Risk Management & Safety Office

Ergonomics of Alternative Keyboards

Sorting out the choices...

Attention to keyboards and keyboard design is not new. However, in recent years, there has been a concerted and heightened interest in this topic. The purpose of the following review is to provide answers to questions commonly asked by users and employers. The text is based on a comprehensive review of over sixty years of scientific papers on keyboard design and ergonomics.

Introduction

A few of the very first "type writing machines" had circular or curved key arrangements. However, since those early experiments, the primary trends in keyboard design have been an evolution toward flatter key arrays.

Since the late 1980's, there has been a considerable increase in choices. Over a dozen new and innovative shapes of keyboards became commercially available in the United States. Many others were written about, though they were never put into production.

The surge in keyboard design innovation is widely attributed to concern about the physical effects of keyboarding on users' arms and hands. Those effects range from fatigue and discomfort to more serious medical problems often referred to as cumulative trauma disorders, or CTDs. Examples of this class of chronic disorders include carpal tunnel syndrome, tendonitis, "tennis elbow" and other ailments.

The basis for this heightened concern regarding keyboards has centered on dramatic increases in CTDs in recent years. The federal Bureau of Labor Statistics documents that since 1978 there have been a sixteen-fold increase in reported job-related disorders associated with repeated trauma. This increase has occurred in tandem with increased use of computers at work and at home, and widely publicized in the media. Another reason for concern about keyboards is a series of well-publicized clusters of arm and hand problems among computer-using newspaper reporters at specific sites and telephone operators at a western phone company. Yet another reason is a series of lawsuits by computer users against computer companies, alleging that keyboards were the cause of the ailments.

The apparent correlation between increasing computer use and increasing repeated trauma disorders may not be as clear-cut as it appears. For example, statistics on these disorders have increased dramatically for the entire American workforce, not just computer users. The government figures have certainly been skewed by an increase in OSHA penalties associated with inaccurate reports, changes in health insurance rules, heightened awareness by the medical community, perceptions of workers, and other factors.

Nevertheless, regardless of whether it is a recent trend or a long-hidden phenomenon, the problem of cumulative trauma disorders among computer users is real and significant. Computer use is ergonomically problematic in many ways. For example, keyboard use is often associated with working in constrained postured with few opportunities for movement; using the hands in non- neutral positions; and performing repetitive tasks.

Although keyboard work is by no means the only ergonomic risk factor associated with office work (handwriting, for instance, is also problematic), computer use certainly may introduce new risk factors or heighten the impact of existing ones. Consequently, any attempt to prevent or mitigate occupational hazards in the office should include attention to the nature of computer and keyboard work.

Keyboards and ergonomics

Designers of new keyboards are concerned with preventing musculoskeletal ailments or enhancing comfort or efficiency. All of the new keyboards represent attempts to address one or more of the known risk factors that contribute to fatigue, discomfort, and hand and arm dysfunctions.

Such risk factors include:

Posture:

Most of the new crop of keyboard designs is aimed directly at the **posture** issue.

Improper postures involving prolonged, non-neutral positions of the joints may stretch, compress, or otherwise stress tendons, nerves, or other tissues. Much attention is directed to promoting "neutral postures", and particularly avoiding postures that involve the extremes of the acceptable range of motion of a joint. The neutral position of the wrist, for example, is considered to be approximately straight and not significantly bent to the side, up or down. The neutral position of the hand and forearm is achieved when the hand and forearm are angled along the forearm in the direction of the small fingers, with the elbows close to the ribs. Further, research suggests that the dynamic characteristics (i.e., the rate of acceleration of the wrist) are an important risk factor that interact with and magnify the effects of wrist deviation.

Repetition:

Repetitive work represents an occupational risk factor when the frequency of repetition exceeds the ability of the soft tissues to recover from this exertion. Keyboard work can involve many thousands of finger movements per day. Commonly recommended "solutions" to such repetition include incorporating pauses or changes in activity into the work process, by slowing down, reducing the requisite number of keystrokes, or by shortening the proportion of time spent performing the repetitive task.

Sustained static exertions:

Sustained exertions involve the prolonged, active holding of a posture or a position. Although on the surface, to antidote to excessive repetition might seem to be eliminating movements, immobility is not considered desirable, particularly when postures are fixated in one position. Commonly recommended solutions include increasing postural support and providing greater opportunities to relax the muscle groups involved.

Forceful exertions:

Forceful exertions become risk factors when muscle capacity is exceeded as a result of an activity. Repetitious keying involving high forces that requires sustained static muscle contractions that have been associated with risk of injury. Research suggests that people presses keys considerably harder than they need to in order to activate the keystroke. Few office jobs require great strength, but some experts say even the effort of depressing keys, repeated thousands of times, increases the amount of force involved. Commonly recommended solutions for reducing forces required from keyboard work include reducing effort required to activate a key with key switch designs. Because of technical complexities and a lack of scientific research, this aspect of keyboard design is not discussed in this paper. Localized mechanical stresses:

Mechanical stresses result from pressure from external surfaces, such as sharp edges of a keyboard. Pressure can affect the function and health of nerves and tendons, chiefly by inhibiting the essential flow of blood and lymph around cells. Ergonomists generally recommend rounding or softening hard surfaces that come in contact with vulnerable areas, particularly the wrists and elbows.

The presence of any of these risk factors (described) may increase the impact of others. For example, poor wrist positions have greater significance when combined with static positions, or high levels of repetition.

Of all these risk factors, attention to improving posture of the fingers, hands, wrists and elbows is most central to the latest crop of keyboards. This paper describes the characteristics of features of these new keyboard designs. It also reviews what is known regarding their potential benefits.

The features of alternative keyboards that are reviewed in this paper represent a significant departure of physical shape from conventional keyboard designs. Correspondingly, they are split, hinged, or otherwise formed to encourage hand and arm postures that are believed to be more comfortable and healthy. These models are also limited to alphanumeric keyboards with at least fifty keys, which are laid out in the usual QWERTY pattern.

Radical departures in keyboard design, such as configurations involving only one hand or with only a few keys, were not considered for this review. Nor does this paper examine the effects of different ways of designing key switch mechanism, which control how the effort required pushing a key or how far it can be depressed. Although such mechanisms are frequently considered to have significant implications for user comfort or health, they are beyond the scope of this paper.

Keyboard research

Ergonomists and designers use a variety of measures to evaluate keyboard designs and keyboard work. Some evaluations have been conducted in real work settings, but most occurred in laboratories, using simulated work settings and controlled conditions. Evaluation measures include:

Subjective Ratings: Keying Comfort

Research studies have typically included user responses regarding their perceived comfort while using the keyboards. Discomfort is frequently measured with Body Part Discomfort Scales. Results of these studies are sometimes difficult to interpret. Comfort is difficult to describe, and may mean different things to different people. This is particularly so especially when users have a history of chronic musculoskeletal disorders.

Subjective Ratings: Fatigue

Researchers may also measure how tired subjects are after using the keyboards, or the difficulty or effort required to use them. Common tools for assessing this dimension may include the Borg Scale, or with bi-polar Likert questionnaire items. Fatigue may also be assessed by asking people to type as long as they can.

Subjective Ratings: User Preferences

Researchers frequently ask users whether they prefer certain keyboard designs over others. While this is essential information, it is often difficult to interpret. Researchers always wonder whether preferences are influenced by novelty, appearance, faulty expectations of health, or other factors. Attitudes towards the product may be influenced by expectations of the researcher, particularly when the research is being conducted by the inventor or manufacturer. Preferences may also be related to specific characteristics of the study. For example, users may express preferences for a particular keyboard when entering text, but not when performing data entry because of characteristics of the numbers keys. The best preference studies probe more deeply and ask users for reasons for their preferences.

Muscle Exertions (EMGs):

Research frequently evaluates the amount of muscle activity required to use a particular keyboard. Higher levels of activity are considered to increase the potential for fatigue. Muscle activity can be determined from electrical signals emitted by muscles involved with a task. The signals can be measured using electrodes attached to the skin over the muscle group of interest. Scientists evaluate these signals by comparing them to an individual's maximum muscle contraction capability. This measurement technique is referred to as Electromyography, or EMGs. These studies almost always happen in laboratory settings.

Physical Symptoms:

Researchers may also measure the prevalence of symptoms of musculoskeletal injuries following the use of new keyboards. Such research may compare the frequency of symptoms among a group of users of alternative keyboards with those of conventional keyboard users, using a variety of questionnaire forms. Other studies compare a group's injury rates before and after using a particular keyboard, perhaps also checking this group s results against another group using conventional keyboards. These studies always use real workers in real jobs.

Performance:

Although a variety of measures of performance may be used, research has primarily investigated whether users can key faster or more accurately with new keyboard designs, compared with conventional ones.

Learning Curve:

How long it takes to regain original typing speed and accuracy (error rate) when starting to use a new design.

Presence of Risk Factors:

This dimension examines whether known risk factors are reduced with new keyboard designs. These commonly center on the presence of wrist, hand, and/or arm postures. When reading about keyboard research, it is important to understand that most studies are flawed in some way, subject to interpretation, or for one reason or another produce results that contradict other studies. Few studies answer research questions firmly and for all time. Some limitations of the existing studies of alternative keyboards are:

- EMG studies can only look at the activity of a few muscles at a time. Effects on other muscles are simply not recorded. In addition, EMG is difficult to perform perfectly, and erroneous results are always possible.
- Many studies use very few people in their evaluation. The smaller the study sample, the less reliable are the results.
- Some studies look at effects on healthy people, while others examine people with existing musculoskeletal discomfort. Reactions of the two groups are often completely different.

- Many studies look at very short periods of keyboard use, as brief as a few minutes. Depending on the effect being studied, short use may not be realistic or give valid data.
- Some studies do not change or control work station variables, and thus evaluate keyboards in an unrealistic or disadvantageous way. For example, some alternative keyboards require exceptionally low placement, and putting those keyboards on desktops gives misleading information.
- Keyboards differ on many subtle factors which may affect outcomes as much as the obvious features. For example, it may be difficult to depress the keys on a particular design. Without quantifying and standardizing these subtle features, results may be attributed to the wrong aspect of the product.
- Likewise, features may interact. A keyboard that slows down the typist, for example, may produce "favorable" EMG readings that are due more to slowness than to the keyboard's design.
- Studies that are sponsored by keyboard manufacturers may (or may not) have subtle biases. For example, a study may look only at the factors that the keyboard designer expected to affect positively, and may not examine factors where the design had negative consequences.
- Finally, even a perfectly executed study with perfectly accurate results may be misleading if the results are not interpreted properly. For example, a "statistically significant" (i.e. highly likely to NOT be the product of mere chance) result may correctly describe a difference that is very small and therefore unimportant.

Types of alternative keyboards

This paper discusses four new types of keyboard design:

Split keyboards

The inventors of split keyboards focused on reducing a hand and wrist position called ulnar deviation. In this position, the wrist is bent to one side, toward the little finger. Ulnar deviation is a non-neutral position that has been shown to contribute to the fatigue of certain muscles; increase friction and pressure experienced by some tendons, particularly in the thumb area, and add pressure to two major nerves running through the wrist.

Keyboard users bend their wrists outward for a number of reasons: to align their hands with the rows of keys, to align the left hand with the diagonal direction of columns of keys (the right hand is fairly well aligned to the diagonal columns), and to reach the space bar with the right thumb. These adaptations usually seem to be done unconsciously.

Split keyboards attempt to straighten the wrist by changing the orientation of keys. One type of design aims each half of the keyboard toward the elbows; another design separates the two halves to about elbow width.

Keyboards that aim the keys toward the elbows can be categorized further: those molded in one piece, with a fixed angle between the two halves, and those with a hinge or other adjustment that allows the user to set the angle. While the fixed versions are less expensive than the adjustable ones, they involve some unproven assumptions. One is that a single angle will work well for everyone. Another is that users do not need to gradually become acclimated, physically and psychologically, to a new shape.

However, research does support the idea that split keyboards can help relieve some posture stresses. They have reduced ulnar deviation and muscle activity in some studies. Users in other studies say split keyboards reduce discomfort, increase feelings of relaxation, and are more "usable" than conventional designs. These positive results are not universally found, however, particularly with regard to discomfort among healthy users. And not all study participants prefer the new designs over the old ones.

The available research indicates that most typists learn to use split shapes quickly. Following an initial drop-off in speed or accuracy, users generally regain their original performance quickly, in as little as a day or two. Experienced typists seem to take longer than inexperienced ones, most likely due to having to unlearn long-standing hand positions, movements, and key locations. Novice typists appear to be able to learn to type as quickly on split keyboards as on conventional ones.

Several split keyboard designs rearrange some auxiliary keys to better suit the split design. They may place those extra keys where they will be used by the thumbs. This raises the issue of overuse of the thumb, and indeed there have been anecdotal instances of thumb strain by users of alternative keyboards with extra thumb keys.

Tented keyboards

Tented keyboards take the split design one step farther. In addition to helping correct ulnar deviation by aiming the two halves of the keyboard toward the elbows, tented keyboards attempt to correct another non-neutral joint posture called "pronation." Pronation involves rotating the hands inward toward the thumbs, thereby twisting the forearms. The amount of possible pronation is related to the posture of the whole arm. With the arms straight, most people can rotate the hands about 270 degrees. When the elbows are bent at right angles, as in a normal keying posture, most people can rotate the hand only about 180 degrees. The palms-down position is close to the limit of motion for most people.

Working with the palms down twists and stretches the muscles that lift the fingers (extensors) while shortening the muscles that curl the fingers (flexors). Muscles that are stretched or shortened work less efficiently and therefore fatigue more easily than muscles at their ideal length. Other muscles in the arm are affected as well, and some of them must contract constantly to maintain this position which is considered to be a forced one. Working with the palms down also twists and shifts tendons in the carpal tunnel, potentially pushing the vulnerable median nerve against the transverse ligament that forms one wall of the tunnel.

Tented keyboards attempt to correct this by allowing the user to work with the palms angled toward each other. Different keyboard designs allow more or less angling, and some adjustable- angle keyboards can be set nearly vertical.

Studies of preference, comfort, and perceived fatigue suggest that tented keyboards have moderate advantages over conventional keyboards, at least for some people. Some, but not all, studies measuring performance found increased speed and accuracy for moderately tented keyboards, which is consistent with the notion that the palms-down position is an inefficient one. However, the "best" angle for performance as well as subjective measures varied dramatically from person to person, implying once again that user control of a keyboard's geometry may be a key factor.

The adaptation or learning curve for tented keyboards appears to be longer than for split keyboards. However, available evidence suggests that most users eventually regain their original performance and some may experience improvements.

There are some apparent drawbacks to tented keyboards. Studies and other anecdotal evidence indicate that visibility of the keys is diminished with some designs and angles. In addition, tented keyboards are dramatically thicker than conventional keyboards and must be set lower, or need considerable arm support.

Negative-slope keyboards

At least one alternative keyboard design has extendable legs at the front, rather than the traditional rear, of the keyboard. Using these supports results in a keyboard with a flat or even backward slope.

The designers of this keyboard were addressing another non-neutral posture called wrist extension, or bending the wrist back. Bending the wrist back has been shown to reduce the diameter of the carpal tunnel, potentially increasing pressure on the median nerve. In addition, it causes some forearm muscles to work in a shortened form, which is an inefficient work mode increasing susceptibility to muscle fatigue.

Two situations commonly involve backward-bent wrists. First, a user may drop his/her wrists to the work surface in order to rest them during typing. A wrist rest can help correct this by preventing the wrists from sagging.

It's also possible to see backward-bent wrists when a keyboard is placed lower than elbow height. A low keyboard in itself is not a bad thing; in fact the available research indicates there may be advantages to working with partially straightened elbows. But a low keyboard slanted toward the user's face inevitably causes bent wrists. Flattening the slope of the keyboard or even sloping it back can induce a straighter wrist posture. This is the objective of support legs on the fronts of keyboards.

There is no published research on the effectiveness of this keyboard design feature. However, some studies have looked at the concept of low, negatively sloped keyboard support trays. This research does suggest that this approach can improve wrist posture, muscle activity, and comfort. In a slight negative slant, key tops can be read easily.

One possible drawback of front supports is inappropriate use, if the keyboard is used high enough to force the hand to bend up and over the front of the keyboard. Another is the potential inability to lower the keyboard as far as would be possible with a conventional keyboard on a back-sloping tray.

Supportive keyboards

Keyboards with built-in wrist or palm rests share the design intentions of keyboards with front support legs --- they attempt to encourage straight wrist postures that are considered to be comfortable, non-fatiguing, and possibly healthy. In addition, they help the user's wrists avoid the sharp, hard edges found on many keyboards and furniture. Built-in wrist rests have rarely been studied. However, there are a number of studies on generic wrist rests. In general, research supports the idea of resting the hands on some kind of a surface during keying pauses. The use of wrist rests has been associated with reduced muscle activity in the arms and shoulders, straighter wrist postures, comfort, and preference. Some research suggests that wrist rest users sit in a somewhat more reclined posture than people without wrist rests, which is known to be comfortable and healthy for the back.

However, wrist rests are not without potential problems. Not all studies of wrist rests show positive effects. Recent research suggests that use of a wrist rest causes the fluid pressure in the carpal tunnel to rise, sometimes significantly. One study indicates that convex wrist rests, which concentrate pressure in a small area, are less desirable than broad, flat ones. And at least one report describes a benign cyst apparently caused by constant pressure on the wrist. Because of this information, ergonomists emphasize that users who wish to have a wrist rest should choose and use them carefully. Typists should use them during keying pauses, not during keying, in order to have free hand and arm movement and to reduce the amount of time the wrist is compressed.

Scooped Key Arrangements

At least two commercially available keyboards arrange their keys in bowl-like shapes. The designers' intention was twofold. One reason is to bring the keys slightly closer together, requiring less reaching and perhaps permitting the addition of an extra row of keys. Reducing reaches is intended to reduce fatigue, and adding extra keys reduces movement of the hands to other parts of the keyboard. The extra row can also have the effect of reducing the size of the keyboard, since side keys may no longer be necessary. The other reason for a scooped arrangement is to avoid having to lift the fingers unnecessarily, especially the longer fingers. Lifting individual fingers is felt to be more stressful than working with all the fingers downward.

There is virtually no published research on the musculoskeletal effects of a scooped arrangement.

Minimum-motion keyboards

Although a major ergonomic principle is moderation, some keyboards are designed to reduce certain movements and muscle actions to a minimum. These keyboards may have keys that operate with slight up-down or side-to-side twitching movements. They attempt to reduce muscle tension by virtually immobilizing the hands and supporting them more complete than conventional keyboards can. In addition, minimum-motion keyboards reduce the amount of tendon travel through vulnerable areas such as the carpal tunnel.

There is virtually no published research on the benefits or drawbacks of these effects. Some studies indicate that minimum-motion keyboard users may not be able to achieve conventional keyboard typing speeds, but at least one study suggests this is not a problem.

Keyboards with straight column arrangements

Since the conventional arrangement of diagonally offset rows is simply an artifact of old mechanical-key designs, there is little reason for diagonal columns other than tradition and the habits of millions of touch typists. Some keyboard designs eliminate this offset, resulting in keys placed precisely above each other as on a telephone or cash register. Some designs vary this by running diagonals one way for the left hand and the opposite way for the right.

This approach intends to help the left hand more than the right, since the diagonal arrangement corresponds to the angle of the right hand's fingers, but runs opposite to those of the left. Ergonomists believe this is one of the main reasons for ulnar deviation of the left hand.

Although this design feature has been discussed and commercially available for at least twenty years, no one has done any real research on it.

Sidebar: Implementation

If you choose to choose to get an alternative keyboard, consider the following tips:

When deciding which keyboard(s) to use, evaluate them carefully.

Evaluate their technology: Are they compatible with your existing computers, as well as with the kind of system you will be using in the future? Check both hardware and software compatibility. The special drivers that come with some keyboards may not work with Windows 95, for example. Decide whether you want certain features such as programmability (the ability to re-define key layouts through software). Make sure the keyboard will work properly with any other input devices you use, such as digitizing tablets, mice, foot switches, or voice recognition.

Evaluate their fit with your existing environment: Some alternative keyboards are extra-wide, long, or high, and don't fit well on ordinary keyboard trays. They may make it impossible to retract the tray under the work surface. Some keyboards, particularly the tented ones, demand low placement, so the keyboard tray issue is a critical one. Check whether the keyboard's shape will affect the placement of adjacent devices such as trackballs.

Consider the sales and service issues: Understand the terms of the warranty and how the keyboard will be maintained or repaired. Ensure you can return the keyboard if it doesn't work out in the first few weeks. Ask whether the company will be changing its design in the future ... and how the design will change. Attempt to get a price guarantee. In this fast-changing market, alternative keyboard prices drop often.

Choose the ergonomic features that are appropriate to the user and their job. If the user is experiencing discomfort or has an injury, involve a therapist or other health professional in the choice. Consider whether the user is a touch typist or a hunt-and-peck typist. Visibility of the keys may be and important issue. If the keyboard will require more postural support than usual (of the arms and back, for example), decide whether this will be a hindrance, especially to people who have to move around a lot. Evaluate whether the job requires use of the numeric keypad and specialized keys. Some alternative keyboards eliminate or move these keys.

Evaluate the keyboard's comfort: Individuals who will be using alternative keyboards should use them on a trial basis before making a final decision. The trial period should be at least two days, because of the learning curve involved with new shapes. If possible, let users use trial keyboards until they feel confident about their opinions. Anticipate some frustration while users get accustomed to the new designs. Most frustration arises from impaired speed or accuracy that typically happens when beginning to use a new design. If the keyboard design is adjustable, encourage trial users to change the geometry gradually. Get feedback from users, but don't necessarily try to "vote" on one keyboard design for all potential users. Preferences and comfort ratings will vary, especially if users are already uncomfortable or injured. Pay careful attention to the reactions of uncomfortable or injured employees. Remember that different keyboard features may benefit different kinds of injuries. Try more than one alternative keyboard during the trial process. Attempt to discriminate between real reactions and reactions due to novelty or prior expectations. Involve someone who is knowledgeable in ergonomics to help in the decision.

Once you have purchased an alternative keyboard design, integrate it into the work situation carefully: Users should be trained in the proper use of the product. Most keyboards can be used incorrectly. If the keyboard is adjustable, users should change the adjustments gradually, starting from a conventional position. Users should pay careful attention to any discomfort they experience, even if it is months after beginning to use a new keyboard. Because of new hand movements or increased use of certain fingers, alternative keyboards can potentially cause new problems. Follow up. Contact the new users frequently and get updates. Help future users by relaying your findings to the alternative keyboard's manufacturer, ergonomists, and other users.

Sidebar - Beyond Alternative Keyboards

The alternative keyboards described in this paper constitute most of the well-known and striking innovations of the last few years. Other commercially available keyboard designs, ranging from the subtle to the outlandish, are outside the scope of this paper but deserve to be mentioned. They include:

Programmable keyboards have keys that can be reassigned to bring often-used keys within closer reach. Programmable keyboards can also change keystroke combination assignments, sometimes called key bindings, from awkwardly-spaced pairs to convenient ones. An example of a keystroke combination is the Alt-Tab combination in Microsoft Windows. In addition to potentially making work more comfortable, programmable keyboards can reduce errors or frustration by putting inconsistently-placed keys, such as \, in the position expected by the individual user.

Some keyboards have unusual but relatively minor differences in key layout. Several keyboards have two-piece space bars, for example. The right half of the space bar functional normally, but the left half executes a backspace or another function. This can eliminate some reaches for other fingers, and makes use of an unused digit (the left thumb). Whether this potentially causes overuse of the thumb has not been scientifically investigated, however.

Concern about the motion of the thumb has inspired an even more unusual space bar mechanism in at least one keyboard. One tented keyboard's space bar can be pressed end-on, in a motion that is considered to be more natural than the downward motion required by regular space bars.

Chord keyboards have very few keys and thus require less overall hand and arm movement. Chord keyboards use "chords" or combinations of keys to represent characters. Chord keyboards can possibly be categorized as a non-QWERTY "minimum motion" keyboards as described in this paper. However, chord keyboards can have a significant learning curve for experienced typists, and research indicates they rarely allow users to type as fast as on a conventional keyboard. Chord keyboards can be beneficial for people with limited mobility or the use of only one hand.

There have also been many variations in the design of the mechanism under each key. Some research suggests that people who key with greater force tend to have more discomfort than people who key softly, although the direction of causality (force causes symptoms or symptoms cause force) is unclear. This information, plus a number of lawsuits file against computer manufacturers alleging that keying force is risky, has led to speculation about whether keying force can be reduced. The picture is complicated by the fact that the amount of force required by a switch is usually far exceeded by most typists. Simply designing an easy-to-depress switch may not change this behavior. Some of the other mechanical variations that may affect behavior are the length of the key's travel, whether and at what point the key gives a tactile or auditory "click," at what point the character appears on the screen, and how abruptly the key stops at the end of its travel.

Finally, the ultimate alternative keyboard may be no keyboard at all. Voice recognition is currently in its adolescence. Despite the inconvenience of pronouncing each word discretely, it has been effective for many users with arm discomfort although most people consider it too troublesome to use --- yet. But voice technology is on the verge of continuous speech recognition. Advances in software and, more importantly, raw computing power may make it a reality in the near future.

Conclusion and Overview

The categories of alternative keyboard features discussed in this paper --- split, tented, supportive, scooped, minimum-motion, and aligned rows --- all have plausible ergonomic rationales. In many cases, however, the available research does not resoundingly confirm their ergonomic, performance, or comfort benefits.

This does not mean the keyboards are without such benefits; it implies that there is much research to be done and that no keyboard features can be recommended with great confidence. Although many good studies have been done, the existing body of research suffers from certain deficiencies, which incidentally are common to many other scientific fields. The principal shortcomings of current research include their short-term nature, small study groups, inconsistent methodologies, and narrow scope. In addition, some important features have not been studied at all.

In an ideal world, alternative keyboard research studies would use large groups of people, both healthy and with different kinds of musculoskeletal discomfort or injury. They would study people over a long period, getting data immediately and long after starting to use new designs. They would study different kinds of keying tasks. They would also compare the effects of conventional keyboards to alternative ones, and compare alternative keyboards to each other, using consistent methodologies and study subjects. Finally, keyboard studies would look at non- keyboard factors such as workstation design and many other things that can potentially change any effects alternative keyboard features may produce.

The existing research indicates that some users, some kinds of discomfort or injuries, and some tasks are probably appropriately served by some alternative keyboard features. The research does not support the idea that one keyboard works for everyone and every circumstance. Nor does the research say that alternative keyboards will not cause discomfort, productivity impairment, or worse.

Anyone considering using an alternative keyboard should understand the proposed benefits of the various design features and carefully evaluate their appropriateness for the situation at hand. More importantly, they should look at the whole ergonomic/comfort picture, which includes the effects of the whole workstation, the nature of the job and the job's schedule, psychological stress, the individual's physical condition, and non-job factors.

Finally, anyone who is considering alternative keyboards because of concerns about existing discomfort should consult a health professional.