The Keybowl: An Ergonomically Designed Document Processing Device

Peter J. McAlindon & Kay M. Stanney
University of Central Florida
Department of Industrial Engineering
Orlando, Florida 32816
`E-mail:  pete@ists.engr.ucf.edu`

N. Clayton Silver
University of Nevada, Las Vegas
Department of Psychology
Las Vegas, Nevada

ABSTRACT

This paper discloses preliminary findings and provides a discussion of a newly designed alphanumeric input device called the Keybowl. The Keybowl was designed and developed primarily as an alternative input device to allow users of various upper extremity disabilities to effectively type, interact with, and navigate current computer interface designs. In addition, the Keybowl's unique characteristics of adapting to the user's needs may provide a solution to the multi-million dollar a year problem of carpal tunnel syndrome (CTS) as it relates to typing. The Keybowl totally eliminates finger movement, minimizes wrist movement, and uses the concept of concurrent independent inputs (i.e., chording) in which two domes are moved laterally to type. Initial results indicated that users of the Keybowl typed an average of 52% of their regular QWERTY flatboard keying speed in as little as five hours. With regard to ergonomic advantage, Keybowl typists' flexion/extension wrist movements were reduced by an average of 81.5% when compared to typists using the QWERTY keyboard. Movements in the ulnar/radial plane were reduced by an average of 48%.

KEYWORDS: keyboard, cumulative trauma, handicap, typing, carpal tunnel syndrome

INTRODUCTION

Few keyboard designs account for the varying abilities of typists. Flexible designs have been for the most part limited to non-physical attributes; several have programmable key mapping capabilities and/or color codes for common multi-key activation routines. Most, however, fail to provide adequate physical flexibility to adapt to the users physical needs. Custom keyboards have been manufactured to suit the specific needs of an individual, but at a premium cost. There are several peripheral devices made to accommodate the typists physical abilities. Many of these interventions are external to those of the keyboard. Wrist rests, arm rests, tilting mechanisms, and keyboard trays are just a few of the physical interventions that have been implemented. What is needed is an all inclusive design that offers the flexibility to accommodate any individual's physical and mental needs for typing and cursor navigation purposes.

Human capability issues and measurement techniques related to the typing task have been applied, at various levels, to complete a fairly robust, albeit static, investigation into the development of an ergonomically designed keyboard. Researchers have addressed several issues related to keyboard design. Key arrangement, hand posture, arm posture, key force, key displacement, as well as several other related factors have been investigated in an attempt to eliminate or significantly reduce the trauma caused by typing to the human body (the wrist in particular) (Bruner and Richardson, 1984; Nakaseko, Grandjean, Hunting, and Gierer, 1985; Shiratori and Obashi, 1986; Hedge, McCrobie, Land, Morimoto, and Rodriquez, 1995). This research has led to several ergonomic keyboard designs which focus primarily on eliminating excessive wrist deviations and excessive key forces. These designs, however, address only a few of the issues uncovered in the research literature. An important, and often overlooked, issue is eliminating or drastically reducing finger movement while maintaining typing comfort.

Attempts at designing ergonomically correct keyboards have been primarily focused on optimizing key layout in an effort to reduce finger travel and fatigue and promote a more natural hand, wrist, and arm typing posture as compared to the QWERTY design. Some of these designs emphasize user performance and employ various chording key activation schemes (using dual inputs per output) in order to enhance typing performance. Others focus primarily on ergonomic advantage (e.g., splitting the keyboard into halves in an attempt to keep the wrists straight and thereby reduce carpal tunnel syndrome (CTS)). No one keyboard, however, offers a comprehensive solution to curbing the injuries incurred from repetitive strain (Norman and Fisher, 1982; Martin, 1993; Morelli, Johnson, Reddell, and Lau, 1995). Over two dozen keyboard redesign attempts have been made to develop a solution to the multi-million dollar a year problem of repetitive strain injury (RSI) as it relates to typing (Hobday, 1988; Fathallah, 1988; Kroemer, 1992; Cakir, 1995; Chen, Burastero, Tittiranonda, Hollerbach, Shih, and Denhoy, 1994; Smutz, Serina, and Rempel, D., 1994; Gerard, Jones, Smith, Thomas, and Wang, 1994; McMulkin and Kroemer, 1994; Morelli, Johnson, Reddell, and Lau, 1995). RSI, or more generally, overuse injury, occurs in many forms. Overuse injury may be caused by almost any activity which involves repeated and rapid movement. Factors such as posture, muscular load/activity, and leverage action may also contribute to overuse injuries (Carter and Banister, 1994). The most publicized typing overuse injury is carpal tunnel syndrome, a progressively disabling and painful condition of the hand that occurs when the median nerve is compressed at the wrist. A study of 2,876 telephone operators conducted by the Communications Workers of America found that 9% were medically diagnosed with carpal tunnel syndrome (Leavitt and Taslitz, 1993). A National Institute for Occupational Safety and Health (NIOSH) study of 533 US West Communications employees confirmed hazards among computer operators: 22% were affected by upper extremity musculoskeletal disorders, with the hand/wrist most frequently involved (12% of participants) (Leavitt and Taslitz, 1993).

CTS has generally been linked to using the de-facto QWERTY keyboard (Cone, 1994). However, insufficient data exist to support the hypothesis that keyboards cause CTS. Additionally, one of the major research voids in the study of hand and wrist overuse injury is the lack of quantification of the relationship between the known kinematic risk factors, such as wrist angle and repetition, and overuse injury risk (Schoenmarklin, Marras, and Leurgans, 1994). Other non-overuse factors may play an important role in contributing to CTS. Findings by Bergqvist, Wolgast, Nilsson, and Voss, 1995, attribute overuse injury to factors such as gender and neck and shoulder discomfort.

This study provides an in-depth analysis and evaluation of factors that influence typing performance to better understand the capabilities of the human and the keyboard, and the manner in which they interact. The primary purpose of this study was to investigate the ergonomic and typing performance in using a newly designed alphanumeric keyboard called the Keybowl. The Keybowl is the first ergonomically designed keyboard that eliminates finger movement and drastically reduces wrist movement while maintaining typing comfort.

KEYBOWL DESCRIPTION

The Keybowl, as depicted in Figure 1, is an alphanumeric input system which uses a pair of devices, each comprised of an inverted bowl upon which the hands comfortably rest. Each bowl is flexibly coupled to a base. The Keybowl was developed to accommodate any user's needs (handicapped users in particular) in an attempt to make typing less physically traumatic and more comfortable. It was designed to eliminate finger movement and eliminate or substantially reduce wrist movement. The bowl design was chosen because it approximates closely the at rest posture of the hand (also referred to as the ‘position of function’), which reduces static muscle fatigue. Other features of the Keybowl include adjustable bowl movement force and displacement, a built in mouse for complete hands on typing, and complete self containment for use in underwater or hostile environments. In addition, the Keybowl is a perfect candidate for miniaturization.

The Keybowl uses concurrent independent inputs, commonly referred to as chording, in which the two inverted bowls are used to type. Chord keyboards, which have been used in court reporting for years, have been gaining greater acceptance as potential alternative devices to replace the standard QWERTY keyboard, which is now considered the de-facto standard for alphanumeric input, due primarily to their keying speed advantages (for more on the QWERTY keyboard see Noyes, 1983).

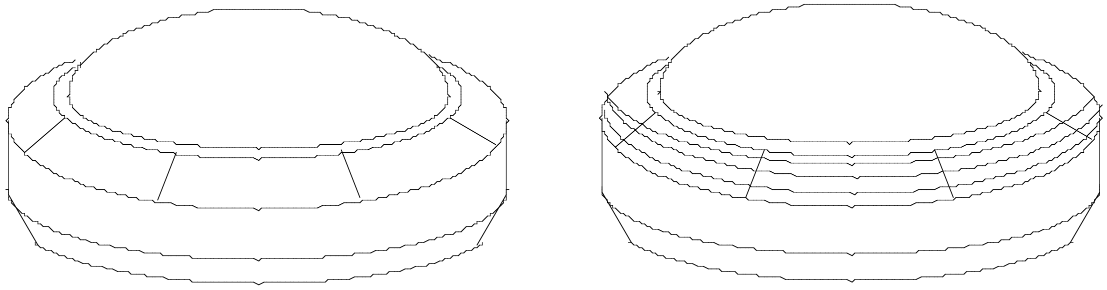
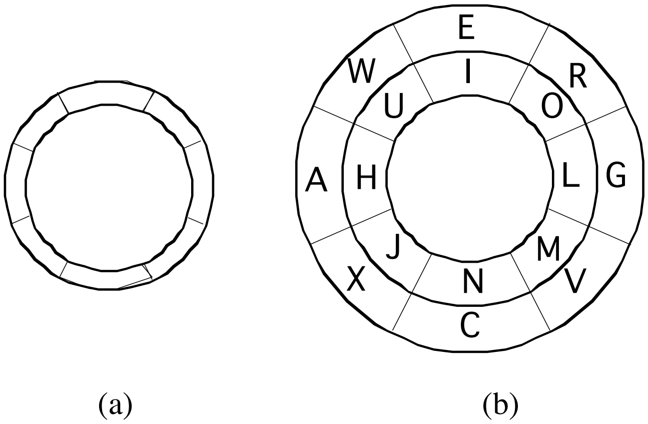

(a) Selector Keybowl (b) Character Keybowl

Figure 1: The Keybowl

The Keybowl is designed to replace both the traditional alphanumeric keyboard and mouse. The fully functioning model of the Keybowl will have a 64 'key' capability (Figure 2b) developed to accommodate all alphanumeric, special character, and function keys as well as an integrated mouse. Both hands are required to type, one hand per bowl (there is, however, a one-handed version being developed). In the simplest key layout design, a selector bowl is used to activate a character bowl. There are 8 concentric character rings on the character bowl. Each concentric character ring contains eight characters defined by discrete movements of the bowl. It may be helpful to think of these bowl movements in a compass arrangement: N, S, E, W, NE, SE, NW, SW. Each bowl is capable of moving into the same 8 compass directions. With reference to Figure 2b, a slightly different layout is presented to demonstrate the Keybowl’s flexible key coding and method of actuation. Each bowl acts as both an activation and character bowl. The ‘balanced’ nature of having each bowl act as a selector bowl and a character bowl may provide equal work for each hand (Figure 2b).

As previously described, the Keybowl typing methodology entails creating a keystroke via a combination of positions of the two bowls. For example, referring to Figure 2a, moving the selector bowl to the "hatched" position enables access to the "hatched" concentric circle of the character bowl (here shown containing the letters I, O, L, M, N, J, H, and U). Moving the selector bowl to the "gray" position would enable the character bowl to access E, R, G, V, C, X, A, and W. Once a position on the selector bowl is selected the characters on the character bowl can be typed by moving the character bowl into the direction of the character the user wishes to type. The lateral movements of each bowl are the same for all characters (i.e., characters on the outer character rings require the same lateral displacement as those on the inner ones).



(a) (b)

Figure 2a: (a) Selector Keybowl (b) Character Keybowl: An example key chording activation scheme. (Note: six more selector positions on the Selector Keybowl exist and six more concentric circles need to be added to the Character Keybowl to allow for 64 'keys'.)

EXPERIMENT WITH THE KEYBOWL

An experimental comparison of the Keybowl to the QWERTY keyboard was conducted. The study focused on evaluating the Keybowl from an ergonomic as well as a typing performance standpoint.

Subjects

Thirty experienced typists between the ages of 21 and 46 participated in the research. They were randomly separated into two groups, one group using the QWERTY keyboard, the other the Keybowl. All were free from wrist ailments and trauma and typed between 22 and 65 gross words per minute (GWPM) (mean= 41, s.d. =12). There were no significant differences in typing speed between the two subject groups as determined by a one minute typing test ($F(1,28)$,=0.0021, $p<0.921$). A one way ANOVA examining spatial and memory abilities revealed no statistical difference between the two groups ($F(1,28)$,=0.1, $p>0.05$) for spatial abilities, and ($F(1,28)$,=0.0001, $p>0.05$) for memory abilities.

Equipment

A reduced character set prototype of the Keybowl was used for initial experimentation. This 16 character version of the Keybowl was used to establish ergonomic and typing performance baseline measures.

The 16 character version of the Keybowl allowed users to type the most common 16 letters of the English alphabet (A, E, R, T, F, D, C, S, U, I, O, P, L, M, N, and H). Bowl movements in any of the eight respective positions on either bowl allowed the user to type one of the sixteen characters.

A standard QWERTY keyboard was used in the comparison study. The QWERTY keyboard was modified to provide the same reduced character set functionality as the Keybowl (i.e., the same 16 characters, with all other disabled through software control). Keys other than the 16 could be pressed but no character would be output.

The Penny and Giles angular measurement system was used to measure wrist motion. A key component of this system is the electrogoniometer. This motion analysis system, along with the goniometer, was designed specifically for clinical assessment of joint function. The electrogoniometers are flexible transducers that consist of a steel wire which has been strain gauged to allow an output of angular displacement of one or two planes respectively. These transducers are available in sizes to suit both large and small joints.

Procedure

Subjects were required to type for 16 sessions, one session per day (subjects were required to type at least 3 days a week). They were instructed to type as quickly and as accurately as possible. For each session subjects typed 18 minutes and 45 seconds (total time of keyboard usage was 5 hours). In the first eight sessions subjects were required to type random characters. In the second eight, random words were typed. In each of the sessions, ten thousand randomly generated characters, or word equivalent, were displayed on a monitor one screen at a time. Ten thousand characters guaranteed that even a typist typing 90 WPM would not finish typing the characters, or words, before the session ended. Characters were highlighted one by one and the subjects simply had to type over the highlighted character. If an incorrect character was typed the character highlighted would reflect the error and the cursor would move to the next character. If the correct character was typed, the cursor would move to the next character. A similar procedure was implemented for sessions 9-16, the random word sessions.

The time for each session was computer controlled; an 18 minute 45 second clock started when the first character was typed and the program automatically terminated after the 18 minute 45 second clock ran out. Performance data on the number of characters typed, number of errors, and times between key presses were recorded for each session. In terms of ergonomic evaluation, data were collected during each session on left and right hand wrist deviations (flexion/extension and ulnar/radial deviation) by way of electrogoniometers.

The Penny and Giles electrogoniometers were fixed to the wrists of the participants using two-sided tape. The participant, with forearm in full pronation, fully flexed their wrist. The telescopic endblock of the electrogoniometer was secured to the dorsum of the hand, over and in line with the long axis of the third metacarpal. The fixed endblock was pulled proximally, until the electrogoniometer was at its maximum length. Then the fixed endblock was attached to the dorsal surface of the forearm parallel to the long axis of the radius. The electrogoniometer was positioned such that the measuring element was centered over the dorsum of the wrist. The electrogoniometer was then calibrated and tested before experimental data was gathered.

RESULTS

The 15 Keybowl subjects had memorized (as determined by a subjective questionnaire) the locations of all 16 characters in the first 4 sessions of the experiment (1 hour 15 minutes). These subjects typed an average of 24 GWPM (s.d. =8) after using the Keybowl for 5 hours. Prior to the experiment, the average QWERTY keyboard typing speed of these Keybowl subjects was determined to be 40 GWPM

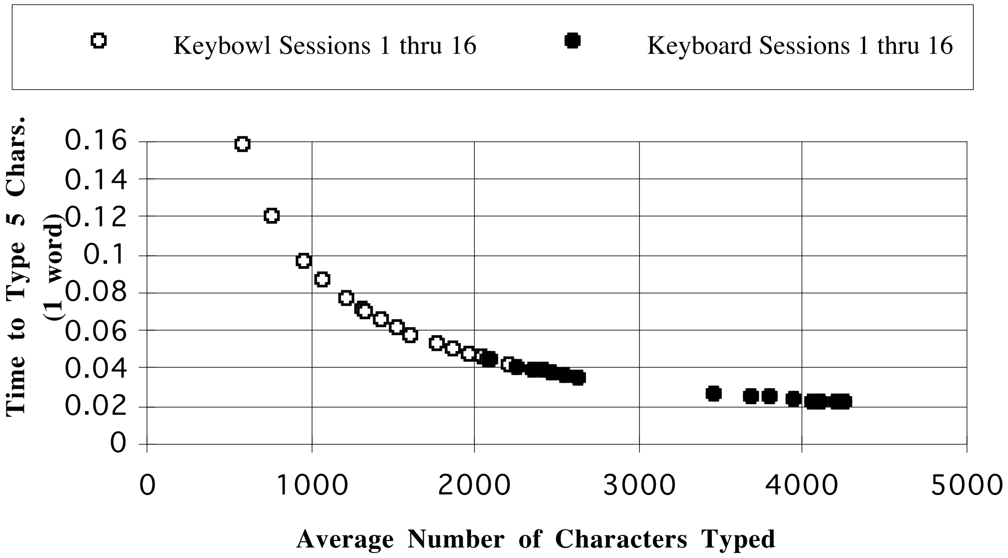


Figure 3: Keybowl and Keyboard typing performance curves.

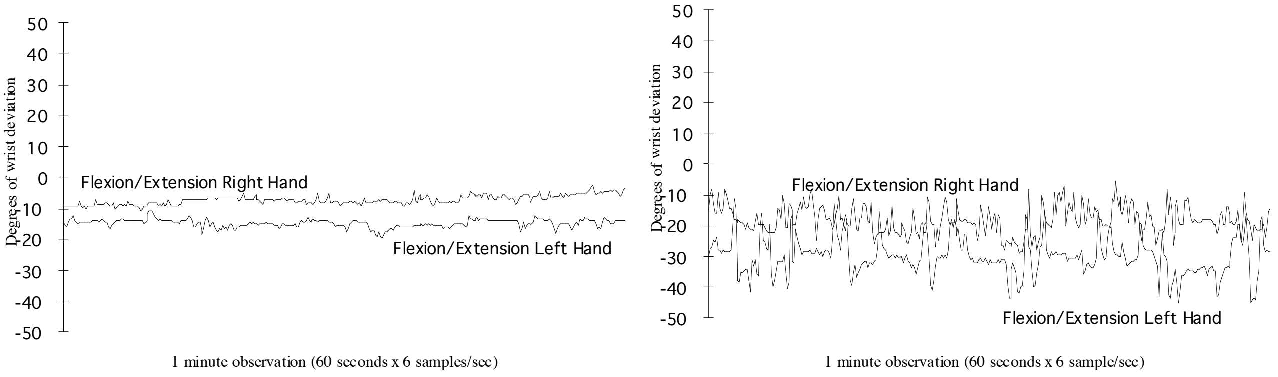
(s.d. =11). In comparison, the 15 subjects in the keyboard group typed an average of 46 GWPM (s.d. =11) after 5 hours. Prior to the experiment, this group typed an average of 42 GWPM (s.d. =14).

In terms of learning rate, there was no significant difference detected between the learning rates of the Keybowl and keyboard subjects ($\underline{t}(15)=0.224$, $\underline{p}<0.829$). In fact, the rates for the Keybowl typists in sessions 15 and 16 were almost identical to session 1 and 2 rates of keyboard typing (Figure 3). This suggests that experienced typists could reach comparable performance on the Keybowl as compared to the keyboard in a relatively short period of time.

As mentioned earlier, ergonomic evaluation of the Keybowl and keyboard was performed by measuring left and right hand wrist deviations using electrogoniometers. Goniometer data was collected during each one of the 16 sessions (Figures 4 and 5). The data were analyzed using a 2 x 2 x 2 x 4 x 8 mixed model analysis of variance (ANOVA). Keyboard type and gender were between subject factors whereas stage, wrist movement, and session were the within subject factors. There was a significant difference detected in wrist movements between the two subject groups (flexion/extension movements of the left and right hand ($\underline{F}(1,26)=58.34$, $\underline{p}<0.0001$) and ulnar/radial movements of the left and right hand ($\underline{F}(1,26)=15.99$, $\underline{p}<0.0001$)). Using the Keybowl, overall wrist variance was reduced by an average of 81.5% in the flexion/extension plane and 48% in the ulnar/radial plane as compared to the keyboard. The Keybowl users' wrist deviations averaged 3 degrees in the flexion/extension plane and 3 degrees in the ulnar/radial deviation plane. The keyboard users' wrist deviations averaged 15 degrees in the flexion/extension plane and 6 degrees in the ulnar/radial deviation plane. In summary, these preliminary results indicate that Keybowl typists may be able to quickly achieve performance levels comparable to that of QWERTY keyboard typists, while eliminating finger movements and drastically reducing wrist movements.

DISCUSSION

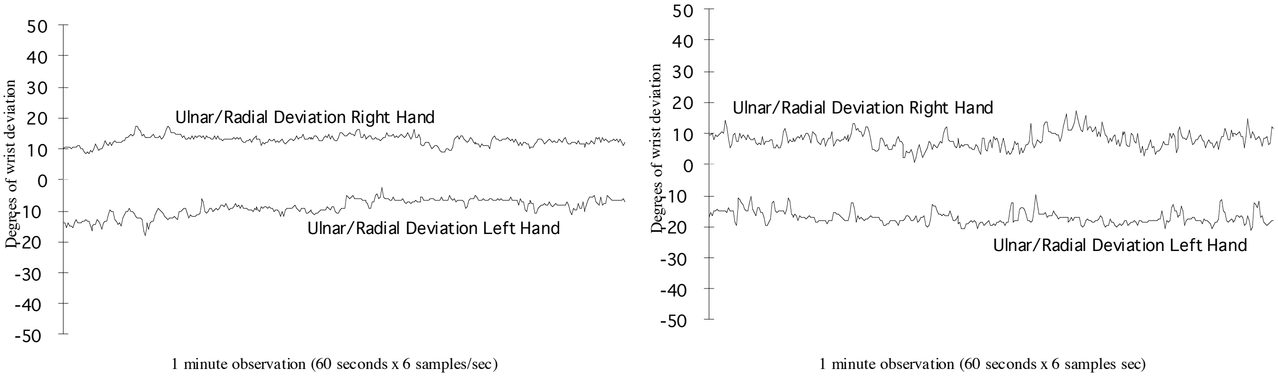
The movements experienced in typing with the Keybowl are greatly reduced with respect to finger and wrist motion. In analyzing where, and how much, other repetitive forces are applied, analysis of the upper extremity motions are required. A number of factors interact with the repetitiveness and duration of the typing work cycle. Work cycles increase the risk of disorder and fatigue (Kilbom, 1994). The main factor is the exertion of external force, which has been well documented both epidemiologically and experimentally. The quantitative relationship between force exertion and disorders in repetitive work is still insufficiently documented, whereas the relationship between force exertion and fatigue after intermittent static exercise is better known from experimental studies (Kilbom, 1994). Repetitive work is sometimes superimposed onto a static load especially in the shoulder (Kilbom, 1994). Repetitive work is often performed by the distal parts of the upper extremity (hands, wrist), while the proximal parts (shoulders) stabilize the arm and thereby perform static work. This can be a common cause of shoulder disorders. Reducing the repetitive distal work is then likely to have a preventive effect on shoulder discomfort and disorders (Kilbom, 1994). The distal work in using the Keybowl is minimal due to the drastic reduction in motion in the fingers and wrists. Because of this, shoulder motion and forearm motion in using the Keybowl are not expected to be any greater than motions used for typing characters that are off the home row keys on the QWERTY keyboard. The functional reach of typing numerics on the top row of the keyboard often exceed the functional movement of the bowl on the Keybowl, thus shoulder fatigue in typing with the Keybowl is expected to be less than that of typing with the QWERTY keyboard.



(a)

(b)

Figure 4. Representative Flexion and Extension Movements of a Keybowl user (a) and a QWERTY user (b).



(a)

(b)

Figure 5. Representative Ulnar and Radial Movements of a (a) Keybowl user and a (b) QWERTY user.

Future Implementations

Integrating a pointer/menu navigation system into the Keybowl may offer even greater ergonomic advantage over the QWERTY keyboard and mouse. The bowls vertical motion enables the device to act as a unique user defined navigation/menu function processing apparatus. With two single vertical clicks of either bowl, the mouse cursor mode is activated. The bowl that is double clicked acts as the cursor control bowl, while the other acts as the menu function bowl (see Figure 6). As an example, consider a user who wishes to highlight and cut text. After typing the text, the mouse cursor mode is initiated by double clicking the right bowl (assume that the user is right hand dominant). The cursor can then be moved to the start of the text by moving the right bowl in the direction of the text. Once the pointer is located at the beginning of the text, the left hand bowl is held in its north position to initiate a click. The click operationally places a cursor bar at the beginning of the text. With the cursor in place, the right hand bowl is moved across the text to highlight it. The text is now ready to be cut. To cut the text the left hand bowl is moved from its north position into its northeast position.

To deactivate the mouse/menu system, a double click on either bowl is initiated.

Studies on the Keybowl with the built-in pointer/menu system are necessary to determine if the Keybowl offers a faster, ergonomically superior, way to process documents. In typing and navigating with the Keybowl, the hands never have to leave the bowls. The time savings from moving the hands from the keyboard to the mouse may make the Keybowl a superior document processing device. In addition, because of the way the mouse functions are laid out, an increase in speed to navigate and activate functions may be realized. Aside from touch typing, computer input processes typically utilize only one hand at a time (e.g., move navigation), though people are fairly good at manipulating both hands in coordinated or separated tasks (Buxton, 1986). Research is therefore required into interaction techniques and styles that make appropriate and advantageous use of both hands. In addition, current user interface software architectures assume a single input stream of information; new approaches are needed to take full advantage of multiple, parallel inputs (Hill, 1986).

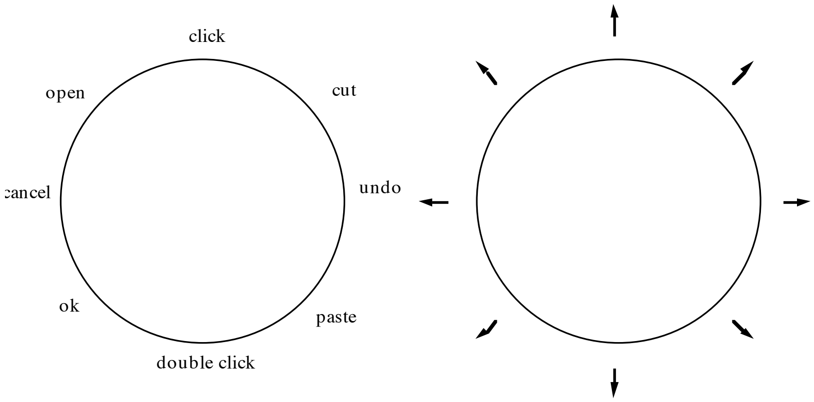


Figure 6: Mouse implementation. Double clicking the right hand bowl gives a right hand dominant user the ability to navigate the interface moving the right bowl in the direction desired and the ability to select common, user defined, menu selection items using the left bowl.

Due to its gross motor movements, the Keybowl typing speeds may never be as fast as the QWERTY's finer, faster motor skill typing speeds. However, because the Keybowl offers great flexibility in accommodating any user who wishes to type, there may be a combination of force and displacement of the bowls that allow some users much greater speeds over what they are able to obtain using a flat, physically static keyboard. An old fable comes to mind: the story of the hare and the tortoise. Those that type too quickly may ultimately be slowed by the pains of RSI; those that type a little more slowly can do it for longer periods of time. In the end, the Keybowl typists may have the healthier upper hand.

The 64 key chording method needs to be examined to determine whether or not typing speeds will meet or exceed those currently demonstrated by typists using the QWERTY keyboard and reduced character set Keybowl. Error analysis (McAlindon, Stanney, and Silver, 1995) may help determine performance at a 64 key chorded level. In addition, a useful account of movement execution is provided by stochastic optimized-submovement models, which have significant implications for designing cursor input devices and menu-driven displays (Walker, Meyer, and Smelcer, 1993).

User Acceptance

It is possible to customize the Keybowl, as well as the standard flat keyboard, so that keys can be re-arranged to accommodate any character set a user wishes to use. This may be a viable option for an individual who essentially uses only one keyboard. It becomes far less practical in a workplace setting where individuals are expected to use a number of different workstations.

The conversion of typing from the flat QWERTY keyboard to the Keybowl would inconvenience those proficient with the QWERTY keyboard. If business and industry would accept and convert to a standard alternative keyboard layout, one preferably more efficient and less traumatic than the QWERTY, the period of retraining would last a few years at most. Even though a few years is a significant amount of time for business and industry to contemplate, the payoff, in terms of productivity and money saved in worker's compensation and liability suits, may be well worth it (Carter and Banister, 1994).

REFERENCES

1. Bergqvist, U., Wolgast, E., Nilsson, B., and Voss, M. (1995). Musculoskeletal disorders among visual display terminal workers: individual, ergonomic, and work organizational factors. Ergonomics, 38(4), 763-776.

2. Bruner, H., & Richardson, R. M. (1984). Effects of keyboard design and typing skill on user keyboard preferences and throughput performance Proceedings of the Human Factors Society 28th Annual Meeting, Santa Monica, CA: Human Factors Society, 267-271.

3. Buxton, W. and Myers, B. A. (1986). A study in two-handed input. Proceeding of ACM CHI'86 Human Factors in Computing Systems Conference, 321-326.

4. Cakir, A. (1995). Acceptance of the adjustable keyboard. Ergonomics, 38(9), 1728-1744.

5. Carter, J. B., and Banister, E. W. (1994). Musculoskeletal problems in VDT work: a review. Ergonomics, 37(10), 1623-1648.

6. Chen, S., Burastero, S., Tittiranonda, P., Hollerbach, K., Shih, M., and Denhoy, R. (1994). Quantitative evaluation of 4 computer keyboards: Wrist posture and typing performance. Proceedings of the Human Factors Society 38th Annual Meeting, Santa Monica, CA: Human Factors Society, 1094-1097.

7. Cone, E. (1994, June). Keyboard injuries: Who should pay? Information Week, pp. 30-36.

8. Fathallah, F. (1988). An experimental comparison of a ternary chord keyboard with the QWERTY keyboard. Unpublished masters thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.

9. Gerard, M. J., Jones, S. K., Smith, L. A., Thomas, R. E., and Wang, T. (1994). An ergonomic evaluation of the Kinesis ergonomic computer keyboard. Ergonomics, 37(10), 1661-1668.

10. Hedge, A., McCrobie, D., Land, B., Morimoto, S., and Rodriquez, S. (1995). Healthy keyboarding: Effects of wrist rests, keyboard trays, and a preset tiltdown system on wrist posture,

seated posture, and musculoskeletal discomfort. Proceedings of the Human Factors Society 39th Annual Meeting, Santa Monica, CA: Human Factors Society, 630-634.

11. Hill, R. D. (1986). Supporting concurrency, communication, and synchronization in human-computer interaction– the Sassafras UIMS, ACM Transactions on Graphics, Special Issue on User Interface Software (5), 179-210.

12. Hobday, S. W. (1988). A keyboard to increase productivity and reduce postural stress. In F. Aghazadeh (Ed.), Trends in Ergonomics/Human Factors V. New York: North-Holland. 321-330.

13. Kilbom, A. (1994). Repetitive work of the upper extremity: Part 1– guidelines for the practitioner. International Journal of Industrial Ergonomics, 14, 51-57.

14. Kroemer, K. H. E. (1992). Use and research issues of a new computer keyboard. Proceedings of the Human Factors Society 36th Annual Meeting, Santa Monica, CA: Human Factors Society, 272-275.

15. Leavitt, S. B., and Taslitz, N. J. (1993). Designing Healthier Computerized Offices. Computer-related injuries: Legal and design issues. 1-5.

16. Martin, M. G.(1993). Of mice and pens: Low risk healthy postures for modern computing. In M. J. Smith and G. Salvendy (Eds.), Advances in Human Factors/Ergonomics, 19B Human-Computer Interaction. Elsevier. 791-796.

17. McAlindon, P., Stanney, K., and Silver, N.C. (1995). A comparative analysis of typing errors between the Keybowl and the QWERTY keyboard. Proceedings of the Human Factors Society 39th Annual Meeting, Santa Monica, CA: Human Factors Society, 635-639.

18. McMulkin, M. L., and Kroemer, K. H. E. (1994). Usability of a one-hand ternary chord keyboard. Applied Ergonomics, 25(3), 177-181.

19. Morelli, D. L., Johnson, P. W., Reddell, C. R., and Lau P. (1995). User preferences between keyboards while performing “real” work: A comparison of “alternative” and standard keyboards. Proceedings of the Human Factors Society 39th Annual Meeting, Santa Monica, CA: Human Factors Society, 361-365.

20. Nakaseko, M., Grandjean, E., Hunting, W., and Gierer, R. (1985). Studies on ergonomically designed alphanumeric keyboards. Human Factors, 27(2), 175-187.

21. Norman, D. A. & Fisher, D. (1982). Why alphabetic keyboards are not easy to use: Keyboard layout doesn't much matter. Human Factors, 24(5), 509-519.

22. Noyes, J. (1983). The QWERTY keyboard: A review. International Journal of Man-Machine Studies, 18, 265-281.

23. Schoenmarklin, R. W., Marras, W. S., and Leurgans, S. E. (1994). Industrial wrist motions and

incidence of hand/wrist cumulative trauma disorders. Ergonomics, 37(9), 1449-1459.

24. Shiratori, Y. & Obashi, F. (1986). Optimum keyboard layout design and evaluation of its operation. Contemporary Ergonomics, Taylor and Francis, London, UK.

25. Smutz, P., Serina, E., and Rempel, D. (1994). A system for evaluating the effect of keyboard design on force, posture, comfort, and productivity. Ergonomics, 37(10), 1649-1660.

26. Walker, N., Meyer, D. E., Smelcer, J. B. (1993). Spatial and temporal characteristics of rapid cursor-positioning movements with electromechanical mice in human-computer interaction. Human Factors, 35(3), 431-458.