

INPUTTING TO A NOTEBOOK COMPUTER

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Inputting to a notebook computer (NPC) can differ from inputting to a desktop style computer. NPCs are self-contained, so if no peripherals are used, the user works with the keyboard layout and style and location of pointing device provided by the manufacturer. In contrast to standard external keyboards, there are few redundancies provided on an NPC keyboard. Another important difference is keyboard location - because the monitor and keyboard of most NPCs are joined, the user must make a location choice that will potentially compromise body comfort in one or more regions. This paper focuses on some inherent restrictions to inputting on a self-contained NPC.

INTRODUCTION

In 1975 there were fewer than 200,000 computers in the U.S. (Juliussen & Petska-Juliussen, 1994); 1994 projections for 1995 exceeded 100,000,000 computers. Results from a 1993 survey revealed widespread workplace use of computers: 1/3 of 100 large, publicly traded companies provided 100 % of their employees with personal computers or terminals (Juliussen & Petska-Juliussen, 1994). Personal computers (PCs, including Apple's computers) account for 90 % of all computers. The portable PC is a rapidly growing market segment, accounting for 15 % of the 50 million PCs shipped in 1995¹. In 1997, it was estimated that mobile computers would constitute 34 % of total U.S. PC shipments in 2000². In 1997, portables were already 40 % of total computer output in Japan (Villanueva et al., 1998).

Though mobility is the primary feature of mobile computers, increasingly NPCs are the choice for desktop use by small businesses and home workers. There is a similar trend in larger companies, as well. A 1996 survey found a 60/40 split in work-related use of mobile computers, between companies with more than 1000 employees and those with fewer, respectively³. Many employees of larger companies are given a choice (NPC or desktop PC (DPC)). Some companies provide peripheral devices for use with NPCs (monitor, keyboard, and/or pointing device).

The benefits of mobile computing technology are numerous. For current computer users, NPCs expand work location opportunities. Telecommuting is one example. Transit time can also now be spent productively. NPCs provide mobility within a facility as well, for presentations, meetings, or to share or record data.

Additionally, mobile computers have expanded and diversified the population of those using computers for work. Medical journals document important uses of mobile computers in telemedicine. This technology provides medical professionals opportunities to work with patients who are in remote locations. Both patients and health care professionals

may be new users. Electric utility linemen in the U.K. are another example of a new group of users (Satyanarayanan, 1995). They are issued NPCs in order to communicate with each other and with control rooms.

There are, however, some occupational health concerns for mobile computer users. Questions of appropriate use, use location, appropriate work postures, and time on task have been raised. For example, some U.S. Occupational Safety and Health Administration (OSHA) compliance officers developed repetitive motion disorders that were determined to be linked to their new, innovative use of NPCs⁴. Essentially, they were using them as dictation devices, typing continuously for hours at a time to record statements in the field. Some concerns associated with mobile computers overlap with concerns for computer work in general (e.g., repetitive finger activity, fixed postures, visual strain), some with concerns for remote workers (e.g., burnout, isolation), while others are specific to mobile computers (e.g., integrated pointing devices, compact keyboard design).

Many studies have examined the impact of computer work on worker health. Gerr et al. (1996) summarized specific limitations of previous studies in an attempt to explain conflicting results, and marginal progress towards understanding the impact of computer usage on workers. However, there are some areas of consistency in the literature. This paper examines some of those areas of consistency that are relative to NPC spatial design and location, as well as some areas in which differences of opinion remain.

Figure 1 depicts a model of NPC design factors and their potential effects on strain outcomes and performance. The model is based on epidemiological and laboratory DPC research, as well as limited NPC research. Although this paper will focus on inputting and input devices, work by Villanueva et al. (1998) indicates that screen design is likely to be as important as input device design in terms of potential to affect health and performance. In that study, smaller screen size was

¹ Sources: International Data Corp and Data Quest.

² Giga, The US Mobile Computer Market Report, 1997.

³ Giga Information Group, Portable PC User Survey 1st Quarter 1996.

⁴ Laptop Computer Usage and OSHA's 11c Program, Memorandum from BR Chadwick, Regional Administrator - VIII, to R.C. Clark, Director, Directorate of Compliance Programs and L.G. Carey, Director, Directorate of Field Programs. http://gabby.osha-slc.gov/OshDoc/Interp_data/INTERP_19940104.html

associated with visual discomfort, more non-neutral body postures, and increased neck extensor muscle activity.

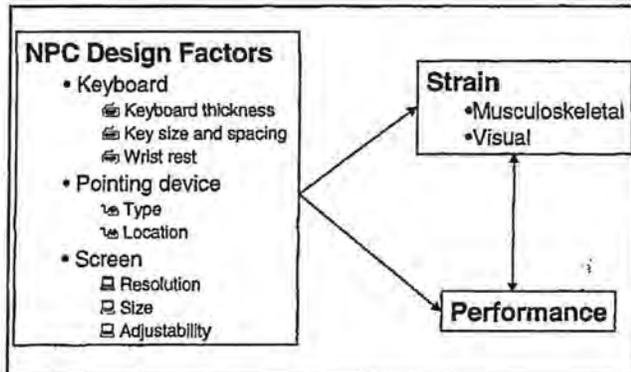


Figure 1. Model of NPC design factors and user strain and performance outcomes.

KEYBOARD DESIGN AND LOCATION

Some aspects of NPC keyboard design are shared with standard keyboards, such as layout of letter and number rows, but others are unique to the NPC, including alterations that reduce keyboard size to comply with the notebook footprint. Keyboard location decision is also important for DPCs and NPCs, but is more complex for NPCs.

Keyboard Layout

Problems with upper extremity posture during keyboard work have been recognized for more than two decades (Duncan & Ferguson, 1974). The root causes of postural problems include user stylistic methods, as well as adaptations in response to keyboard design or location. Pronounced ulnar wrist deviation during keying has been consistently linked to discomfort (Duncan and Ferguson, 1974; Hünting et al., 1981; Sauter et al., 1991). Non-neutral wrist postures have been associated with levels of carpal tunnel pressure (CTP) that are known to adversely affect nerve physiology (Dahlin, 1991). For some individuals, CTP can exceed physiologic levels during typing on a standard keyboard, due to the extent of ulnar deviation (Sommerich, et al., 1998) or wrist extension (Rempel et al., 1994). These issues are common to DPC and NPC keyboards, but there are some design factors that may exacerbate problems with the NPC.

One layout situation that occurs primarily in NPCs is the lack of redundant keys. Standard DPC keyboards often have an integrated number pad, in addition to a number row. They may also have two sets of function keys. These extra keys afford users opportunities, when typing numbers, to assume shoulder, elbow, and wrist postures that differ from text typing postures. Though some NPC letter keys can be converted to function as a number pad, the location does not afford opportunity for posture changes. Table 1 shows upper extremity (UE) posture data from pilot work in which subjects performed a word typing task and then a number typing task. Subjects performed both tasks on a self-contained NPC and

then on a standard full-size keyboard with built-in number pad. With the NPC subjects remained in virtually the same posture for both tasks, indicating a high degree of postural fixity. However, using the number pad on the standard keyboard allowed subjects to vary UE posture, and assume a more neutral shoulder posture when typing numbers.

Table 1. Right upper extremity joint postures for three pilot subjects during typing; units are deg. DPC: standard keyboard with number pad; NPC: self-contained notebook PC. t/n: alpha text typing/numbers typing.

	Shldr Lat Rot	Shldr Flex	Elbow Flex	Wrist Flex	Wrist Rad Dev
P01					
DPC-t/n	-19 / 9	20 / 6	104 / 100	-15 / -24	-4 / 3
NPC-t/n	-18 / -21	30 / 29	122 / 121	-17 / -16	-9 / -17
P02					
DPC-t/n	-21 / 5	18 / 7	99 / 98	-18 / -22	-13 / 2
NPC-t/n	-19 / -22	22 / 22	106 / 112	-4 / -8	-9 / -16
P03					
DPC-t/n	-23 / 1	27 / 12	114 / 99	-27 / -10	-19 / -10
NPC-t/n	-27 / -26	29 / 21	112 / 103	0 / -1	-18 / -22

Keyboard Sizing

Sizing issues include key size, key spacing, and keyboard thickness. NPC keyboard dimensions can differ from those of a standard keyboard. In a study comparing text entry on a DPC with text entry on several NPCs, one NPC keyboard was only one-third as long as the standard external keyboard, and another was 2.5 times as thick (Villanueva et al., 1998). Yoshitake (1995) determined that touch typists with large fingers (finger tip breadth), were disadvantaged when working on keyboards with key spacing below 16.7 mm (19-21 mm is standard), while typists with narrow fingers could type just as well with spacing as small as 15 mm. Spacing differences were achieved through changes in center-to-center spacing alone, or combined with changes in keytop width. Loricchio & Lewis (1991) tested numeric keypads of various key spacing/size configurations, and found no effect on error rate, but found effects on preference and input rate between a standard keypad and one with both narrower spacing and reduced width keys.

Villanueva et al. (1998) standardized the height of each keyboard relative to each subject, but still found differences in elbow flexion and wrist extension in comparing postures during text entry with a DPC and four progressively smaller NPCs. Keyboard sizes differed between the DPC and the three smaller NPCs. Medial shoulder rotation increased as keyboard size decreased, though abduction was not affected. Keying difficulty was judged greater for the NPCs compared to the DPC, and was greatest for the two smaller keyboards. Keying performance was reduced for the two smaller NPCs.

Palm/Wrist Rests

Lack of UE support has been linked to UE discomfort in VDT workers (Hünting et al., 1981), particularly in situations with limited rest break opportunities (Bergqvist et al., 1995). However, the means by which support is provided seems

critical for achieving, simultaneously, the goals of reducing shoulder muscle loads, facilitating neutral wrist postures, not hampering productivity, and not introducing localized contact stress. Support provided only at the palm/wrist, as with support areas provided by NPCs or an external wrist pad, does not seem to achieve these four goals (Horie, Hargens & Rempel, 1994; Parsons, 1991; Fernstrom et al., 1994). In contrast, Aarås and colleagues, using standard keyboards, have shown benefits to locating the keyboard back from the edge of the support surface, such that the forearms are fully supported (Aarås et al., 1998; Aarås et al., 1997). It could be assumed that NPC users might benefit from such an arrangement, if thickness of the NPC were similar to a standard keyboard. Many are thicker, however, which could lead to pronounced wrist extension if forearms were fully supported on the work surface that also supported the NPC.

Keyboard Location

The modular design of the DPC allows for independent location of keyboard and screen. Per Straker et al. (1997), "...independent adjustment of screen and keyboard is important to allow users to position the tactile and visual interaction components, in a way that encourages a good posture." While there is disagreement regarding appropriate monitor location (Bauer & Wittig, 1998; Hill & Kroemer, 1986), most desired locations can be achieved as a result of this modular design. However, with most NPCs, screen and keyboard locations are not independent. The limited research on NPCs indicates that keyboard position has priority.

Straker et al. (1997) examined posture, discomfort, and performance in adults who regularly used computers. Each typed on an NPC and a DPC for 20 min. Subjects were allowed to adjust the workstation before working with each computer, so that for both computers subjects could be considered to be in preferred orientations. Differences were only found in neck flexion and head tilt; shoulder, elbow, and wrist postures were not affected. These results indicate that subjects chose to position the keyboards of the two computers similarly, while the location of the NPC screen was lower than the location chosen for the DPC. Price & Dowell (1998) found significant differences in posture and discomfort associated with NPC placement. Comparing an NPC placed low (to optimize arm posture) to an NPC placed high (to optimize neck posture), discomfort in all body parts, including the neck, was greater with the higher placement.

Results of these two NPC v. DPC studies, though only involving short term use, appear to be consistent with epidemiological findings on keyboard height. Elbow level keyboard placement seems to offer a compromise between shoulder discomfort induced by higher locations and wrist discomfort induced by lower locations (Bergqvist et al., 1995).

Regarding performance, Venda et al. (1994) found a bell shaped effect of keyboard height on typing rate for two subjects performing text entry on NPCs for 3 min and 30 min time periods. The 30 min curve was more peaked, with lower amplitude, than the 3 min, signaling that work surface height was more critical for the longer task.

POINTING DEVICE DESIGN AND LOCATION

Choices for external pointing device design and location are extensive. In contrast, the variety of devices that are built into today's NPCs is quite limited, and the types provided have been shown to adversely impact performance.

Type of Pointing Device

There are many types and designs of external pointing devices, and studies have shown performance differences between them. However, NPC users generally have a choice of only two types of integrated pointing devices: a touchpad or a pointing stick, both of which have been shown to hinder performance when compared to other types of devices.

For novice users, Card et al. (1978) found positioning time and error rates for text selection were less for a mouse in comparison to a rate-controlled isometric joystick, step keys, or text keys. Epps (1986) found a mouse was faster for target acquisition than a rate-controlled force joystick. Trackball performance was slightly better than mousing, and touchpad performance was better than joystick, but not as good as mousing. In contrast, MacKenzie et al. (1991) found a trackball was worse than a mouse or a stylus and tablet, based on move time for dragging and pointing, and quantity of "dropping" errors. Comparing pointing devices in target acquisition and text selection tasks, Loricchio (1992) also found mouse performance superior to that of a rate-controlled force pushbutton device. These studies are consistent in their findings of performance benefits of a mouse over touchpads, joysticks, and button-type pointing devices.

Pointing Device Location

Studies have documented effects of pointing device location on biomechanical and subjective outcomes. Cook & Kothiyal (1998) compared muscle activity and posture when using a mouse located normally (to the side of a keyboard with built-in number pad), in a far right location, and in a compact location (to the side of a keyboard with no number pad). Muscle activity in the anterior and middle deltoid increased as mouse position became more lateral. Karlqvist et al. (1998) found that shoulder posture and muscle activity were dependent upon medial-lateral and fore-aft mouse position.

Kelaher et al. (accepted) identified effects of the location of an integrated touchpad on UE posture, discomfort (neck, upper back, and shoulders), perception of performance, and preference in a group of right-handed subjects. A bottom center location (common in NPCs) and four alternatives (top center, top right, right side, and bottom right) were evaluated. Results suggested that the bottom center location may not be optimal. Rankings for it were generally in the middle for most outcome measures, including preference.

Integrated v. Peripheral Pointing Devices

When integrated and peripheral devices are compared, effects may be due to type of device, device location, or a

combination of the two. Price & Dowell (1998), in studying various configurations of an NPC with and without peripheral devices, found greater discomfort in the right wrist/hand for two conditions requiring use of the integrated pointing device in comparison to four conditions requiring use of a mouse. This provides an interesting contrast to work by Harvey & Peper (1997), who reported that using a mouse to the right of an extended keyboard required more activity in the deltoid and trapezius muscles compared to a trackball centrally located below the space bar on an NPC. In considering the findings of these two studies, it may be that the benefits of postural change override the "cost" of increased muscle activity.

Recent pilot work sought to compare posture as a function of task (word typing v. pointing device use) and tool (NPC with a pointing stick v. standard full-size keyboard with a mouse positioned to the side of the built-in number pad). The data indicated that use of the mouse afforded subjects opportunities to vary shoulder rotation position between the tasks. In comparison, subjects assumed similar postures for both tasks when using the NPC.

SUMMARY

There is no occupational epidemiological research on the use of NPCs and adverse health outcomes. However, it may be wise to incorporate what is already known from research on DPCs in making choices when working with NPCs, with regards to NPC selection, work postures, use of peripheral devices, and patterns of use.

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