Keyboard Human Factors: An Annotated Bibliography

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Summary

A search of the recent professional and technical literature was conducted to assemble information related to human factors in the design of keyboards. The results of this effort are presented in the form of an annotated bibliography.
Introduction

This document stemmed from an effort to design a computer keyboard for a specialized wordprocessing application. Since operator comfort and performance were important considerations, the human factors literature was consulted early in the design process. Although library computer searching facilities were not employed, a thorough and careful examination of major, publicly available, professional journals, company technical reports, and popular literature was made.

The information garnered from this search was assembled in the form of the current annotated bibliography. The author and date of publication for each of these bibliographies are listed on the following page.

This list is followed by the annotated bibliographies themselves. The documents are listed in alphabetical order, by author. Each entry includes a complete reference and a concise summary of the keyboard human factors information that it contains.

The annotated bibliographies are followed by “Appendix A,” which is a list of pertinent references that are either cited in the examined documents or otherwise generally considered helpful for the keyboard designer.
List of Authors and Dates of Publication

1. Alden, Daniels, & Kanarick, 1970.
Annotated Bibliographies


[Note: This document was later published as: Alden, D. G., Daniels, R. W., & Kanarick, A. F. Keyboard design and operation: A review of the major issues. Human Factors, 1972, 14, 275-293.]

Summarizes the literature of the 1960’s that is pertinent to the design of keyboards. Some of the most interesting conclusions of the authors (p. 22) are:

(1) Keys of 0.5 in diameters, with 0.75 in center-to-center distances between keys are suggested since these specifications have become fairly standard for electric typewriters.
(2) Although force and displacement were found to have little effect upon keying performance, the ranges preferred by operators were: forces of 0.9 to 5.3 oz and displacements of 0.03 to 0.19 in (from Kinkead & Gonzalez, 1969).
(3) Feedback, whether visual, auditory, or kinesthetic, has little effect upon the performance of experienced operators. However, visual feedback is important during training and for error correction (from Deininger, 1960(a), 1960(b); Kinkead & Gonzalez, 1969).
(4) Keyboard slope has little influence upon operator speed and accuracy (but Kroemer, 1964, 1965 – both in German – disagrees, stating that sloped keyboards improve performance). However, some inclination from the horizontal was preferred by typists. Ten to thirty-five degrees appears to be an acceptable range (Scales & Chapanis, 1954; Galitz, 1965).
(5) Operator preferences do not correlate highly with performance (Kinkead & Gonzalez, 1969).
(6) Key and keyboard characteristics must be evaluated in their system context for maximum validity and reliability.


These European authors provide a thorough discussion of keyboard design. The authors make the following statements:

(1) In order to minimize reflection, keytops should be matte finished (p. 125).
(2) Since square keytops provide a larger surface on which the fingers may strike, this shape keytop is preferred over circular keytops (p. 125).
(3) A dished keytop profile is preferred over those that are stepped and sloped. Without citing a specific reference, the authors state (p. 125) that, “This [dished] arrangement is reported to improve the keying rate for skilled operators and, when combined with slightly deeper depressions in the home row keys, to ‘instil a sense of confidence in the operator.’”

(4) The profile angle of the keyboard should be between 5 and 15 degrees in order to minimize physiological stress in the hands and, hence, to improve keying performance (p. 126).

(5) To reduce arm stress, it would be best to have the thinnest possible keyboard resting directly on the thighs of a seated user (p. 126, 200).

(6) Authors subscribe to the German standard of having the distance between the base of the keyboard and the home row being 30 mm or less (p. 126).

(7) Although determined primarily to be due to design convention rather than to extensive research, keytops should be square, with a size of 12-15 mm, and an intercenter spacing of 18-20 mm (p. 127).

(8) The size of key legend characters should be 3 mm or greater (p. 127). [This value was derived by following the questionable rationale that, ideally, the keyboard should be the same distance from the user as the VDT screen, and thus, minimum acceptable character sizes should be the same as on the screen.]

(9) Function keys should be labeled with words, abbreviations, or codes, except where standard symbols exist (as with cursor movement arrows) (p. 127).

(10) Keytop character legend sizes should not vary. All alpha characters should be the same large size, regardless of whether shifted values are available or not (p. 127).

(11) To save time and reduce keying errors, user-programmable keys are suggested for long or frequently used text phrases [ex. “Acme Widget, Gadget, and Ratchet Company”] (p. 127).

(12) The recommended force required to initiate key displacement is 0.25 – 1.5 N (p. 129).

(13) The recommended key displacement (or travel) is 0.8 – 8 mm (p. 129).

(14) Audible feedback when a key press has been successfully received by the system may reduce undetected keying errors made by skilled and unskilled typists (p. 129).

(15) To cause keys to repeat, “typamatic” keys, which repeat after being held down for about half a second, are preferred over a separate repeat key which must be pressed in conjunction with the key to be repeated (p. 131).

(16) Gray-colored keys appear to be superior to “black” and “other colours,” when judged with respect to ratings of glare, fatigue, and eye discomfort (pp. 134-135).

Compared typing performance using conventional and membrane keyboards. Although performance with the membrane keyboards improved with practice, it did not match that with conventional keyboards. Therefore, to maximize keying performance, conventional keyboards should probably be used.


Human factors virtues of the IBM PC keyboard include:

1. The ability to move and change the angle of the keyboard.
2. The sculpturing of the keys.
3. The keyboard’s curved-plane surface.


The authors define three types of keyset interlocks and their effects on keying performance:

1. No interlock – when two keys are pressed simultaneously, an erroneous code is produced, and a spurious output is made (p. 3).
2. Two-key rollover – when two keys are pressed simultaneously, no output is made; must release one key before pressing another (p. 4).
3. “N” key rollover – due to a very quick key pulse (1 msec), humans generally cannot cause the keyboard to register two keys as being pressed simultaneously; code from first key pressed is stored in buffer until second key is pressed, thus, first key does not have to be released before second key is pressed (p. 4).

In their study of touch typing using these three different keyboard interlocks, no difference in typing speed was found. However, significantly more errors were made with the “no interlock” system than with either the “two-key rollover” or “‘N’ key rollover” techniques. No strong subject preferences were recorded. The investigators note, however, that subject preference has been found to be an unreliable index of objectively measured performance (Kinkead & Gonzalez, 1969).
In conclusion, the authors suggest the use of “‘N’ key rollover” or “two-key rollover” interlock techniques for touch typists. Furthermore (p. 25), since the “‘N’ key rollover” interlock technique involves less potential blocking than the “two-key rollover” technique, it is assumed that typed intercharacter times of 4 ms are possible with the “‘N’ key rollover” interlock technique. It appears, then, that the “‘N’ key rollover” interlock is superior to the other interlock techniques.

However, although the interlock features may have been pervasive in the mechanical keyboards of the past, it is unlikely to be a problem in today’s electronic keyboards.


The following standards (pp. 243-244) are pertinent to keyboard design:

- (1) 5.15.3.3 Control Input Response – Operator control input speed shall not be delayed or paced by delays in control input response. Control response delays or lockouts shall not exceed 20 milliseconds.
- (2) 5.15.3.7 Fixed Function Keys – Fixed function (dedicated) keys should be used for time-critical, error-critical, or frequently used control inputs.
- (3) 5.15.3.8 Altering Normally-Standard Function Keys – When keys are reprogrammed or turned off, a visual warning, such as a red-lit [green may be preferred because it is easier to detect and connotes “Go”] keycap or portion thereof, should alert the user that the standard function is not currently accessible via that key.
- (4) 5.15.3.9.4.2 Keyboard Entry – Data being entered via keyboard shall be displayed, as keyed, on the screen.
- (5) 5.15.3.9.4.3 Overlays – Mechanical overlays, such as coverings over the keyboard or transparent sheets placed on the display, should be avoided.
- (6) 5.15.4.5.4 Display Freeze – A display freeze mode [perhaps via a dedicated function key] shall be provided to allow close scrutiny of any [rapidly changing] selected screen. An option should be provided to allow resumption at either the point of stoppage or at the current, real-time point. The operator shall be warned if an important event occurs while the display is frozen.


This translation of the German standards includes the following information relevant to the human actors of keyboard design (DIN section 4.3):
1. Keyboards must be detachable from visual display terminals (p. 16).
2. Slide stops must be included on the keyboard to prevent accidental shifting of the device during operation (p. 16).
3. The height of the keyboard (from table top to middle [home] row) must not exceed 30 mm (p. 16).
4. The angle of the keyboard is to be as low as possible, angles f less than 15 degrees are preferred (p. 16).


Compared typing performance using German regulation 30 mm keyboards and those of 38 and 45 mm. Objective performance and subjective preference ratings were superior for the 38 and 45 mm curved (sculpted) keyboards. Therefore, the German standard of 30 mm keyboards may be inappropriate.


The authors make the following suggestions (p. 6.2-15) for keyboards (some drawings are included):

1. Width of each key: 10 to 19 mm (0.4 to 0.75 in); but special keys can be wider and miniature devices can utilize smaller keys.
2. Key displacement: 1 to 5 mm (0.04 to 0.19 in).
3. Center-to-center key distance: 19 mm (0.75 in) preferred, but 16 mm (0.625 in) is acceptable.
4. Key press resistance: 25 to 150 g (0.9 to 5.3 oz).
5. Keyboard slope: 10° to 35° preferred, with up to 60° acceptable.
6. Feedback to inform the operator of control actuation is essential. This can be a detent, or a display action.
7. Keyboard switches are used frequently. Therefore, if a detent is included to provide feedback, it must be very light. Also, operating force must be kept low (Kinkeade & Gonzalez, 1969).
8. The operator can more easily establish finger location if the “home” keys, “4-5-6” on a calculator keyboard and “A-S-D-F-J-K-L-“ on a typewriter have a distinctive surface. [Apple IIe has "pimples."]

This text includes many recommendations. The following are cited (p. 503-504) from a keyboard literature review conducted by Alden, Daniels, and Kanarick (1972):

1. Key dimensions: Diameter – 0.5 in (1.27 cm); Center-to-center spacing – 0.75 in (1.81 cm).
2. Force and displacement: Force – 0.9-5.3 oz (25.5-150.3 G); Displacement – 0.05 to 0.25 in (0.13-0.64 cm).
3. Feedback is important during training; but has little effect with experience typists.
5. Operator preferences in various studies did not correlate highly with measured performance.

Hutchingson (1981, p. 504) suggests using square or rectangular keys with rounded corners to prevent slipping between keys. Also, concave surfaces help to center the fingers.


Examines the literature pertinent to miniaturized keyset design problems. Major conclusions include:

1. Users can successfully adapt to a wide variety of keysets. [A good example is the mastery with which pianists can manipulate an 88 key piano.]
2. The design of a keyset is heavily influenced by the requirements of the system (for example, data entry keysets require as near perfect entry of information as possible and, hence, should be designed with this consideration).
3. Miniaturized keysets can be operated [in the hunt-and-peck fashion?] without negatively influencing input rates or errors.
4. Input rates are influenced by the system. The input rates of touch typists, for example, would be severely hampered by a poorly designed keyboard.
5. The flexibility of a keyboard is also influenced by the system. A keyboard that has been tailored to a specific task may improve the performance of that task, but at the same time, make other more general tasks harder to perform. There is often an inverse relationship between flexibility of the system and ease of operation. Therefore, when designing a keyboard, one must consider both the flexibility of the system and the flexibility of the keyboard to adapt to these system changes.
(6) The author claims (p. 9) that normal downward forces (100 to 800 grams) are not fatiguing.

(7) When typing, as with most keying tasks, there are three types of feedback available (Kinkead, 1967, p. 101):
   1. Kinesthetic, from pushing the key.
   2. Auditory, from the print mechanism.
   3. Visual, from the copy being produced.
   However, visual feedback is not as important to practiced keyboard operators. They can generally detect their own transcription or omission errors. Studies by Deininger (1960a; 1960b) have also found that auditory feedback from button presses had no significant effect on keying performance.

(8) The value of subjectively measured keyboard operator preference is uncertain. Studies (Lee & Snodgrass, 1958; Deininger, 1960b) have found no relation between preference and performance.

(9) Using a ten-key visual-hunt keyboard, an early study (Scales & Chapnis, 1954) found that although operators preferred some tilt, no performance differences were found tilts from 0 to 45 degrees. [Incidentally, this study demonstrates the absence of a correlation between subjectively measured performance and objectively measured performance.]

(10) Although a between-key distance of 0.75 in has become the de facto standard of the keyboard industry, a much lower limit probably exists for keyboards operated in the visual-hunt manner.

(11) Fatigue is not an important factor in most keypressing tasks.

(12) Due to differences in experimental procedures, it is not a good practice to generalize the results from one keyboard study to another [This makes the comparison of experimental results very difficult and may help account for the absence of general, industry-wide keyboard design standards, the German DIN standards notwithstanding.]


The authors examined typing speed and accuracy using different typewriter keyboards. Performance was best (p. 24) on the keyboard with low force and low displacement (initial force = 30 g, operating point force = 40 g, total travel force = 50 g, operating point displacement = 0.025 in, total displacement = 0.050 in). Performance was worst on the keyboard with high force and high displacement (initial force = 75 g, operating point force = 150 g, total travel force = 250 g, operating point displacement = 0.0375 in, total displacement = 0.050 in). It was also found (p 34) that performance on the snap-action keyboards (keyboards with an irregular force-displacement curve) was not superior to those keyboards with no snap-action.
The investigators also mention (p 27) that an extremely low force pressure is not recommended. For initial forces below 10 g, inadvertent finger pressure would produce unwanted keystrokes.

Regarding operator preference, the only instance in which subjective preference matched objective preference was on the keyboard with high force and low displacement. Operators disliked this keyboard and performed poorly when using it. Generally, though, no correspondence was found between subjective preference and objectively measured performance.

Also, the investigators mention (p 34) that the minimum interkeying time is 25 msec. Therefore, systems should be designed so that all inputs must be at least 24 msec apart.

Finally, Kinkead and Gonzalez (1969, p 35) recommend that future product assessment typing tests be conducted in situations that simulate the “normal job” as closely as possible. This includes the physical surroundings.

13. Moore, R. Apple’s enhanced computer, the Apple IIe. *Byte, 8*(2), February 1983, 68-86.

This article reviews the new Apple IIe. Of significance is the observation that the “D” and “K” keys (the home row keys on which the middle fingers of a touch-typists hands fall) have small bumps on their surfaces. Touch typists will therefore know that their hands are in the appropriate home row position.


Describes the pocket-size, user-friendly IXO Telecomputing System. Has the following features:

1. Unusual keys (for example, “HELP”) are brightly colored to attract attention.
2. Other special keys (for example, “CLR”, “BREAK”, “ESCAPE”) are dark blue or gray. They therefore tend to keep the more complex keys in the background in order not to distract or intimidate the beginner.

An interview with the primary developers of the Apple Lisa revealed that in addition to the standard “RETURN” key, the designers added an “ENTER” key near the space bar on the lower right-hand side of the alphabetic keyboard. In this manner, the alphabetic keyboard and numeric pad were functionally independent. Each has an “ENTER” key.


Current hardware and software make it unnecessary to provide visual feedback to typists. This study examined the effects of providing visual feedback in terms of different numbers of characters, from 0 to 79. Visual feedback only influenced the number of corrections made by the typists. When the number of characters viewed exceeded nine, the typists could see more of their work and, hence, made more corrections.


A wide-ranging review of keyboards and their use. The following points are especially relevant to keyboard human factors:

1. System interlock times between keystrokes are to be avoided. A study (Minor, 1964) in which mechanically forced time lags were inserted between keystrokes (0.125 sec between keystrokes) found that typing speed was reduced. Shorter “interlock” time (0.077 sec between keystrokes) led to approximately 4% greater output per unit of time, a slightly lower overall error rate, but approximately three strokes in 10,000 greater undetected errors.

2. The more directly the typist can attend to the task at hand, the more efficient will be the keying operation. Therefore, avoid such distracting machine demands as specific formats, margins, unique spatial locations, special and unusual symbols, and cumbersome correction procedures.

3. The performance of the keying task should be made as easy as possible. The motor difficulty experienced by the operator when making particular entries, such as awkward keyboard reaches, influences overall rate of entry, error rate, and variability in the time intervals between successive entries.

4. Standardization of keyboard layouts will improve system compatibility. Samples of “standard” typewriter keyboard design for location of each key (including unusual keys like “<”) are provided on pages 323-324.
The keypunch machine arrangement for numeric keyboards (123 on top row, 789 bottom row) is superior to that of the common adding machine arrangement (789 top row, 123 bottom row) for unskilled subjects (Conrad & Hull, 1968; Minor & Revesman, 1962; Conrad, 1967).

For numeric key pads, data relevant to selecting the location of the zero key are not easily interpreted. However, the ten-key telephone arrangement (123 on top row) places the zero key below the eight (bottom, middle) key.

Self-detected error correction must be quick and easy. Otherwise, production rate (speed) will be adversely affected. Therefore, have backspace and delete keys, and other correction aids. A simple back up and write over is the preferred mode of error correction.

The major source of feedback for the highly skilled operator is the kinesthetic-proprioceptive-tactual feedback which the operator gets from actually making the movement and striking the key (Chase, Harvey, Standfast, Rapin, & Sutton, 1961; Chase, Rapin, Gilden, Sutton, & Guilfoyle, 1961).


These investigators compared typing performance with curved keyboards featuring a variety of slopes (5, 10, 15, and 25 degrees). The authors make the following points:

1. No statistically significant performance differences were found for the 5, 10, 15, and 25 degree sloped keyboards. However, subjective preferences were recorded for the 10 and 15 degree slopes.

2. For flexible keyboards (which are recommended), an adjustable range of 10 to 25 degrees is suggested. The investigators also mention other studies (Emmons & Hirsch, 1981; Galitz, 1970; Miller & Suther, 1981; Scales & Chapanis, 1954) that support the use of keyboards which are adjustable for slope or tilt.

3. For fixed slope keyboards, the authors recommend a range of 10 to 18 degree slopes.


Recorded choice response times to word, arrow, and word-arrow stimuli. Also examined permissive ("Right Turn Only") versus negative ("No Left Turn") signs. Researchers found a response time advantage for arrow symbols as indicators of
direction. Furthermore, subjects responded quicker to permissive rather than negative signs. [This research therefore suggests that one should label cursor direction keys with arrows rather than words.]


The author makes many unreferenced keyboard design suggestions. They are:

1. Use spare keys for special functional requirements.
2. The keyboard should accept key strokes at a rate of 20 per second, with short burst rates of up to 50 key strokes per second.
3. The force required to actuate the typical typewriter key should not exceed about 5 oz (142 g).
4. To reduce inadvertent actuation, there should be at least 2 oz (57 g) of resistance provided (an adjustable force control is suggested).
5. Use the color green to suggest that the machine is ready [green = “Go”; therefore, use a green light, for example, to indicate that upper case letters are locked].
6. Use slightly concave keys [Does not specify how “slight.”].
7. Use black on white to label keys, different (contrasting) colors for space bar, shift keys, back space key, and so on.
8. Use a keyboard with a 15 degree slope. Twenty-five degrees is an absolute minimum.
9. The horizontal and vertical distance between centers of adjacent keys should be 0.75 in.
Appendix A – Additional Pertinent References

A list of references either cited in the documents reviewed for this annotated bibliography or thought to be pertinent to keyboard human factors.


Gould, J. D. Man-computer interfaces for informational systems, lecture to human engineering short course, University of Michigan. 1979.


