Of Moles and Men: The Design of Foot Controls for Workstations*

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Abstract

Workstations require use of the hands both for text entry and for cursor-positioning or menu-selection. The physical arrangement does not allow these two tasks to be done concurrently. To remove this restriction, various alternative input devices have been investigated. This work focuses on the class of foot-operated computer input devices, called moles here. Appropriate topologies for foot movement are identified, and several designs for realising them are discussed.

Introduction

Contemporary workstations make heavy use of hand-mediated input devices, primarily the standard keyboard and some cursor-positioning device, such as a mouse, joystick, trackball, tablet, lightpen, touch-screen, or other device [Alli] [Buxt83a] [Evan81]. In a text-editing context, a certain amount of time is lost as the hand moves from the keyboard to the cursor-positioner and, with realignment, back again. The realignment itself will occasionally be erroneous, resulting in additional time lost in the correction of typos. This "homing" problem was first discussed by Card, Moran, and Newell [Card80] and a variety of solutions have been investigated. In general terms, if pointing and typing could occur concurrently, utilizing subconscious "muscle memory" as much as possible, then the "bandwidth" of man-machine interaction would be broadened.

One approach is to build the cursor-positioner into the keyboard unit. This minimizes homing time, but typically still causes one hand to leave the home position on the keys, necessitating realignment. This technique has been applied with the touch tablet [Gavi] [Preh] [Xero] and joystick [KADe].

Another approach is to replace the two-handed keyboard with a single-handed one, thus freeing the other hand for cursor positioning. Examples of one-hand chording keyboards are that of Engelbart and English [Enge68], Rochester, Bequaert, and Sharp [Roch78], and others [Came] [Owen78] [NewO78] [Micr]. Maltron [Malt] makes a non-chording single-hand keyboard. The use of a special keyboard has drawbacks with respect to operator training and recall of seldom-used characters[Buxt85, p.5].

Although most mice have a few keys on them, the DePraz mouse [Logi] features a special chording keyboard designed to handle the full alphabet. Thus, the mouse allows simultaneous typing and positioning. However, the attempt to do both may generally degrade the performance of both tasks [Buxt85].

Another one-handed device for both positioning and text-entry is the intelligent multipoint touchpad currently under investigation by Shackelford [Shac85]. The concept here is that particular patterns of finger contacts, no matter where on the touchpad they are, can be recognized as encodings for alphabetic characters (or for words, commands, or data objects).

As Buxton [Buxt83b] has pointed out, many hand functions could be handled by other physical body movements. For example, a wrist position sensor has been used for pointing at a large screen [Bolt80]. More relevant to the current context, several researchers have investigated eye motion [Youn75] [Bolt84, chp. 4] or head motion [Enge84] [Pers85] as an input source. Using a "select what you see" approach for cursor positioning has the advantage of freeing the hands for typing, although it has disadvantages in terms of expensive and cumbersome equipment. Voice input [Redd76] [Bolt84, chp. 3] [Murr83] as an alternative to the keyboard may also be applicable.

Surprisingly, little work has been done on the use of the lower extremities for these types of tasks. This paper will provide an overview of what has been accomplished, and present two designs for foot-operated devices that are comparable in function to mice. We call such devices *moles*, since the beasts are "under foot". (Footmouse is another good name, but it has already been grabbed as a trademark.)

Moles: Origin of a Species

The prehensile thumb has rightly been given much credit for humankind's tool-using ability. Yet the foot also has had its role. The horseman's stirrup, the farmer's hayfork and shovel, the pipe organist's bellows and footkeys, and the potter's kickwheel, are all pre-Industrial-Revolution examples of foot against tool, transmitting both power and control. As mankind captured in turn the power of falling water, burning hydrocarbons, and splitting atoms, rotary motion and electricity became commonplace, and human muscle was first multiplied and then significantly surplanted by machinery. Consequently, the function of newer foot-tools is no longer to apply both power and control, but chiefly control alone.

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Present-day examples are the foot pedals of automobiles (and their arcade-game emulators), gas pressure controls on glove boxes, wah-wah and fuzz pedals for guitars, rubber sensing aprons for automatically-opening doors, and foot/knee pedals for sewing machines and dictaphones.

Other examples represent a foot-mediated input to a dedicated computer: certain flight controls in large aircraft or their flight simulators, for instance, or volume and sustain controls on music synthesizers. Krueger [Krue83,chp 3,4] has used a grid of hidden floor switches to sense the location of people in a room, which is used in conjunction with a computer, video cameras, and a large-screen display to provide a playfully interactive aesthetic environment.

In the narrower context of workstations and personal computers, pioneering work on cursor positioning hardware was done at Stanford Research Institute in the 1960's. Early, largely unreported experiments [Enge84], were carried out with a "Skate", essentially a large mouse strapped to the shoe. Fine control was difficult, and leg cramps a problem. Subsequently, better control was achieved by using an accelerator pedal to position the cursor vertically. Horizontal control was managed by detecting the swinging of the knee from left to right.

This evolved into the knee control discussed by English, Engelbart, and Berman [Engl67]. The latter was an inverted U-shaped metal yoke, that hung vertically from the underside of a desk, and straddled the lower thigh just above the knee. A limited amount of up-and-down travel was available, as well as left-and-right pivoting. This was translated into the corresponding cursor position. The limited travel and mechanical awkwardness of the device resulted in a poor preformance vis à vis the mouse and most other input devices investigated.

In a similar vein, Samet [Same85] suggested the use of a "Treadle", modeled upon a manually-powered sewing machine treadle. Presumably there could be two such treadles, for both horizontal and vertical cursor motion.

In passing it should be noted that Amiga [Amig83] manufactures a joystick-emulating toggleboard, Joy-Board, which interfaces with the Atari 2600 game computer. One stands on the centrally-supported board with both feet, and by shifting weight to tilt it in various directions, participates in a game such as an emulation of downhill skiing. (Unfortunately, the device as designed is not of sufficient linearity or reproducability to make it really usable for cursor positioning.)

It appears no one has suggested an obvious "spin-off" from the above approaches: put a large trackball on the floor. And a quite delightful idea, conjured up by Blonder [Blon85], is to monitor the tilt and swivel of an office chair, thus creating a "Tush Mouse"!

There have been a number of proposals to use a simple binary foot switch to mimic the function of a particular keyboard key, for example, the control key [Pfis84] , meta key [John85], or "edit" key [Wilc85] . We have heard of a dental office where a foot switch was wired into the Print-Screen key of an IBM PC. Postel [Post85] uses a foot switch to switch cursor focus between a VDT and a graphics screen.

More ambitiously, the four arrow keys of the IBM PC are emulated by Versatron's Foot-Mouse [Vers84] [Info84] [Sand85] [Data85], a wedge-shaped block with a pedal atop it. The pedal, spring-loaded to return to the central position, slides left or right a short distance to activate a horizontal arrow command. Similarly, it slides (actually, pivots about a point at its extreme left edge) up and down. As would be expected, repeated arrow commands in the same direction are accomplished by "holding the key down", that is, holding the pedal at one extreme of its travel. The arrow keys are normally used for cursor positioning by certain text editors; thus the Foot-Mouse is designed for cursor positioning with granularity defined by the text font and line spacing, typically 80 characters wide by 25 lines high.

Choreography for a Cursor

We have chosen to investigate designs for moles that fully emulate mice, and therefore can utilize existing software. Mice have both cursor-positioning and limited keystroke capabilities, with 1-4 keys being the normal accoutrement. One simple design approach is to segregate these two capabilities to separate feet.

Consider just the cursor-positioning function. We have chosen the following goals:

1) Assuming the user is seated at a standard desk with a workstation screen on it, provide a within-deskwell device comparable in precision and accuracy to a mouse.
2) To ensure placement precision, maximize the amount of physical movement associated with a given cursor movement. This is constrained by the size of the space available in a typical full-sized deskwell; for example, All-Steel's [AllS] is 24.75" W × 26.5" D × 25.375" H (62.9 × 67.3 × 64.5 cm).
3) In choosing the nature of the physical movement, take into account the dimensionality, variability, and kinesthesiology of the human body [Wood64] [AFSC69] [Seib72] [Tich78] [Bail82], in order to make motion as natural, precise, and fatigue-free as possible. Avoid depending in any strong way on the size of the shoe or length of the lower or upper leg.
4) Avoid strapping anything to the foot or leg. This would preclude a skeletal harness [Batt72] or special slippers [Krue83, p. 187].
5) Construct a sufficiently strong mechanism to withstand the weight and force of a human leg.

Consistent with the second goal, we have focused on designs where the foot as a whole is moved, rather than pedal/treadle designs with a fixed heel position. In this approach, the orientation of the foot itself carries no meaning; only its location (i.e., the location of the pedal it's resting upon) is of interest.

Figure 1 shows various types of surfaces easily swept out by a moving foot /leg constrained within a deskwell. The simpliest topology, shown in 1a, corresponds to sliding the foot along a tilted planar surface. Slightly more complex is a cylindrical surface, 1b, with a horizontal axis which ideally passes through the average location of the knee joint, and a radius corresponding to height of the knee. More complex still is the toroidal patch, 1c, with a horizontal radius corresponding to the length of the upper leg, as it pivots horizontally about the hip joint. Finally, 1d shows a spherical surface, with center of radius at or slightly above the knee. Each drawing shows a representative grid, indicating the mapping from foot motion to cursor motion; for any particular topography, a large choice of grids is available. For example, the y-axis spacings may be "convergent", as shown with 1c, or "parallel", as with 1a, 1b, and 1d.

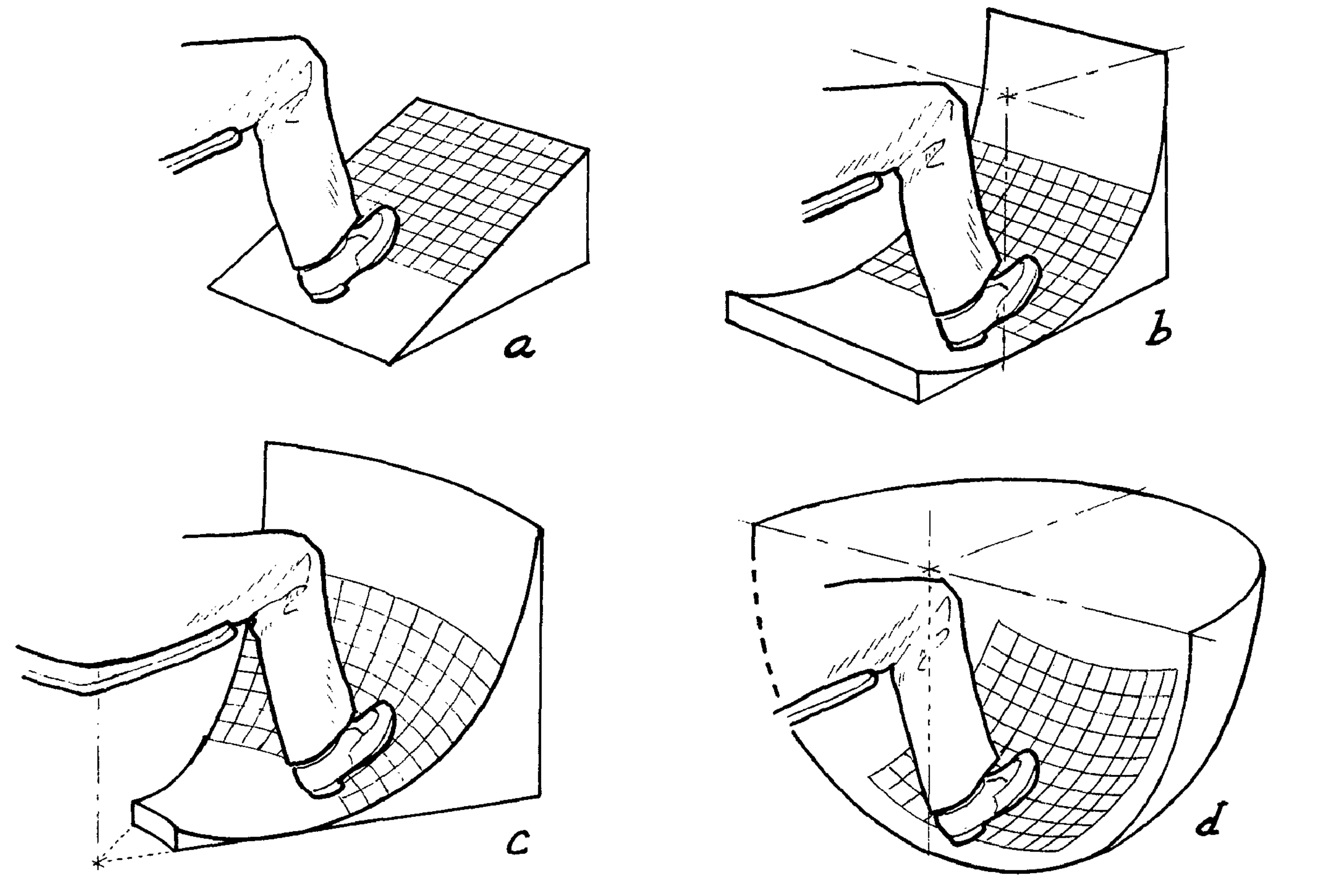

Figure 1: Topologies for Foot Movement - Swept surfaces that are (a) planar, (b) cylindrical, (c) toroidal, and (d) spherical. These are mathematically simple surfaces; more complex ones are certainly possible.

We have given serious consideration to implimentations of all but 1c. Three broad implementation approaches suggest themselves:

The "No Moving Parts" Approach

Have the foot supported by a rigid slippery surface. Several possibilities exist for locating the foot. A camera, coupled with image processing to do outline detection and big-toe inference, would be an instance of the general approach used by Krueger [Krue83, p.64,65,130,187]. This may be expensive when done in real-time and prone to interference from clothing. Alternatively, embedded capacitive sensors could be used, but the result may be too dependent on the shape of the shoe's sole. A third way is a horizontal grid of infrared diodes and sensors, as used (vertically) with some touchscreens.

The latter is moderately expensive but feasible, particularly with 1a's planar topology, and could be achieved by alteration of existing touchscreen frames [EMS] [Carr] to be large enough to enclose a shoe. Unfortunately, this technology requires a minimum spacing between adjacent diodes of about 0.125 inch (32 mm), to avoid beam interference and misalignment [EMSC]; 0.225-0.275" (57-70 mm) is typical of standard frames. Even with software averaging techniques, the best resolution of toe location is limited to about 0.06 inch (16 mm). The resolution could be further improved by stacking one frame above the other, with a slight offset, but the cost would also double. Thus, the light grid approach is probably most suitable for low-resolution text-editing tasks.

The "Swing" Approach

The foot rests upon a non-slippery pedal, which is suspended above the floor by some mechanism. The mechanism imposes a topology upon the pedal's location, as well as a mapping of pedal movement to cursor movement. The "swing" mechanism, appropriate for topology 1c and particularly 1b, may be thought of as analogous to a playground swing, with the support frame shrunken sufficiently to fit under a desk. The pedal slides left to right along the "seat" of the swing, which will henceforth be called the moleseat. This sliding is either linear (1b) or arced (1c), and the pedal may tilt or rotate as required for comfort.

Figure 2 shows in simplified form the detailed design for the 1b-style swing mole we are currently constructing. The support frame hugs the inside of a standard desk well. It is bolted to a piece of 5/8" (1.55 cm) thick particle board, upon which the desk rests. There is a cutout in the board beneath the deskwell. This arrangement provides both a secure mooring for the mole, and raises the desk height 5/8", thereby providing additional knee clearance.

The swing mechanism is supported from the frame by two bearings. Their common axis of rotation is 24.7" (62.7 cm) above the floor and 9.5" (24.1 cm) inside the deskwell from the front desk edge. When used with a right-foot pedal whose top surface is 1.4" (3.5 cm) off the floor in its lowest position, this axis passes slightly above the position of an average-sized person's right knee joint. The moleseat is a parallel pair of hardened steel rods. The pedal is supported by a carrier, incorporating a pair of linear bearings, through which the rods slide. Unlike the flexible chains of a playground swing, rigid metal channeling supports our moleseat. The design allows easy alteration of the bearings' position and of the channels' length, and thus of the radius of swing. The pedal swings toward the back of the desk, up to about 33° from the vertical, at which point the toe touches the rear panel. Similarly, it swings about 6° in the other direction, until the heel hits a chair leg. Thus, the pedal surface has a range of about 16" (40.6 cm) circumferentially, as well as a linear range of 12-13" (30.5-33 cm) along the moleseat.

The left foot rests upon a platform that is "floated" slightly above the seat; thus, the seat bars pass beneath it as the lower leg is swung. The top surfaces of the platform and the pedal have the same height and orientation above the floor, when the pedal is about 10 ° off its lowest position. This suggests that the ideal user's chair would have its seat 1-1.5" (2.5-3.8 cm) higher than the usual optimal. Incorporated into the platform are switches to simulate mole keys (discussed below).

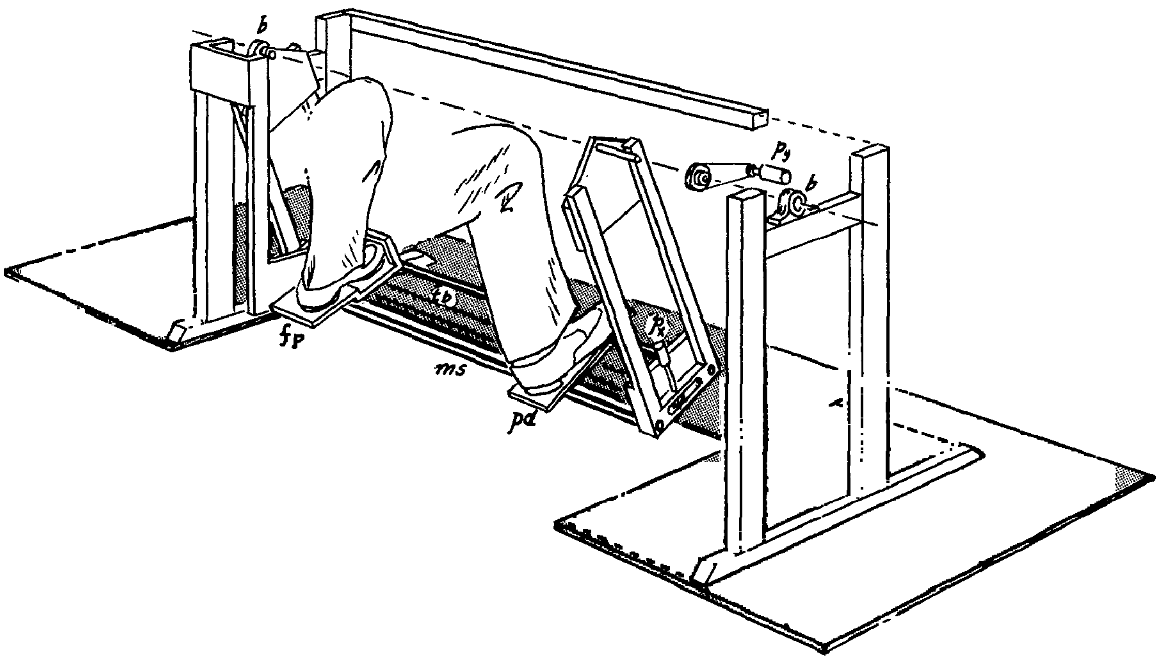

Figure 2: Prototype Swing Mole. Parts identified are the bearings (b), the 1-turn y-axis potentiometer (p_y), the 10-turn x-axis potentiometer (p_x), the moleseat and its two steel rods (ms), the cursor-positioning footpedal and its supporting carriage (pd), the timing belt that connects the carriage to the x-axis potentiometer (tb), and the left foot platform (fp; see also figure 4).

To sense movement corresponding to a vertical cursor motion, a 1-turn potentiometer is attached, via a timing belt with a 2.4:1 gear ratio, to one of the swing bearings. For horizontal motion, a long timing belt is stretched between two small toothed pulleys mounted at the left and right ends of the seat. The belt passes between the two rods, and is attached to the pedal carrier at a single location. One of the pulleys is attached to a 10-turn potentiometer. The resistance of each potentiometer is measured as a voltage, which is digitized and passed to a small dedicated microprocessor. The latter runs software that provides mouse emulation.

There are several advantages to this somewhat-complicated design. It provides a great deal of freedom of movement, with the legs unhampered by the support elements that most simpler swing designs would entail, and yet is strong enough to be used as a convenient footrest. The absence of any structures above the knees means that the only incursion upon the limited knee clearance found under average desks is that associated with the pedal/platform height. Mitigating this further is the additional 5/8" elevation of the desk. Another advantage is that the sensing and interpretation of motion is straightforward and of high precision.

The chief disadvantages appear to be that the complexity would add to the manufacturing cost of a mass-produced version, and the mechanism is somewhat intrusive when not in use (although allowing the moleseat to be pushed towards the back of the desk and locked there would lessen this shortcoming).

The "Pendulum" Approach

After investigating the swing mole, we intend to build a pendulum mole. Again, one foot rests upon a suspended non-slippery pedal, but the spherical topology of 1d is used. Figure 3 shows two variations upon the basic design, which is that of a suspended pedal coupled to an inverted joystick mounted directly above the knee.

In 3a, the foot pedal is suspended at its four corners by flexible cords. The cords run up to a spreader (used to prevent cord rubbing against the leg) and continue up to a pair of same-sized rectangular plates. The uppermost plate is mounted to a support structure (not shown) located at the top of the desk well. This plate has an inverted joystick mounted upon it, whose elongated handle passes through a hole in the lower plate. The lower plate's movement is constrained to stay roughly parallel to the upper plate. The constraints upon the pedal's motion is somewhat complex, but clearly there is a one-to-one mapping from pedal position to joystick position.

In 3b, the setup may be thought of as a very large, heavy-duty inverted joystick, with the pedal directly attached to the tip of the "handle". Thus, pedal movements inherently correspond to X and Y joystick movements. The sensing of these movements is done by two semi-circular "cages", which press against the "handle" and translate the latter's movement into rotations about orthogonal axes.

With either arrangement, the other foot rests upon a platform containing the mole keys (not shown), which is identical to that used in the swing design, except that it could be floor mounted instead of floated. (However, our intension is to use the same support frame used for the swingmole, and thus the same platform.)

Mole Keys

Like a mouse, a mole may have 1-4 binary keys associated with it. It may also have an extra "clutch" key, which, while depressed, disengages movement of the mole from movement of the cursor. This is analogous to lifting a mouse up and repositioning it within its work area on the desktop. An alternative treatment of the clutch key would be as a momentary-contact switch: each time it's tapped, the engaged/disengaged status changes, thus "gluing" and "ungluing" the cursor. A mole without a clutch key must use absolute pedal positioning, while a mole with may use relative positioning.

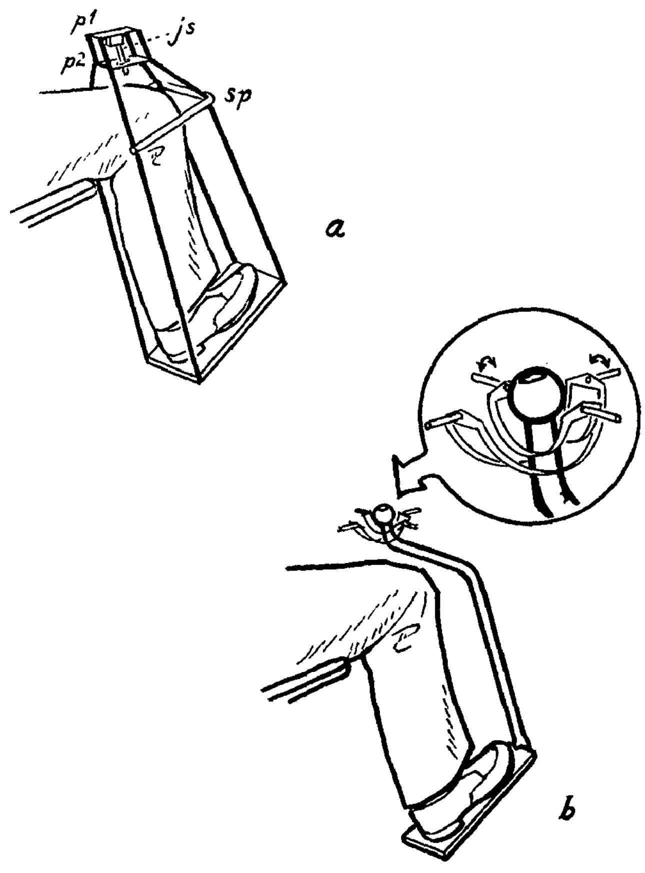

Figure 3: Prototype Pendulum Moles.

Version (a) uses flexible cords, shown as heavy black lines, to support the pedal in a stirrup-like fashion. Other parts are the three-sided spreader (sp), the pair of equal-sized parallel plates (p1 & p2), and a conventional joystick, mounted upside-down (js). p1 is rigidly fixed.

Version (b) uses a rigid rod, perhaps of tubular steel, to support the pedal from a spherical joint. Only the ball of the joint is shown. The closeup shows the pair of crossed sheet-metal "cages", which sense the orientation of the rod and transform it into the shaft rotation of two potentiometers (not shown).

Some or all of these keys could be mounted upon the keyboard. For instance, low-profile pressure-sensitive membrane switches could be adhered beneath or to either side of the space bar, where they would be both unobtrusive yet easily hit by the thumbs.

But we are pursuing the more challenging task of including moles keys as part of the functionality of the feet. Figure 4 shows the current design. There is a fixed platform for the left heel. The tip of the shoe extends about 1" (2.5 cm) through a rectangular frame, which is perpendicular to the platform, and of inside size roughly 3" (7.6 cm) wide by 2" (5.1 cm) tall. The four interior walls of the frame are mechanically independent bars, and each is attached to a spring-loaded switch. The switch movement is arranged in such a way that as any bar moves away from the center of the frame, its switch is closed. The springs restore the bars inward. The lower horizontal bar has sufficient upward spring loading (about 3 lbs/1.5 kg) to allow the foot to rest upon it without depressing it. The other bars have lighter springs.

This arrangement will allow certain chordings. Any adjacent "vertical"-horizontal pair of bars can be chorded by a diagonal toe movement. Further, chording of the two vertical bars can be done (or of the two vertical bars with either of the horizontal bars) by shoving the shoe forward, using it as a wedge. However, this may require one of the vertical bars to be adjustable for the individual's shoe.

An equivalent system could be designed with the toe of the shoe jammed into a "cup pedal", where a projecting part from the cup (or its support) is the active agent that moves within a smaller frame.

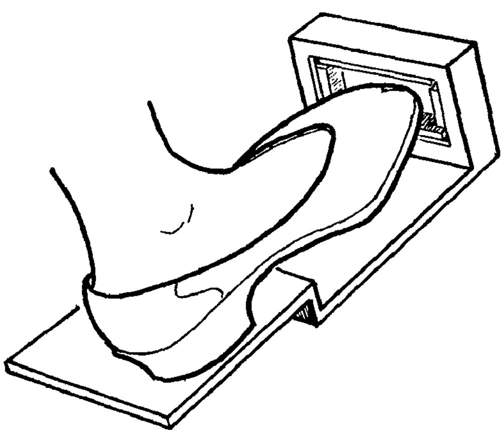

Figure 4: Closeup of the left foot platform with its four Mole Keys. The switches that the keys activate are hidden within the frame. In use, the foot could be slid forward somewhat further than shown.

Future Directions

The use of moles instead of mice appears to be a promising area of research. The swing mole is currently under construction. Following its mechanical assembly, an electronic mouse-emulating interface will be fabricated, using a single-board microcomputer. Candidate workstations for attachment include a Xerox Dandelion with Mesa/XDE [Xero84], and a Sun 2 with C/Unix[Sun82]. Software will be developed for human-factors experiments, initially to optimize the swing length and grid map of the mole, and later to compare various moles and mice in text-editing and other tasks. Parameters to be considered are ease of learning, speed, accuracy, convenience, muscle fatigue, and overall usefulness for particular applications.

Acknowledgements

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"The only use I made of a foot pedal was as a switch to determine which of two screens a mouse was to track on. The situation was that there was an alphanumeric display that had text windows and let the user point to things with a mouse, and there was a storage tube graphics display for a drawing subsystem in NLS that let [one] point at things in creating and editing pictures made up of lines, circles, rectangles, arrowheads, etc. The foot pedal was (and is) used to decide if [the user] was pointing to the text display or the graphics display. The graphics could be associated with the text. One could point to a text statement and give a command to display the picture asssociated with that text statement, then push the foot pedal to select which window on the graphics screen the picture should appear in...."

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[Wilc85] Wilcox, Clark, of Xydak, Menlo Park, CA, personal communication, Sept 19, 1985. Pedal was installed by Nick Veizabes and used briefly by Wilcox at Stanford University in '75-'76. The "edit" key turned on the 8th (high-order) ASCII bit. When used like a shift-key with another key, it created a byte that was interpreted as a command by the editor.

[Xero] Keyboard units for the Xerox 860 Information Processing System have an optional "CAT" circular touch pad; Xerox Corp, 1341 West Mockingbird Lane, Dallas, Texas 75247.

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