equality for those undergoing the rite of passage. The rite generally encompasses powerful symbolic acts, rhythmic sounds and music, specific aromas, and coordinated movements of a dance-like nature. Special foods may also feature as part of the intense transformational experience. The combination of sensory input is novel and engrossing. Often the participants are expected to discipline themselves, as physical stamina may be required to carry out the performance of the ritual. When a group of people are collectively subjected to such rituals, not only will they experience liminal status, but in their betwixt-and-between state they may well enjoy communitas (Turner E. 2012: 176–96).

It is plausible to suggest that the liminal periods experienced by protagonists in most rites of passage have particular importance in enabling a permanent consolidation of neural pathways. 'For individuals and groups, social life is a type of dialectical process that involves successive experience of high and low, communitas and structure, homogeneity and differentiation, equality and inequality. The passage from lower to higher status is through a limbo of statuslessness' (Turner V. 1967). During the liminal state, patterns of brain connectivity may be regarded as undergoing a gestalt switch, in which the components remain much the same, but the internal logic of cognitive inference is transformed, as previously unmyelinated axonal pathways are massively brought into play.

The collective experience of entrainment (Trost, Labbé and Grandjean 2017) may be fundamental to the entry into the liminal state. The convergence of normative and orectic aspects of the dramatic scenarios of ritual provides a compelling and convincing invitation to think with and to feel with the other participants. The powerful salience of such experiences makes them unforgettable, and our brains become engraved with a new, shared, culturally distinctive design.

The important point is that these are circumstances in which one can reasonably expect major reconfiguration of neural circuits in the brain, a reorganization that must be durable to have any value for survival. This occurs most particularly in social contexts of liminality, when custom and habit become at best irrelevant, when the masks of social competence are dropped, when the present becomes far more important than the past or future. In these circumstances, our neural circuits scramble to reconfigure themselves, to adapt to the novel reality – but into patterns that are common across the participants, who share intense and compelling experiences.

## Experimental Validation

Curiously enough, a MedLine search for ‘ritual and myelin’ gives no hits whatsoever. But to perform an experiment that could empirically demonstrate changes in myelin directly related to the experience of a rite of passage is by no means impossible. The most important source of contrast in magnetic resonance images of the brain happens to be myelin. One of the most fundamental of nuclear magnetic resonance parameters, the longitudinal relaxation time T1 provides a quantitative index of the degree of myelination (Stüber et al. 2014). Development of infant brains can be monitored by sequential mapping of this parameter (Lebenberg et al. 2019), and changes in T1 due to training specific to known white matter pathways has been measured in adult brains (Caeyenberghs et al. 2016).

As social organization and social stability vitally depend on the effectiveness of rites of passage, which are far too easily taken for granted, it is surprising that there has been no experimental exploration of this universal human institution.

## Conclusions

Decision making for action requires discrete options. For actions to make beneficial sense to social animals, such as humans, their objectives need to be identifiable and recognizable. Collectively we build cultures, comprising shared and assimilated knowledge that provides such definable options. Operationally, such knowledge is embedded in patterns of connections in our central nervous systems, which are rendered durable by the selective myelination of the most vital pathways. Retrieval of knowledge, as a performance, comes about when neural activity that helped to consolidate these pathways is replayed, either by environmental triggers, or by personal recall, voluntary or involuntary. Our human lives progress through discrete stages, such that the stage that we have reached defines the set of choices and options that we can expect.

As we move into a different stage, our beings must be transformed to make use of these choices. The neural rewiring that this entails is complex and difficult. Ritual provides a context for transformation, by processes of entrainment brought about by intense multisensory experiences, collectively organized for those undergoing social transformation by others who have already gained social maturity. To bring about effective transformation, entrainment must take place in liminal contexts, which open up the possibility of change and also powerfully remind the protagonists of their fundamental likeness as human beings. Such transformations are able to engender the rewiring of brain connections, forming fresh shared social gestalts, by means of the extensive reserves of brain plasticity embodied in our not-yet-myelinated axons.

Experimental validation of the hypothesis I have described has not yet been explored, although the techniques required are already widely available.

**Robert Turner** played a key role in the invention of actively shielded gradient coils used widely in magnetic resonance imaging (MRI), in the development of diffusion-weighted imaging of human brain, and in the discovery of functional MRI by measurement of the effects of blood oxygenation changes. He studied maths and physics at Cornell University and completed his doctorate in physics at Simon Fraser University, Vancouver. Following three years postdoctoral physics research at the Cavendish Laboratory, University of Cambridge, he attended University College London, where he obtained a postgraduate diploma in social anthropology. After ethnographic fieldwork in a Scottish fishing village, funded by the Social Science Research Council, he returned to physics, which he taught for four years at Napier College, Edinburgh. Appointed as a lecturer at Nottingham University from 1984 until 1988, he built his own MRI scanner, designed and built gradient coils for MRI, and assisted Sir Peter Mansfield in the development of snapshot echo-planar MRI. Between 1988 and 1994, he was a visiting scientist at the National Institutes of Health (NIH). He then became a Wellcome Principal Research Fellow and professor at the Functional Imaging Laboratory of the Institute of Neurology. He was director, from 2006 until 2014, of the Department of Neurophysics at the Max-Planck Institute for Human Cognitive and Brain Sciences in Leipzig, Germany. Now living in Cambridge, England, he is emeritus director at the Max-Planck-Institute for Human Cognitive and Brain Sciences, Leipzig, and honorary professor in the Physics Department, University of Nottingham, and in the School of Psychology, Cardiff University. In 2020 he was awarded the Gold Medal of the International Society for Magnetic Resonance in Medicine.

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