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INTERNATIONAL STANDARD

ISO/IEC 15411-2

1999-03-08

Information technology - Segmented keyboard layouts

Technologies de l'information - Dispositions de claviers segmentés

Reference number 15411-2

Contents

Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC also take part in the work.

In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC1. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75 % of the national bodies casting a vote.

International Standard ISO/IEC 15411 was prepared by Joint technical Committee ISO/IEC JTC 1. *Information technology*, Subcommittee SC 35, *User Interfaces.*

Annex A and Annex B of ISO/IEC 15411 are for information only.

Introduction

This International Standard provides guidance on the technical requirements which are important in the three dimensional layout of segmented keyboards.

Segmentation of the alphanumeric section of the keyboard allows the two segments to be placed in non-coplanar and non-linear alignment. Segmented keyboards are intended to allow altered spatial layout of the keyboard segments relative to the user. The altered orientation may allow the user to attain greater comfort, to decease the rate of onset of fatigue and to reduce the possibility of pain.

Major contributing influences on the effectiveness and productivity provided by a segmented keyboard are the typing skills of the user. Touch typists can take full advantage of the differing angles provided, whereas, unskilled users may find some alternative keyboard layouts unusable.

It should be noted that, for a significant portion of the population, the standard keyboard may provide the correct spatial configuration. Enforcing unwanted keyboard angles upon these individuals could have negative effects.

Information technology - Segmented keyboard layouts

1 Scope

This International Standard defines the differing requirements necessary when considering the various types of segmented keyboards. The scope of this standard, encompasses the three dimensional layout of segmented, traditional style keyboards classified as having:

a. Adjustable alphanumeric segments;
b. Fixed angle alphanumeric segments.

This standard covers the following keyboard areas:

- Alphanumeric area
- Function area
- Text editing area
- Numeric area
- Cursor control area

2 Normative references

The following standards contain provisions that, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 7000:1989, *Graphical symbols for use on equipment - Index and synopsis*.

ISO 9241- 4:1998, *Ergonomic requirements for office work with visual display terminals (VDTs) – Part 4:*
Keyboard requirements

ISO/IEC 9995-1:1994, *Information technology - Keyboard layouts for text and office systems – Part1: General principles governing keyboard layouts*

ISO/IEC 9995-2:1994, *Information technology - Keyboard layouts for text and office systems – Part 2: Alphanumeric section*

ISO/IEC 9995-3:1994, *Information technology - Keyboard layouts for text and office systems – Part 3: Complementary layouts of the alphanumeric zone of the alphanumeric section*

ISO/IEC 9995-4:1994, *Information technology - Keyboard layouts for text and office systems – Part 4: Numeric section*

ISO/IEC 9995-5:1994, *Information technology - Keyboard layouts for text and office systems – Part 6: Editing section*

ISO/IEC 9995-6:1994, *Information technology - Keyboard layouts for text and office systems – Part 6: Function section*

3 Definitions

For the purposes of ISO/IEC 15411, the following definitions apply.

3.1 Adjustable segmented keyboard: A keyboard which has the alphanumeric section divided into two segments which can be moved relative to each other in any plane.

3.2 Alphanumeric keyboard: A matrix of keys as specified in ISO/IEC 9995-1.

3.3 Alphanumeric section: As defined in ISO/IEC 9995-2.

3.4 Cursor control keys: As defined in ISO/IEC 9995-5.

3.5 Editing section: As defined in ISO/IEC 9995-5.

3.6 Fixed angle segmented keyboard: A keyboard which has the alphanumeric section divided into two segments which are fixed relative to each other, not necessarily linear or co-planar.

3.7 Function section: As defined in ISO/IEC 9995 - 6.

3.8 Home row of keys: Row C as defined in ISO/IEC 9995-1.

3.9 Keyboard: An arrangement of typing and function keys laid out in a specified manner.

3.10 Lateral inclination (γ): The angle (γ) formed by the inclination of the central regions of the alphanumeric segments relative to the horizontal plane. Calculated from the angle of the line formed by the tops of the undepressed keys C01 and C05 on the left segment, and C06 and C10 (see Key position numbering system ISO/IEC 9995-1) on the right segment and the horizontal plane, see figure 2. Lateral inclination is intended to alter pronation/supination angles.

3.11 Neutral posture: For flexion/extension and ulnar deviation/radial deviation, neutral wrist posture is defined in ISO 9241-9.

For this standard, neutral wrist posture also encompasses pronation and supination. This is the rotation of the forearm where the person does not exert significant muscular effort in rotation of the forearm in either pronation or supination.

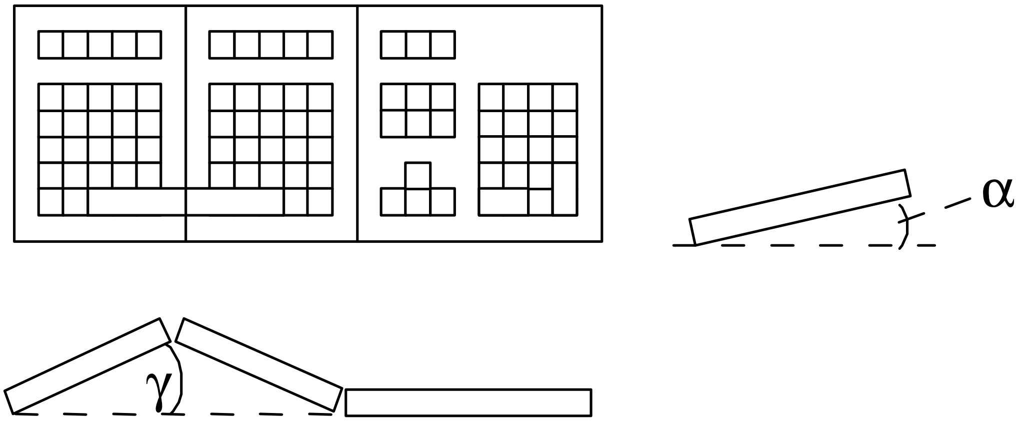

Figure 2. Slope α and lateral inclination γ of a segmented keyboard

3.12 Numeric keyboard or numeric keypad:
An array of three rows of three keys (for the numerals 1 - 9), a zero/decimal area and any additional optional keys. The numeric keypad may be permanently affixed, detachable or separate from the alphanumeric segments.

3.13 Numeric section: As defined in ISO/IEC 9995-4.

3.14 Pronation: As defined in ISO 9241-9.

3.15 Radial deviation: As defined in ISO 9241.

3.16 Shoulder abduction: Movement of the upper arm laterally away from the body.

3.17 Shoulder flexion: Movement of the upper arm in a forward direction.

3.18 Slope (α): The angle (α) formed by the elevation of the back (or front) of the keyboard. Calculated from the height difference between rows A and E. See figure 2. Slope adjustment can influence wrist flexion/extension.

3.19 Splay angle (β): The angle (β) formed by the two alphanumeric segments; measured as the angle formed by the perpendiculars of the line drawn through the centres of the home row of keys: For the left segment, the centre of keys C01 and C05; for the right segment C06 and C10 (see ISO/IEC 9995-1). Splay adjustment is used to reduce ulnar deviation (see figure 1).

3.20 Supination: As defined in ISO 9241-9.

3.21 Ulnar deviation: As defined in ISO 9241-9

3.22 Visual Display Terminal (VDT): The equipment by which users interact with a computer system. A VDT will generally present information on a display. It also provides the means for inputting information into a computer system, most commonly by means of a keyboard. The term VDT includes both the display and the keyboard and any other electronic equipment required to support the terminal.

3.23 Wrist extension: As defined in ISO 9241-9. Also known as dorsiflexion.

3.24 Wrist flexion: As defined in ISO 9241-9.

3.25 Wrist rest: A surface or apparatus to support the forearm at the wrist during typing or in between typing bouts.

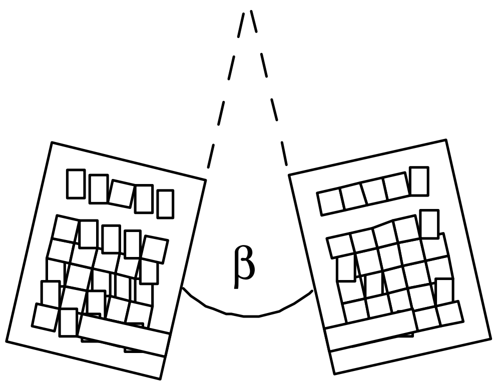

Figure 1. Splay angle β of a segmented keyboard

4 Guiding Principles

Design of the segmented keyboard requires the consideration of the population's and individual user's: gender, anthropometric dimensions, ranges of movement and positions of comfort. Both adjustable and fixed angle segmented keyboards have the aim of improving wrist and upper limb posture by segmenting the alphanumeric sections of the keyboard and angling them to advantageously alter their spatial relationship relative to the user. This segmentation allows for the reduction of pronation and ulnar deviation. The altered positions are intended to permit the attainment of neutral wrist postures without adversely altering the natural posture of the rest of the body or the productivity of the user.

Major contributing influences on the effectiveness and productivity provided by a segmented keyboard, are the typing skills of the user. Touch typists can take full advantage of the differing angles provided, whereas, unskilled users may find some alternative keyboard layouts unusable. For the unskilled user, the ability to be able to easily sight the keys is an essential part of typing. Acute lateral angulation (γ) may make it more difficult to see the key legends. Similarly, increasing the splay (β) angle can create a split in the visual field.

The adjustable segmented keyboard allows the user to find the appropriate angles for their individual anatomical and work requirements. By varying the splay (β) and lateral inclination (γ) of the left and right keyboard segments, the user of the adjustable segmented keyboard should be able to adjust the keyboard to attain the greatest amount of comfort and productivity during typing. That is, the keyboard should allow the user to obtain neutral wrist postures by elevating the central region of the keyboard to reduce pronation; and to provide a separation of the alphanumeric segments to reduce ulnar deviation. The user may empirically find the most suitable angle for comfort and productivity.

The fixed, angle segmented keyboard also aims to allow neutral wrist postures by compensating for pronation and ulnar deviation of the forearms and wrists. These keyboards, because of their intrinsic fixed designs, approximate the required angles for the general population. Design of the keyboard will by necessity be a compromise between the choice of angles, the population's variances and the typing skills of the users. These variables need to be considered by the manufacturer in their selection of segment angles.

5 Design requirements and measurement metrics

Mandatory requirements are identified by the presence of the word "shall"; "should" statements are recommendations and usually objectively quantified.

Design requirements have three sections:

a. The general requirements for segmented keyboards within the scope of this International Standard (clause 5); and further specific requirements describing:

b. Adjustable segmented keyboards (clause 6). Both ISO/IEC 9995 conformant (clause 6.2.1) and non conformant (clause 6.2.2); and also

c. Fixed angle segmented keyboards (clause 7).

5.1 General design of the keyboard

5.1.1 Segmentation of alphanumeric section

The alphanumeric section shall be divided such that columns to the left of and including column 05 (see ISO/IEC 9995-1, clause 7) shall be allocated to left hand usage and columns to the right of and including column 06 allocated for right hand usage.

5.1.2 Key position E6

Key position E6 may be allocated to either left or right hand usage.

5.1.3 Numeric key pad alignment

If there is a numeric keypad provided, its angle relative to the user should not be dependent on the adjustment of the main section.

5.1.4 Dimensions of the keyboard

The minimum size of the keyboard is limited by the requirements for key spacing and key top size (see ISO 9241-4). The overall dimension of the keyboard should exceed this minimum size by as little as possible.

5.1.5 Slope of the keyboard (α)

The slope of the individual key segments shall comply with ISO 9241-4.

5.1.7 Adjusting mechanism

All keyboards may be adjustable in slope, and in the case of adjustable segmented keyboards, in splay, and lateral inclination from the horizontal.

Where an adjusting mechanism is provided, it shall not compromise stability, ease of use and placement. Adjustment should not change unintentionally. Tools shall not be required for adjustment purposes.

5.2 Positioning of keys

5.2.1 Key positioning and centre line spacing

For the adjustable segmented keyboard in the closed state, the spacing between columns 05 and 06 may be greater than the 19 mm centre to centre, the normal requirement for the adjustable keyboard in the closed state. For the fixed angle segmented keyboard, this distance will depend on the splay angle between the alphanumeric segments and their fixed positions relative to one another.

5.2.2 Cursor keys

Cursor control keys should be positioned as defined in ISO/IEC 9995-5. In the case of some segmented keyboards, geometrical and space considerations may necessitate moving the cursor keys to other non-standard positions. Although this is permissible, placement should be in the bottom right corner of zone ZA3 (see ISO/IEC 9995-1) for adjustable segmented keyboards. For fixed angle segmented keyboards, cursor keys can be placed between the alphanumeric segments.

5.2.3 Function keys

Function keys should be positioned as defined in ISO/IEC 9995 – 6. In the case of some segmented keyboards, geometrical and space considerations may necessitate moving the function keys to other non-standard positions but these designs shall attain compliance via clause 6.2.2 of this standard.

5.2.4 Numeric key pad

If provided, the ten digits, zero to nine shall be allocated to keys in section ZN0 (Layout and allocation of the numeric section are specified in ISO/IEC 9995-6).

Segmented keyboards may have detachable numeric keypads that could be placed on either side of the alphanumeric sections.

5.2.5 Text editing keys

Layout and allocation of the text editing section should be as specified in ISO/IEC 9995-5. Alternative positions may be used for symmetry and space reasons.

5.2.6 Keys in row Z

One row of cursor keys may reside in row Z; and the space bar may be made deeper to occupy both row A and row Z.

6 Requirements for adjustable segmented keyboards.

6.1 Adjustment requirements

The adjustable segmented keyboard should allow the user to adjust the left and right hand alphanumeric segments so that the greatest comfort during use may be achieved. That is, obtain neutral wrist postures by elevating the central region of the keyboard sections to reduce pronation (angle γ); and permit an opening splay angle (angle β) at the leading edge of the segments to reduce ulnar deviation in both arms.

Some combination of these adjustments should allow neutral wrist postures. Inadvertent increases in radial deviation, wrist flexion or extension should be avoided.

6.1.1 Slope angle

As defined in ISO 9241-4.

6.1.2 Lateral inclination angle (γ)

The maximum adjusted lateral inclination angle (γ) from the horizontal should be in the range 0° to 45°.

The keyboard should be constructed so that the left and right outer segment edges cannot be higher than the centre region. That is, it should not increase pronation of the forearms.

6.1.3 Adjustment for splay (β)

The splay angle (β) between the two alphanumeric segments should be adjustable within the range 0° to 30°. Splay should not be greater than 30°.

The keyboard should be constructed so that it cannot assume a shape that allows the front edge to have a smaller opening than the back edge. That is, it should not increase ulnar deviation of the hands.

6.1.4 Height of adjustable segmented keyboard

The height of the key rows shall be measured from the centre of the key top of an undepressed key in each row to the supporting work surface of the keyboard.

The adjustable segmented keyboard shall have at least one position of adjustment where the height of the keyboard at the home row (row C) complies with ISO 9241-4.

It is recommended that for any adjusted position, the height of the C06 key should not exceed 100 mm above the desk surface.

6.2 Adjustable keyboards: ISO/IEC 9995 conformant and non-conformant

Keyboards with segmented and adjustable alphanumeric sections are divided into two requirement sub-clauses: those that conform with ISO/IEC 9995-2 in at least one position of adjustment and those that cannot conform to ISO/IEC 9995-2 in any of their ranges of adjustment. Keyboards in both sub-clauses shall conform to sub-clauses 5.1 to 6.1.4 of this standard.

6.2.1 Adjustable keyboards: ISO/IEC 9995 conformant

A keyboard with adjustable alphanumeric segments shall have at least one position that allows it to conform to ISO/IEC 9995-2, with the proviso of sub-clause 6.2.1.1.

6.2.1.1 Separation between columns 05 and 06

Where the segmentation between the two alphanumeric segments occurs (between columns 05 and 06), a larger distance between two adjacent keys than that required by ISO 9241-4 sub-clause 6.2.1 may be used.

In the closed position, this distance should be minimized so that the keyboard does not differ significantly from a non-segmented linear keyboard conforming to ISO/IEC 9995.

6.2.2 Adjustable keyboards: ISO/IEC 9995 non-conformant

Due to its shape or function, an adjustable, segmented keyboard may not conform to ISO/IEC 9995-2 in any of its ranges of adjustment but will conform with this standard provided that the requirements of clauses 5.1 to 6.1.4 are met, and that it complies with the test method defined in ISO 9241-4.

7 Fixed angle segmented keyboards

For conformance, keyboards with fixed angle segmented alphanumeric sections shall conform to all general requirements of sub-clauses 5.1 to 5.2.6 plus sub-clauses 7.1 to 7.4.

7.1 Lateral inclination angle

The keyboard should be constructed so that the alphanumeric segment's outer edges are not higher than the centre region ($\gamma \geq 0°$). That is, the keyboard should not increase pronation of the forearms.

7.2 Splay angle

The splay angle (β) should range from 0° to 18°, and should not exceed 25°.
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7.3 Wrist rests

The keyboard can be provided with optional wrist rests. If provided, wrist rests shall not impair normal typing.

7.4 Conformance and testing

To obtain conformance in this category, the keyboard shall undergo testing via ISO 9241-4.

8 Conformance

A segmented keyboard may attain conformance with this ISO/IEC 15411 standard by meeting the requirements of one of three conformance levels.

Level 1 Conformance for adjustable keyboards:

A segmented adjustable keyboard is in conformance with this International Standard at level 1 if it meets the requirements specified in clauses:

5.1 to 5.2.6: General design requirements and measurement metrics;

6.1 to 6.14: Requirements for adjustable segmented keyboards and;

6.2.1 to 6.2.1.1: Adjustable keyboards: ISO/IEC 9995 compliant.

Level 2 Conformance for adjustable keyboards

An adjustable keyboard that cannot be adjusted to conform to the Level 1 conformance level may attain conformance at Level 2 of this standard by conforming to the clauses specified below and by direct comparison to a standard reference keyboard. The test protocol is defined in ISO 9241-4.

The test methodology requires the test persons to adjust the keyboard to their desired configuration or comfort positions and undergo the test in that configuration. In the case of fixed angle keyboards, the subjects can only adjust the keyboard position distance and slope (α).

This protocol's intention is to ensure that the keyboard is satisfactory for the broadest spectrum of the population and does not enforce positions that are not suitable for some groups of users. Conformance with this standard may depend on interaction between the hardware and workstation elements

A segmented adjustable keyboard is in conformance with this International Standard at level 2 if it meets the requirements specified in clauses:

5.1 to 5.2.6: General design requirements and measurement metrics;

6.1 to 6.14: Requirements for adjustable, segmented keyboards and;

6.2.2: Adjustable keyboards: ISO/IEC 9995 non-compliant (i.e., shall undergo usability test according to ISO 9241-4).

Level 3 Conformance for fixed angle segmented keyboards
A fixed angle segmented keyboard is conformant to this International Standard at level 3 if it meets the requirements specified in clauses:

5.1 to 5.2.6: General design requirements and measurement metrics and;

7 to 7.4: Fixed angle segmented keyboards (i.e. shall undergo usability test according to ISO 9241 - 4).

Compliance report
A compliance report shall be compiled which includes the following minimum information:

1. Supplier details (including name and address, product type numbers, etc);
2. Full details of the equipment (and elements) relevant to the conformance test, its setting(s), configuration(s), fixed and software driven characteristics;
3. Conditions of use;
4. Special requirements.

The test program should take note of the manufacturers' guide for installation and use.

The assessment requirements requiring the use of ISO 9241-4 Usability test shall be carried out with the participation of a human factors specialist.

8.1 Conformance metrics

There are three conformance metrics methods included in this standard:

1. Direct measurement
2. Direct observation
3. Performance test

All required specifications (including a "shall" statement) include a test metric.

8.1.1 Direct measurement

Direct measurement is the use of a standard instrument or tool to obtain a quantifiable measurement of a feature.

8.1.2 Direct observation

Direct observation is the perception or notation of specific characteristics of the keyboard by one or more independent observers who represent the target user population. Direct observation typically results in a binary decision (e.g., Yes or No). This decision depends on a subjective assessment concerning the presence or absence of a feature.

The metric associated with each "shall" requirement contains:

a) The question to be asked or statement to be verified,
b) An indication of which response is associated with compliance (Yes or No),
c) Specific requirements (if any) about the types of users to be represented in the test population,
d) The minimum number of independent observers that are required.

If more than one observer is required, then 90% of the observers must provide the appropriate response for the requirement to be met. Observers shall represent the typical target population who will use the keyboard.

8.1.3 Performance test

A performance test is the collection of quantitative performance data from several test persons. Each performance test is specifically designed to evaluate one or more requirements, and the specific name of the test is indicated in the test metric. Statistical analyses on these data are used to determine whether the "shall" requirement has been met.

The test metric associated with each "shall" requirement contains a short description of the critical variable(s) being evaluated and indicates the result that is associated with compliance.

The test method and its requirements for compliance are described in ISO 9241-4: Appendix A.

Annex A - Segmented keyboard layouts
(Informative)

This annex is non-normative and discusses the diversity of users and their needs.

A.1 The individual

The functional limitations of the human anatomy: gender, anthropometric dimensions, ranges of movement and positions of comfort, vary among individuals throughout the population. These parameters need to be considered in the context of keyboard design.

Segmentation of the alphanumeric section of the keyboard allows the two segments to be placed in non-coplanar and non-linear alignment. Segmented keyboards are intended to allow altered spatial layout of the keyboard segments relative to the user. The altered orientation may allow the user to attain greater comfort to decease the rate of onset of fatigue and to reduce the possibility of pain.

Major contributing influences on the effectiveness and productivity provided by a segmented keyboard are the typing skills of the user. Touch typists can take full advantage of the differing angles provided, whereas, unskilled users may find some alternative keyboard layouts unusable.

It should be noted that, for a proportion of the population, the standard keyboard may provide the correct spatial configuration. Enforcing unwanted keyboard angles upon these individuals could have adverse effects on their comfort, productivity and could predispose them to painful results.

Depending on the individual, the normal and fixed angle keyboard could place the user in uncomfortable and inappropriately constrained, awkward postures that contribute to the early onset of fatigue and possible pain. These postures, which vary throughout the population, include:

a. The outward rotation of the hands (ulnar deviation).
b. The rotation of the hands to a flattened position on the keyboard (pronation).
c. The up or down position of the hand relative to the wrist (extension/flexion).
d. In order to reduce pronation of the forearms, the user might elevate the elbows (shoulder abduction) and place unwanted strain in the neck and shoulder region.

Conversely, alternative keyboard designs that aim to alleviate these postures may inadvertently or through design compromise, produce postures that are also inappropriate. These may include:

a. Radial deviation
b. Shoulder abduction
c. Wrist flexion and extension
d. Shoulder flexion
e. Altered neck posture.

A.2 Typing skills

The technique the user adopts for typing is highly relevant in the context of keyboard design. Touch typists, touch typists requiring visual assistance, and the occasional (hunt and peck) users have widely varying requirements from an ergonomic keyboard.

A.2.1 Touch typists

Touch typists know the position of all the keys on the alphanumeric section of the keyboard and therefore do not need to visually sight the keys for continuous typing. For this class of typist, the keyboard may be angled to the best ergonomic position. As these typists are also most likely to spend long periods typing, they are also most likely to benefit from the ergonomic advantages the segmented keyboard provides for their particular requirements.

A.2.2 Touch typists requiring visual assistance

This typist within this classification knows the position of most of the keys but needs to occasionally look for some infrequently used characters. These typists can benefit from the angulation of the alphanumeric segments (γ from the horizontal), but this must be limited so as to allow easy visual identification of the keys, without either reducing efficiency or straining the neck to obtain a better vantage point.

For this group, there needs to be a trade-off between comfort and visual requirements. Generally, up to 25° inclination (γ) can be used before visual acuity is adversely effected.

A.2.3 Occasional typists

This group must visually locate the appropriate keys for typing. The keying is performed with one or more fingers, not necessarily in a predetermined or allocated fashion.

Although slow and inefficient, these users are more able to maintain the hands in positions of relative comfort. That is, the hands need not be placed in full pronation and ulnar deviation or to maintain their position on the home row of keys. Also, this group is able to further reduce the unwanted postures by transferring the movement from the prone fingers, and corresponding muscles and tendons, to arm or wrist movements at very much decreased frequencies.

The Occasional typist (hunt and peck) can benefit from angulation of segmented keyboards, as some pronation is inevitably used to actuate the keys. However, the easy visual identification of keys will be the dominant requirement. Therefore, keyboards that visually separate the keys to any great extent in the horizontal plane will disadvantage this group of users.

Some hunt and peck users may use or favor one hand during typing. These users may be disadvantaged when typing on a keyboard which is segmented in either the vertical or horizontal planes.

A.3 Keyboard and workstation: spatial relationship to the individual

The human - keyboard interface cannot be treated as a static parameter. For the most efficient typing, and for the reduction of shoulder stress, the keyboard should be placed close to the user to attain neutral arm and shoulder posture. However, because some users are unable to achieve this posture without fatigue and pain, alternative positions are taken. These positions may include shoulder abduction, finger contortions and ulnar deviation. A common strategy is to push the keyboard away from the user. As the keyboard is shifted away from the user:

a. The angle of the hands will alter and decrease the necessity for ulnar deviation compensation.
b. The angle at the shoulder joint increases and this allows easier pronation and therefore decreases the required angulation to the horizontal.
c. The desk surface becomes a wrist rest in itself (but will provide an incorrect amount of wrist extension).
d. Postural changes occur at the shoulder joint, requiring increased muscular recruitment in this region as well as the back and shoulders.

Seat height, desk height and slope of the keyboard may vary from one workstation to another. The user's posture will shift during the working day with levels of fatigue and psychological fluctuations.

A.4 The work performed

With respect to finger movement, changing the positions of the alphanumeric segments relative to the user will alter the task of mechanically actuating the keys. In addition to this, the keys can be:
a. Aligned in straight columns rather than sloping up to the left.
b. Arranged in arrays that approximate the length of the fingers.
c. Placed in 3 dimensional arrays which approximate the arc of finger movements (dished).
d. A combination of a, b and c.

A.5 The space bar

The division of the alphanumeric section into two segments and the alteration of the various angles of the keyboard relative to the user could create a position where the thumbs aren't in a position to comfortably actuate the space bar. Depending on several factors, the thumbs may not fall comfortably on the two space bar halves.

In the case of the adjustable segmented keyboard, extending the space bars either mechanically or making the separation between the two alphanumeric segments slightly larger, to carry the space bar into the void, are two solutions. The fixed angle segmented keyboard can have the space bar extending between the segmented alphanumeric sections or in two halves, to facilitate actuation by the thumbs.

On a standard layout keyboard, with the fingers placed on the home row, the actuation of the space bar requires the thumbs to be brought closer to the keys. In this position, the hands would generally need to be moved into ulnar deviation. That is, the placement of the thumbs on the space bar splays the hands outward. It may be useful to make the space bars deeper (extend into row Z) to allow neutral wrist postures to be attained.

Annex B:
(Informative)

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