Comfortable Portable Computing: The Ergonomic Equation

A WHITE PAPER

FORWARD

The origin of the most common types of discomfort experienced by computer users can often be traced to faulty placement of the computer screen and input devices (such as keyboards and mice). Although it may seem a subtle distinction, discomfort often arises when these devices are placed too high or too low or too far or too near to the user. Placing the monitor too high or too low causes the user to extend or flex their head and neck; holding those extended or flexed postures for more than a brief time quickly leads to discomfort. At the same time, a too-highly placed computer screen tends to expose more of the surface of the eye, which causes the protective tear layer to dry more rapidly than it would otherwise. The laptop computer, which now comprises more than half of all computers sold, can be especially problematic with regard to height placement because of the fixed height of the screen relative to the keyboard.

A basic maxim of ergonomics is that the work should fit the worker, rather than making the worker adjust to fit his or her work. Adjustable supports allow a user to tailor his or her workstation to match their individual characteristics, providing the maximum of comfort and productivity. Achieving the necessary fit with laptops can be difficult, if not impossible, without the use of either auxiliary input devices or displays. Use of either of these devices facilitates appropriate adjustment of the laptop computer workstation so that the work fits the computer worker.

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“WORK SHOULD FIT THE WORKER”

"

COMPUTING

SHOULD

NEVER

HURT

"

Figure 1

This White Paper combines ergonomic principles based on academic research with over 25 years of manufacturing and computing experience to provide valuable, easy to use rules of thumb for comfortable computing that once understood, anyone can apply.

After years of escalating sales, the popularity of portable computers (laptops, notebooks and tablet PCs) has reached an all-time high, and while desktops will always have a place in the computer market, it's clear that, with people increasingly on-the-go, computer use has expanded well beyond the brick and mortar walls of the traditional office. Accordingly, computer manufacturers are turning out high-performance "road warriors" that combine faster processing, greater storage capacity, high-resolution screens, lighter, more rugged cases and longer run-times—all at a competitive cost. Bolstering this demand are the expanding and newly emerging markets of a global economy whose consumers are eager to participate in the wireless lifestyle.

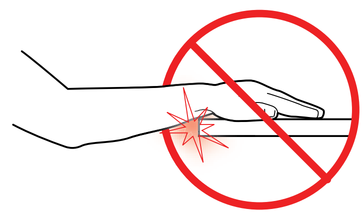
Portable computers allow people to correspond, study, play and conduct business across time and space with unprecedented speed and mobility. So it shouldn't come as a surprise that, with the price and performance gap between them narrowing, portable computer sales in 2007 outnumbered desktop[1] sales, and many are used as the primary work computer. Office workers who were surveyed about their computing habits estimated that the flexibility of portable computers added nearly eight hours of productive work time[2] to their week. And if the use of portables for work at home was adopted on a broad enough scale, they could even contribute to the greening of our environment by conserving fuel, decreasing traffic congestion and alleviating commuter stress. These and other innovations in communication technology, like remote audio and video conferences, have the power to erase the geographic boundaries that have traditionally separated people from each other.

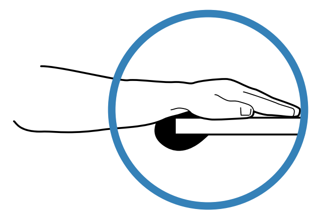
Ideally, portable computers will enhance our lives, making us more efficient and productive than ever. As man's "new best friend" portables can go wherever we go. But as they begin to appear with greater frequency in clinics, transport stations, dormitories and kitchens—not to mention some really exotic settings (imagine measuring the saltwater concentration in the Nile River delta)—we have to ask if there are accompanying risks. Owing to the unpredictable nature of the environments in which they can be used and the potential for prolonged use in unstable conditions, the negative effects of using a portable computer must be considered from a human factors point of view.[3]

"HUMAN FACTORS IS A DISCIPLINE THAT SEEKS TO IMPROVE PERFORMANCE, COMPATIBLE WITH THE ABILITIES OF THE USER"

The size and power requirements of traditional desktop computers are inherent constraints that portables have evolved away from, but which, paradoxically, offer a degree of reliability in terms of comfort, and therefore, productivity—the heart of the matter in any discussion of ergonomics. Yet in published side-by-side comparisons of the features and benefits of portable versus desktop computers, a case for comfortable computing is rarely argued. In other words, the average consumer isn't getting the full picture when purchasing a portable or desktop computer.

The negative consequences are felt in terms of health and cost,[4] because the design of a typical portable computer is ergonomically flawed: the keypad and display screen are as close to each other as two halves of a clam shell. An ergonomic set-up would place the keyboard at elbow height and the top of the screen near eye level. Ironically, size and mobility, which are the portable computer's major assets—those features that most differentiate it from the desktop computer—are also its ergonomic downfall. And the situation is exacerbated with the current trend away from 4:3 screen aspect ratios in favor of 16:9 aspect ratio screens, a reality created by the manufacturers of the glass used in computer displays[5]





If, by now, you're convinced that ergonomics and computer portability are mutually exclusive, it should be encouraging to know that the graphics in this paper were illustrated, and the text you are reading was typed, entirely and comfortably on a portable computer with the application of basic ergonomic principles, a dose of common sense and a little creativity.

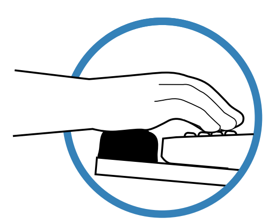
The purpose of this paper is to demonstrate that portable computers can be used productively and comfortably with the application of ergonomic principles based on an understanding of how our bodies relate to the computer and immediate environment.

PART ONE

The Science of Ergonomics

Literally stated, ergonomic [6] means work law. The impetus behind these laws of work is to sustain productivity by ensuring the comfort and wellbeing of the worker, a catch-all term that applies by extension to anyone involved in task-oriented endeavors: parents, athletes, artists, musicians, scholars, etc.

Ideally, the items used in routine tasks (sports equipment, construction tools, garden implements, computer keyboards and mice) should be designed to complement the size and shape of our bodies and should serve us in the appropriate environment with undue risk. In reality, we often put ourselves at risk, whether through commission, like removing the safety guard on an electric saw, or by omission, like failing to read the instruction manual for the saw. On a daily basis, we subject ourselves to hazards known and unknown. Warning labels and "Don't Walk" signs have become



almost invisible due to their constant presence. Ergonomics should be taken seriously, but until you start to hurt, and can't think of any reason why, helpful tips on posture, stretching and rest aren't very compelling. Before we examine the use of portable computers in an ergonomic context, let's take a brief survey of what is otherwise at stake.

The science of ergonomics has developed over many years of study[7] of the human body at rest and in motion. The resulting measurements, collectively known as anthropometric data,[8] are used to promote a healthy interface between people, their tools and their work environments. Understanding the relationship between these three factors is vital for the prevention of a variety of clinical disorders that result from fatigue and stress.

THE PORTABLE COMPUTER: MODERN MAN'S NEW BEST FRIEND?

Preventing Computer-Related Disorders

As you read this, you are probably sitting down; approximately 70% of all work done in America today is performed seated at workstations.[9] In itself, this statistic seems innocuous, but when you consider that sitting increases low back pressure five times more than standing,[10] the implication is truly alarming. For instance, it is reported that thirty-one million Americans have low back pain at any given time; that a third of all Americans over the age of 18 have had a back problem in the past five years severe enough for them to seek professional help, and that the cost of this care is estimated at $50 billion per year. [11]

Ergonomists and physicians involved in the diagnosis and clinical management of neuromusculoskeletal disorders have long recognized the correlation of risk factors with a variety of painful and often temporarily disabling syndromes. But the warning signs, ranging from mild to severe, are easily dismissed or misinterpreted. Symptoms such as numbness, decreased joint motion, swelling, burning, pain, aching, redness, weakness, tingling clumsiness and cracking or popping of joints don't necessarily indicate the source of the discomfort. Unchecked, a stressed area of the body can initiate a downward spiral of generalized, chronic pain. There is a rising awareness of this among healthcare providers who are taking measures to educate patients about how to communicate the intensity, duration and location of their pain for faster, more accurate diagnosis.

Like tie colors and the length of skirts, certain "disorders" become fashionable while others lose favor. So many acronyms[12] (often featuring "R" for repetitive) have been used to explain a wide variety of aches and pains: RMIs, RMDs, RSIs, RSIs, OOS, WRMSDs–we risk inciting despondency instead of sparking awareness in sufferers. And despite extensive scientific literature linking them to faulty work postures, the disorders listed above don't entirely reveal the many interrelated factors leading to their symptoms because, well, people are incredibly complex beings. To put a new spin on an old saying, we humans are much more than the sum of our individual parts: ergonomists know this all too well.

Table 1, right, organizes Cumulative Trauma Disorders into six specific groups, putting the diagnosis where it is experienced, rather than how it occurs. This is

Table 1

Specific Diagnoses
Referred to as Cumulative Trauma Disorders (CTDs)

Tendon Related Disorders	**Peripheral Nerve Entrapment**
Bicipital tendonitis	Carpal tunnel syndrome
Ganglion cyst	Cubital tunnel syndrome
Lateral epicondylitis (tennis elbow)	Guyon tunnel syndrome
Medial epicondylitis (golpher's elbow)	Pronator terres syndrome
Peritendonitis (strain)	Radial tunnel syndrome
Rotator cuff tendonitis	**Muscular**
Stenosing tenosynovitis of the fingers (trigger finger)	Focal dystonia
Stenosing tenosynovitis of the thumb (DeQuervain's)	Fibromyositis
Tenosynovitis	Myositis
Joint/Joint Capsule	Tension neck syndrome
Bursistis	**Vascular**
Osteoarthritis	Hand-arm vibration syndrome (Raynaud's phenomena)
Synovitis	Ulnar artery thrombosis
Neurovascular	
Thoracic outlet syndrome	

data supplied by the
National Institute for Occupational Safety and Health
Center for Disease Control and Prevention,
US Department of Health and Human Services

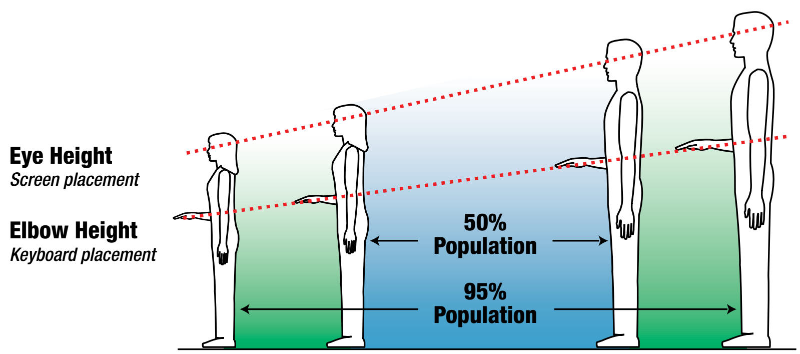
an important distinction. So often "repetition" is emphasized as the source of discomfort, when sustained static or faulty posture may be the real culprit. Computer users who experience pain and discomfort over the course of time are suffering the ill effects of a host of interrelated problems. Isn't it logical to expect that treatment should take into consideration all aspects of the body, as must any strategy aimed at prevention?

The trick is to start with what you've got: your own body. When working on a computer, consider how your body interfaces with the various elements involved in your task and how those elements, in turn, relate to each other: the chair, desk, computer, keyboard and mouse, the room temperature and lighting, ambient sounds, the thickness and height of the walls, etc. All are designed to ensure your comfort. The degree of success, that depends on good design based on good research: anthropometric data, organized by gender, size and age (Table 2 below). Engineers and designers take these human dimensions into consideration when planning furniture, appliances, tools, rooms and even fast food restaurant spaces.

In Table 2[13], at right, the dimensions for Eye Height lead to recommendations for the ergonomic height of a computer screen while Elbow Height establishes the ergonomic height of a computer keyboard and mouse. The data is organized in five columns of increasing proportions: 5% female, average female, average person, average male and 95% male; here's a practical application of the data in Table 2 for working at a portable computer follows:

> Sitting at a desktop computer, if your body dimensions match those of the middle column, "Average Person," then the distance from the floor to the top of your computer display screen should be 46.1" and the distance from the floor to the top of your keyboard should be 24.9". Since the distance between your eyes and elbows is 21.2", your screen and keyboard should be separated by the same amount—clearly not possible for a portable computer with its clam shell design.

Table 2

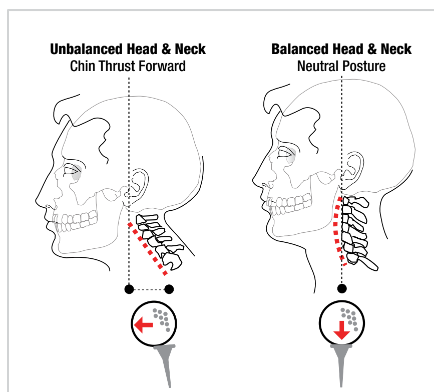


Eye Height	5% Female	Average Female	Average Person	Average Male	95% Male
Standing	55.7″	59.4″	61.7″	64.4″	68.6″
Sitting	40.8″	44.0″	46.1″	48.5″	52.1″
Elbow Height					
Standing	36.5″	38.8″	40.4″	42.5″	45.4″
Sitting	20.8″	23.0″	24.9″	27.0″	29.5″

Body Mechanics – Balance

Scientific research has revealed that approximately 70–80% of human energy is expended in the maintenance of the body's mass in space and the movement of the body's mass through space. As a survival mechanism, humans have an innate desire to conserve energy. The least amount of energy expenditure occurs when the body's mass is maintained in a balanced position over its base of support (Figure 2). The mechanical support structures for the maintenance of the head's position in space, whether moving or still, are the spinal vertebrae and discs, an intricate network of ligaments, cartilage and joint capsules, and numerous pairs of counterbalancing muscles in the front, back and on either side of the body.

Figure 2



For seated workers, the optimal position of the head is centered over the midline of the body when viewed from either the antero-postero (front to back) or lateral (side) plane or with a slight forward lean of about four degrees. The human head weighs between 8 and 14 pounds (proportionate to total body mass). If the head is held out of the neutral position (for instance thrusting the chin forward to focus on small screen image or tipping the chin up to avoid screen glare), the force exerted on the spine is compounded by a factor of ten for every inch off center.

Figure 3, right, illustrates the optimum neutral head position (four degrees forward) and the maximum neutral head position, 20° forward. Tipping the head backward slightly 4 degrees (to the zero degree position) is also within the neutral range, however it is not recommended.

A small amount of neck flexion is generally more tolerable than neck extension; however, experts generally recommend that both the amount of neck flexion and the time during which the neck is flexed should both be limited.[14]

In the illustration that follows (Figure 4), the neutral head position is shown in relation to the natural eye scan and the recommended distance of the eye to a computer screen, further being better; you can increase the font size if your comfort level surpasses general recommendations.

It can be stressful for the eyes to focus on near objects. In order to focus on near objects, the extra-ocular muscles turn the eyeballs inwards and the ciliary muscles work to shape the lenses. Prolonged viewing of near objects leads to eyestrain and visual discomfort. One solution is to place the near object (computer screen) well below the user's eye level. Although this can be effective in reducing the stress to the user's eyes, it unfortunately may cause the user to flex his or her neck, leading to musculoskeletal discomfort. Fortunately, keeping the monitor at a minimum viewing distance and at an appropriate height relative to the user's eyes is effective in maintaining both visual and musculoskeletal comfort for computer users. Refer to endnote for text size calculation.[15]

Figure 3

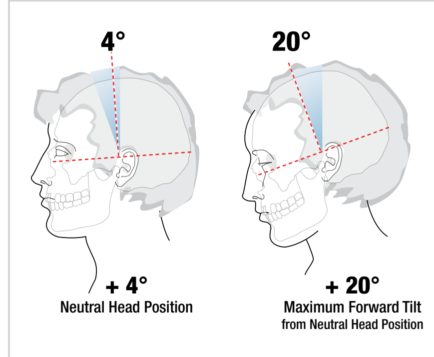


Figure 4

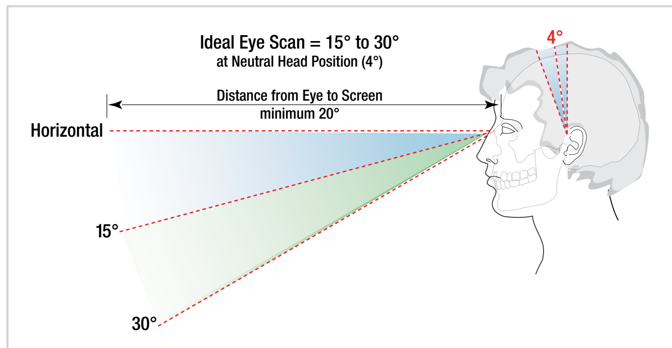


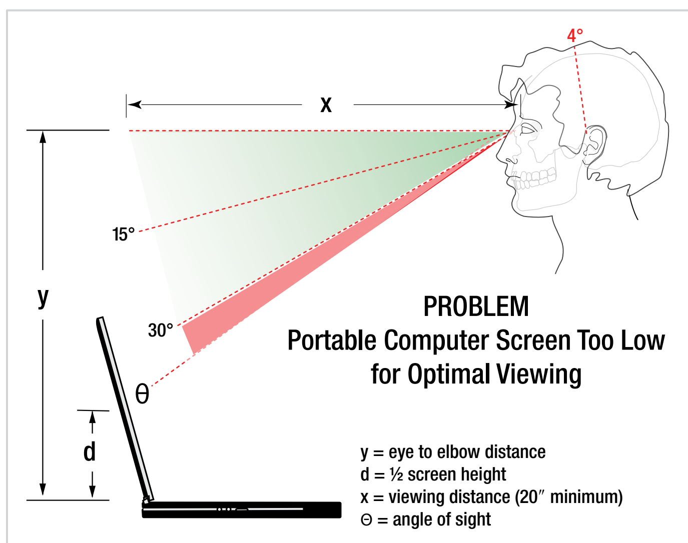
Figure 5 corresponds to the formula proving the nature of the ergonomic problem with portable computers:

If "y" represents a fifth percentile female whose eye to elbow distance is 19.2" (as shown in Table 2 of this paper), the logic proceeds that:

If a portable computer screen is 15" diagonal
And the screen aspect ratio is 4:3 (see endnote[16] for 16:9 aspect ratio example)
And viewing distance is the minimum 20 inches
Then the viewing angle = 36.3°.

But
Because the ideal viewing range is from 15 to 30° below horizontal
The portable computer screen is below acceptable range.

Figure 5



Current research and technical standards recommend that the monitor height should be determined by the user's eye height; the top of the screen should be no higher than eye level and the center of the screen should be about 15º to 30º below the level of the user's eyes. An easy way to assess the angle between eye level and screen center is to measure the distance between the user's eyes and the screen, then the distance below horizontal eye level to the center of the screen. The distance of the screen center below eye level should be about one half of the viewing distance.[17]

The Evolution of the Human/Computer Interface

Studies of the human body have led scientists to recommend both the length of time certain positions can be sustained without fatigue leading to injury, as well as the amount of time it takes to recuperate from the stress-inducing activities. These recommendations are affected by a number of factors, including gender, age, dominant side of the body (left vs. right) and the amount of force required to move equipment related to the activity. The data guides manufacturers in designing products that fit us.

The original CRT or VDT devices introduced in the late 1960s, while representing exciting new technology, were very poor from an ergonomic standpoint. They were simply housed in block boxes with an attached keyboard. A bit of progress was made in the second generation where the keyboard was separated from the display terminal. In the early 1980s a couple of entrepreneurial young companies[18] recognized the need to improve the human interface to these devices and began to design and offer tilt/swivel stands. These devices offered a number of ergonomic benefits including lifting the monitor 75 to 100 mm (3 to 4") above the desktop to provide better viewing for most people; they also offered a monitor tilt and pan function. By 1988, this technology had swept the world. By that time, literally all CRT monitors being produced came standard from the factory with the now familiar plastic bowl tilt/swivel accessory.

Advances in computer monitor ergonomics lay dormant for the next 15 years. It was during this period when computer operation held the dubious honor of being the most stressful occupation in US industry, according to the US Government Department of Occupational Safety and Health (OSHA). It was also during this period that the science of ergonomics became much more widely recognized and brought into practice as people began to recognize the growing health problems associated with the operation of these computers. The world's standards organizations also became involved to help ease the plight of computer operators by agreeing upon data like that in Table 3.

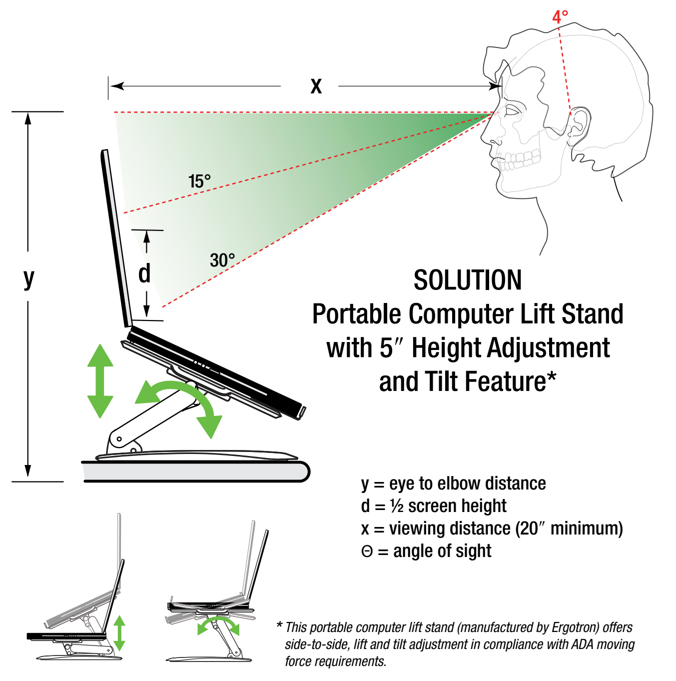
The advent of adjustable flat panel monitor desk stands represent the greatest improvement in the human/computer interface since video display technology was introduced over forty years ago. For the first time, computer users could adjust their computer display screen for optimum viewing.

Table 3

Ergonomically Acceptable Adjustment Forces

Gender	Age	LIFT Left (lbs)	LIFT Left (kg)	LIFT Right (lbs)	LIFT Right (kg)	PRESS Left (lbs)	PRESS Left (kg)	PRESS Right (lbs)	PRESS Right (kg)
Male	30	9.00	4.10	14.00	6.36	13.00	5.91	17.00	7.73
Female	30	6.00	2.72	9.34	4.25	8.67	3.94	11.34	5.15
Male	50	7.65	3.48	11.90	5.41	11.05	5.02	14.45	6.51
Female	50	5.10	2.32	7.94	3.61	7.37	3.35	9.64	4.38

Figure 6



** This portable computer lift stand (manufactured by Ergotron) offers side-to-side, lift and tilt adjustment in compliance with ADA moving force requirements.*

Adjustable support surfaces for laptops, screens and input devices generally require the user to operate controls, either to lock/release a support in position or to position the device. The amount of force required to operate these devices can be a significant impediment to aged or disabled workers. The Americans with Disabilities Act (ADA) strongly recommends that such forces be limited to 5 pounds force or less (22.5 Newtons).[19]

Figure 6, above right, shows an ergonomically correct portable computer mount that is designed to provide tilt, pan and screen rotation with no more than 5.1 pounds (2.32 kg) force—the amount that can be comfortably applied by the left arm of the average fifty-year-old woman and, of equal relevance, the amount of force required for compliance with ADA.

PART TWO

The Ergonomic Equation

Ergonomic recommendations for computer use typically consist of a parade of data tables like the ones presented in Part One. The facts and figures are accurate, but the burden of applying them to a real-life computer setting is placed on the user. This can lead to frustration and errors, which is a shame, when you realize that the path to healthy computing begins with your own body.

The next part of this paper will attempt to bridge any gaps between the statistical and the practical elements of ergonomics. Creating a healthy balance between the body, the computer and environment can be simplified by grouping key ergonomic concepts by their type and sequence. The result is an innovative, three-step process called the Ergonomic Equation:

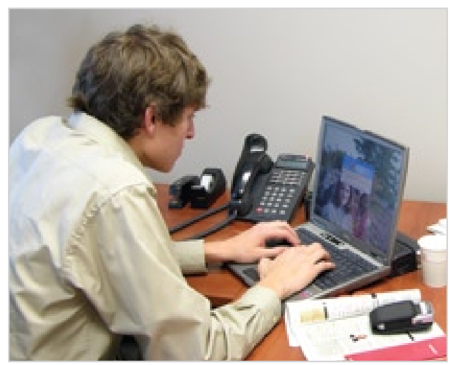
Neutral Posture + Voluntary Motion + Restorative Time
= Comfortable Computing

"THE THREE STEPS OF THE ERGONOMIC EQUATION LEAD TO A BALANCED BODY AND A COMFORTABLE COMPUTING EXPERIENCE"

Understanding the Ergonomic Equation is the equivalent to having a customized computer station, based on your computer equipment, your environment and your dimensions. First, let's look at the logic behind each step and then take some time to study pages 10 and 11, where the steps are illustrated and explained in greater detail.

1. Neutral Posture: Imagine the "neutral posture" as one your body assumes naturally and comfortably. The neutral posture places the smallest demand on energy expenditure and results in the least amount of structural stress and related fatigue. The neutral posture also helps preserve the normal forward curve of the neck vertebrae. The four counterbalancing front to back curves of the spinal column are designed to absorb shock and reduce structural and gravitational stress on the spine, which serves to protect the brain, spinal cord and attached network of spinal nerves and their functions.

Don't be misled into thinking that the neutral posture means staying in one place. Anthropometric data also defines an acceptable "range of motion"—the three-dimensional space surrounding the neutral position within which you move. People should avoid holding any body part "still" for more than a few minutes. Holding still is also known as static loading of muscles, which produces toxic waste products and fatigue. Range of motion links the first step of the Ergonomic Equation to the next step: Voluntary Motion.



2. Voluntary Motion: In coordination with neutral posture, voluntary motion works at maintaining a body in balance with itself and its surroundings. It refers to movements of our body that occur unconsciously, but with an important purpose: to prevent strain and fatigue. That sort of discomfort may be localized in the short term, but prolonged or repetitive exposure can lead to more serious damage.

In Step 1, you arranged your computer for optimum interface with your body's optimal neutral posture. The goal of the second step is to ensure the effortless, voluntary movement our body needs to maintain balance and prevent the build-up of toxins that result from static posture.

Have you ever focused your attention on the computer screen to such an extent that you've lost track of what's going on around you? The same thing is happening with your body: clenched jaw, locked elbows, crossed knees and unblinking eyes are at the root of many of the conditions we hope to avoid. If our tools or support structures discourage voluntary movement (e.g., legs are numb because the chair restricts circulation; the neck is twisted in order to see the computer screen because the computer stand doesn't adjust; the keyboard is too unstable to allow one to reach for a glass of water), we are only making a bad situation worse.

Busy people who share a computer with others are particularly at risk if they don't take the time, or don't have the option, to adjust the computer set-up for their comfort. For these reasons, it is vital that we choose support systems (desks, chairs, computer stands and arms, carts, etc.) designed to accommodate the dimensions and abilities of a wide range of people and computers with the following criteria in mind:

Adaptable or Adjustable
Flexible or Universal
Intuitive or Fail-safe[20]

Of the three Ergonomic Equation steps, the value of Voluntary Motion is most likely to be misunderstood and possibly ignored, making the final step, Restorative Time, that much more critical.

> "WHEN ANALYZING A COMPUTER SET-UP TO DETERMINE IF IT IS ERGONOMICALLY CORRECT, BEGIN AT THE HEAD AND WORK DOWN TO THE FEET"

3. Restorative Time: The final step of the Ergonomic Equation prescribes a period of rest to compensate for periods of constraining or repetitive action. Abnormal work postures produce asymmetrical compression on the spinal discs and excessive mechanical loading stress on the supportive ligaments and joint capsules. When unbalanced static muscle loading is experienced repeatedly and for prolonged periods, it results in a build-up of toxic waste products within muscles with resulting fatigue and loss of efficiency. Simple movement and stretching helps the body rid itself of the poisonous by-products of muscle metabolism.

Physical discomfort cannot realistically be banished from every type of human task, but Step 3 of the Ergonomic Equation focuses on the vital role of time in balancing stressful activities with restorative activities: for every two hours of active computer use, your body requires 15 minutes of recovery time. When working on a computer, you should take a two to three minute break at least every half hour, and be mindful that rest can take many forms, both passive and active. To help you relax and revitalize the areas of your body which interface with the computer and support equipment, establish a restorative routine that includes stretching, resting the eyes, deep breathing, sensible nutrition and drinking plenty of water.

Using a Portable in the Home or Work Office

If portable computers were designed to be used outside the office, many of us didn't get the memo! Businesses increasingly purchase portables as the primary tool for one or more employees within the same facility. For these people, as well as those who use their office portable at home or in the field, the best strategy is to set up an ergonomic workstation with the portable connected to a separate display (CRT or flat panel), keyboard, and mouse. If the option exists, a docking station (port replicator) is a valuable addition, since equipment cables and power cords don't need to be re-organized and connected with every move of the portable. Establishing a semi-permanent workstation centered around the portable computer means spending money on more equipment, but the investment is small relative to the cost of a regular CPU workstation, and it multiplies productivity by allowing several people to use the same computer in a variety of locations.

Figure 7, on the next page provides specific instructions for setting up a portable computer station with the Ergonomic Equation. The numbered details in the left column under Neutral Posture correspond to the lettered details in the right column under Voluntary Motion. The diagram is designed to reinforce the interrelatedness of the three Ergonomic Equation Steps. On the page after that, you'll find suggestions for stretches and breathing exercises in Figure 8.

Figure 7

Step 1– Neutral Posture

1. HEAD Directly over shoulders without straining forward or backward.

2. EYES About an arm's length from screen. Your gaze should fall near the center point of the screen, 15° to 30° below horizontal.

3. NECK Relaxed, with chin tucked in, not thrust forward.

4. SHOULDERS Kept down with the chest open and wide.

5. BACK Upright or reclined slightly. Maintain the slight natural curve of the lower back with a cushion.

6. ELBOWS Relaxed, at about a 90° to 120° angle.

7. ARMS Supported by chair arms or cushion—especially important for the arm using mouse.

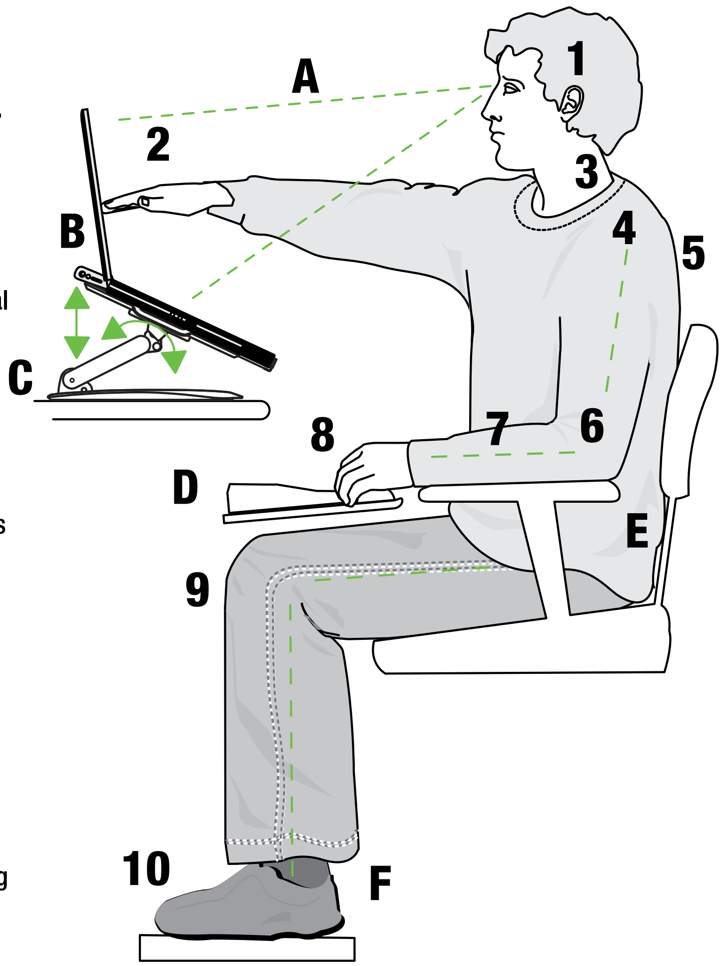
8. HANDS, WRISTS relaxed and in a natural position, without flexing up or down. FINGERS gently curved and supported.

9. KNEES Slightly lower than the hips with 2 or 3 fingers' width space between the back of the leg and the chair.

10. FEET Should be flat on the floor—don't cross legs or ankles. If possible, alternate working in a standing position to ease the strain sitting puts on spine.

The Ergonomic Equation

Neutral Posture + Voluntary Motion + Rest Time = Comfortable Computing



Step 2 – Voluntary Motion

A. SCREEN Augment portable with separate screen if possible for optimum ergonomic height. Screen stand should have tilt, pan and height adjust ability. Legible text size = 12 pt. at 20" minimum distance from eye (007 rule). Use screen controls for comfortable contrast and brightness. Minimize glare by tilting screen. Users with bifocals can obtain lenses specially ground just for computer use.

B. DOCKING STATION Adds "plug and play" convenience to portables so power cords and accessory cables don't need to be disconnected every time portable is removed.

C. DESK STAND Choose a portable computer stand like the one pictured for optimum screen height, tilt and pan adjustment.

D. KEYBOARD & MOUSE Augment portable computer with separate keyboard and mouse positioned at elbow height with rear of the keyboard sloping back 5°. In dark situations, direct light on keypad to prevent eye strain.

E. CHAIR Should provide adequate lumbar (back) and arm support; seat should meet minimum width and depth guidelines, and slope slightly forward to facilitate proper knee position.

F. FOOT REST Use a foot rest if the feet do not touch the floor.

Before doing any of these stretching movements in Figure 8 on the next page, consult your doctor to be sure they are compatible with your health profile. Don't bounce in or out of positions illustrated; they should be achieved slowly and held for a few counts; you should feel tightness, but not pain (if you experience pain, stop immediately and contact your doctor). Repeat motion on other side. Do three sets of each stretch.

Deep Breathing: Breathe through your nose, not your mouth; use your diaphragm to push all the air out of your lungs, pause, and then take a long, deep breath and fill your lungs as much as you can. Deep breathing regulates your heart beat and increases the supply of oxygen to your brain and muscles dissipating the toxic end products of muscle metabolism: carbon dioxide, lactic acid, uric acid. Several times each day, close your eyes and focus on your breath to relax and improve concentration.

Eye Rest: Turn your eyes away from the computer screen; direct your view to the opposite wall or through a window, focusing on a distant object to work your eye muscles. Gazing at a computer screen for extended periods can affect blinking leading to dry, itchy eyes and more serious complications. Have your eyes checked regularly and if you use reading glasses, you may be able to get lenses ground especially for computer use.

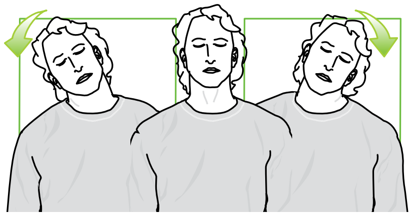
Stay Hydrated and Feed the Brain: Drink plenty of water, juice or herbal tea throughout the day; avoid caffeine and carbonated beverages. Fuel your brain with complex carbohydrates such as fruit, vegetables, nuts and seeds.

Figure 8

These stretches are recommendations only; you should always check with your own doctor before trying any exercise to make sure it is compatible with your own health profile.

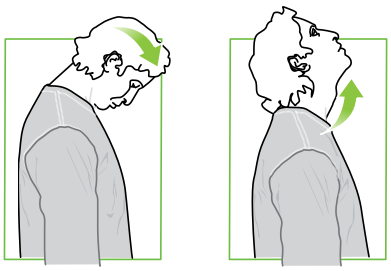
Step 3 – Rest Time – Relax & Revive

Head Tilt

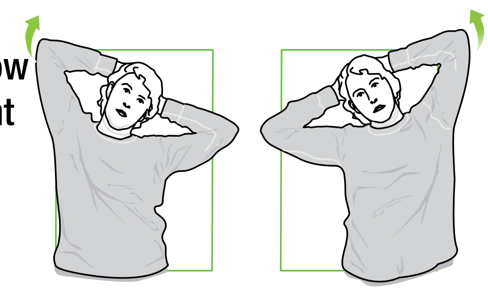


Head Pan

Chin Tip



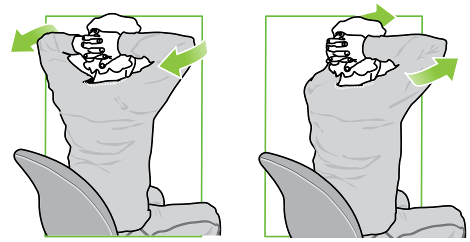
Elbow Point



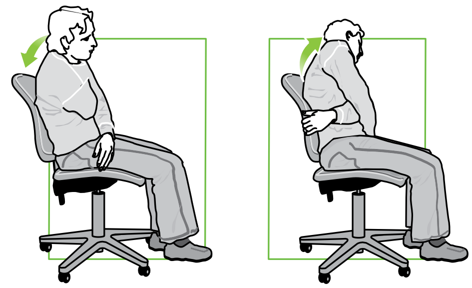
Forward Bend

Deep Breathing Rest Eyes

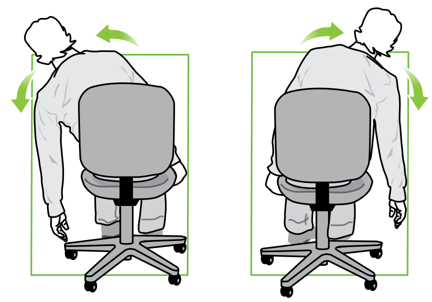
Shoulder Pulls



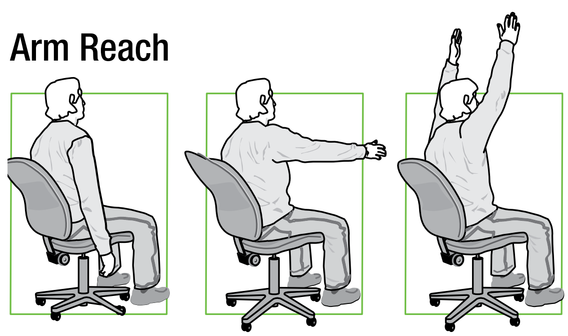
Waist Bend



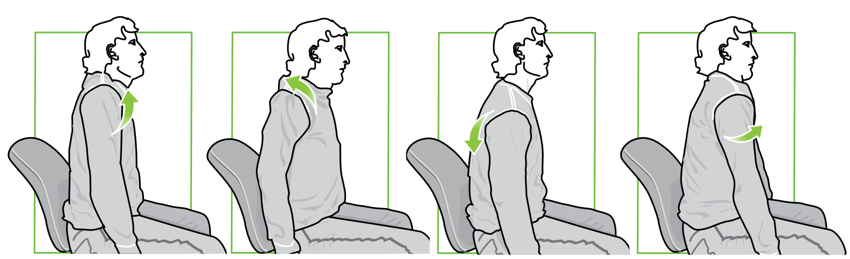
Side Bend



Arm Reach



Shoulder Roll – up, back, down, forward



Reverse Roll – down, forward, up, back

Portable Computing in the Field

If you are not bound by a desk but do the bulk of your computing on the road, Figure 9, right, highlights some of the causes of fatigue, pain and poor circulation. While the computer user in this example may look comfortable, we know that this position will not provide the support he requires over an extended period of time.

Now turn your attention to Figure 10, a scenario identical to the one above, and recall the assertion made earlier that common sense and creativity play an important role in the use of portable computers; if you remember how to achieve the neutral position, you will begin to recognize available objects around you that can remedy a less than perfect situation. Remember, too, that the principles of the Ergonomic Equation are always the same, you just have to put some effort into their application to suit the circumstances.

Generally, the best way to compensate for the flawed ergonomics of a portable computer is to attach separate output/input devices: flat panel display, standard size keyboard and mouse. These peripherals can easily be arranged according to ergonomic guidelines. But since it is not practical to bring extra equipment along everywhere you go, a certain amount of compromise is inevitable—at either the viewing end or the input end. In lieu of a desk or table, here are some tips for using a portable computer in the field:

Place portable on a flat surface to create stability and protect your legs from the heat of the processor.

A 3-ring binder placed under the portable provides negative tilt for keying and makes a handy foot rest.

Using a non-slip pad (for instance rubber shelf liner) prevents equipment from sliding; having to balance expensive computer equipment causes needless distraction and strain.

Pairing the portable with a docking station is a great strategy for people who divide computer use between permanent (office or home) and temporary (business travel/internet café) settings.

Figure 9

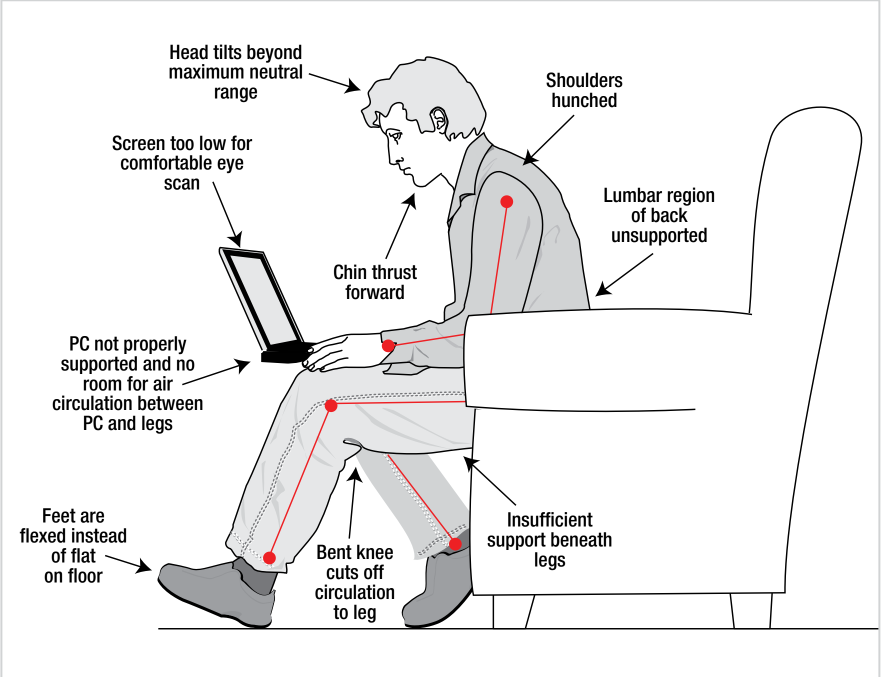
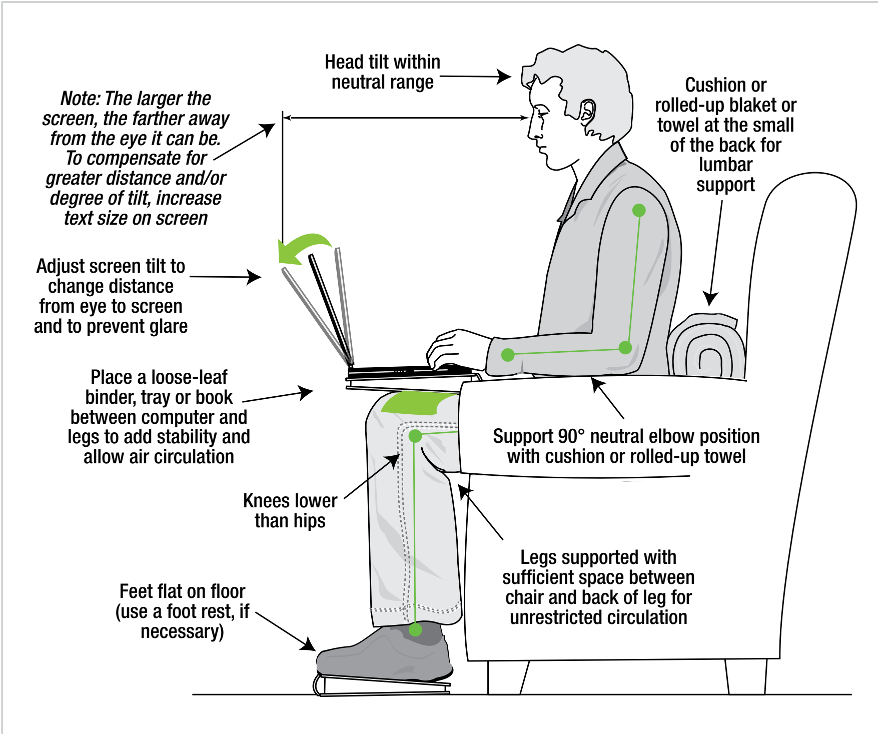


Figure 10

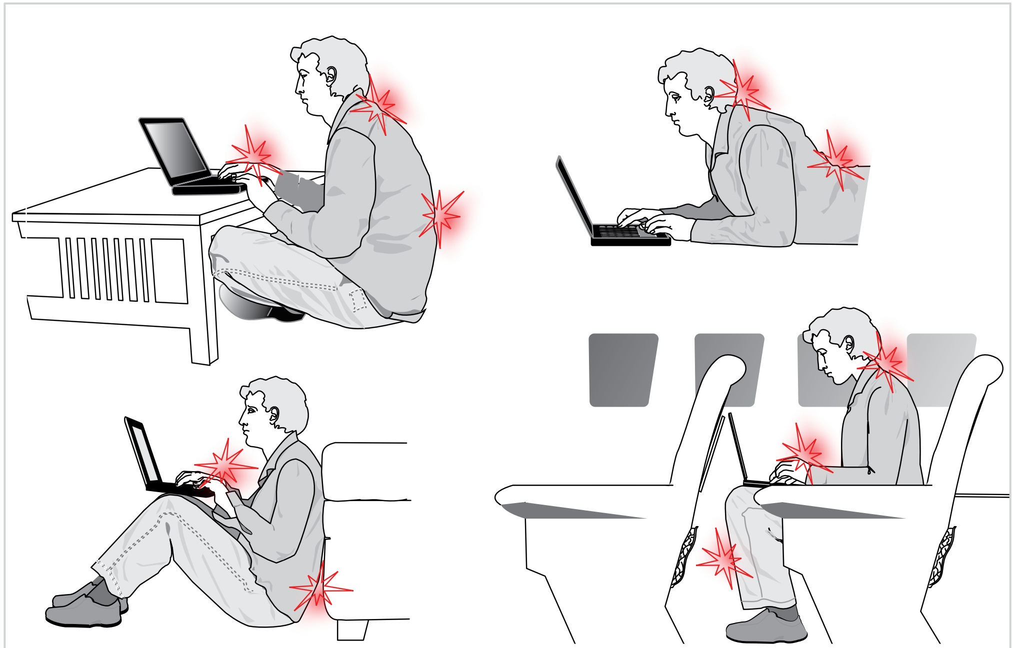


"Finding the right reach distance to input devices is uncomplicated: the elbows should be close to the sides of the user's torso, with the upper arm vertical or slightly forward of vertical." [21]

PART THREE

Making Portable Computing Comfortable

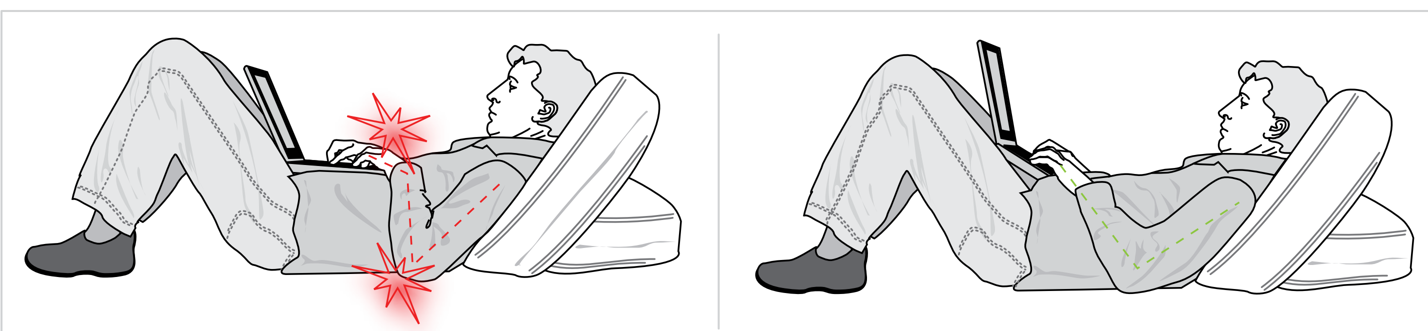
Figure 11



While the Ergonomic Equation forms the basis for comfortable computer use, any number of factors may influence how you apply the three concepts to a particular situation. The guidelines will almost certainly require modification and even compromise, wherever the assumptions upon which they are based diverge from the ideal. With that in mind, let's see how the Ergonomic Equation can be applied to our "road warrior," the portable computer.

The illustrations in Figure 11, right, represent some common portable computing postures that people adopt when computing at home or on the road. Now turn your attention to Figure 12. Can you tell the difference between the reclining figures? The one on the left shows signs of pain and fatigue, but why don't these symptoms appear in the illustration on the right? The remedy comes from a simple shift of the portable computer's position which resulted in a change of the angle of the elbow and wrist. Moving into a neutral posture helps make the user more comfortable, and enables longer computing time. Figure 12 is a good example of how to make the computer adapt to your body, rather than forcing your body to adapt to the computer!

Figure 12

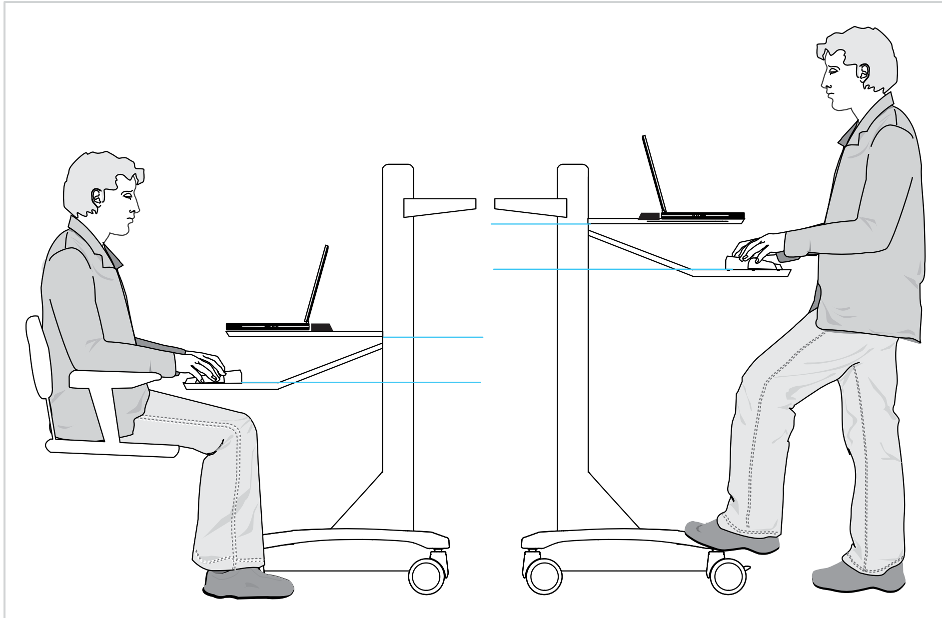


Correct and Comfortable Standing

Up until now, our discussion of portable computers has been limited to sitting applications, but portables are as likely to be used in standing applications, especially in medical or industrial situations. The many benefits of standing (or even walking on a treadmill) while at work is supported by recent research and appears to be gaining momentum as a recommended work stance. Standing encourages healthy body movement, a tenet of the Ergonomic Equation, and has positive effects on the metabolism.

The ergonomics of computer use remain constant whether standing or sitting. Of course, there is a difference in the elbow height and eye height, since both are higher when standing than when sitting, but the essentials are the same: maintain the correct distance between the portable computer screen and the keyboard; choose support equipment with tilt, pan and lift adjustment to ensure eye scan meets the middle of the screen within the optimum 15 to 30° viewing angle range; bend elbows at about 90° and can be keep arms close to the body (not extended); keep head balanced over shoulders, do not slump forward and don't allow the chin to jut forward. Periodically check your posture and correct wherever you've slipped out of the neutral posture.

Figure 13

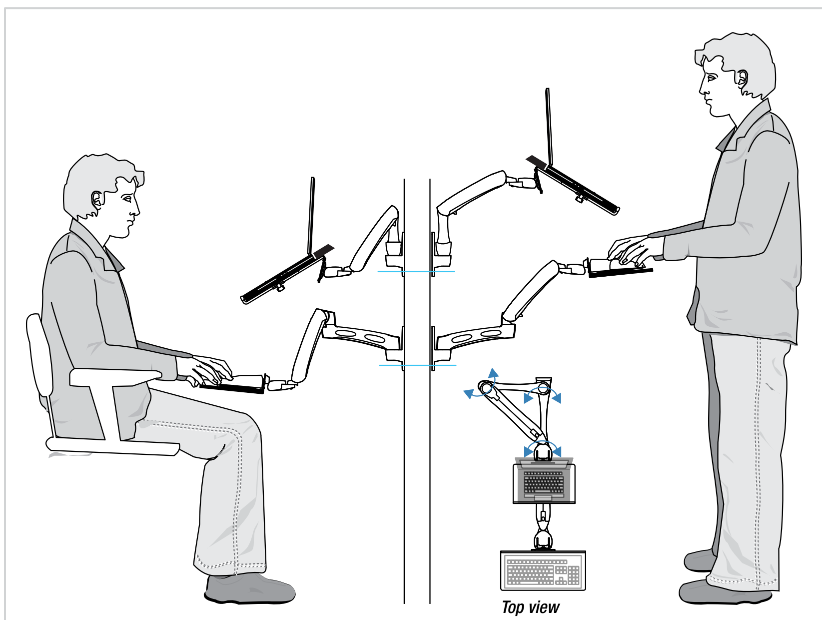


When standing, make sure a rail, foot rest or box is available for you to rest one foot upon. This encourages voluntary motion, so you can shift your weight from one side to the other. Don't neglect to take frequent mini-breaks (two to three minutes every half hour), and longer 15 to 20 minute breaks after every two hours of work.

Figure 13 illustrates the use of a portable computer on a cart which provides twenty-one inches of height adjustment, covering the eye to elbow distance of the population spanning from 5% female to 95% male, in both sitting and standing positions. [22]

The supplemental keyboard and mouse have been located on a lower level than the portable computer because the screen of the computer occupies the lowest allowable eye scan range. This is necessary in order to maintain, as much as possible, the same distance from screen to keyboard as there is from the operator's eye to elbow.

Figure 14



In Figure 14, we see the same range of motion utilizing a pair of articulating, vertical mounted arms, which can be repositioned easily, within the recommended force range noted in Table 2, page 5. Notice that the arms supporting the computer and keyboard are mounted at the same height, yet the workstation can accommodate changes in height, tilt and pan for the majority of users, whether they choose to sit or stand. In this computer/operator interface, the user has complete control.

The cart and arm support solutions illustrated here offer great advantages in situations where multiple users share a single computer set-up. At the same time, the needs of a single user are met, because the equipment is built to adapt to the person with quick, effortless adjustment.

CONCLUSION

Portable Computers and the Ergonomic Equation

Portable computers deliver benefits to consumers across every demographic. As the prevalence of portables increase, it is more important than ever to educate people to be proactive about incorporating ergonomics in their office, home or field setting. The manufacturers of computers and computer support systems are in a unique position to promote ergonomic principles to their customers and to demonstrate how well-designed products support this endeavor.

The Ergonomic Equation, introduced within the pages of this paper, proposes an innovative approach to teaching ergonomics to computer users. It incorporates the most current research available to improve how humans interface with computers to prevent fatigue, pain and the clinical disorders that can develop over time due to incorrect and static posture.

Anthropometric tables, measuring devices, calculators and levels are the tools of engineers, industrial designers and ergonomists; but ultimately, good ergonomics depends on the willingness of every individual to make their computing experience comfortable and productive.

Understanding that the starting point of ergonomics is your own body, and that you must control your interface with the computer so that it adapts to your needs, rather than the other way around, is an essential concept behind the Ergonomic Equation.

If you employ the three steps of the Ergonomic Equation—Neutral Posture, Voluntary Motion and Restorative Time—you will create balance between you, your computer and your environment!

> "IN THE HUMAN/MACHINE INTERFACE, THE MACHINE SHOULD ADAPT TO THE HUMAN, NOT THE HUMAN TO THE MACHINE"

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Manager, Technical Publications,
Human Factors and Ergonomics
Ergotron

Joseph J. Sweere, D.C.
Professor, Clinical Sciences Division,
Chairman of the Department of Occupational Health
Northwestern Health Sciences University

ENDNOTES

1 Articles: Global PC Market Remains Strong, by Ian Williams, vnunet.com, September 14, 2007; And Survey: Notebooks Surpass Desktop Sales For First Time, by Scott Campbell, *CRN*, August 22, 2005 Issue.

2 Desktop Replacement Productivity Impact Study, 2004, Dell, Inc.,

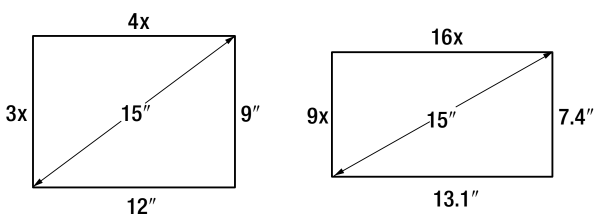
3 Human factors is a discipline that seeks to improve human performance in the use of equipment by means of hardware and software design that is compatible with the abilities of the user population. The terms “human engineering,” “usability engineering” and “ergonomics” are often used interchangeably for the process utilized to achieve highly usable equipment.

4 Medical expenses, lost wages, lower productivity and other expenses from work-related musculoskeletal disorders total an estimated $116 billion according to the Bureau of Labor Statistics. *Do it by Design, An Introduction to Human Factors in Medical Devices*, Sawyer, Dick, Office of Communication, Education, and Radiation Programs (OCER), Published by the U.S. Department of Health and Human Services, Public Health Service, Food and Drug Administration, Center for Devices and Radiological Health

5

Screen dimensions for 15″ diagonal portable computer

4:3 aspect ratio	16:9 aspect ratio
$(4x)^2 + (3x)^2 = 15^2$	$(16x)^2 + (9x)^2 = 15^2$
$16x^2 = 9x^2 = 225$	$256x^2 = 81x^2 = 225$
$25x^2 = 225$	$337x^2 = 225$
$x^2 = 225/25$	$x^2 = 225/337$
$x^2 = 9$	$x^2 = 0.667$
$x = 3$	$x = 0.81$



Maximum angle to screen center (below horizontal eye) = 30°
Minimum viewing distance (ANSI/HFES 100-2007) = 20″

Assume base of screen is at elbow height

6 From the Greek εργον, meaning work, and νομοσ, meaning law.

7 The Ergonomic Data referenced in this paper is based upon anthropometric measurements of the U.S. population gathered in several scientific studies including, among others, the 1988 Anthropometric Survey of U.S. Army Personnel. All values and recommendations are based on many theoretical assumptions and are provided as guidelines only. The user is urged to consult with a certified ergonomist for corroboration of the recommendations made for each application. This data provides a foundation upon which this White Paper is based, and should be referenced as such.

8 “Ergonomics includes the evaluation and study of all the various stress factors that could affect the physical, mental, and emotional health or workers ... stress factors include the structure of your workstation, air quality and ventilation in the workplace, possible chemical hazards, temperature regulation, noise modulation, and even labor-management relations. Individuals in the field also

research and develop safety communication systems, laborsaving mechanical devices, and personal protective equipment and clothing, and consider the shape and size of hand tools." *Golden Rules for Vibrant Health in Body, Mind and Spirit*, 2004, Joseph J. Sweere, D.C.

9 Ibid.

10 Carolina Back Institute.

11 Thirty-one million Americans have low back pain at any given time (1). One half of all working Americans admit to having back symptoms each year (2). One third of all Americans over age 18 had a back problem in the past five years severe enough for them to seek professional help (3). And the cost of this care is estimated to be a staggering $50 Billion yearly—and that's just for the more easily identified costs! (4).

1. Jensen M, Brant-Zawadzki M, Obuchowski N, et al. Magnetic Resonance Imaging of the Lumbar Spine in People Without Back Pain. N Engl J Med 1994; 331: 69-116.
2. Vallfors B. Acute, Subacute and Chronic Low Back Pain: Clinical Symptoms, Absenteeism and Working Environment. Scan J Rehab Med Suppl 1985; 11: 1-98.
3. Finding from a national study conducted for the American Chiropractic Association. Risher P. Americans' Perception of Practitioners and Treatments for Back Problems. Louis Harris and Associates, Inc. New York; August, 1994.
4. This total represents only the more readily identifiable costs for medical care, workers compensation payments and time lost from work. It does not include costs associated with lost personal income due to acquired physical limitation resulting from a back problem and lost employer productivity due to employee medical absence. In Project Briefs: Back Pain Patient Outcomes Assessment Team (BOAT). In MEDTEP Update, Vol. 1 Issue 1, Agency for Healthcare Policy and Research, Rockville, MD, Summer 1994.

Courtesy of the American Chiropractic Association.

12 *RMI*—Repetitive Motion Injury; *RMDs*—Repetitive Motion Disorder; *RSIs*—Repetitive Motion Injuries; *RSIs,*—Repetitive Strain Injuries or Repetitive Stress Injuries; *CTDs*—Cumulative Trauma Disorders; *OOS*—Occupational Overuse Syndrome; *WRMSDs*—Work Related Musculoskeletal Disorders

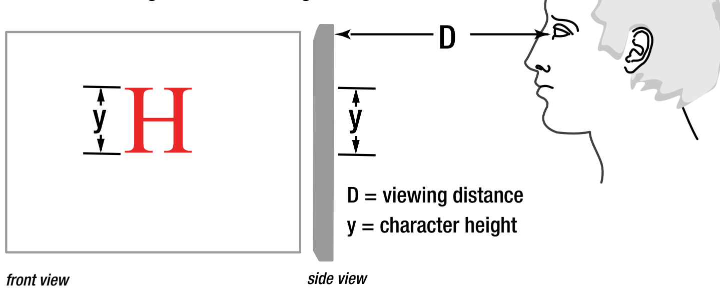
13 Refer to the Ergonomic Mounting Height Tables, page 18, for more information, including the equivalent metric measurements.

14 Tom Albin, PE, CPE
High Plains Engineering Services, LLC

15 Ibid.

THE 007 RULE

"Character height should be at least 0.007 times viewing distance to be legible."



EXAMPLE
At 20 inch viewing distance, 007 rule says that minimum character height is 0.14 inch (.007 x 20″). Therefore, 12 point type at 20″ viewing distance satisfies the rule.

[16] The same calculation using a Screen Aspect Ratio of 16:9 is as follows:

If portable computer screen is 15 inches diagonal
and screen aspect ratio is 16:9
and viewing distance is minimum 20 inches
then viewing angle = 38.8 degrees
But
because ideal viewing range is from 15 to 30 degrees below horizontal,
the portable computer screen is below acceptable range

[17] Tom Albin, PE, CPE
High Plains Engineering Services, LLC

[18] One of these "entrepreneurial young companies" is Ergotron, Inc., founded by Harry Sweere, a creative visionary whose passion for the well-being of his customers and employees was a model to all who knew him.

[19] Tom Albin, PE, CPE
High Plains Engineering Services, LLC

[20] Also known as "double redundancy" or the less flattering term, "fool proof," as applied to product design, "fail safe" means that every possible misuse of the product has been taken into consideration and accounted for.

[21] Tom Albin, PE, CPE, High Plains Engineering Services, LLC

[22] Table 2 illustrated the differences between eye and elbow height for a wide range of computer users. This underscores the need for adjustment of monitor and input device supports. Although adjusting monitor supports has been complicated in the past by the weight and bulk of CRT displays, this is now less of an issue due to the lighter weight of flat panel displays.
Tom Albin, PE, CPE, High Plains Engineering Services, LLC

Ergonomic Mounting Height Tables

INCHES

Anthropometric* Data **For Average Range of Operators (inches)**

	Eye Height			Elbow Height			Eye/Elbow Height Variance	
	Stand	Sit	Var.	Stand	Sit	Var.	Stand	Sit
Average Female	59.4	44.0	15.4	38.8	23.0	15.8	20.6	21.0
Average Person	61.7	46.1	15.6	40.4	24.9	15.5	21.3	21.2
Average Male	64.4	48.5	15.9	42.5	27.0	15.5	21.9	21.5
Variance F/M	5.0	4.5		3.7	4.0			

Anthropometric* Data **95% Female & 95% Male Range of Operators (inches)**

	Stand	Sit	Var.	Stand	Sit	Var.	Stand	Sit
5% Female	55.7	40.8	14.9	36.5	20.8	15.7	19.2	20.0
95% Male	68.6	52.1	16.5	45.4	29.5	15.9	23.2	22.6
Variance F/M	12.9	11.3		8.9	8.7			

*Anthropometry: The study of human body measurements. Data based on studies of US population

MILLIMETERS

Anthropometric* Data **For Average Range of Operators (mm)**

	Eye Height			Elbow Height			Eye/Elbow Height Variance	
	Stand	Sit	Var.	Stand	Sit	Var.	Stand	Sit
Average Female	1509	1118	391	986	584	401	523	533
Average Person	1567	1171	396	1126	632	394	541	538
Average Male	1636	1232	404	1080	686	394	556	546
Variance F/M	127	114		94	102			

Anthropometric* Data **95% Female & 95% Male Range of Operators (mm)**

	Stand	Sit	Var.	Stand	Sit	Var.	Stand	Sit
5% Female	1415	1036	378	927	528	399	488	508
95% Male	1042	1323	419	1153	749	404	589	574
Variance F/M	328	287		266	221			

*Anthropometry: The study of human body measurements. Data based on studies of US population

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