4.1.4

Knowledge in Hand: Explorations of Brain, Hand and Tool

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> It is not possible to picture a carpenter or joiner apart from his tools… . To such experienced bench-hands the tools were co-operators in the common service of life, the character of the tool becoming like that of the owner. There existed a subtle unity of disposition between the tools and their proper users, which was simply the outcome of much common use, a peculiarity in the working of the tool born of a corresponding peculiarity in the method of the user. The joiner became accustomed to handling it, to its distinctive shape and grip, its temper and weight. (Walter Rose, 2001 [1937]: 49–50)

Walter Rose's tribute to the village carpenter records a profession and way of life in his native Buckinghamshire on the eve of the twentieth century. The chapters of his slim book describe the impressive, but at the time standard, variety of work that his family shop undertook, manufacturing everything from wooden water pumps to coffins, erecting door frames and timber roofs, and repairing furniture and windmills. His reminiscences of the timber yard and workshop vividly portray an environment animated by skilled handwork, the rhythmic chorus of saws, whispering bench planes and thundering mallets, the smell of freshly cut timber, and a light-hearted exchange of banter. The orchestration of hands, tools and raw materials features prominently, and Rose emphasizes the need for skilful handling and mindful maintenance of one's tools: 'Treat the plane as a human being, it will respond to good treatment, but will be ruined by careless, haphazard use' (2001: 54–55). The intimate relation between a craftsman and his tools is eloquently captured in the opening quote, which expresses the progressive manner in which carpenter and tool reciprocally form one another in shape and posture, in performance and efficiency.

This essay investigates the brain–hand connection, and the way that handtools become an extension of the body during the course of practical training and use. Carpenter and columnist Jeff Taylor poetically evokes the experience of that union: 'At a certain point, upon a day, you almost become the work, a moving and cognitive part of the tool in your own hand' (1996: 5). Mastering a tool modifies and expands our integrated cognitive and physical capabilities. Tools are cultural artefacts that possess their own history of use and shared meaning, and through practice we are, so to speak, 'socialized in the tool'. Skill, therefore, is both context dependent and culturally nurtured (Preiss and Sternberg 2005: 204). The following inquiry grows out of my previous fieldwork with masons in Yemen (Marchand 2001), then Mali (Marchand 2009), and my recent vocational training with woodworkers in England.[1] I also draw upon related literature on skill and craft, and upon the rapidly growing body of research from the cognitive and neurosciences exploring the intricate relation between brain, hand and tools. My objective is to encourage anthropological thinking about the relation between the three.

BRAIN, HAND AND TOOLS

> The hand is not a thing appended, or put on, like an additional movement in a watch; but a thousand intricate relations must be established throughout the body in connection with it such as nerves of motion and nerves of sensation…. But even with all this superadded organisation the hand would lie inactive, unless there were created a propensity to put it into operation. (Charles Bell 2009 [1833]: 87)

The hand is the most effective body part for manipulating objects and for configuring and modifying our physical environment. Hands, too, are an important medium for communicating, expressing and even shaping ideas and emotions, either on their own or more typically in coordination with utterance, spoken language, facial expression or posture. Hands point, gesture and sign; make fists, protect or express tenderness; support our body, head and other appendages; climb or break a fall; grasp, hold, carry, wield and manipulate external objects; and operate tools. My present concern is with the nature of 'skilled handtool use' which might be defined at the outset as practised coordination between brain, hand and tool, acting in direct relation with the environment, and with the intention of manipulating or reconfiguring objects or materials. But what does such 'coordination' entail?

Nearly two centuries of scientific progress separate the studies made by Scottish surgeon and anatomist Sir Charles Bell and American neurologist Frank Wilson, but their accounts of the hand converge on the same finding: namely, the existence of a special and intricate connection between brain and hand. Echoing Bell, Wilson points out that brain and hand resist differentiation into neatly bounded categories and are instead intimately joined by the nervous system, each stimulating activity and development in the other. The nervous system connects brain, spinal cord, peripheral nerve, neuromuscular junction, and onward 'down to the quarks' of our fingertips, and back again. Wilson astutely concludes that 'brain is hand and hand is brain' (1998: 307).

A handtool, by contrast, is an inanimate artefact, seemingly plainly distinguishable from the brain–body that wields it. A handtool can be generically defined as an implement or device that is grasped and employed to act upon another object or to alter the state of a material, lending greater efficiency to what can be achieved by hand (or other body part) alone. In action, however, a handtool becomes an extension of the forearm, hands or fingers, and thereby integrated within a brain–hand–tool complex. Margaret Mead eloquently drew attention to this phenomenon in a UNESCO report: 'Where technology is simple, the tool is an extension of the body; the shuttle elongates and refines the finger, the mallet is a harder and more powerful fist. The tool follows the rhythm of the body; it enhances and intensifies but it does not replace and does not introduce anything basically different' (1953: 257). The question of how this phenomenon is achieved is fascinating, and should be equally so to anthropologists, archaeologists, anatomists, neurobiologists, cognitive scientists, and all those who share a scholarly interest in the nature of human knowledge, learning, practice and material culture.

THE HAND IN ANTHROPOLOGY

It seems from the coalescing body of evidence from archaeology, physical anthropology, anatomy and neurology that our relation with tools stretches back nearly two million years (Leakey 1971). Evolution of the brain–hand was necessary for making and using tools. But, likewise, tool use played a pivotal role in the further evolution of the human hand (Marzke 1997; Marzke and Marzke 2000) and the brain (Peeters et al. 2009; Washburn 1960), as well as in the development of gestural communication and language (Frey 2008; Greenfield 1991), and in the construction of culturally defined notions of intelligence (Maynard, Greenfield and Childs 1999; Maynard, Subrahmanyam and Greenfield 2005). Co-evolution of brain, hand and tool endowed humans with the remarkable capacity for transferring a proximal goal (e.g. grasping a mallet) to a distal one (e.g. driving a wooden peg). This demands tight coordination between multiple cognitive domains and physical strategies. Our ability to conceptually identify and understand the uses of a wide variety of tools, to plan with tools and satisfy goals, and to manipulate tools with high levels of (manual) dexterity is a defining trait of our species.

Hands are our primary means not only for engaging with but also learning about the overwhelming majority of tools that humankind has invented and fashioned.[2] Mastery of the tools of any trade – whether masonry, carpentry, smithing, culinary, surgical, or other – typically involves specialized training within a community of practitioners. Training normally focuses on hand skills, though the anthropology of craft and apprenticeship reveals that training equally includes the formation of values, ethos and social persona, and the learning of related professional competencies (Coy 1989; Dilley 1986; Downey 2005; Goody 1989;

Herzfeld 2004; Lave and Wenger 1991; Makovicky 2010; Marchand 2008; O'Connor 2005; Portisch 2010; Rice 2010; Sinclair 1997; Stoller 1989; Wacquant 2004). Hand skills are more complex than simply training the hands to perform a series of correct actions. They entail balanced posture and complementary movements of other body parts in synchrony with the dominant hand; a sophisticated coordination between sensory knowledge and motor activity; an ability to flexibly adjust and respond to the material being worked; and the know-how to make corrections and repairs, often in ways invisible to all but the craftsperson. Nevertheless, the skilled hand is *the* focal point of craft work, and as Wilson reports, 'for a great number of people, the hand … becomes the critical instrument of thought, skill, feeling and intention for a lifetime of professional work' (1998: 277). The ability to engage in skilled handiwork lends practitioners a vital sense of agency to make, undo, repair and transform their world, and the world of others, in an immediate, practical, hands-on way (Crawford 2009; Paradise and Rogoff 2009; Rose 2004). In spite of this, the hand as instrument and expression of knowledge and agency has been overlooked by social and cultural anthropology, with a few notable exceptions.

In 1888, Frank Baker, Professor of Anatomy at the University of Georgetown, published his essay 'Anthropological Notes on the Human Hand' in the very first issue of *American Anthropologist*. Baker's aims were twofold: first, to describe the role of the hand as charm and fetish in warding off disease, changing fortunes, and bringing luck; and secondly, to propose a more rigorously scientific physiognomy that would illuminate the inextricable links between hand and mind, and supersede the quack's art of chirognomy. His animated explorations of 'curious superstitions' take the reader across time and space, from ancient Greece and medieval France, to the 'laying on of hands' by English monarchs, and to the counties of England and to Baltimore's Catholic community where hands of the deceased were still used for curative purposes. At the time of Baker's publication, Charles Bell's study of *The Hand* remained an authoritative source, and new empirical evidence from the operating theatre and dissection room was confirming the thorough integration of nervous with muscular systems. Baker cleverly employs the demonstrable anatomical connection between brain and hand to support his anthropological thesis that the hand is an enduring and universal symbol of human and divine power (1888).

Four years later, anthropologist Frank Hamilton Cushing published his fascinating and detailed essay on the influence of hand-usage on cultural development. Initially curator of ethnology for the National Museum in Washington, Cushing became a leading expert on indigenous Zuni culture, living for extended periods in a Zuni Pueblo and arguably founding the methodological practice of participant observation. Cushing's essay opens with a description of the 'three great steps in the intellectual development of man': namely, 'the biotic', referring to humankind's ability to walk erect and have free hands; 'the manual', or our capacity to make an environment by hand, which in turn gave rise to the ability for rational devising; and 'the mental', enabling humankind's quest for the 'ascertainment of *truth*' (1892: 289–290, original emphasis). Following a series of cross-cultural investigations into hand influence on the formation of spoken language terms, recorded numerals and ceremonial succession, Cushing determines that 'the hand of man has been so intimately associated with the mind of man that it has moulded intangible thoughts no less than the tangible products of his brain' (1892: 308).

The topic of 'handedness', pursued only briefly in Baker and Cushing, was taken up more fully by French sociologist, and student of Durkheim, Robert Hertz in his essay 'The Pre-Eminence of the Right Hand' (2007 [1909]). Hertz notes at the outset the asymmetrical neurological connection between the 'preponderance of the right hand' and the 'greater development in man of the left cerebral hemisphere' (2007: 30). Significantly, he was also the first to formulate the analogical association between the religious polarities of sacred and profane with the symbolic powers of the right hand and left hand, respectively. His study, grounded mainly in available ethnographic data on the Maori, proposes that practices of suppressing the left hand are an attempt to restrain the sorcery and occult powers associated with it. Subsequent structural and symbolic studies of handedness (i.e. Mines 1982; Needham 1960, 1967; TenHouten 1995) have offered stimulating insight into the constellation of relationships mapped between human bodies and religious beliefs; the complexity and contradiction inherent in collective representations; and evolving social status and power relations among neighbouring groups and castes in a changing world.

Dedicated anthropological exploration of the wondrous connection between hand and brain, however, seems to have dissipated somewhere near the turn of the nineteenth century, the inquiry having been surrendered to the natural sciences.[3] I therefore propose that social and cultural anthropology revisit the subject first expounded by Charles Bell and probed by Baker, Cushing and even Robert Hertz, but now drawing the role of handtools more squarely into the hand–brain puzzle, and taking on board what is being learned by other disciplines. In retaining the traditional strength of anthropology, fieldwork should be carried out in places of everyday work and activity in order to take full account of the impact of social interaction and environment on learning hand skills, developing personal style, and problem solving *with* tools and materials.

A BRIEF ACCOUNT OF THE PHYSICAL HAND, GRASPING AND BIMANUAL COORDINATION

The coupling of brain and hand within the weave of the nervous system makes it practicably impossible to draw any definitive functional boundary between them. Our fingertips have evolved to contain some of the densest concentrations of nerve endings in the body, and because of this, the 'sense of touch' is most powerfully associated with the hand. In the evolutionary history of the brain–hand connection, the development of human bipedalism was arguably the most critical stage. The freeing of our upper limbs and hands allowed for more complex manipulation of the physical environment. And with the evolution of the opposable thumb came the ability for articulated grasps and firmer grips of objects, and the manufacture of increasingly sophisticated artefacts and tools. These activities together multiplied and refined brain–hand links to the point that the hand has become the most physically adept and nimble part of the human anatomy, capable of more intricate and precise manipulation than that in the comparable extremity of any other animal.

In *Homo sapiens*, the hand's skeletal structure contains 27 bones – remarkably, the two hands together account for a little over a quarter of the total number of bones in the body. These include the carpal bones of the wrist, the metacarpals making up the palm, and the phalanges of each finger. The metacarpal at the base of the thumb is joined at the wrist's multifaceted trapezium-carpal in such a way that the thumb can be rotated 90 degrees perpendicular to the palm and can be brought opposite to the fingers in order to pinch and grasp objects. These capacities make the thumb the most mobile digit of the hand and a crucial component in the history of human tool use and skilled hand work.

Movement is made by muscles animated by electrochemical exchanges of signals between neurons. Hand movement is initiated in the shoulder muscles. Shoulder movement automatically anticipates and supports hand movements, 'transporting' the hand to its intended target (Wilson 1998: 73). The basic mechanics of the arm and fingers are operated by two kinds of specialized muscles: one producing flexion (e.g. biceps) and the other extension (e.g. triceps) of a single joint. More specifically, the so-called extrinsic muscles of the hand consist of the long flexors originating on the underside of the forearm and extending through the palm into the fingers; and the extensors originating on the topside of the forearm and extending into the fingers along the hand's dorsum. Flexors and extensors allow for bending and straightening of the fingers, respectively. In combination, the extrinsic muscles are responsible for the wide range of possible hand motions, but their control over hand and digit movement is crude in comparison with the so-called intrinsic muscles of the hand. The intrinsics originate on the bones of the hand and are accountable for fine hand and precision finger movement, and for the coordination of such movement in parallel and sequence. In addition to extrinsics and intrinsics, the thumb is also composed of other small, specialized muscles, lending it its 'opposable' abilities and making possible a number of sophisticated grasp formations.

Grasping is a 'prehensile' action in that it involves gripping and holding an object either partially or wholly with an extremity.[4] Wilson distinguishes between 'power grips' and 'precision grips', defining the former as 'any holding posture using the palm as a buttress' (e.g. using a mallet), and the latter as using 'any combination of thumb in opposition to fingers' (e.g. squeezing pliers) (1998: 120). Grasping an object entails 'a highly precise registration of neurological preparations for the biomechanical requirement of the task' (Wilson 1998: 120). The arm must move the hand to the target guided by vision (or possibly sound or touch), and the hand must orient itself, simultaneously forming the palm, fingers and thumb in a manner appropriate for grasping, then manipulating, the target object. As contact is made, the fingers and palm receive haptic information and responsively adjust and fine tune the grip, and apply the necessary force to lift, then carry, manipulate or operate. Touch is both reactive and proactive, seeking tactile data that informs the shape of the grip, the application of pressure and the subsequent hand movements.[5] The orientation of the hand, the configuration of the grip and the adjustments of palm, fingers and thumb differ considerably whether the target is a teacup or a hammer; or for that matter whether it is granny's dainty bone china teacup, a sturdy coffee mug or a Chinese tea bowl.

Tools and tasks demand a diversity of grasps, grips and dexterous manipulations, each configuration dependent upon the goal of the exercise, and the practice and experience of the individual. In discussing grips, Richard Sennett notes that with training and long hours of practice 'grips develop in individuals just as they have developed in our species' (2008: 152). Such individual stylization applies equally to dextrous manipulations, notably including the ways that we learn to coordinate the actions of our dominant and non-dominant hands in bimanual activities. Coordination, Sennett observes, is best achieved if both hands are engaged in learning the task from the start as opposed to incrementally mastering each segment, and subsequently trying to suture the actions together in a seamless performance (2008: 164–165). The reason for this, explains Wilson, is that the two unequal hands perform complementary functions, the non-dominant hand counterbalancing and 'framing' the activities of the dominant, or continually adjusting the position and orientation of the material being worked, or worked upon (1998: 159). 'The spatial and temporal scales of movement of the two [roles] are different', writes Wilson, 'the dominant being 'micrometric' (i.e. lower in amplitude and faster in repetition) and the non-dominant being 'macrometric'… [involving a wider] variety of improvised holds and move sequences' (1998: 160–162).

Take, for example, a right-handed carpenter using a paring chisel to remove waste from a simple housing joint.[6] With her dominant hand, she grips the chisel handle with a power 'pad-to-side' hold, index finger and thumb pointing downward along the hardwood shaft to maximize control over the sharp cutting edge. As she moves the tip of the chisel into position along the bottom of the rectangular channel of the housing joint, she takes hold of the long, flat metal blade with her non-dominant left hand, applying a precision grip by lightly bracing its width between her thumb and four fingertips. Before beginning to pare away timber, she carefully aligns the chisel tip with the edges of the channel, relying on sight and the 'feel' conveyed by tool to hands, adjusting her posture, position and cutting angle accordingly. Monitoring and adjustment will proceed in this way throughout the activity, responding also to the sound of the blade and the character of the timber. Once started, her dominant right hand and forearm control the angle, rhythm and force of the backward-and-forward thrust of the cutting edge along the wood surface, and the left lends increased command over the directionality of the cut and over the sequential application and removal of force to the material. While the grip and movement performed by her right hand remain largely unchanged throughout the exercise, she transfers the fingers on her left up and down the length of the blade to balance force with accuracy. Her left hand is also periodically employed to remove wood shavings from the channel (accompanied by a blast of air issued from pursed lips) and to feel its surfaces for smoothness, shape and depth. By Wilson's account, the complex but generally repetitive muscular tasks performed by the carpenter's dominant hand are, to some extent, 'automized' by her brain, thereby requiring minimal sensory monitoring, whereas the non-dominant hand moves in 'supportive anticipation… conforming its movements both to the behaviour of an external object and to the action of the other hand, to ensure that the object and the handheld tool will intercept at the intended time and place' (1998: 162).

HAND–EYE COORDINATION

Skilled handwork involves fast and fluid exchanges of various kinds of sensory information, motor action feedback, semantic knowledge, and reflective thought on goals, present actions and tasks completed (see Ingold 2006). When this exchange of action, information and thought is synchronized, a woodworker, for example, experiences a sense of unity to what he sees, hears, feels and does with tools and materials. As with athletes, the carpenters I trained with referred to this experience as 'being in the zone' or 'the Zen of woodworking'– body, mind and soul fully absorbed in the present event of the task. Even when certain tool-wielding actions are mastered and the neuromuscular system performs them in a seemingly automatic way, they become 'routinised but not mindless' (Rose 2004: 78), for the carpenter is acting not merely *upon*, but *with* materials and *with* tools whose inherent qualities 'respond' to the work. Responses are perceived and processed by the senses, which, in turn, shape reflective thought and guide the carpenter's continual, and usually subtle, adjustment of posture, bimanual activity and force.

In his discussion of carpentry, Mike Rose writes that the biomechanical skills involved in the craft 'build on and enhance basic sensory, kinaesthetic, and cognitive abilities that emerge through natural development' (2004: 76). In Cristina Grasseni's study of 'skilled vision' among Northern Italian cattle breeders, for example, she argues that the long apprenticeship beginning in childhood includes learning to actively search for certain kinds of information in the daily living environment, cultivating a distinct way of seeing both bovine and landscape (2007). Skilled vision is also coveted among woodworkers. 'Having a good eye is synonymous with being a good carpenter', reports Wendy Millroy, who signed up as an apprentice furniture-maker during her ethnomathematics fieldwork in South Africa (1992: 173). Though woodworkers rely on touch, hearing and even smell to monitor and adjust their operations, skilled vision is commonly employed for assessing the figure of timber, for judging smoothness, straightness, angles, symmetry and proportions, and for approximating dimensions and volumes – or in Millroy's term, for 'mathematizing' (1992). In addition, skilled vision is critical to good hand–eye coordination.

The subject of hand–eye coordination in tool-using activities gives rise to an important set of related questions: How do we grasp what we see? How is information supplied by vision regarding '*what* a tool is' and '*where* it is located'[7] integrated with motor cognition? More precisely, how does visual information serve as input to the coordinated motor operations involved: first, in delivering the hand to the tool and forming an appropriate grasp, and secondly, transferring the hand and, more to the point, the functional end of the tool to a precise location on the material or artefact being worked? The short answer is that the brain–body must solve the 'correspondence problem', meaning that it must integrate signals from vision and haptics in a manner that combines information referring to the same object located in space in dynamic relation to the moving hand (Downey 2010: S28; Takahashi, Diedrichsen and Watt 2009). But, again, how does this occur? And how is hand–eye coordination honed through training and practice? Or, conversely, diminished through injury, slackening regimes of practice, changes to design, technologies and procedures, or the inevitable fact of ageing and deterioration? To my mind, there is an obvious role for anthropology and long-term ethnographic fieldwork in addressing these questions.

EXTENDING THE BODY

> Where the tool has its stories, the hand has its gestures… . But 'bringing into use' is not a matter of attaching an object with certain attributes to a body with certain anatomical features; it is rather joining a story to the appropriate gestures. (Tim Ingold 2006: 73)

Handtools in use supplement and extend, and are psychologically incorporated into, the physiology of limbs. Carpentry handtools, in particular, enable us to execute a large number of actions with and upon wood more efficiently and with higher levels of precision than by hand and arm alone (M. Rose 2004: 78–79; see also Weber, Dixon and Llorente 1993: 485–486). These include pounding, tapping, pulling, cutting, chopping, carving, bending, shaping, boring, scraping, smoothing, bracing, holding, pinching, cramping, joining and measuring. Language contains preliminary clues to the embodied relations we have forged with carpentry tools. In English, for example, the proper names for a variety of specialized tools, tool parts or common wood joints refer metaphorically to human or animal anatomies, thereby inciting some level of somatic identification and abetting a more immediate, 'visceral' understanding of their form, function or fit.[8] General category terms such as saw, hammer, chisel and plane are both noun and verb in a number of languages,[9] describing equally the kind of handtool, its function and the action associated with using it. The fact that proper noun and functional verb share the same lexical term (or root) may be a contributing factor to the neurological finding that an area in the left temporal lobe associated with processing action words is also activated when naming tools (Martin et al. 1996).

In a neurological experiment using fMRI (functional magnetic resonance imaging), Grafton, Fadriga, Arbib and Risolatti (1997) confirmed that both 'seeing tools' and 'silently naming them' activate the left dorsal premotor cortex in equal measure. However, 'silently naming tool *functions*' (i.e. 'hammering') increases activation of the left dorsal premotor cortex, and additionally activates another area in the premotor cortex as well as the supplementary motor area (SMA) associated with planning and coordinating complex movements like bimanual tool use.[10] They concluded from these results that motor cognition plays a significant role in assisting our recognition, identification and understanding of objects that have a 'motor valence'. In other words, motor cognition is part and parcel of our meaning-making processes, and the information it supplies is incorporated into the mental representations we entertain about artefacts like tools. After all, the meaning of a tool is not fully accounted for by the object's appearance, but centrally includes its function which is animated by a user in combination with materials.

Thus, to think of a smoothing plane implies not only thoughts of it as an object but as an *object-in-use*. 'No object considered purely in and for itself, in terms of its intrinsic attributes alone, can be a tool' writes Ingold. 'To describe a thing as a tool is to place it in relation to other things within a field of activity in which it can exert a certain effect' (2006: 71). Elizabeth Grosz similarly observed that 'it is only insofar as the object ceases to remain an object and becomes a medium, a vehicle for impressions and expressions, that it can be used as an instrument or tool' (1994: 80). Tools are already a part of the world that we are born into: they have a history of use, and the basic properties and function of many have changed little since ancient times (Mercer 2003). A familiar tool whose 'story' we know invites us, so to speak, to take it up, becoming a 'vehicle for learning about the properties of materials themselves' (Rose 2004: 79), a means of problem solving, or an enabler for modifying and transforming our physical, and possibly social, world. This quality that invokes even the most fleeting urge to pick up and use is the tool's 'motor valence' – a property powerfully conjured up in John Updike's poem, *Tools* (2003):

> […]
> Tools wait obliviously to be used: the pliers,
> notched mouth agape like a cartoon shark's; the wrench
> with its jaws on a screw; the plane still sharp enough
> to take its fragrant, curling bite; the brace and bit
> still fit to chew a hole in pine like a patient thought;
> […]

Close sensory engagement with tools can result in their temporary incorporation into a sense of what belongs to our body, or 'body schema'. The body schema is a non-conscious system regulating the proprioceptive sense of our body's posture and movement, and dynamically updated by information supplied by all sensory modalities, including visual, auditory, haptic and motor (Holmes and Spence 2004). A changing sense of what constitutes the body has corresponding effect on the body's relation to its surrounding space. Indeed, the brain's representation of peripersonal space (a sense of space within reaching distance) and extrapersonal space (the sense of space beyond reaching distance) are shown by cognitive experiments to be remapped when using a tool. The tool, as an extension of the mechanics of body in space, extends one's sense of 'nearness' (Berti and Frassinetti 2000). Similarly, peri-hand space in which vision and touch are integrated is expanded during tool use, and directly correlated with the length of the tool, and more specifically, with its functionally effective length (Farne, Iriki and Ladavas 2005). The results of experiments carried out by Takahashi et al. (2009) further indicate that when using a handheld tool, the brain treats the haptic signal as though it were coming from the operational end of the tool, not the hand. This allows the brain to combine haptic and visual information coming from the very same distal location (i.e. the head of the nail being clasped by the jaws of the pliers), thereby solving the previously introduced correspondence problem.

I conclude with a final example. Results of recent neuroscience experiments on grasping imply that when employing a handheld tool such as pliers to grasp another object, motor representations of the way that we would grasp that object with our own hand are instantiated to guide the tool's grip orientation. fMRI data indicate that the same areas of the motor cortex were activated when planning a grasp either with the hand or with the mechanics of a handheld tool. This strongly suggests that motor-based mental representations for manual actions performed directly with our biological effectors provide the operational basis for orienting and manipulating the clasping or gripping components of a handheld tool, thereby facilitating the 'transfer of skill' between hand and tool (Jacobs, Danielmeier and Frey 2010; see also Umilta et al. 2008). During use, the tool becomes one with the skilled practice of mind–body.

CONCLUSION

The complexity of the brain–hand–tool relationship lays to rest any lingering credence in mind–body dualism, and goes one step further by disclosing the inseparable relation between mind, body and environment. Importantly, it makes plain the unfeasibility of a fully 'natural' or 'normal' body. The physical, neurological and psychological convergence of human and machine makes it difficult, if not impossible, to determine where the body begins and ends. In their *Assembling Bodies* exhibition catalogue,[11] curators Anita Herle, Mark Elliot and Rebecca Empson observe that '[t]echnologies intended to augment or enhance the body often extend the body [through time and space] beyond its corporeal boundaries. They do not make the body 'whole', but add to it in a process that has no preordained end' (2009: 77).

The relation between brain, hand and tool is at once evolutionary, physical, neurological, psychological, cultural and social in nature. This multifaceted relation holds the key to what makes us human. Anthropology's continued involvement in exploring the everyday manifestations of this remarkable union is essential to the growth and development of the discipline's expertise in the related fields of craft, skill, technology, work and sport, as well as to its ongoing contributions in the fields of medicine and health, and gender, sexuality and the body.

NOTES

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2 Exceptions include, for example, drinking straws, which are manipulated, at least in part, with the mouth. Upper-limb amputees also learn to use their feet and mouths to perform many of the tasks that handed individuals habitually execute with tools.

3 Exceptions include a number of excellent anthropological studies of the use of hand gesture and deictic pointing in communication, including, for example, Edwin Hutchins and Leysia Palen (1993), John Haviland (2000) and Nick Enfield (2005).

4 Prehensility is displayed not only by hands but also by toes, monkey tails, elephant trunks and the snouts of marsupials. In differentiation from prehensile movements, non-prehensile ones are hand and finger interactions with an object, instrument or material that do not involve grasping.

5 See Sennett (2008: 152) for a more detailed discussion of the proactive and reactive properties of touch.

6 A housing joint is a simple rectangular channel cut across the grain of a board that 'houses' the end of another board slotted in perpendicularly (e.g. a shelf in a bookcase).

7 My survey of the brain science literature turned up an underlying assumption that human spatial understanding is universally manifested from an ego-centric perspective. However, ethnographic studies of spatial relativity (i.e. Levinson 1996; Senft 1997) reveal that some individuals or cultural groups display a strong propensity to calculate the location of an object or thing relative to neighbouring objects or to absolute frames of reference (see also Downey, this volume).

8 For example: snipe bill plane; swan neck chisel; shoulder plane; bullnose plane; granny's tooth plane; head, striking face and claw of a hammer; saw tooth; cheek of a frame saw; mouth, throat, frog, toe horn and sole of a bench plane; neck of a chisel; jaws of a ratchet brace; tusk peg; dovetail joint; tongue and groove joint; finger joints; male and female components of a mortise-and-tenon joint.

9 In Arabic and French, for example, object noun and action verb are derived from the same root. In Arabic nouns are derived from the verb form: saw (n) منشار (v) نشر; hammer (n) مدقة (v) دق; chisel (n) منقاش (v) نقش; plane (n) مسحخ (v) سحخ; French saw (n) *scie* (v) *scier*; hammer (n) *marteau* (v) *marteler*; chisel (n) *ciseau* (v) *ciseler*; plane (n) *rabot* (v) *raboter*.

10 The premotor cortex and supplementary motor area are part of the overall motor cortex located at the posterior of the frontal lobe.

11 *Assembling Bodies: art, science and imagination* was held at the University of Cambridge Museum of Archaeology and Anthropology, March 2009 to November 2010.

REFERENCES

Baker, Frank 1888. 'Anthropological Notes on the Human Hand', in *The American Anthropologist*, vol. A1, issue 1, pp. 51–76.

Bell, Charles 2009 [1833]. *The Hand: its mechanisms and vital endowments as evincing design*. Breinigsville, PA: General Books LLC.

Berti, Anna and Francesca Frassinetti 2000. 'When Far becomes Near: remapping of space by tool use', in *Journal of Cognitive Neuroscience*, 12(3): 415–420.

Coy, M.W. (ed.) 1989. *Apprenticeship: from theory to method and back again*. Albany, NY: SUNY Press.

Crawford, Matthew 2009. *Shop Class as Soulcraft: an inquiry into the value of work*. London: Penguin.

Cushing, Frank Hamilton 1892. 'Manual Concepts: a study of the influence of hand-usage on cultural growth', in *American Anthropologist*, 5(4): 289–318.

Dilley, R. 1986. 'Tukolor Weavers and the Organisation of Their Craft in Village and Town', in *Africa: Journal of the International African Institute*, 56(2): 123–147.

Downey, Greg 2005. *Learning Capoeira: lessons in cunning from an Afro-Brazilian art*. Oxford: Oxford University Press.

Downey, Greg 2010. 'Practice without Theory: a neuroanthropological perspective on embodied learning', in T. Marchand (ed.), *Making Knowledge*, special issue of *Journal of the Royal Anthropological Institute*, S22–S40.

Enfield, N.J. 2005. 'The Body as a Cognitive Artifact in Kinship Representations: hand gesture diagrams by speakers of Lao', in *Current Anthropology* 46(1): 51–80.

Farne, Alessandro, Atsushi Iriki and Elisabetta Ladavas 2005. 'Shaping Multisensory Action-Space with Tools: evidence from patience with cross-modal extinctions', in *Neuropsychologia*, 43(2): 238–248.

Frey, Scott 2008. 'Tool Use, Communicative Gesture and Cerebral Asymmetries in the Modern Human Brain', in *Philosophical Transactions of the Royal Society B – Biological Sciences*, 363(1499):1951–1957.

Goody, E. 1989. 'Learning, Apprenticeship and the Division of Labour', in M.W. Coy (ed.), *Apprenticeship: from theory to method and back again*. Albany, NY: SUNY Press, pp. 233–256.

Grafton, S.T., L. Fadriga, M.A. Arbib, M.A. and G. Risolatti 1997. 'Premotor Cortex Activation During Observation and Naming of Familiar Tools', in *NeuroImage*, 6, 231–236.

Grasseni, Cristina 2007. 'Communities of Practice and Forms of Life: towards a rehabilitation of vision', in M. Harris (ed.), *Ways of Knowing: new approaches in the anthropology of experience and learning*. Oxford: Berghahn, pp. 203–221.

Greenfield, Patricia 1991. 'Language, Tools and Brain: the ontogeny and phylogeny of hierarchically organized sequential behavior', in *Behavioral and Brain Sciences*, 14(4): 531–551.

Grosz, Elizabeth 1994. *Volatile Bodies: towards a corporeal feminism*. Bloomington, IN: Indiana University Press.

Haviland, John 2000. 'Pointing, Gesture Spaces, and Mental Maps', in David McNeill (ed.), *Language and Gesture*. Cambridge: Cambridge University Press, pp. 13–46.

Herle, Anita, Mark Elliot and Rebecca Empson (eds) 2009. *Assembling Bodies: art, science and imagination*. Cambridge: Museum of Archaeology and Anthropology, University of Cambridge.

Hertz, Robert 2007 [1909]. 'The Pre-Eminence of the Right Hand: a study of religious polarity', in Margaret Lock and Judith Farquhar (eds), *Beyond the Body Proper: reading the anthropology of material life*. Durham, NC: Duke University Press, pp. 30–40.

Herzfeld, Michael 2004. *The Body Impolitic: artisans and artifice in the global hierarchy of value*. London: University of Chicago Press.

Holmes, Nicholas and Charles Spence 2004. 'The Body Schema and the Multisensory Representation(s) of Peripersonal Space', in *Cognitive Processing*, 5(2): 94–105.

Hutchins, Edwin and Leysia Palen 1993. 'Constructing Meaning from Space, Gesture, and Speech', in Lauren Resnick, Roger Säljö, Clotilde Pontecorvo and Barbara Burge (eds), *Discourse, Tools, and Reasoning: essays on situated cognition*. Berlin: Springer, pp. 23–40.

Ingold, Tim 2006. 'Walking the Plank: meditations on a process of skill', in J.R. Dakers (ed.), *Defining Technological Literacy: towards an epistemological framework*. New York: Palgrave Macmillan, pp. 65–80.

Jacobs, Stéphane, Claudia Daniel Meier and Scott Frey 2010. 'Human Anterior Intraparietal and Ventral Premotor Cortices Support Representations of Grasping with the Hand or a Novel Tool', in *Journal of Cognitive Neuroscience*, 22(11): 2594–2608.

Lave, Jean and Etienne Wenger 1991. *Situated Learning: legitimate peripheral participation*. Cambridge: Cambridge University Press.

Leakey, Mary D. 1971. *Olduvai Gorge: excavations in beds I and II, 1960–1963*. Cambridge: Cambridge University Press.

Levinson, Stephen 1996. 'Relativity in Spatial Conception and Description', in J. Gumperz and S. Levinson (eds), *Rethinking Linguistic Relativity*. Cambridge: Cambridge University Press, pp. 177–202.

Makovicky, Nicolette 2010. 'Something to Talk About: notation and knowledge making among Central Slovak lace-makers', in T. Marchand (ed.), *Making Knowledge*, special issue of *Journal of the Royal Anthropological Institute*, S80–S99.

Marchand, Trevor H.J. 2001. *Minaret Building and Apprenticeship in Yemen*. Richmond: Curzon.

Marchand, Trevor H.J. 2007. 'Crafting Knowledge: the role of "parsing & production" in the communication of skill-based knowledge among masons', in M. Harris (ed.), *Ways of Knowing*. Oxford: Berghahn, pp. 173–193.

Marchand, Trevor H.J. 2008. 'Muscles, Morals and Mind: craft apprenticeship and the formation of person', in *British Journal of Educational Studies*, 56: 245–271.

Marchand, Trevor H.J. 2009. *The Masons of Djenné*. Bloomington , IN: Indiana University Press.

Marchand, Trevor H.J. 2010. 'Making Knowledge: explorations of the indissoluble relation between minds, bodies and environment', in T. Marchand (ed.), *Making Knowledge*, special issue of *Journal of the Royal Anthropological Institute*, S1–S21.

Martin, A., C. Wiggs, L. Ungerleider and J. Haxby 1996. 'The Neural Correlates of Category-Specific Knowledge', in *Nature*, 379(6566): 649–652.

Marzke, Mary W. 1997. 'Precision Grips, Hand Morphology, and Tools', in *American Journal of Physical Anthropology*, 102(1): 91–110.

Marzke, Mary W. and R.F. Marzke 2000. Evolution of the Human Hand: approaches to acquiring, analysing and interpreting the anatomical evidence', in *Journal of Anatomy*, 197: 121–140.

Maynard, A., P. Greenfield and C. Childs 1999. 'Culture, History, Biology, and Body: native and non-native acquisition of technological skill', in *Ethos* 27(3): 379–402.

Maynard, A., K. Subrahmanyam and P. Greenfield 2005. 'Technology and the Development of Intelligence: from the loom to the computer', in R. Sternberg and D. Preiss (eds), *Intelligence and Technology: the impact of tools on the nature and development of human abilities*. London: Lawrence Erlbaum Associates, pp. 29–54.

Mead, Margaret (ed.) 1953. *Cultural Patterns and Technical Change*. Paris: UNESCO.

Mercer, Henry C. 2003 [1929]. *Ancient Carpenters' Tools*. Mineola, NY: Dover Publications.

Millroy, Wendy Lesley 1992. 'An Ethnographic Study of the Mathematical Ideas of a Group of Carpenters', in *Journal for Research in Mathematics Education*, i–210.

Mines, Mattison 1982. 'Models of Caste and the Left-hand Division in South India', in *American Ethnologist*, 9(3): 467–484.

Needham, Rodney 1960. 'The Left Hand of the Mugwe: an analytical note on the structure of Meru symbolism', in *Africa: Journal of the International African Institute*, 30(1): 20–33.

Needham, Rodney 1967. 'Right and Left in Nyoro Symbolic Classification', in *Africa: Journal of the International African Institute*, 37(4): 425–452.

O'Connor, Erin 2005. 'Embodied Knowledge: the experience of meaning and the struggle towards proficiency in glass-blowing', in *Ethnography*, 6(2): 183–204.

Paradise, Ruth and Barbara Rogoff 2009. 'Side by Side: learning by observing and pitching in', in *Ethos*, 37(1): 102–138.

Peeters, R., L. Simone, K. Nelissen, et al. 2009. 'The Representation of Tool Use in Humans and Monkeys: common and uniquely human features', in *Journal of Neuroscience*, 29(37): 11523–11539.

Portisch, Anna 2010. 'The Craft of Skilful Learning: Kazakh women's everyday craft practices in western Mongolia', in T. Marchand (ed.), *Making Knowledge*, special issue of *Journal of the Royal Anthropological Institute*, S62–S79.

Preiss, David and Robert Sternberg 2005. 'Technologies for Working Intelligence', in R. Sternberg and D. Preiss (eds), *Intelligence and Technology: the impact of tools on the nature and development of human abilities*. London: Lawrence Erlbaum Associates, pp. 183–208.

Rice, Tom 2010. Learning to Listen: auscultation and the transmission of auditory knowledge', in T. Marchand (ed.), *Making Knowledge*, special issue of *Journal of the Royal Anthropological Institute*, S41–S61.

Rose, Mike 2004. *The Mind at Work: valuing the intelligence of the American worker*. London: Penguin.
Rose, Walter 2001 [1937]. *The Village Carpenter*. Hertford: Stobart Davies.
Senft, Gunter 1997. *Referring to Space: studies in Austronesian & Papuan languages*. Oxford: Clarendon Press.
Sennett, Richard 2008. *The Craftsman*. London: Allen Lane.
Sinclair, Simon 1997. *Making Doctors: an institutional apprenticeship*. Oxford: Berg.
Stoller, Paul 1989. *The Taste of Ethnographic Things: the senses in anthropology*. Philadelphia, PA: University of Pennsylvania Press.
Takahashi, Chie, Jorn Diedrichsen and Simon Watt 2009. 'Integration of Vision and Haptics during Tool Use', in *Journal of Vision* 9(6): 3.1–13.
Taylor, Jeff 1996. *Tools of the Trade: the art and craft of carpentry*. San Francisco, CA: Chronicle Books.
TenHouten, Warren 1995. 'The Eclipse of the Sacred and the Paradoxical Liberation of the Right Hand', in *Anthropology of Consciousness*, 6(2): 15–26.
Umilta, M., L. Escola, I. Intrskirveli, et al. 2008. 'When Pliers Become Fingers in the Monkey Motor System', in *Proceedings of the National Academy of Sciences of the United States of America*, 105(6): 2209–2213.
Updike, John 2003. 'Tools', in *Poetry*, 182(3): 134.
Wacquant, Loïc 2004. *Body and Soul: notebooks of an apprentice boxer*. Oxford: Oxford University Press.
Washburn, Sherwood 1960. 'Tools and Human Evolution', in *Scientific American*, 203(3): 63–75.
Weber, Robert J., Stacey Dixon and Antolin M. Llorente 1993. 'Studying Invention: the hand tool as a model system', in *Science, Technology and Human Values*, 18(4): 480–505.
Wilson, Frank R. 1998. *The Hand: how its use shapes the brain, language and human culture*. New York: Pantheon Books.