Chapter 2
Technology, Psychology, and Evolution

"Move over, King Kong. A chimpanzee named Tushi is putting up some regal resistance at the Royal Burgers' Zoo in Arnhem, the Netherlands. That's where she knocked a filmmaker's drone clear out of the sky in April using a 1.8-meter-long stick. Researchers report online today in the journal 'Primates' that this is strong evidence of planned, deliberate tool use among chimps, adding to evidence that these primates can think ahead and be creative in their toolmaking. A Dutch TV crew had set out to make a public relations documentary of the troop—part of several groundbreaking studies since it formed in 1971—and tried to use a drone to capture close-ups and overhead shots of Tushi and the other chimps. The filmmakers first tested their drone without a camera, arousing the interest of the troop. Four chimps—including Tushi—climbed several meters up the scaffolding in their enclosure. Tushi and another female carried willow switches. When the drone returned, this time with a camera, Tushi used hers to swat it out of the sky. Still filming, the drone tumbled to the ground, where it was examined by other members of the troop. Researchers say it's not clear whether Tushi was annoyed by the drone or only curious—they say her facial expression suggests she wasn't particularly afraid. But the footage is evidence that her actions were planned and deliberate, and it shows just how resourceful chimps can be at using whatever materials are available as tools."

Source: Chimps destroy documentary drone with twig tools, Vogel (2015)

The description above is an interesting observation on the quaint ways in which animals use tools. Similarly, in the last chapter, we had mentioned two marvels, one man made, that is, the Taj Mahal in India and the other a product of nature, namely the gigantic nest created by a newly found bird in Java who has been observed collecting material from forests to craft its nest, much like its own Taj Mahal. The commonality between the two is simple. As discussed earlier, both were created by master craftsmen who were not using scientific theory for their creations, providing evidence that some form of activity had evolved among living beings, even without the cognition of the principles of science. And, even more importantly, technology, or at least a sense of technology, (that is, to use things, manipulate them, or simply indulge in mimicry), seems to manifest itself right through the evolution of behavior, among both human and other living beings. In this chapter we will focus on the forms of structures and functions that emerged in the course of evolution and made

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living beings capable of not only displaying technological behavior but also creating artifacts of technology.

> ***Anthropomorphizing**: attributing characteristics of living creatures to lifeless objects*

We must also remember that, as mentioned in the last chapter, technology, per se, is interactive. The creation of some gadget and later, the possession of that gadget is not simply about having it somewhere around us. We play with it, we care about it, and we even attach our emotions to it. What do we mean when we say, "my car is my baby, I care about it the way I would care for my baby"? We refer to it as "my Mustang" and even attribute animal features to it. According to anthropologists, we are **anthropomorphizing**. This is in line with the thoughts and writings of Ihde (1979, see Chap. 1) who believes in the non-neutrality of technology and that the world is reflected back to us through technology. The things we create generate bundles of relations and carry our interests and emotions. Consider the statement of a young child who is ever so possessive of his mobile phone: "my phone is my biggest buddy because it helps me communicate with my sister living in another city." Thus, it is not attachment to just nature and its products that have been an integral part of our evolution (remember Eve and her obsession with the apples in the forbidden garden!). This attachment became even more so when such products were not only found useful but were also seen to help us to augment our adaptation to an unsympathetic environment. Over a period of time, it was but natural that such an attachment translated to other man-made artifacts which served similar purposes. In other words, not only did human structures and functions evolve to the stage that it became possible for us to create objects to aid our adaptation and survival but that we also developed an attachment for such objects, whether they originated in nature or were made by man.

2.1 Could We Have Remained a Tech-Devoid Society? The Evolution of Technology

If one studies the course of technological development, one can see a clear evolutionary pathway. Each step of technological innovation can be traced to how it enabled man to gain mastery over an uncooperative environment.

Thus, hearing aids were devised to help the hearing-impaired person overcome his helplessness in communicating with others. When humans started moving around and were often beyond the range of normal hearing, the Morse code and the telephone were invented. Inability to communicate with people across multi-continent business led to improvements in videoconferencing technology. The above are examples from one field, namely communication technology. The ever-evolving internet, technology in the field of manufacturing and robotics, technology in banking and finance, and technology in rehabilitation are all examples of tools that have helped humans in gaining mastery over the environment. Each invention, from the wheel, to the printing press, the steam locomotive, the electric bulb, computers, spaceships, nuclear power generators, wind and solar power generators went a long way in helping man to adapt to a changing environment.

The question however is, is this need to adapt to the changing environment, a product of the present-day society, when speed has become imperative? Or going farther into the past, is this urge limited to the last few centuries (since the Industrial Revolution) or maybe to the ancient civilizations of the Egyptians, the Greeks and the Romans, or the Aryans of India, when the construction of colossal buildings, monuments, and statues necessitated the use of the wheel, the pulley, and the lever system? We would have to stretch ourselves to a much older period of time for understanding this need to control the environment. The urge to adapt dates back, in fact, to millions of years and is not restricted to man or even to primates. Adaptive behavior has been found in animals much lower down in the phylogenetic scale.

The fact is that nonhumans also employ a wide variety of tools to enhance their survival. When organisms find that their natural capabilities do not allow them to overcome problems around them, they start thinking of other ways, many of which are through the use of tools devised for a particular purpose.

2.1.1 Technology and Animal Behavior

We start with an example of animal behavior that all students of psychology are familiar with. Psychologists have shown how animals are capable of manipulating objects in a novel situation. A popular experiment on chimps conducted by Kohler (1917, 1925) required them to stack boxes to reach a banana that was hanging out of their reach. When standing on the boxes stacked one upon the other failed to get them to the enticing bananas, they acted smartly by fitting the two shorter sticks into a longer one to retrieve the banana. Essentially, Kohler was deviating from the mechanistic explanations offered by behaviorists suggesting that the cognitive skills needed to solve problems of this technological nature are far more complex than our knowledge of neurology or even the behavioral history of the animal.

A second example, that we would like to present, is the work of the famous primate researcher, Jane Goodall. In an interview with Jane Goodall, on October 12th 2015, she was asked what made her decide to work with chimps. Her reply was that it was not she who had chosen this field of study. It had been decided by Louis Leakey, the famous paleontologist and her mentor.

> "He believed there was an ape-like, human-like common ancestor six million years ago. He wanted to get a feeling as to how early man might have behaved. His reasoning was that if I would find behavior similar or the same in humans and chimps today, possibly those behaviors were also existent in the common ancestor. That's why he sent me in the forest" (Bethge & Grolle, interview with *der Spiegel*, 2015).

Once sent to the Gombe Forest of Tanzania, she started observing the chimps there, very closely, and, with the intent of discovering commonalities between chimp behavior and that of humans. What, at that time, seemed most amazing was the ability of chimps to make and use tools. Today, of course, there are many examples of how a variety of animal species use tools but this was the first time that the phenomenon was actually observed. Dame Goodall rose to become the world's most famous primate researcher and published the main body of her work in the volume entitled, *The Chimpanzees of Gombe: Patterns of Behavior*, in 1986. She describes how very early in her study she observed a chimp, whom she had named David Greybeard, experiment with a wide variety of twigs and to finally use an appropriate one to burrow through the soil and find a termite for his meal. She called this "termite fishing" and it was the first time that the traditional belief of man as the only toolmaker was challenged. Besides termite fishing, she also observed chimps taking twigs from trees and stripping off the leaves to make the twig more effective as a tool (Goodall, 1999), a behavior, one would all agree, that falls under the category of object modification and a stage often said to be the preliminary one to actual toolmaking. So revolutionary were these findings that her mentor Louis Leakey was of the view that we must either redefine man and tools or accept chimpanzees as human.

Today, it is also known that chimps use rocks to crack nuts. When unsure of the depth of water, gorillas use a stick to find out the depth of water and also use it like a walking stick to cross the water. Despite having no hands, elephants are known to tear branches from trees to fend themselves from flies or to scratch their bodies. They also have been seen to mount rocks one upon the other, to elevate their standing position. So, without doubt, there is ample proof that toolmaking is not of recent origin but dates back to our ape ancestry, being carried through the evolutionary process for the simple reason that it proved adaptive.

Goodall talks of how these chimps would manifest emotions much like we do and for very much the same reasons. In the interview with *der Spiegel* (2015) mentioned above, she gives examples of how chimp communities manifested not only simple emotions such as joy, anger, and jealousy, but also more subtle ones such as awe, curiosity, and embarrassment. Other scientists have been able to induce depression in animals by keeping them in cages or by manipulating other aversive conditions experimentally. Recent research in a relatively new area of study, namely, **animal sentience**, helps scientists to understand the biological mechanisms underlying such behavior.

> ***Animal sentience****: the study of animal ability to feel, perceive, or experience subjectively*

Controlled laboratory studies by a number of psychologists including Pavlov, Skinner, and Kohler and corroborated by observations by Goodall and other primate researchers also prove that animals are capable of learning new skills. While everyone will agree that adaptation is a type of learning, it may surprise many, that both Pavlovian and instrumental learning have been seen even in invertebrate organisms such as the mollusk (Brembs, Lorenzetti, Reyes, Baxter, & Byrne, 2002) and roundworm (Zhang, Lu, & Bargmann, 2005). In mammals and primates, on the other hand, there is clear evolutionary history revealing that with each successive stage of evolution, the brain also evolved, increasing its capabilities in manifold ways.

As the brain evolved, the organism became capable of new functions, at the same time being able to retain those that had proved adaptive in the past. Developments in the understanding of evolutionary growth of animal behavior and their comparisons led to the growth of **neuro-ethology**, a multidisciplinary branch of study involving many areas of biology and psychology. Basically, it seeks to find out how the nervous system translates relevant information from the environment into natural behavior. One example of this is the study of bats that are known to use echolocation for navigation and finding their prey. Neuro-ethology helps us understand the ways in which the acoustic system of bats is equipped with the ability to convert sound features into a sensory map of behavioral significance. It is neuro-ethology, again, that enables us to understand the cortical substrates of a phenomenon known as **Area Restricted Search** (ARS) and which may provide answers to why we could not remain a tech-devoid society.

> ***Neuro-ethology****: the study of how nervous system translates information from the environment into behavior*

> ***Area Restricted Search****: restricting the search for new foraging areas to places earlier known to be high density food supply areas*

2.1.2 The Cognitive Shaping of Technology: Area Restricted Search

For survival, every organism must find resources, the primary ones being food, mates, and territory. Foraging activity normally involves locomotion in search for food. Hunting activity by predators gradually causes depletion in the number of animals that are being hunted and, after a certain point of time, habitation of that area becomes unviable because of depleting dietary resources. Once such depletion has taken place, there are two choices that are available to the animal: one, that he moves to other areas in the search for food, and two, that he remains in this familiar area but suffers hunger as a result. It is at this time that the animal must start making a choice. The choice is an important one, one that is directly related to survival and concerns whether to move around and search for food, or, stay at one place, conserve energy but remain hungry. One wrong choice and the animal is doomed. Those animals that are able to make the right choice survive, while others die. Studies on foraging behavior show that most animals tend to remain in the vicinity where food had been available in abundance at an earlier point of time, or that their search for food seems restricted to known areas. Very aptly, this type of behavior has been termed Area Restricted Search (ARS). In an early study of search behavior among rats, the famous psychologist Tolman (1948) noticed that rats would move about in the vicinity of the same areas where they had earlier obtained food. He explained this through the concept of **cognitive maps** or representations of spatial directions in the brain. Later studies by Hills, Todd, and Goldstone (2008) clarify that foraging behavior among animals seems to follow a similar search strategy. When faced with the same problem, namely foraging, at a later date, the animal will use cognitive maps created

> ***Cognitive maps****: representations of spatial directions in the brain*

from earlier search behavior and will, thereby, be able to conserve energy and time by restricting its later search to locations known to be rich in food resources. Most organisms will prefer to stay in areas earlier found rich in resources and move away from low resource density areas.

It is clear that such area restricted search behavior has adaptive value. One line of evidence is that it is seen in a variety of organisms, ranging from the simple *E. coli* bacteria (Eisenbach & Lengeler, 2004) to species as diverse as houseflies, bumble bees, and even humans (Hills, Brockie, & Maricq, 2004). In every case, the choice was to move towards known high resource density areas and stay near them.

In other words, ARS is goal-directed behavior. During the course of evolution, the brain also evolved and the basal ganglia formed links with the upper centers of the brain, particularly with the frontal cortex, and it is these structures that are responsible for executing movements of the limbs. According to Hills (2004), "the evolution of goal-directed cognition emerges out of mechanisms initially in control of foraging," (p. 3). And, one result of such goal-directed cognition is the evolution of technology. The way in which tools helped was that these tools made it possible for man to make those choices that are adaptive. However, the development of these tools would not have been possible if our brain had not evolved to the point that such reward-seeking behavior became possible (Fig. 2.1 delineates the primary parts of the human brain and spinal cord).

From the literature on ARS, it seems clear that animals at various levels of the phylogenetic scale are able to make choices that enable them to not only find food

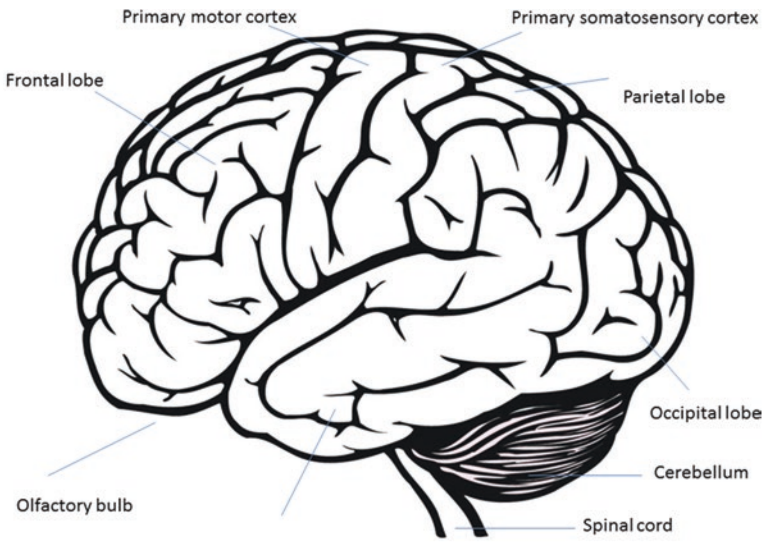

Fig 2.1 Diagram of the primary areas of the brain and the spinal cord

and thereby survive in the face of imminent death, but also to gain mastery over the environment. ARS enabled adaptive choices and offered a vehicle for a trade-off between time taken for exploration and exploitation, thus enabling the organisms to save precious time and energy.

> ***Dopamine****: a neurotransmitter which plays an important role in a variety of behavior*

Being adaptive, ARS survived through the evolution of species and neuroscientists provide many lines of evidence for this, the most important being the common denominator of the neurotransmitter **dopamine** and dopamine modulated functions across species (Hills & Dukas, 2012). Higher levels of dopamine tend to increase turning angles while selectively killing dopamine neurons reduces the capacity for ARS (Hills et al., 2004). The importance of dopamine is clear from the large number of functions that are controlled by it (Barron et al., 2013).

Recent advances in neurosciences and empirical research also clarify that at the base of this ability to gain mastery over the environment is choice making. Leotti, Iyengar, and Ochsner (2010) make this point very clear through a paper aptly entitled, *Born to Choose: the origins and value of the need for control*. According to them, not only is choice the vehicle for exercising control, but there are clear neural substrates for this ability to choose.

> "Converging evidence from animal research, clinical studies, and neuro-imaging work suggest that the need for control is a biological imperative for survival, and a corticostriatal network is implicated as the neural substrate of this adaptive behavior" (Leotti et al., 2010, p. 457).

This ability to make choices was an important adaptation and seems to date back some 530 million years ago. The vertebrate brain became similar to what is ours today, and it made possible the ability to make calculated choices or to make what can be termed a cost–benefit analysis. It was the development of this ability that made it possible for vertebrates to take a holistic view of the environment and move around in the search for rewards (Murray, Wise, & Rhodes, 2011).

It is as if we are hardwired to make choices, with those that prove to be adaptive being retained while others being lost over a period of time. By exercising choice, we are able to select adaptive behaviors and reject nonadaptive ones. This seems to act as an intrinsic motivation to repeat that same behavior, reinforcing the choice making process and inducing feelings of confidence and success, or what has been termed self-efficacy (Bandura, 1997). It is also seen that while restriction of choice is aversive to both humans and other animals (Morgan & Tromberg, 2007; Clubb & Mason, 2003), wrong choices produce negative feelings which hamper later learning and can lead to learned helplessness (Patall et al., 2008). In other words,

Behavior is chosen====⇒desired outcome====⇒perceived control====⇒ repetition of chosen behavior

As the behavior becomes more and more under the voluntary control of the species, people are able to restrict their behavior to those choices that have previously yielded desired results. Various reports conclude that when choices are provided to a person working on a task, the results are more fruitful than the ones that are obtained when no choice is provided. So powerful is the effect of choice that Brown and his coworkers refer to it as "*The lure of choice*" in their article of the same name (Brown, Read, et al., 2003).

Neurologically too, there are specific areas of the brain related to the ability to adapt and this is seen not only in animals but even in young infants long before they have had a chance to learn the value of autonomy from the society. Greater discharge is seen in areas of the pre-frontal cortex when rewards are delivered instrumentally, that is, after some form of behavior, than when they are given passively and regions of the Pre-frontal Cortex (PFC) and the striatum form a network to produce motivational states associated with choice and control (Leotti et al., 2010). Imagine two situations, one in which a child gets a reward for good behavior and the other, when he is simply given something he likes, but that something cannot be called a reward because he did not earn it. The PFC area of the brain would show much greater activation in the former situation than in the latter, motivating the child to further seek such rewards by repeating the same behavior. Also, different areas of the brain are activated depending on whether the choices are opportunities or are in the context of greater or lesser threat, thereby helping the individual to minimize threat and maximize opportunities. According to Leotti et al. (2010), the areas in the brain for choice opportunity and choice in the context of threat involve different locations, which have been uncovered through imaging of the medial sections of the left hemisphere. These are as follows:

- Choice opportunity: mainly involving the striatum for reward experience and Medial Pre-Frontal Cortex (MPFC) for increased self-relevance
- Choice in the context of threat: MPFC for control of emotion and amygdala for negative effect

It would be relevant to point out that the modulator of these anatomical structures is none other than the neurotransmitter dopamine that is crucial in directing foraging behavior and ARS besides playing an important role in a variety of functions ranging from reward seeking, to helping in adaptation to sleep deprivation to executive brain functions so important for adaptive decision-making.

The dopaminergic system, too, has evolved through phylogeny. We see it in lower organisms such as zebra-fish (Schweitzer & Driever, 2009), fruit flies (Liu et al., 2012), sea-urchins (Adams, Sewell, Angerer, & Angerer 2011), and of course, in mammals such as rodents, (Izquierdo & Jentsch, 2012; Arias-Carrion & Poppel, 2007), lamprey (an organism that diverted from the mainstream development of mammals, Murray et al., 2011; Thompson, Ménard, Pombal, & Grillner, 2008; Nieoullon & Coquerel, 2003), through the entire gamut of mammalian evolution, and finally in humans, allowing us to do a lot more in addition. Evolution has brought in its wake, human beings with a bigger, better brain (Kool & Agrawal, 2012, 2009) with clear dopaminergic and serotonin pathways found important for so many different functions of the body, including learning and reward seeking, pain and pleasure, etc (see Fig. 2.2).

Thus, we not only seek rewards but also like to talk about rewards and, going a step further, are even able to develop a mental time travel ability (the ability to

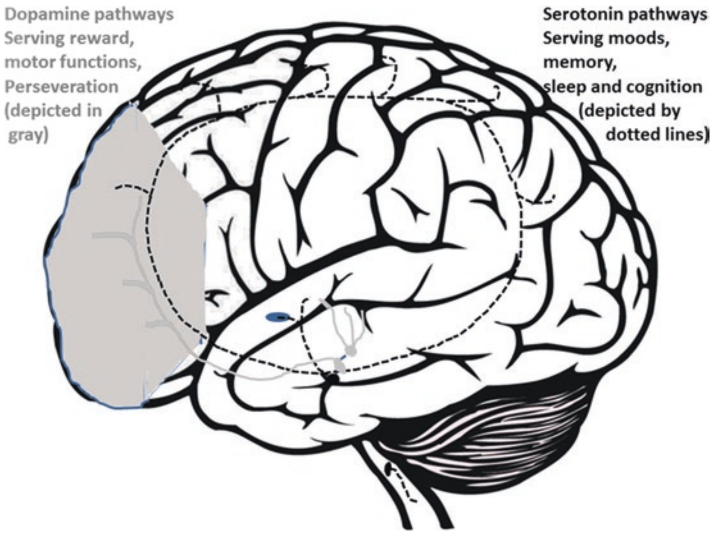

Fig 2.2 Dopamine and serotonin pathways in the human brain. Adapted from National Institutes of Health, United States Department of Health and Human Services

remember the past and predict the future (Corballis, 2009), and an ability to minimize costs (Mazzoni, Hristova, & Krakauer, 2007). Are not these two abilities, ever so important for the development of technology? Keeping in mind the needs of the future generations or even the present generation in changing times helps both the designer and the manufacturer to present technology that is not only effective but also cost-effective. Think of any realm of technology, from the lowly safety-pin to a space capsule, technological innovation does not happen in a vacuum: it builds on past knowledge. What is termed innovation is not really an innovation: it has evolved from some technology that preceded it. Such a path to innovation becomes imperative because of the very anatomical structures and physiological processes that are entailed in any cognitive processing, and beyond doubt, technology emanates from cognition.

But can this facility of choosing become maladaptive? Our own experiences probably vouch for this, that when faced with too many options, we start feeling stressed and avoid decision-making or leave it to others. Would you believe that this phenomenon, too, is supported by neurological evidence? Neuroscientists such as Fleming et al. (2010) point to the problems faced when we have far too many choices and what is the result of too many connections between the PFC and basal ganglia. The ways in which dopamine levels have changed in the course of evolution and its effects on the human mind have been described in Box 2.1.

From the above it becomes clear that the ability to make and use tools is not limited to humans or even to hominids but extends down to organisms much lower down the phylogenetic scale. Over the millions of years, the human brain evolved, becoming what it is like today, through the evolutionary processes of natural

Box 2.1: The Dopaminergic Mind Hypothesis

Recently, neuroscientists have postulated what has been called the dopaminergic mind hypothesis. It focuses on the differences between modern man and their hominid relatives in terms of changes in dopaminergic levels. It theorizes that due to the consumption of meat, there was an increase in dopamine levels some two million years ago. With further dietary, environmental, and social changes some 80,000 years ago, further changes in dopamine levels have been said to have taken place.

As a result, we modern humans are far richer in our dopamine levels than other apes and there have been consequent changes in our personality. A high dopamine personality is said to be typified by the following: high intelligence, sense of personal destiny, and a religious/cosmic preoccupation. At the same time, such an individual also shows a high risk taking and an obsession with goal achievement to the extent of becoming ruthless emotionally detached.

When all of us start showing these characteristics, it constitutes what has been nomenclatured, a dopaminergic society. Much like the constituent members, the society is extremely goal oriented, fast paced and, perhaps, even manic in its pursuits of goals. The society is seen to focus more on competition and aggression rather than on nurturance and communality.

While we do not have direct neurological evidence for such increased levels of dopamine in comparison to other members of the ape family, we do have sufficient behavioral evidence and some indirect anatomical evidence in favor of this hypothesis (Previc, 2009; Raghanti et al., 2008).

Does not the above ring a bell in our mind? Should we say that the extreme materialism and rat race seen in twenty-first century individuals, almost all around the globe, are because of this?

selection and adaptation. Evidence has also been provided to show that this toolmaking ability can be said to be based on the more primitive ability of foraging for food where making viable choices was important for the survival of the animal. In the words of Leotti and coworkers,

> "Collectively, the evidence suggests the desire to exercise control, and thus, the desire to make choices, is paramount for survival. The opportunity for choice enhances an individual's perception of control, and thus, exercising choice may serve as the primary means by which humans and animals foster this psychologically adaptive belief. Just as we respond to physiological needs (e.g. hunger) with specific behaviors (i.e. food consumption), we may fill a fundamental psychological need by exercising choice. While eating is undoubtedly necessary for survival, we argue that exercising control may be critical for an individual to thrive. Thus, we propose that exercising choice and the need for control—much like eating and hunger—are biologically motivated. We argue that while people may be biologically programmed to desire the opportunity for choice, the value of exercising specific choices likely depends on the available cognitive resources of the decision-maker in the given context, as well as the subjective value of the choice contents, influenced by personal experience and social and cultural learning" (Leotti et al., 2010, p. 459).

2.2 Beyond Darwin and Its Implications for Cognition and Behavior

Advances in modern science and technology could not have taken place if the human brain had not been of the shape and size that it is today. Paleontologists provide sufficient evidence to prove that over the millions of years of the history of mankind, the human brain has undergone considerable change in shape, size, and weight. Much of the changes that have taken place can be explained through the evolutionary processes posited by the father of evolutionary biology, Charles Darwin.

At the same time, modern advances in neurosciences and state-of-the-art neuroimaging techniques clarify that we have come a long way from the initial concepts advanced by Darwin, who explained evolutionary changes in species on the basis of the principles of natural selection and adaptation. While the former isolated structures that would help in the survival of the species, the latter fine-tuned these structures to help in the optimization of the functional aspects of the naturally selected structures. As a result, in each successive generation of species, those organisms that were able to change and adapt survived while others failed to do so. However, over the years, it has become increasingly difficult for scientists to explain the plethora of functions and structures found in any species on the simple principle of adaptation. For example, one can think of the human mouth cavity with the teeth, the mandibles, the upper palate, the lips, etc. The shape of the teeth and the jaws were predicated by the uses to which they had to be put. As man changed, from a carnivore to an omnivore, the size and the shape of the jaws and the teeth changed or became adapted to suit the changing dietary patterns. But were the teeth or the other structures of the mouth cavity basically structured for talking? This is a function being performed by structures that had been formed the way they are for some other purpose, namely, for eating and chewing (Fitch, 2011). A remnant of this function is the canine teeth still found in the human mouth. Another example is the human hand. Our predecessors had claw-like fingers and nails much akin to those of apes and chimpanzees. Look at the beautifully manicured nails and fingers of the men and women of today. As our diet changed, so did our teeth and jaws. As ways of procuring that diet changed and as lifestyles changed, so did our hands. The independence of the thumb from the other fingers was needed for holding objects firmly. But, had it been created to play games on a video console? Had it been created for hitting the space bar on the computer keyboard? How do we describe such changes? Are they adaptations, in the Darwinian sense of the word? Since they do not have a true historical genesis, in the way envisaged by Darwin-Gould and his colleagues (1982) coined another term for such changes, calling them exaptations. **Exaptations** are structures that had been adapted for one purpose but have been later co-opted for another purpose. They are initially products of adaptations that arose through natural selection for optimizing some function but are later being used for some other function.

> ***Exaptations****: evolutionary structures that have been adapted for one purpose but later co-opted for a different purpose*

Apart from such exaptations, there exist other structures that were not initially adaptations for the simple reason that they did not have adaptive value at that time. They were thrown up in the process of adaptation and can therefore be thought of as by-products of the process of adaptation, much as natural gas is a by-product in the process of crude oil refinement. Or, an even better analogy would be the spaces that are created when bridges are built. In order to support these mammoth structures, pillars are put into place. They do not serve as bridges but they are absolutely imperative for the bridge to become a bridge. In the same way, when natural selection takes place, new structures have to be put into place and in this very process of restructuring, new structures much like the pillars of the bridge have to be created. Our large sized human brain is one such example. As it became more and more complex, it threw up hundreds, no, thousands, of by-products which did not have any purpose at that time. But nature is never wasteful. These by-products were later co-opted for other purposes as and when they were needed. They were very much like the support structures of bridges and flyovers, the pillars on which the very structure of the bridge rests. These pillars create spaces that are later used for housing the homeless or for creating green spaces amidst the concrete jungle. In the same way, the restructuring of the brain created spaces that were later used to house functions such as religion and music when man invented them. And, continuing to use the analogy between bridges and brains, just as these open unused spaces under the bridges are known as spandrels, such by-products of adaptation were also termed **spandrels** (Buss, Haselton, Shackelford, Bleske, & Wakefield, 1998; Gould & Lewontin, 1979).

> ***Spandrels****: structures thrown up as a result of adaptations for which no specific use exists at the time*

2.2.1 Significance of Exaptations and Spandrels

By introducing two new tools for the evolutionary scientist, Gould and Vrba (1982) were in no way refuting the Darwinian principles. It is important to understand that structures formed either through exaptation or through spandrels would not have been possible without the base process of natural selection and adaptation. Natural selection remains the primary process for creating complex biological design. It is natural selection that is responsible for creating the original adaptations which are later co-opted to become exaptations, and, again, it is this process of selection that is also responsible for producing adaptations of which spandrels are an incidental by-product. But, the importance of exaptations and spandrels is that though for a period of time, they may look like non-adaptations, they provide the flexibility that any open and resilient system needs (Kool, 2008). They form the wellspring and reservoir and the source of raw material for further selection and are probably one of the causes for the degree of complexity one sees in human functions today and which makes humans better than most other animals, including mammals. This is also the reason why our cognitive system is so much more complex than that of other animals, including primates, leading to our capability to design objects, including technology, so as to make our environmental fit better.

Today the principles of Darwin have come to be applied to a wide variety of not only psychological traits and behaviors but to areas of interest as diverse as economics, anthropology, linguistics, and even computer science, leading to what has been called *Universal Darwinism*, probably coined by notable physicist Richard Dawkins (1983) and advanced by a number of other thinkers and writers including Campbell (2009), Nelson (2007), and Hodgson (2005). Some interesting examples of how exaptations and spandrels have been used to explain changes in various areas have been described in various boxes (Box 2.2, 2.3, and 2.4) in this chapter.

Box 2.2: The Importance of Exaptations and Spandrels

The ability to appreciate and create music: evolutionary adaptation or cultural creation?

Laurel Trainor (2015) from the *McMaster Institute for Music and Mind*, Ontario, Canada attempts to explain the biological basis of music and provides an excellent example of how Darwinian principles of natural selection and adaptation cannot explain the complexities of human behavior.

While most people will insist that music is a creation of culture, there is ample evidence to show that not only is music unique to humans, it is universally seen and exhibits ontological patterns of development and should therefore have some adaptive value. Scientists have long debated on the adaptive value of music, ranging from infant management to social bonding and mating, the important question is whether musical ability is a true evolutionary adaptation or whether it is based on structures that were naturally selected for some other function but later utilized for musical ability?

In his discussion, Trainor questions whether the control and expression of musical behavior at the cortical level should be attributed to structures that can be understood to be as adaptation, exaptation, or as a spandrel. If it is controlled by a true adaptation, one should be able to isolate structures that were not there earlier but were formed to specifically serve the purpose of control of this behavior. He goes on to point out that if one looks at the capabilities needed for musical behavior, it is obvious that pitch perception, time perception, pattern recognition, and rhythm perception are of prime importance, some of which have commonality with other aspects of auditory perception such as those used in auditory scene analysis, which has an older origin and also a clear adaptive function across species. Examining evidence from human ontology along with some phylogenetic evidence, Trainor concludes that the neurological structures underlying musical behavior cannot be explained on the basis of mere evolutionary adaptations. Rather, we can understand musical behavior better if we think of it as a cultural creation which when proved adaptive, exapted structures originally selected for other aspects of auditory perception. At the same time, it is possible that some music-specific abilities rest on aspects that were actual adaptations of earlier structures.

Source: Trainor (2015)

Box 2.3: The Spandrels of Dunkin Donuts, or How the Munchkin Came to Be

Visitors to the Northeast are probably familiar with the miniature Dunkin Donuts confection, the Munchkin.

Think of a normal doughnut. What you have is a circular piece of dough with a hole in the center. You prepare a tray of doughnuts but what are you left with? You are left with as many pieces of dough, each circular in shape, only much smaller than the original doughnut, and of not much use. You have two options: you either throw away that extra dough or as most of us would do, put all the small circles together, knead it all over again and prepare some more doughnuts. But the catch is that each time you will be left with small circles that are of not any use.

Here comes in the creative baker! Rather than throwing away those circles or using more energy and time to create new doughnuts from the leftover dough, he uses them for a new purpose. In the words of Chang,

> "The Munchkin illustrates the concept of exaptation well, though it requires a baker as selector, whereas natural selection operates with no selector. A doughnut in this example is a circular piece of dough with an empty circular middle. Imagine that the shape is created by making a round of dough, and then cutting out the middle piece, leaving you with the doughnut and some extra dough. Imagine further that the baker typically throws the middle piece aside as it serves no purpose. The middle piece here is a spandrel it serves no function to the baker, but is rather a leftover portion of the functional dough the doughnut."

Chang goes on to explain how this exaptation, that is, the munchkin will also be subject to further adaptations. Maybe people will like chocolate munchkins rather than the plain ones, so gradually the baker may concentrate on the chocolate ones and the plain ones may die out.

Source: Posted in *Evolution and Psychology,* Chang (2009)

Box 2.4: Bright Idea: The First LASER

Peter Franken recalls how the laser discoveries excited physicists (interviewed by Joan Bromberg, 1985)

Franken:

> "Let me tell you about the OSA [Optical Society of America] meeting. It was held in Pittsburgh, in 1961 in Pittsburgh.... That was Panic City. The halls were packed. Normally with an invited paper at the Optical Society, you might draw a hundred people. There might be two or three click-click-clicks of cameras taking pictures of the slides. These halls were packed; the ballroom was packed, for this invited paper. I remember as a high point Charlie [Townes]—I'm sorry, Art Schawlow getting up, giving a talk: every slide he projected, there was a veritable staccato machine gun fire of Minoltas going off. It was unbelievable! Panicville. Everybody wanted to get in on it."

(continued)

Box 2.4 (continued)

What caused this excitement? Scientists were demonstrating and talking about the one invention that literally set the world on fire. This invention was the LASER and we all know of the varied uses to which it has been put, from giving sight to millions of sightless people through surgery using lasers, to communication technology and its use of the optical cable capable of transmitting many hundreds of telephone conversations via a fiber thinner than a human hair, to its uses in cosmetic surgery and other forms of more invasive yet painless surgery, and of course to its countless uses in commerce (the laser scanner used at store checkouts, the CDs and DVDs and MP3s, the laser holograms on the credit card). You could probably think of many more uses to which the laser is being put.

But did you know how the invention came to be? How scientists at various laboratories funded by both government and private corporations were trying hard to amplify radiation but failed? The theoretical know-how had been there since the early 1900s when Einstein predicted that rays could stimulate more atoms to emit rays of the same wavelength. Yet scientists at research labs such as Bell Laboratory, Westinghouse, and IBM were not successful even in the 1950s. It was finally Theodore Maiman at Hughes Laboratory who realized that all they needed was a flash lamp. He searched manufacturer catalogues and finally found a helical shaped lamp in which a ruby could be fitted.

> "A flash lamp would do. Scouring manufacturers' catalogs, he found a very bright lamp with a helical shape. Just right, he thought, for fitting a ruby inside. He assembled the components with the aid of an assistant, Irneed'Haenens, and on May 16, 1960 they observed pulses of red light. It was the world's first laser."

This is a clear example of how exaptation takes place in technology. The lamp had not been manufactured for the production of laser beams and would have soon been outsmarted by other more modern lamps and lost in oblivion. But the innovativeness of the smart scientist put to use this lowly lamp to produce something that has such an impact upon our lives.

> "Fantasies of a dreadful death ray led to the discovery of a device which helps people in a million ways"

Source: *American Institute of Physics* (2013)**; (**https://www.aip.org/history/exhibits/laser/interviews/franken_laserexcited_interview.html**)**

So important are these exapted structures that they even form the basis for cultural evolution. How does one explain religion or morality for that matter? We may construe religion as an adaptation that provided survival value when all else seemed beyond hope (Wade, 2015). Or we may think of religion as an exaptation of cognitive structures that had already adapted and evolved to a certain level for other purposes more directly related to survival and were later used for religion (Saad, 2012).

One can even think of cultural traits such as the ones isolated by Hofstede in his classic study of cultural differences around the globe (Hofstede, 1980). A gene-culture evolution approach has been used to explain differences on the cultural trait of individualism-collectivism and Chiao and Blizinsky (2010) have obtained a link between this trait and the frequency of a variant of the serotonin gene across 29 countries.

As our brain underwent exaptations and new spandrels were thrown into existence, our cognitive system advanced to never before known levels. Scientists attempted to understand natural phenomena while engineers used the theory so formulated to develop newer technology from the old. We can use the same concepts of adaptation, exaptation, and spandrels to understand how evolution of technology takes place.

There is however one difference. As Cattani (2008) says,

> "Intentional factors are on the contrary incorporated into an evolutionary theory of technological change. A key difference between biology and technology is that foresightful evolution can actually occur in the context of technology. As Ziman (2000) pointed out, this difference stems from the observation that "…technological change is driven by variation and selection—but these are clearly not 'blind' or 'natural.' This work is being done largely by conscious human effort, without apparently needing guidance from any 'hidden hand,' whether of Nature, the market, or God," (Cattani, 2008, p. 588).

We were able to find novel uses for obsolete technology (one example of how LASER was invented is presented in the box above). While the LASER was said to be a solution without a problem (the uses were thought of much later), some of these exaptations even led to the evolution of technology in line with customer needs and entrepreneurial activity (Dew, Sarasvathy, & Venkataraman 2004).

2.3 Could Technology Have Developed in Any Other Way: The Human Body

Although we have made significant developments in the field of biology, the understanding of the structure and functions of the human body and particularly its executive, the brain, still demands considerable investigation. With about 75 trillion cells in operation and approximately one million in attrition every day, the intricate nature of our human brain is difficult to understand (see Box 2.5).

What is not understood or sometimes not paid heed to is the fact that the things we use on a daily basis are not always compatible with the functioning of the human body. You could call it lack of scientific knowledge in our designing or manufacturing of a product, or putting it more simply, an unfortunate situation imposed upon us for commercial reasons. The keyboard of a computer or the old typewriter is one such glaring example. We have known for a long time that certain letters on the keyboard, such as the letter "a", are used more frequently than others and yet, the current layout of "a" on a QWERTY keyboard is at the far left of the middle row and as per our training in typewriting, this puts a heavy burden on the weakest and

Box 2.5: The Brain Has Been a Matter of Awe Not for Biologists or Psychologists Alone

Poet, Emily Dickinson, has put this awe into words:

> "The brain is wider than the sky
> For, put them side by side,
> The one, the other will contain, and you beside,
> The brain is deeper than the sea,
> For hold them blue to blue,
> The one the other will absorb,
> As sponges, buckets do.
> The brain is just the weight of God,
> For lift them pound for pound
> And they will differ, if they do
> As syllable from sound."

Source: Emily Dickinson, ca 1860, published in 1921

smallest finger of our left hand. Consider what changing the layout of the design of the keyboard would mean? Well, everyone would have to *unlearn* their current skill in typewriting because of a different location of the letter "a" and then engage themselves in *relearning* a new set of movements to operate the keyboard smoothly. Ideally, this is doable, but practically, it has still not been done.

After its invention, when anything is manufactured and enters the market for consumption, the two most important considerations are profitability and ease of use. In some ways, the two issues are interrelated, but it is the latter that we, as psychologists, and even more so, as psychologists studying psychology of technology, are interested in. As far as the manufacturer is concerned, the primary issue is regarding how to get the object into the hands of the consumer such that he/she can operate it with ease. How many companies test their product, thinking about the limits of human functioning? If companies had actually engaged in such thinking, why would people be talking about the ill effects of the excessive use of the ubiquitous cell phone or the carpal tunnel syndrome resulting from continuous working on a computer?

In other words, before any technology is developed, the physical and mental limits of the individual who will use it have to be kept in mind. These limits are set by both phylogenetic and ontogenetic processes, in so far that the limits of the human body are different from those of other animals (**phylogenetic processes**), and that these limits change with the age of the person (**ontogenetic processes**). Let us attempt to understand these limits. We can start by enumerating the systems of the human body. These are as follows:

Phylogenetic processes*:* *differences between organisms of different species*

Ontogenetic processes*:* *differences due to age of the organism*

- The **nervous system** consisting of the brain, spinal cord, and nerves.
- The **muscular system** composed of three types of muscles: smooth, cardiac, and skeletal.

- The **respiratory system** managing the supply of oxygen in the blood through the lungs.
- The **circulatory system** consisting of heart, arteries, and veins and regulating the flow of blood.
- The **digestive system** supplying energy through the operation of esophagus, stomach, liver, and intestines.
- The **excretory system** managing the waste collected in the body through the kidneys and the bladder.
- The **reproductory** system that helps in the formation, release, and transportation of semen and the development and fertilization of the ova followed by the development of the fetus in the womb of the mother.

It was in the wake of the industrial revolution that manufacturing of a great many products was started. While the next few decades saw the arrival of many new products in the market, the focus was hardly on the comfort of the consumer. One just needs to think of the first watches and clocks, the first telephones, or the first typewriters. With time, they have not only become sleek but also more comfortable to use.

Undoubtedly, the scenario has changed but we are still struggling to create products that are best suited for human use. One reason could be the fact that individuals differ in so many ways and that the notion that "one size fits all" does not work. Consider a seat in the airplane which may be too small for an obese person, a car driver whose legs fail to reach the brakes, or left-handed persons using gadgets made for those who are right-handed. Moreover, whether we think of the dimensions of the human body as statistical means, median, or the mode, one thing is for sure, measurements have to be made to arrive at these central tendencies so that we can design products accordingly. Despite the difficulties entailed, it has become possible to measure the human body and its parts, through what has come to be known as anthropometry.

2.3.1 Measuring the Human Body: Anthropometry

In 2006 and later in 2010, famous anthropologist Zeresenay Alemseged and his team reported evidence for the use of tools used some 3.39 million years ago from Dikiki, Ethiopia (Alemseged et al., 2006; McPherron et al., 2010). He posited that though humans and chimps probably share a common ancestor, as revealed by tools used by chimps, man is probably the only primate to make sharp edged tools to hunt for food. Moreover, these primitive 3.39 million year old tools can be said to be the precursors of all the technologies today.

But, more than one question remains unanswered: why was the tool developed? Why did man need a tool more than any other animal? And, even more, what decided the nature of the tool? Purposeless action is not the rule of nature. It must have aided human adaptation in some way. The answer seems to lie in the structure, shape and size, body proportions, and movement potentialities of man vis-à-vis those of other mammals. The human species developed a much larger brain about twice the size of that of the average gorilla or chimpanzee. It reached its largest size during the Neanderthal period and was larger than that of Homo sapiens. In order to feed this brain, good quality, high energy yielding protein and fat was needed, not found in the berries and roots on which man was subsisting. Secondly, while man realized that such good quality nutrients could be obtained from the bodies of other predators, his legs were not powerful enough to chase these larger and stronger animals and his structure was not strong enough or even big enough to overpower them. The alternative was to find dead bodies of animals and eat the meat thereof. It was this primary motivation—namely, starvation and death versus adaptation to the environment that lead to the development of tools of the type discovered in Ethiopia. Man was under evolutionary pressure to make and use tools. But in order to do so, the bones of the hands also needed to evolve, such that they could grip a tool, tightly and precisely. A recent study (cf. Gibbon, 2015) has been able to clarify when and how, in our evolutionary history, this grip developed (see Box 2.6).

Box 2.6: How Human Ancestors Got a Grip

> "Squeeze a baseball or pen between your thumb and the tips of your fingers: You are using what researchers call a precision grip, a highly evolved adaptation thought to be unique to modern humans and our most recent ancestors. Chimpanzees, for example, have thumbs too short to allow them to grip objects so precisely. But a new study suggests that human ancestors in South Africa had a good grip perhaps as early as three million years ago—and so may have wielded stone tools earlier than expected."

While our ancestors have been known to be using tools at least 2.6 million years ago, the identity of the first toolmaker was not clear since a number of different species were alive at that time, including several species of Australopithecus, *A. africanus* and *A. afarensis*, along with our genus, Homo. While stone tools had been discovered, scientists had not been able to find a fossil hand gripping a tool. Some evidence is there from earlier studies that our direct ancestor, Homo erectus, used a precision grip 1.7 million years ago, and that Lucy's species, *A. afarensis*, had started using their hands more like the way in which we do some 3.1 million years ago. But it is only recent technological advances which have provided clear evidence.

As Gibbons writes in her report (*Science,* 2015), a new method of analyzing CT scans of fossils by Matthew Skinner and Tracy Kivell, a husband–wife team of paleoanthropologists has found new evidence.

According to the report,

> "When the team scanned hand bones from four members of ***A. africanus*** that lived in South Africa between two million and three million years ago, they found that the pattern of the trabecular bone was asymmetrical, as in modern humans and

(continued)

Box 2.6 (continued)

Neandertals that use tools frequently (as they also show in their study). This suggests that ***A. africanus*** was using a "human-like" precision grip "much earlier and more frequently than previously considered," the authors write. They stop short of saying that ***A. africanus*** was using and making stone tools and acknowledge that these grips could have been used for a number of different activities with tools. However, the similarity of the pattern with modern humans suggests that hominins had the capacity for stone tool use more than half a million years before such tools are securely dated in the fossil record. They also have scanned hand bones of other members of ***Australopithecus***, including Lucy's species, ***A. afarensis***, but the pattern of use was not preserved in that species' trabeculae."

Source: Gibbon (2015) and Kivell and Skinner (2015)

The second question that begs an answer is "what predicated the size and the shape of the tools?" It was the functional limits of man decided by his body structure. In fact, the anatomy, physiology, and biochemistry of the body of each creature on earth lead to not only certain strengths but also certain constraints. Homo sapiens may stand at the zenith of the animal world, yet, no matter how hard we try, we can extend our arms only so far, we can run only so fast, we can hear sounds of a limited frequency, we can see only a very small fraction of the total light spectrum. Box 2.6 explains how evolutionary processes caused changes in the human hand such that our ancestors became capable of gripping objects, so necessary for the use of any tool.

The human body occupies a limited physical space. In a fixed human position, say while standing, our range of motion is limited to the extent that we can move our limbs. Within this range of operation, we can perform better at certain angles but are vulnerable to injury in others. For example, applying pressure through your feet is not uniform for all postures.

The measurement of these body structures and its limits is the subject matter of what is called **anthropometry** (anthro = human, metry = measurement). Specifically,

> Anthropometry deals with physical characteristics of man in time and space, particularly with individual variation, ontogenesis and generic development," (Nowak, 1996).

Anthropometry*: deals with physical characteristics of man in time and space, particularly with individual variation, ontogenesis, and generic development*

CAD/CAM*: computer-aided design and computer-aided manufacturing*

Such measurements are used today, not only by anthropologists and population geographers to study migration of populations but even more so by design engineers, whether they are designing the home gadgets or a complex space station and have led to the fields of human factors engineering, ergonomics, and biomechanics, all of paramount importance for the development of any technology. With the advent of **CAD/CAM** technologies, engineers simply need to link anthropometric data to the design component and lo and behold, we have cars, airplanes, space stations that can be easily

Box 2.7: Using Anthropometrics for Garment Design

Just think about it: you go into a store looking for a shirt. Knowing that a size 40 fits you perfectly, you choose one from the size 40 shelf, pay for it and walk out. Imagine your consternation and irritation when you open the shirt to wear it and find that the sleeves are an inch short or that it is tight around the shoulder, even though it fits perfectly around the chest. How could this happen? Simple: the manufacturer did not follow the sizing chart for that region of the globe.

With an ever increasing demand for ready-to-wear clothes, sizing has become an important issue. Even in remote countries such as Albania, sizing is important even more so, now that it is becoming an important garment manufacturing center. And, with global travel on the rise, one has to cater to US sizes, European sizes, and UK sizes, just to name a few.

How is this done? While most companies were relying on one-dimensional measurements (1D) till now, 3D measurements are now becoming popular. As Spahiu and his colleagues put it,

> "Anthropometric data are a critical issue for developing products with the right fit. In the clothing industry anthropometric data are very useful for ensuring clothing fit. Using advanced technology for 3D garment design has changed the way of garment production. In Albania the garment industry is one of the most important sectors of the economy regarding to the weight of exports and number of employers. There is a growing number of garment and footwear companies working with their own brand for the home market, but with the lack of a national sizing system. The larger anthropometric studies taken years ago are not up-to-date. Actually there is a need for a national sizing system in Albania. These will help garment and footwear companies which operate in the home market to produce garment and footwear with the right fit. These anthropometric data could be used in different application.
>
> Implementation of 3D laser scanning system and advanced software for 3D data manipulation showed a fast, accurate and repeatable methodology for taking anthropometric data. Automation of the procedure for extracting anthropometric data from 3D body models will shorten the time. Now, a large group of population can be processed for extracting anthropometric data and creating Albanian sizing tables" (Spahiu, Shehi, & Piperi, 2015, p. 2141).

Source: Spahiu et al. (2015)

and conveniently manned by humans. Rehabilitation equipment designers use such data to create wheelchairs, crutches, braces, and all types of prostheses. Clothing manufacturers use them to manufacture ready-to-wear clothes (Box 2.7) and even the architect needs to know how high the door has to be. Would you believe that robotics, too, is using anthropometrics to create robots that can simulate the human being?

Unfortunately, there is a lack of sufficient anthropometric data on the general civilian working population and many a time, the only major source for safety and product development has been restricted to data drawn from studies on military

Box 2.8: Dustin Curtis' Examination of Thumb Reach for Apple Phones

Four inches is only now barely acceptable on iPhone 5 because:

iPhone 5's huge reduction in weight makes it easier to hold while contorting your hand to touch the hard-to-reach areas of the screen.

The screen's width remains narrow and only grows vertically, meaning it's still easy to reach the entire width of the device;

The device is 20 % thinner, which allows your hand to wrap around more fully and to gain slightly more reach; and

iOS's tab bars are anchored to the bottom of the screen, where your thumb more naturally rests, so it remains easy to change app sections (contrast this with Android's tab bars, which are usually located at the top of the screen, and sometimes out of reach).

Source: Curtis (2012)**,** https://dcurt.is/4-inches

(In the Apple 6S iPhone, which is much larger, double touching the home button brings the entire screen closer to the thumb and so "reachability" is ensured).

personnel (Hsiao et al., 2002). Obviously, these data are very different from those of the average general population. With the current focus on the use of multidimensional data, as against unidimensional data, (as stated in Box 2.7), the ideal goal should be to take into account as many users as possible. There are, however, two practical considerations that have been restricting the application of new knowledge. First, many product developers are unaware of the usefulness of anthropometric data and second, the cost of implementing the use of such knowledge could be exorbitant and is therefore, sometimes, considered impractical. At the same time, the good news is that there has been a significant rise in the number of companies engaged in designing and marketing ergonomic products. For example, Apple has taken into consideration the use of the thumb dimension in developing its larger versions of mobile phones (Box 2.8).

Over the years, comprehensive anthropometric atlases have been formulated and these reveal that there are wide differences between individuals with reference to age, gender, race, ethnic groups, etc. We can, therefore, categorize anthropometry in terms of the following:

- **Population anthropometry**: body characteristics pertaining to a particular population, say, the Chinese, Caucasians, or the Germans.
- **Ontogenetic anthropometry:** changes in body proportions, etc., with age.
- **Phylogenetic anthropometry**: body proportions typical of a species, say, the Homo sapiens.

All three aspects are useful for the development of technology and have been widely used by engineers from all industrial sectors.

Molenbroek and coworkers at the Delft University of Technology describe some of the ways in which anthropometric data has been used in the development of products (Box 2.9).

Box 2.9: On Using Anthropometric Data

"There are several ways in which anthropometric data are used:

- **Ego-design**: your own body dimension as a guide.
- **Average-design**: body dimensions of the average as a guide.
- **Design for P5**: body dimensions of the smallest person as a guide.
- **Design for P95**: body dimensions of the largest person as a guide.
- **Design for P5-P95:** body dimensions of the smallest and largest person as a guide. This type is used most commonly and means that excluding 10 % is acceptable."

> "Many ergonomists are not aware that of the fact that the anthropometric data they use is mostly 1D. This does not mean it is of less value, but… it is important to realize ….how information can be extended to 2D and 3D or maybe even 4D information, which may be more appropriate and valuable for daily use in a design or evaluator's environment" (Molenbroek & Bruin, 2005, p. 289).

Source: Molenbroek and Bruin (2005)

2.3.2 Basic Principles of Anthropometry

We will now illustrate, very briefly, the basic principles of anthropometry in the context of psychology of technology.

1. Anthropometrics takes into account two aspects. While **static anthropometry** measures the human body parts at rest and includes indices such as skeletal dimensions, distance between joints, space taken by soft tissue and contours of the body, **dynamic anthropometry** focuses on body reach with extended arms or legs or fingers, sitting and standing heights, or clearance, as it is technically known.
2. **Anthropometric diversity**: like most other human characteristics, anthropometrics also follows a normal distribution curve, with 90 % of any population falling between the 5th and the 95th percentile. This is, however, only for populations of the same gender. When measurements are taken across gender, that is, when we take a sample comprising 50 % males and 50 % females, 95 % of the population is covered between the 5th and the 95th percentile. At the same time, just as for all other normally distributed characteristics, there are deviations, both across distributions for different groups

Static anthropometry*: measures the human body parts at rest*

Dynamic anthropometry*: focuses on body reach with extended arms, legs or fingers, sitting and standing heights, or clearance*

Anthropometric diversity*: variations in body measurements for different groups of people* of people (measured by degree of skewness and kurtosis) and within distributions (individuals whose anthropometrics fall at the extremes of the distribution). The former could be due to gender, developmental stage, ethnic differences, or occupational differences, because certain parts of the body develop at differing rates depending on their usage in different occupations, while the latter is related to normal individual differences.

3. **Sitting height**: sitting height is generally 53 % of the standing height of the person. Stature differences between different groups of people whether across gender or across ethnic groups tend to get reduced while sitting down. Thus, while designing work places and when sitting down head clearance is to be considered, far more people will be covered between the 5th and 95th percentile than when these same people are standing up.

> ***Sitting height**: the height of the person when in a sitting posture*

4. **Racial differences**: different groups have different body proportions. One such difference is that native Africans have longer legs than Europeans who, in turn, have longer limbs than their Asian counterparts. The kinds of impact that this could have on technology design is clarified by considering a piece of equipment used very widely, namely, a respirator. These are artificial aids to be used either for patients who are having difficulty in breathing or for people in jobs that have potential inhalation hazards. While most of the respirators that are being used in the USA are based on anthropometric data of the USA, we must bear in mind that the workforce of the USA today is much more heterogeneous than it was earlier. Statistically significant differences have been obtained for facial measures in terms of gender, age, and ethnic groups (Zhuang, Landsittel, Benson, Roberge, & Shaffer, 2010). This is a factor that would be a mandatory consideration for designers of respiratory or even other personal protection equipment such as masks used in mining operations or even in the construction sector.

> ***Racial differences**: differences in anthropometric measurements of people of different races*

5. Height steadily declines after 20 years of age, becoming even more pronounced after 40 years of age because of shrinkage of the intervertebral disks of the spine (Box 2.10). Did you realize that your height also varies with the time of day because the spinal cord tends to get compressed by body weight and by evening, you may be 0.9 in. shorter? At the same time, over the years, the human skeleton has also become lighter (Box 2.11).

> ***Differences in body morphology**: genetic and congenital differences in body built*

6. **Differences in body morphology** have been studied over the years and we are all aware of Sheldon's somatotypes—the ectomorph, who is thin and slender; the mesomorph, who is wide and muscular; and the endomorph, who is fat and pear shaped. Just think of an obese person trying to squeeze himself into a "normal" chair. Changes in body morphology require adaptations and changes in the design of workstations and equipment to be used by them. Gordon and Bradtmiller (2012) discuss the consequences that obesity can have on office ergonomics.

Box 2.10: The Baltimore Study on Decrease in Height with Age

In a paper in the *American Journal of Epidemiology,* published in 1999, a study was reported which attempted to study the trend of height decrease among a group of individuals over a period of time. The paper was written by Dr. John D. Sorkin of the *Intramural Research Program at the National Institute on Aging*. While the study is almost two decades old, it does provide evidence for decrease in height with age.

To determine the magnitude of height loss due to aging, a longitudinal study was undertaken between the years 1958 and 1993 on a sample of 2084 men and women from the age group 17 to 94 years.

According to the author,

> "On average, men's height was measured nine times during 15 years and women's height five times during 9 years. The rate of decrease in height was greater for women than for men. For both sexes, height loss began at about age 30 years and accelerated with increasing age. Cumulative height loss from age 30 to 70 years averaged about 3 cm for men and 5 cm for women; by age 80 years, it increased to 5 cm for men and 8 cm for women. This degree of height loss would account for an "artifactual" increase in body mass index of approximately 0.7 kg/m^2 for men and 1.6 kg/m^2 for women by age 70 years that increases to 1.4 and 2.6 kg/m^2, respectively, by age 80 years. True height loss with aging must be taken into account when height (or indexes based on height) is used in physiologic or clinical studies." (*American Journal of Epidemiology,* 1999;150, 969–77).

Findings such as the above have important implications for not only design engineers but even garment manufacturers. It means that designers for the aged must use a different set of metrics in line with the decreasing height and the corresponding increase in body mass.

Source: Sorkin et al. (1999)

Box 2.11: Have Human Skeletons Become Lighter over the Years?

Chimp bones are packed with microscopic structures known as spongy bone; modern human bones aren't, increasing risk of fractures and osteoporosis. Two studies propose an explanation for this change: Chirchir et al. (2014) found that skeletons from modern chimpanzees, Australopithecus africanus, Neanderthals, and early Homo sapiens all had higher densities of spongy bone than modern humans, suggesting that our sedentary lifestyle is to blame. Ryan and Shaw (2014) also found lower spongy bone density in the hip joints of ancient farmers compared with hips from nonhuman primates and ancient hunter-gatherers, supporting the idea that a lack of rigorous exercise, not evolutionary pressure, is responsible for our weak bones.

(continued)

Box 2.11 (continued)

This too would have implications for design engineers. Since our skeletons have become lighter, we would probably not be able to exert as much pressure as our forefathers were able to do. At the same time, the amount of weight we are able to carry without hurting ourselves has also gone down. A direct consequence of this reduction in ability to carry weights is seen in the recent changes in checked-in luggage allowed while travelling to and fro from the USA. Till a decade back, this limit was two suitcases of any size and weight. It has now been reduced to two suitcases of 50 pounds each. A pound more and you must pay for extra luggage. The reason provided by airlines is that the porters who help in the transportation of such heavy luggage have often suffered injuries, as a result of which airlines have had to pay heavy insurance premiums for ensuring the personnel engaged in this type of work.

Source: Chirchir et al. (2014) and Ryan and Shaw (2014)

7. **Reach, zone of convenient reach and optimal visual field:** there is a clear difference between what one can reach and what one can conveniently reach. Just think of the times when you have had to stretch your arms in order to pick up a phone lying at the other end of your desk causing you to strain your arm muscles and compare it to the feeling of when you have to pick up a phone that is placed at a convenient distance from where you are working. The muscle pull in the former case is very uncomfortable and in extreme cases could even cause muscle strain. We can define the normal work area as the area a person is able to conveniently reach with his arms and hands with elbows flexed at 90° with a rotation potential of about 25°. However, what must also be kept in mind is the optimal visual field which is much less than the entire 180° in front of us.

***Reach**: the maximum distance one can reach when arms are outstretched*

***Zone of convenient reach**: the distance one can conveniently reach without discomfort when arms are outstretched*

***Optimal visual field**: the area over which one can see clearly without turning one's head*

2.4 Ergonomics

Advertisements constantly bombard us with products such as "ergonomic chair," "ergonomic mattress," and "ergonomically designed workstations." But what does the term really mean? Why is there so much stress on ergonomically designed products and why are they more expensive than those that are not so designed? The word ergonomics comprises two Greek words, "ergos" meaning work, and, "nomos" meaning laws. Thus, **ergonomics** refers to the laws of work and can be defined as the science of matching work or tasks to the body. This is accomplished by taking into consideration anthropometric data, physiological characteristics, biomechanical and psychological capabilities. The current emphasis on ergonomics is because it creates win-win solutions for both the organization and the employee that is user. The user, especially the employee, is much more comfortable, both physically and psychologically, and therefore manifests higher levels of job satisfaction and work morale, which in turn, makes for higher productivity, better quality of work, and reduced wastage. At the same time, there is lower fatigue, improved health and safety all leading to decrease in injuries and illnesses and thus lowering worker compensation. Which employer would not be happy, even ecstatic to have human resources of this genre?

***Ergonomics**: the science of matching work to the body*

2.4.1 How Does Ergonomics Work?

We could probably begin by attempting to understand the difference between ergonomics and anthropometrics. As Ryan (2013) puts it,

> "Anthropometrics is "the study of the human body and its movement."… Ergonomics, on the other hand, is "the study of people and their relationship with the environment around them. When anthropometric data (measurements/statistics) is applied to a product, e.g. measurements of the hand are used to design the shape and size of a handle, this is ergonomics" (www.technologystudent.com)."

The**ANSI Z94.0-1989** provides a more detailed explanation of ergonomics. It is,

> "The application of a body of knowledge (life sciences, physical science, engineering, etc.) dealing with the interactions between man and the total working environment, such as atmosphere, heat, light, and sound, as well as all tools and equipment of the workplace."

The beauty of the study of ergonomics is that it draws from a variety of disciplines, ranging from anthropometry, physiology, and psychology to kinesiology and even to human factors, industrial medicine and management. The fundamental process is fourfold:

1. Identify the physical, physiological, and psychological demands of the job.
2. Identify the physical, physiological, and psychological capabilities of the worker.
3. Identify the physical, physiological, and psychological mismatches between the demand and the capability.
4. Minimize the mismatches through education and training, and work, tool, equipment, and environmental design.

A related term is **biomechanics**, which deals with the application of principles of mechanics to living biological material, especially in terms of the level of stress that the body and its parts can withstand, as when the body is put through acceleration (be it in a car, a go-cart, or even a roller coaster). Modern technology has greatly reduced the amount of physical

***Biomechanics**: applications of principles of mechanics to living material* stress the human undergoes, but it has not always been able to reduce the stress on small body parts. This is where the principles of biomechanics are useful, using which ergonomists attempt to design workstations and equipment whereby minimal stress is put on the human body and efficiency is improved and fatigue is reduced.

2.4.2 Ergonomics and Prevention Through Design

An important use of anthropometric data in combination with ergonomics is in the design of tools, workstations, and equipment in general so as to reduce occupational hazards, accidents, and illnesses. Governments have taken it upon themselves to introduce a variety of steps, one such being the *National Initiative for Prevention through Design, (PtD)*, undertaken by the NIOSH (*National Institute for Occupational Safety and Health*, USA) (Box 2.12). According to the *Center for Disease Control and Prevention*, it is clear that,

Box 2.12: Prevention Through Design (PtD)

The traditional method of preventing occupational accidents has been to provide safety measures and equipment such as those used for firefighting, gas masks used in mining, etc. These of course are necessary and will always be used. However, with recent awareness of psychology of technology, a new perspective based on ergonomics has emerged, called *Prevention through Design* (PtD). The idea is that worker accidents can be "designed out" through designing, redesigning, and even retrofitting and that by doing so, many an accident would be prevented and many occupational diseases would be eradicated.

It is with this in view that the *National Initiative for PtD* has been launched. PtD "is a comprehensive approach, which includes worker health and safety in all aspects of design, redesign and retrofit/will provide a vital framework for saving lives and preventing work-related injuries and illness is the roadmap."

According to CDC, "PtD encompasses all of the efforts to anticipate and design out hazards to workers in facilities, work methods and operations, processes, equipment, tools, products, new technologies, and the organization of work. The focus of PtD is on workers who execute the designs or have to work with the products of the design. The initiative has been developed to support designing out hazards, the most reliable and effective type of prevention……. The ultimate goal of the PtD initiative is to prevent or reduce occupational injuries, illnesses, and fatalities through the inclusion of prevention considerations into all designs that impact workers. Along the way, intermediate goals will be identified to provide a path toward achieving the ultimate goal. NIOSH will serve as a catalyst to establish this Initiative, but in the end, the partners and stakeholders must actively participate in addressing these goals to make PtD business as usual in the 21st century."

Source: NIOSH (2013)

> "One of the best ways to prevent and control occupational injuries, illnesses, and fatalities is to "design out" or minimize hazards and risks. NIOSH leads a national initiative called Prevention through Design (PtD). PtD's purpose is to promote this concept and highlight its importance in all business decisions" (NIOSH 2013).

While the concept of PtD is highly attractive and of great value, implementing PtD is easier said than done. One reason is the demographic changes that are taking place in the workforce in almost every industrial and business sector. As compared to even three decades back, that is, shortly before the turn of the century, the workforce, today, is far more heterogeneous. For one thing, women have entered spheres of work normally seen as male bastions. Secondly, with rapid advances in communication technology and means of travel, widespread globalization has ensued, causing the workforce to be comprised of people from a variety of ethnic groups. Thirdly, modern medicine and better health conditions have seen to it that there are more people from the age group of 60 years plus still occupied on a part-time basis if not on a full-time basis. Due to each of these, the workforce today comprises people from both genders, different age groups, and from different regions of the world, implying that if tools, equipment, and workstations have to be ergonomically designed, we would require anthropometric data for each of the above groups. The *National Institute for Occupational Safety and Health* is facing exactly this problem and the box below (Box 2.13) clarifies one such problem and the ways in which it is being handled.

Box 2.13: NIOSH Study on Truck Drivers (2015)

As mentioned by John Howard, Director, *NIOSH*, in the foreword to the report,

> "Work-related highway incidents are a leading cause of occupational deaths and injuries in the United States. Prevention of work-related highway injuries and deaths poses one of the greatest challenges for occupational safety researchers. Compared with other work settings, the work environment surrounding trucking and other transportation-related activities is fluid and dynamic. As such, it is difficult to exert direct control over a range of factors (e.g., fatigue, inattention, subpar road and weather conditions) that may negatively influence a worker's safety. Despite these challenges, *NIOSH* has been actively engaged in a range of research efforts that are likely to have the greatest impact on the reduction of work-related highway incidents. One of these research efforts is focused on reducing hazards to truck drivers by improving ergonomic design in medium-duty and heavy-duty truck cabs" (p. 176).

While American manufacturers have long realized that safe trucks cannot be designed without accurate and up-to-date anthropometric data, an earlier survey was not found to be up to the mark. In view of this *NIOSH* launched the first ever federal anthropometric study of truck drivers in the USA, in 2006, with data being collected between the years 2009 and 2010 on 1779 male and 171 female truck drivers from various states of the USA.

(continued)

Box 2.13 (continued)

The results of the study have important implications for truck designers and manufacturers. What has come to light is that there have been "widespread changes in the demographics of the American truck drivers in the last 25–30 years. In 1983, the combined category of truck drivers (heavy and light) and driver-sales workers consisted of 11.7% African American, 5.6% Hispanic, and 3.5% females (BLS, 1983). In 2009, the driver-sales workers and truck drivers' category consisted of 13.4% African American, 18.7% Hispanic, and 5.2% females (BLS, 2009). This new demographic reality necessitated an updating of the anthropometric data used for the design of truck cabs because anthropometric data are related to various demographic characteristics (NIOSH, 2013; Gordon et al., 1986; ISO, 2006)" (p. 1).

The results show the extent of the changes in the body dimensions of truckers. While the average male truck driver was found to be 13.5 kg heavier, the female truck drivers were 15.4 kg heavier than their counterparts from the general population. The male truck driver of today is about 12 kg heavier than those 25–30 years back. While they are not taller but they are certainly larger in body girth and body width, both important while considering seat and driving chamber design. These changes make an obvious case for revising the sizing and designing of trucks.

On the basis of the data collected on a list of 33 anthropometric dimensions, 15 body models have been worked out independently for males and females, each model representing a unique combination of body size and physique. *NIOSH* is of the view that these models will surely benefit the design of the next generation of the driver cabins of trucks.

Source: NIOSH Study on truck drivers (2015)

2.5 Applications of Anthropometry

There are a variety of ways in which anthropometry and ergonomics have been able to help man. Some of these have been detailed below. We shall start with the principles of creating a suitable workstation and go on to show the ways in which anthropometrics can make a world of a difference in a simple piece of home furniture such as a chair. From there we move to the complexities involved in the design of a manned space station. In order to illustrate how anthropometrics can help design equipment for the aged, we have included a section on anthropometrics and the aged. Another important application of anthropometrics is in the field of rehabilitation of people with impairments, thereby mandating a section on rehabilitation, and finally, we show how gender differences in body proportions can be used to create comfortable workstations for women.

2.5.1 Anthropometry and Workspace Design

A fair amount of work is done using tools that are laid out around the individual worker. In other jobs, the worker may be having a panel of switches, knobs, buttons, gears, etc., in front of him. The principle concern in each of these cases is how to lay out the material such that the worker can reach each object most conveniently and with least discomfort. Another consideration is that worker injuries have to be kept at the minimum. Thus, the workspace must be so constructed that it leads to maximal efficiency coupled with maximum effectiveness. Using anthropometric data such as given above, principles for the design of workspace layout have been delineated. Alan Hedge of Cornell University has, very lucidly, laid out certain anthropometric considerations useful for workspace design (Hedge, 2011a).According to him, workspace layout should follow five principles:

__Kinetosphere__: The set of all reachable points for a subject at a given position

(a) **Importance:** items most important should be placed in the center part of the **kinetosphere**. "The dynamic reach envelope, or kinetosphere, describes the set of all reachable points for a subject at a given position. This shell of reachable space, when it is intersected with the working plane, provides what we have been referring to as the reach envelope" (Toney & Thomas, 2007).
(b) **Function**: items of similar function should be placed together.
(c) **Frequency of use**: most frequently used items have to be placed at the most convenient place.
(d) **Sequence of use**: items should be arranged according to the sequence in which they are to be used.
(e) **Normal posture**: items should be accessible from the normal posture.

A large part of work is performed in the sitting posture, with arms or maybe legs, hands or feet performing the actual task as in the case of car drivers, airplane pilots or even computer operators and other office tasks. In most such cases the apparatus on which the person is working, its knobs and handles, switches, etc. are in front of the person. Normally, everything is laid out on a table or platform in front of the person. But the crucial factor in deciding efficiency is the height of the platform and the total area to be covered by the hands and fingers. A classical study was the one conducted by renowned ergonomist Dempster and Gabel (1959). Though conducted over 50 years back, it still forms the backbone for ergonomists even today. Using very complex recording equipment and even more complex mathematical procedures, various indices were worked out. The limits of the space reached while sitting, the left and right hand overlap in this space, regions of maximum hand flexibility, mean hand positions, and degree of variability have been obtained. Using such functional anthropometrics, effective hand positions have been worked out for use in the designing of worktables, control panels, etc. But do data like the above cater for all people? It is very easy to design chairs, tables, consoles, and general workstations and most of the population would find them comfortable. But how about those whose body proportions fail to conform to the standards observed for any particular culture, age, or ethnicity? One such group would be the obese. Useful guidelines have been provided by Gordon and Bradtmiller (2012) on how obesity requires changes in office ergonomics.

2.5.2 Anthropometrics and Chair Design

Ever think about that lowly object that supports your body for the greater part of the day? The word "chair," per se, conveys little. It is only when you prefix it, arm chair, office chair, deck chair, dining chair, garden chair, and so on, that images start popping up. Make it more extravagant, and it becomes a sofa, a settee, a throne. Belittle it, and what is it now: a bench. The basic idea is the same in all, just that the dimensions vary, and some dimensions, such as the seat back taking on a value of zero, for a bench.

Four major dimensions are normally required for the design of any chair. These are seat height, seat depth, seat width, and back height. Variations occur along each of these for two reasons: firstly, the dimensions of the user and secondly, the purpose for which it is to be used. If you are speaking on the phone in office, the distance between you and the phone will decide your posture. If you are reading a novel or flipping through a travelogue, you will probably want to lean back in your chair, or even curl up; but, when you are going through an important office file, you usually tend to lean forward.

How does the maker of the chair determine the dimensions of the chair? As early as during the Roman and Greek days, various methods had been delineated to map the physical structure of man as a function of posture. Whereas the Greek used geometrical formulations and arrived at what they called the Golden Rectangle and the Golden Mean (made famous by Euclid), Leonardo used what has been termed the Vitruvian man after the Greek architect, Vitruvius, who actually took measurements of the human body. It was only much later, in the twentieth century that le Corbusier, again an architect, started looking at and measuring the human body in a more intricate manner. The greatest impetus to anthropometry, however, came during and after World War II. The landmark year is probably 1992, when a large-scale international survey was instituted. Nomenclatured **CAESAR** (the Civilian American and European Surface Anthropometry Resource), it was a collaboration between more than 35 companies and 6 different countries. The survey was based on 4431 American and European adults from both sexes aged 18–65 years (Salvendy, 2005). Each subject was scanned in 3 different poses, 59 point-to-point measurements were calculated, and 40 traditional body measurements were taken by measuring tape. The survey was the first to provide 3D human models with anthropometric data coupled with demographic data (Robinette & Daanen, 2003).

> ***CAESAR**: the Civilian American and European Surface Anthropometry Resource*

The chair in modern times has benefitted greatly from such surveys and has made ergonomically designed chairs possible. But this has not always been the case. Any chair will comprise three factors, function, aesthetics and material (Nelson, 1994). While some chairs focus on function, others focus on aesthetics and that is why we hear of terms such as status furniture and technical furniture (Nelson, 1994). Should there not be some sort of reconciliation between the two?

2.5.3 Anthropometry and Space Station Design

The designing of a space station takes much more than normal anthropometric data and ergonomics. There are a number of other concerns that have to be addressed. First and foremost, what anthropometric standards should be used? It is not a limited space like a workstation is and, yet, it is a workstation; it is not limited in its functional purpose such as a chair or bed is and, yet, it has chairs and beds; and lastly, astronaut postures are not fixed as on an assembly line or a computer operator, and, yet, he/she has to operate computers. Thus, the normal anthropometric parameters used for designing a workstation, a chair, or a computer are useful but with a host of other considerations factored in. Another major problem faced by design engineers of space stations is that it is extremely difficult to define the user population. Earlier, people sent into space were from a very limited population. If it was an American space ship, the users would be Americans; if the space ship was Russian, the users would also be Russians, and so on. Now, however, the population from which the selection is often made has a much wider spectrum and international anthropometrics has to be considered. Since we already know that anthropometric measurements vary across race and ethnic groups and gender, aggregation across countries is the only way out.

A detailed guide has been worked out by **NASA** from which some points are being described below. Till a few years back, the *NASA Technical Standards Program* was using a document called *NASA-STD-3000.* This was a very detailed document for manned space ship design and function and includes 14 chapters ranging from anthropometrics and biomechanics, to human performance capabilities, crew safety, workstation design, hardware and equipment and even facility management and extravehicular activity. As far as measurements for space ship and space station users are concerned, NASA has provided the outer limits. The guide provides anthropometric data for the Japanese, who are generally considered small people, and for the North American, who are generally large people. Though these parameters have been provided, NASA advises that an aggregation of different population anthropometrics be used. The detailed manual also provides guidelines for design considerations including the changes that occur in both static and dynamic anthropometric indices due to weightlessness and how these are affected by interindividual, interracial, and secular differences. NASA also advises that the same anthropometrics can be used for clothing of space ship users, that is, for the design of space suits. Of late, it has been felt that this document has become outdated and has now been replaced by a new document, entitled, *NASA-STD-3001* (2014) divided into two volumes which are as detailed, if not more, than the earlier document.

Another important facility is the *Anthropometric and Biomechanic Facility* (ABF) which is collaborating with NASA to design spacesuits keeping in mind the requirements of the future, for example, for astronauts who may be from different anthropometric pools. Rather than using specific anthropometrics, the newer concept is using whole body posture based analysis using both anthropometric data and biomechanic data (Thaxton & Rajulu, 2007).

The challenges that will face space technology in the future are very obvious. It was only a few years back that a new feat was accomplished when a spaceman skydived 24 miles from space, breaking the sound barrier and came spinning down. CBS News reported that Skydiver Felix Baumgartner made the highest skydive ever on Oct. 14, 2012. He jumped from 128,000 ft (39,000 m), or about 24 miles up, during the Red Bull Stratos mission. It was also reported at that stage that though the feat was accomplished and that too without any mishap, one serious shortcoming was that the space suit being worn by the astronaut was not suitable for this type of performance. It is in areas such as these that anthropometrists face many challenges but can provide valuable insights.

2.5.4 Anthropometrics and Designing for the Aged

Another challenge facing the twenty-first century, the world-over, with the increasing number of elderly people is in the designing of clothing, equipment, etc. for the aged.

Studies show that marked changes occur in our body proportions and ability to move around with age. According to Perry (2010), the following are the most marked changes with age:

- **Strength:** 25–30 % decrease in strength after 65 years of age.
- **Flexibility**: 18–20 % decrease with age.
- **Balance:** 1/3 of 65-year-olds fall each year.
- **Sight**: all aspects deteriorate.
- **Reaction time and speed**: both show decreases.
- **Manual dexterity and tactile feedback** undergo decrease.
- **Body fat** increases.

There is also evidence to support the observation that parameters for certain body parts are altered with aging. A box in the previous section (Box 2.9) details how height decreases with age. The most affected parts appear to be the thigh, lower leg, upper arm and forearm (Muri et al., 2008; Pavol et al., 2002), as well as the muscle mass distribution (Janssen, Heymsfield, Wang, & Ross, 2000). As a result, locomotion and mechanical work ability becomes hampered (Schuch, Balbinot, Boos, Peyré-Tartaruga, & Susta, 2011).

Apart from these physical changes there are physiological changes causing fatigue issues, problems of the respiratory and cardiovascular systems, systemic blood pressure, and ability to withstand extreme temperatures. These are further complicated when one adds the psychological changes due to aging, such as not being flexible to work schedules, requiring more structured training and education and showing greater disenfranchisement and disengagement (Perry, 2010).

In view of the above, there would be a variety of changes that would be required for elderly workers. If we think of office work, redesign of chairs and tables would be necessary to accommodate anthropometric changes with age. According to Kothiyal and Tettey (2001), even more crucial would be the placement of storage shelves for the aged. Since people tend to become shorter with age, they could have trouble reaching out for things placed at the usual heights. Another aspect that needs attention is public transport and bus seat dimensions. As larger numbers of older people set out to work, shop, or simply manage their household chores, they would need to travel. At the same time, driving often becomes tedious if not impossible, and so there would be a greater reliance on public transportation systems. Normally, trains and buses have only a few seats reserved for senior citizens. As time goes by, these will not be enough and transportation managers may have to reserve more seats for such people. Providing barrier-free environments would also be necessitated because of more people relying on wheelchairs, crutches, or braces.

2.5.5 Use of Anthropometrics in Rehabilitation

> ***Natural speed**: the speed that tends to optimize accuracy of movement*

> ***Energy cost**: total amount of energy to be expended on a particular movement*

Movement time: watching people in day-to-day living, one can easily decipher that there is what has been called a "**natural speed**" for performing any act, whether it is reaching out for an object or turning off the kitchen faucet. It has generally been said that this is because of a speed accuracy trade-off and the natural speed is that speed which tends to optimize accuracy of movement. Mazzoni, with the help of empirical research on PD (Parkinson Disease) patients, has, however, helped to analyze this further and has obtained empirical evidence regarding another factor that needs to be considered. This factor is the **energy cost**. We tend to optimize this energy cost, too (Mazzoni et al., 2007). So sometimes, if a particular act requires considerable energy or more energy than we are capable of putting in, we tend to slow down. This seems to be the case for PD patients but could also be true for those who are physically challenged, convalescents, or even the aged. Design for the aged would need to keep this in mind. Knobs and switches that require fast reaction times, say as on an elevator, a kitchen stove that heats up quickly and needs to be suddenly slowed down or even the length of the pedestrian light at crossroads need to be designed in such a manner that such people do not have problems simply because they have become slow.

Workspace design uses various anthropometric indices, one of the major ones being zone of arm reach. For many people with upper limb disability, the zone of arm reach could be different. Five anthropometric indices, namely, stature, trunk depth, arm overhead reach, arm reach forward and lateral were used by Nowak (1996) to obtain measurements for both people without disability and those with disability. There was enough evidence pointing to differences on all parameters.

Another use of anthropometric data for the disabled is in the manufacture of clothing. While general tailor measurements are used, there are someother measurements that are also necessary. These include the elongation of certain body parts while performing movements in which arms, legs, or other parts of the body are stretched out as also what has been termed **motion comfort**. Clothes for people who are ambulatory and those who use wheelchairs require different clothing-fits.

***Motion comfort**: designing of clothes so that it is comfortable to execute movements*

2.5.6 Workplaces for Women Workers

Certain occupations require overhead work. These include the automobile assembly plants and construction works. Unless designed ergonomically such tasks could lead to cardiovascular and musculoskeletal strain (Haslegrave et al., 1997). One can imagine the costs of such strain. Not only would efficiency be lower, fatigue would also be greater and injury very possible. What are some of the dynamic parameters for such work?

- The greater the distance between the body and the point of hand exertion, the less is the force exerted.
- Slight changes in foot placement also affect force exerted.
- Lying supine produces lower force exertion than sitting or standing up.
- However while supine, the maximum force exerted is increased as reach distance is reduced.
- Kneeling on two knees leads to lower force exertion than kneeling on one knee.
- Lifting and pressing lead to higher force while laterally exerted force is lower.

All of the above have been obtained for male workers and male subjects. What happens when females are put in similar situations? The last few decades have witnessed larger and larger numbers of women at the workplace and not just in office jobs and small assembly jobs but in almost all types of factories across industry sectors. Reduced efficiency vis-à-vis their male counterparts is, to a very large extent due to the fact that workplaces and tools have been designed for use by men. In view of the above, Chow and Dickerson (2009) attempted to devise indices for women. Chow and Dickerson concluded that women manifest lower shoulder strength than males, namely, that for females is 2/3 that for males. At the same time, the direction and angle of the force exerted is also important, especially when working at or above shoulder level. Maximum force could be exerted when the subjects were standing with the work handle placed at an angle of 60° from shoulder height and moved the handle downwards. In marked contrast, when this handle was placed at 90° and subjects were asked to push forwards in the horizontal plane, the force exerted was the least. In general, force was greatest in the vertical direction and least in the horizontal direction. An important recommendation made by the researchers was that since they found that different women used different postures to maximize the amount of strength exerted, workers should be allowed to alter their postures to gain maximum advantage (for example, sitting, standing, or supine).

2.6 When Anthropometrics Is Neglected

Hurtability*: the degree to which it is possible to get hurt while using a product*

How do we make the above happen? What happens when we do not think of the above? The answers to both of these are linked to anthropometry to a very great extent. While Norman (2008) explains how to build these features into the design of the product, Guimaraes and Antunes (2012) focus on the other issue: how bad design can cause **hurtability**, the opposite of which would be, usability. When because of commercial reasons, all we can think of is getting more and more people to buy the product, we stop thinking of how people could buy the product but also get hurt while using the product because of certain design features. Guimaraes and Antunes give us a large number of such examples of poor usability ranging from sardine cans, to ketchup packaging, bus handle supports, filing cabinets, and even things as simple as the bookbinders being used by school children. In most cases, the design is faulty because the capabilities of the human hands and fingers, the reaction times while operating certain systems, and even our mental capability in understanding system requirements are not being considered. The success of the product should not be measured by the number of pieces sold, but by user reactions concerning the achievement of her goals, with its efficiency plus with the all-important last corollary, namely, without being hurt.

2.7 Going Beyond Anthropometrics

It had long been thought that most human structures fail to show plasticity beyond the developmental period. However, recent research into expert performance clarifies that not only do cognitive structures adapt to the situations at hand, but so do anatomical structures and physiological processes. At the same time, these adaptations are easier and larger during childhood, especially during critical periods of development. Once adulthood is reached, adaptations do take place but are slower and the gains are also smaller. We have earlier said that our auditory capacities are limited not only with reference to the range of frequencies that we can sense but also with reference to our power of discrimination between sounds of different frequencies. Talent in music is based to a great degree on the power to differentiate between notes and what has been termed absolute pitch. While in the general population, only .01 % show absolute pitch, and it is generally believed that adults are unable to retain this capacity even if they manifested it in childhood, the crux of research bears on the fact that absolute pitch can, in fact, be acquired by anyone, though only a limited period of development (Takeuchi & Hulse, 1993). Even physiological and anatomical aspects show adaptation. For example, there have been observed changes in the sizes of hearts and lungs, the flexibility of joints, and the strength of bones (remember that these are all anthropometric measurements) due to appropriate training (Ericsson, Krampe, & Tesch-Romer, 1993). In fact, with a clear exception of height, a large number of anatomical structures undergo adaptation because of training (Ericsson & Charness, 1994). What is also important is that these changes have not happened through gradual refinement but by restructuring the performance and acquiring new methods and skills: clearly, an example of exaptation. That adaptation can occur in the cognitive processes is clear from empirical studies and case histories of people with exceptional memories. In most cases it has been observed that through practice the very structure of the cognitive process undergoes adaptation, in that, people learn how to circumvent the limited capacity of the Short-Term memory (STM) and directly store data in the Long-Term memory (LTM). However, even these adaptations have limits. Sustained overtraining leads to injuries and burnout and the only therapy, at that stage, is to stop practice completely. We have presented material above to show that there are normal declines with age along a number of anthropometrics. On this ground too, it has been seen that experts are found to age slower than novices, but this is limited to the particular domain in which they are experts (Salthouse, 1991).

How does all of the above relate to the development of not only technology, per se, but also to developing a coherent psychology of technology? In order for technology to develop along lines that would optimize human effort, it is clear that not only do we have to keep the human structural and functional limits in mind, but we must also not fall to the ploy of cheap commercialization. At the same time, the fact that many of our structural and functional aspects are able to undergo adaptations and even exaptations, anthropometrics should not be the ultimate limiting factor in the design of technology. Probably, Alan Hedge of Cornell University has addressed this issue in a more coherent manner. By discussing the myths of designing, he points to the many challenges facing the designer of technology (Hedge, 2011b). Designing for the average person does not solve the problem since there are no people whose body proportions are all at the 50th percentile. Neither does designing for people who fall in the 5th to 95th percentile: at the most you are covering for 90 % and not all 100 %. The best would of course be to design for an adjustable range. But would that be cost-effective?

2.8 Mapping the Body and Technology: The Unique Role of Psychology of Technology

Anthropometric data provide information about the characteristics of the body which are vital for the design and use of any equipment. When firefighting equipments, such as hoses, were heavy unlike those made of lighter materials, it was considered to be a profession mostly for men. The same can be said about heavy truck drivers who needed to lift heavy materials. Traditionally, whenever we have attempted to assess the interaction between man and machine, we have focused on the following three features:

Strength: Is the thing very heavy? How we wish the computer was in our hand or lap?
Reach: How we wished the remote control was available to us when we first used the television?
Clearance: can we avoid clutter and operate smoothly?

So, when we mentioned the designing of the Apple phone, earlier in this chapter, we noted that anthropometric data have gone far beyond the mere use of physical features, for example, the hand and its physical dimensions. While such physical dimensions continue to be relevant, we also need to evaluate the functional features of the hand in relation to the use of things. In the absence of data regarding the performance of the human body under different conditions, a considerable amount of morphological information might not be very useful or may even become counterproductive. We, therefore, need to go beyond the static and dynamic dimensions of anthropometry mentioned in the section on principles of anthropometry. The operation of most equipment is no longer based on the simple mechanical manipulation of knobs and switches, which are based on gross motor skills of the hands and feet. Instead, with most equipment becoming computerized, the operations now require the use of complex fine perceptual motor skills (for example, just think of the skills required for using a mouse to select functions) and have necessitated a deeper understanding of the mechanics of motion.

Figure 2.3 shows a force-sensing glove which is being used to collect such data regarding functional aspects of the human body for ergonomic research. Thanks to improvements in biotechnology, we now have information on several dimensions enabling us to determine how best to create conditions for human interaction with machines. Is this not a huge step forward from "human factors engineering" in which human beings were considered as simply one more factor in the design and use of machines?

The second important issue in working with tools relates to a shift from physical load to mental load. Traditionally, anthropometry dealt with physical data in terms of strength, reach, etc., as discussed above, and was considered more as an area for biology and engineering and was therefore rarely mentioned in classical books on psychology. The focus was on collecting anthropometric data useful for operating tools, appliances, or cars. Recent technological developments have changed the

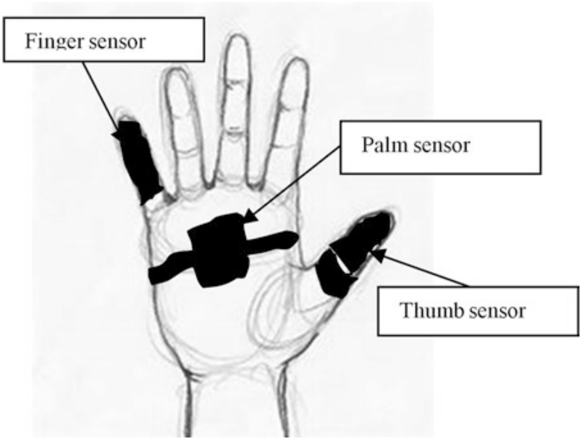

Fig 2.3 Bresslergroup's force-sensing "glove" for ergonomics. Adapted from http://www.designingforhumans.com/

scenario with a shift from manual dexterity and heavy physical operation to increased mental loads. For example, if we think of twenty-first century communication technology, the designer must consider the interface between the user's sensory and cognitive interface consisting of her associated auditory, visual and motor processes and the machine system or display. In other words, modern anthropometry looks beyond the body and gives precedence to designing for the mind. A good example is the efforts put in developing smartwatch design or Apple's mobile phones. In short, in interactive technology, the repetitive, mechanical actions of the body have now become closely linked to cognitive processes for which an understanding of the cognitive structure has become as important as that of the physical structure.

The above developments have led to the redesigning of the older workspaces. One example of how this is being done has been provided in a previous section which details how the NIOSH is attempting to improve the workspace for truck drivers of today, who are, by and large, heavier and need a workspace suited for their operations. Psychology of technology offers a platform for understanding behavioral patterns associated with a large number of unique situations that are otherwise taken for granted and thought to be "normal." In other words, it affords an opportunity to encompass the needs of different people in differing professions.

We believe that it is in this role that psychology of technology could contribute significantly at the global level. If workspaces can be improved, accidents can be prevented and anthropometric data can meet the needs of people in different cultures, the science of psychology, in general, and psychology of technology, in particular, will play a key role in the lives of people around the globe. It will help the activities of the *International Organization for Standardization* and recognize the contribution of initiatives such as PtD (Prevention through Design) mentioned earlier.

Finally, the success of any human enterprise, including the development of science and especially that of psychology which has had a weaker say in public affairs, depends on the inclusiveness of its clients. So far, anthropometry has not been able to enter the mainstream of our lives mainly because it has been seen that the principle of "one size fits all" just does not hold. Or, can we say that focusing on the majority and neglecting the minority has made a product important and personalized? We believe that the role of psychology of technology affords an opportunity for psychologists to highlight the significance of their subject in dealing with issues of global significance. As technology is proliferating at an astonishing rate, we have the momentum asking us to take a variety of initiatives. The need is to take advantage of this gathering momentum and derive psychological principles which will not only help designers of technology but also facilitate the designing out of accidents and other technology associated hazards. In this chapter, we have focused on some limited but important issues that need to be examined, clarified further, and evaluated within the classic scenario of psychology in particular and the interdisciplinary context in general. On this platform, biology and technology would find psychology a useful partner for future research.

Chapter Summary

The chapter starts by describing the use of tools and technology by animals, proving that it is not humans alone who use tools. Technological development seems to follow a similar evolutionary pathway. Neural evidence has been provided to show that we were "born to choose" and that technology does not just happen. Rather, there is a cognitive shaping of technology with each step of technological innovation enabling man to gain mastery over an uncooperative environment, thereby also proving that we could never have remained a tech-devoid society. It continues with the Darwinian process of evolution, stating that we have come a long way from the purely Darwinian analysis of evolution in terms of the laws of natural selection. Neo-Darwinism postulates that the process of evolution, including that of the human brain, throws up new structures in the form of exaptations and spandrels, which are then used for a variety of new behaviors, including new forms of cognitive abilities. The second part of the chapter asks the question that could technology have developed in some other way and answers it by providing a detailed description of anthropometrics and its application in the design of a variety of technologies, including space station design, design of equipment for the elderly and those used for rehabilitation purposes. The chapter ends by giving examples to show that though it is possible to go beyond anthropometrics, the possible consequences of neglecting anthropometrics should also be kept in mind.

Suggestions for Further Reading

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