Original article

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Children and gender—differences in exposure and how anthropometric differences can be incorporated into the design of computer input devices

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Objectives This study attempted to determine whether the current "one-size-fits-all" paradigm used for computer input devices meets the needs of the current computer-using population.
Methods Wrist posture and muscle activity in the flexor digitorum superficialis and extensor digitorum communis muscles were measured and compared between 14 children (ages 5 to 8 years) and their same-gender biological parents. The participants performed a standardized mousing task with a standard and child-proportional mouse. The literature on finger anthropometry was systematically reviewed to determine finger size variation as a function of age, size percentile (5th, 50th, 95th), and gender and its influence on the design of computer input devices.
Results With the standard mouse, the children used a greater [18.4 (SD 11.3) degrees] ulnar deviation and less [9.4 (SD 12.9) degrees] extension than their adult counterparts. With the child-proportional devices, their ulnar deviation [4.0 (SD 6.4) degrees, P=0.04] was significantly reduced, as was their forearm muscle activity (P<0.01). Both the children (P<0.01) and the adults (P=0.05) performed the standardized mousing task faster with the small mouse. The anthropometric data showed that finger anthropometry differed up to threefold between the children and the adults. They also indicated that the size of computer input devices is likely based on anthropometric clearance issues to accommodate the larger 50th to 95th percentile of male users.
Discussion This study indicates that the current "one-size-fits-all" paradigm for computer input devices is unlikely to meet the needs of a large percentage of the computer using population. It is recommended that researchers and companies manufacturing computers and computer input devices work together to determine the appropriate range and size offerings of these devices.

Key terms anthropometry; child; computer; computer keyboard; computer mouse; woman.

Computer input devices represent a set of tools for which a one-size-fits-all paradigm has predominantly been applied. Despite the emphasis that has been placed on fitting adult workers to their tools and workstations, the design of computer input devices has taken place with little focus on accommodating different-sized persons (eg, women and children).

Several studies have shown that relatively intensive computer use can lead to musculoskeletal symptoms. For example, a recent epidemiologic study demonstrated that just over 50% of newly hired adults who worked 15 hours or more on the computer per week developed some form of musculoskeletal symptoms in the first year of employment (1). In general, in child, college, and adult populations, there is growing evidence of a relationship between duration of computer work and the self-reporting of musculoskeletal symptoms (2–7).

For children, the age of exposure to computer use is getting lower and lower, and the number of usage hours per day has dramatically increased over the past two decades (8). Current data from the United States Department of Education (8) indicate that 80% of the children in the United States are using computers by 5 years of age. Current best evidence reveals that 30% to 60% of school-age children self-report having some form of musculoskeletal discomfort that they thought was exacerbated by computer use (4, 9–10).

Due to the large percentage of children using computers at such a young age (actually an occupational tool), these early exposures to adult-scaled input devices may place children at risk of injury both during their

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formative years and later in life. Force, repetition, and posture are well-documented occupational risk factors for musculoskeletal injury (11–14), and we feel children may be unduly exposed to higher muscle loads and nonneutral postures due to their use of larger size devices with activation forces designed for larger, stronger adults. In addition, the cumulative exposures to force and repetition among these children, who represent the next generation of workers, will be greater than any prior generation. The impact of these greater exposures on the current generation of young computer operators is unknown, and it may make sense to error on the side of caution and take a proactive approach to provide children with devices designed specifically to match their size, strength, and statures. In addition, several studies on computer work have shown that women tend to have higher relative exposures than men (15–18). Furthermore, women have been shown to have higher prevalence's for many types of musculoskeletal disorders (19). As a result of these gender differences in physical exposures and the higher likelihood of women developing musculoskeletal disorders, women may also benefit from having computer input devices designed to better match their size, strength, and stature.

Through recent research and a systematic analysis of anthropometric data, this study demonstrates how computer input devices have been designed on the basis of anthropometric clearance issues to accommodate the largest users (50th to 95th percentile of males), potentially at the expense of smaller-statured populations. Currently, women and 5- to 14-year-old children represent 60% of the world population (20). If there are size disparities, then computer input devices designed to accommodate the larger adult males may put additional stress on the soft tissue of smaller-statured populations, potentially leading to higher or earlier susceptibility to musculoskeletal disorders. By identifying key anthropometric differences between men, women, and children, we want to demonstrate that researchers, computer companies, and computer input device manufacturers need to work together to determine how the size and strength disparities identified in this study may affect the design of future computer input devices.

Study population and methods

Study population

In a laboratory-based study, 14 healthy schoolchildren (7 female, 7 male) between the ages of 5 and 8 years, along with their same-gender biological parent (total of 28 participants), were recruited. They performed a series of standardized computer tasks with a standard-size (12.6 × 6.8 × 4.0 cm) and a smaller (8.8 × 5.1 × 3.4 cm) computer mouse (figure 1). The smaller mouse was proportionally smaller in size, reflecting the anticipated size differences, based on anthropometric calculations, between our adult and child computer users. Study procedures were approved by the Human Subjects Committee at the University of Washington. The parent participants reviewed and signed consent forms, and the child participants gave oral assent when entering the study.

Procedures

The participants sat in adult-size adjustable-height chairs at an adjustable-height work surface. To accommodate the seating of the smaller-size children, platforms were placed on the floor to support the feet and additional back support was provided so that the children could sit comfortably.

The participants repeatedly performed an omnidirectional-pointing task that consisted of alternately clicking on 18 evenly-spaced circular targets arranged in a large circle. Wrist posture and muscle activity in the finger flexors and extensors was measured and compared between the adults and children and between the large and small devices while the standardized task was performed. The mouse order was randomized.

An electrogoniometer (model SG-65, Biometrics, Gwent, United Kingdom) and a portable data logger system (Muscle Tester ME6000, Mega Electronics, Kuopio, Finland) were used to measure the wrist angles. The measurements were made from the right hand only and the goniometer transducers were secured to the hand and arm with double-side tape. The goniometers were attached as recommended and described by Jonnson & Johnson (21). Neutral position of the wrist was defined as recommended by the American Academy of Orthopedic Surgeons (22), according to which the hand should be flat and relaxed while the arm is held by the experimenter. The offsets in the goniometer data during the neutral calibration position were subtracted from

Figure 1. Mouse models tested, (left) the standard size mouse (Microsoft IntelliMouse; Model 92654; Microsoft Corp.; Redmond, WA, USA) and (right) the smaller size mouse (Kensington Pocket Mouse, Model K72114G, Kensington Corp, San Mateo, CA, USA).

each axis so that the neutral position was zero degrees, then the 10th (minimum), 50th (median), and 90th (maximum) degree angles were calculated.

Muscle activity was measured with electromyography (EMG) from two muscles on the right arm, the flexor digitorum superficialis (FDS), a muscle involved in finger flexion, and the extensor digitorum communis (EDC), a muscle involved in finger extension. For each muscle studied, three, self-adhesive, 12-mm disposable surface electrodes (model N-00-S, Ambu, Ølstykke, Denmark) were attached to the surface of the skin over the muscle. The electrode locations were based on recommendations included in the *Anatomical Guide for the Electromyographer* (23). Before the electrodes were attached, the skin was prepared by shaving away any excess hair, rubbing the skin with a mildly abrasive pad to remove dead or dry skin, and cleaning the skin's surface with rubbing alcohol. The EMG measurements from the muscle were collected continuously on a portable data logger over the whole duration of the experiment.

The goniometer and raw EMG signals were collected from the target muscles at 1000 Hz. After the data collection, the EMG and goniometer data were postprocessed. The EMG signal was rectified and averaged using a 125-ms moving average window, and the offsets in the goniometer data during the neutral calibration position were subtracted from each axis so that the neutral position was zero degrees. At the end of the experiment, all of the EMG data were normalized relative to each participant's maximum voluntary contraction (MVC). For the EDC muscle, MVC values were obtained by having participants sit and rest their hand flat on a table and extend their fingers with maximal force against resistance provided by the experimenter. With the index finger only, the maximal FDS activity was obtained using the same posture except that the participants pressed down with as much force as possible against the table. Three trials were performed with each muscle, and the highest trial was used to normalize the EMG data as the percentage of the maximum voluntary contraction (%MVC).

Table 1. Anthropometric measurements and differences between the children (N=14) and adults (N=14). The percentage size is the size of the children relative to that of the adults.

Measurement	Study population						
	Children		Adults		Difference	P-value	Size (children/ adults, %)
	Mean	SD	Mean	SD			
Shoulder breadth (cm)	31.0	2.2	42.5	2.3	11.5	<0.0001	73
Arm length (cm)	50.8	4.7	71.3	4.5	20.5	<0.0001	71
Hand length (cm)	13.6	1.0	18.8	1.1	5.2	<0.0001	72
Hand width (cm)	7.5	0.6	10.0	0.9	2.5	<0.0001	75
Index finger length (cm)	4.8	0.1	7.2	0.5	2.4	<0.0001	67
Index finger width (mm)	14.6	1.1	20.3	2.4	5.7	<0.0001	72
Index finer mass (g)	10.1	1.9	28.0	7.8	17.9	<0.0001	36

In order to identify any anthropometric differences that may have an impact on exposures and the design of computer input devices, a systematic evaluation of child and adult anthropometry was carried out using data from United States and United Kingdom populations from the CHILDATA (24) and ADULTDATA (25) anthropometric databases. Of primary interest were the hand anthropometric measurements of the children between the ages of 5 and 14 years and a comparison of anthropometry between males and females. The specific anthropometric measures analyzed were finger length, finger width, and finger mass. These anthropometric measures were studied since it was thought that they may influence the sizes of computer input devices, button or key activation forces, and the minimum forces required so that computer operators can rest their fingers on the buttons or keys without fear of accidental or unintentional activation.

Data collection and analysis

From the laboratory study, the goniometry and EMG data were analyzed, and the mean postural and 10th, 50th and 90th percentile levels of muscle activity were calculated (26). The group mean values with one standard deviation are presented. Between the child and adult participant groups, the statistical comparisons were made using a repeated-measures analysis of variance (RANOVA). Significance was accepted when the P-value was <0.05. The anthropometric databases were used to determine finger length and width as a function of age, size percentile (5th, 50th, 95th), and gender. Finger mass as a function of age and gender was derived by taking the index finger length (h) and the proximal interphalangeal joint diameter (r) from the ADULTDATA and CHILDATA anthropometric resources, calculating finger volume ($\pi \cdot r^2 \cdot h$), and multiplying the volume by the density of human hand tissue, 1.16 g/cm^3 (27). Due to the finger potentially having a greater proportion of bone tissue than the hand, this density may be a slight underestimation of actual finger density, but it represents the current best estimate. We were unable to find any studies containing finger density estimates or measurements in the literature.

Results

Differences in anthropometry between the adult and child participants

Table1 shows the differences in anthropometry between the adult and child participants. For the measures of stature or length, on the average, the children were 72% the size of their adult parents. However, one notable exception was finger mass. When index finger mass was estimated as described in the methods, the children's index finger mass was only 36% that of the adults.

Postural and muscle activity differences among the children

As shown in figure 2, when using the standard mouse, the children worked with a greater ulnar deviation mean [18.4 (SD) 11.3 degrees, P<0.0001] and less extension [mean 9.4 (SD 12.9) degrees, P<0.0001] than their adult counterparts (figure 2). When the children used the smaller mouse, the ulnar deviation was reduced by 4.0 (SD 6.4) degrees (P=0.04) with very little change in wrist extension.

As shown in figure 3, similar trends were found for muscle activity, with significant decreases in the 10th, 50th, and 90th percentile of muscle activity for both the finger flexor and extensor muscles when the children used the smaller mouse. The adults' muscle activity was also reduced with the smaller mouse, but the differences in muscle activity did not reach significance. Mouse performance, defined as the average time used to move between targets in the omnidirectional pointing tasks, was also measured. As shown in table 2, when the performance was compared between the standard and small mice, both the adults and the children were slower with the larger standard mouse.

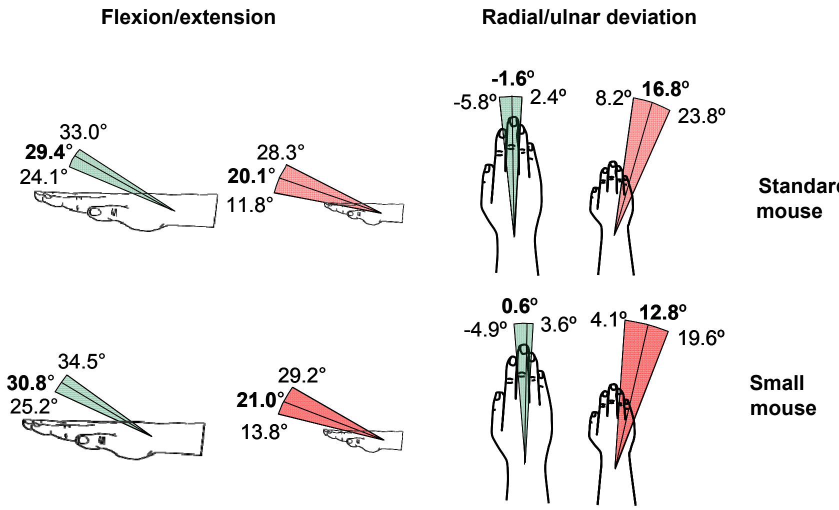

Figure 2. 10th, 50th, 90th percentile values for extension (left) and radial or ulnar deviation (right) between the adults (larger hands) and children (smaller hands) when using the standard mouse (top) and small mouse (bottom). [N=14, each group]

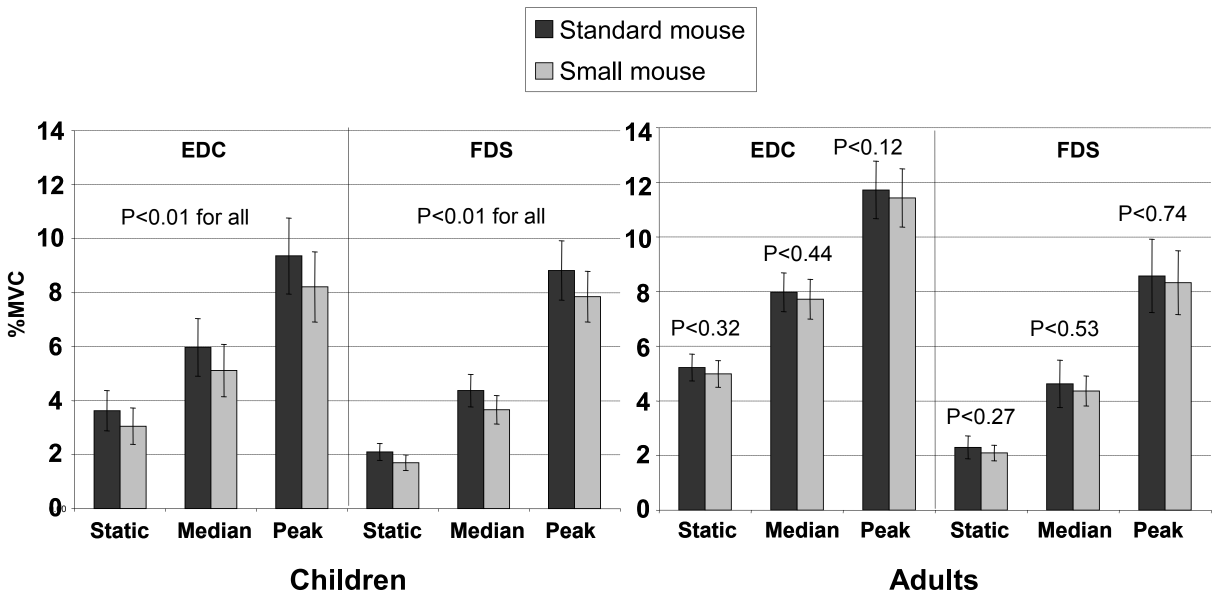

Figure 3. Differences between the standard and small mice in static, median and peak muscle activity in the extensor digitorum communis (EDC) and flexor digitorum superficialis (FDS) muscles for the children (left) and the adults (right). Muscle activity expressed as a percentage of the maximum voluntary contraction (%MVC) [N=14, each group]

Table 2. Comparison of movement times during the performance of the standardized pointing task for the adults and the children when using the standard and small mouse.

Group	Movement times (ms)						
	Standard mouse			Small mouse		Differ-ence	P-value
	N	Mean	SD	Mean	SD		
Adults	14	870	108	812	103	58	0.05
Children	14	1630	535	1461	451	169	<0.05

Differences in finger mass and length as a function of gender and age

The results from the systematic anthropometric analysis corroborated the laboratory findings. As shown in figure 4, the index finger mass of the 50th percentile of adult males was three times greater relative to the 50th percentile of the 5-year-old children's. The relative differences in index finger length were not as large with the 50th percentile of the adult males' fingers, 1.5-fold greater in length, than the 50th percentile of the 5-year-old children's. These finger mass differences were not limited to the adults and children, but also existed between the genders. As demonstrated in figure 4, in adulthood, gender differences reached a maximum. The 50th percentile adult male's index finger weighed almost one-third more than the 50th percentile female's; however, the differences in the length of the index finger were smaller, the males' finger being only 6.7% longer than the females'.

Differences in finger width and its relationship to keyboard size

Figure 5 shows the changes in index finger width by gender and size percentile as a function of age. Current ANSI (28) and ISO (29) standards for keyboards recommend a key size and key spacing of 19 (SD 1) millimeters. Figure 5 demonstrates how key size and spacing is probably based on anthropometric clearance issues to accommodate the larger 50th to 95th percentile of adult Western males.

Discussion

This study provides some insight into the differences between children and adults when they use standard-size computer input devices. The first key finding of this study was that adults and children have dissimilar wrist posture when using a standard-size mouse, and both groups benefit from using a smaller-size mouse. Children had to operate the standard-size adult mouse with significantly greater ulnar deviation. The greater ulnar deviation of the children was the result of two factors. First, the space taken up by the keyboard in proportion to the breadth or width of the shoulders was much greater for the children than for the adults. As a result, the children had to rotate their arms outwardly and ulnarly deviate their wrists more to operate the mouse. Therefore, children may benefit from smaller keyboards or at least adult-size keyboards without a

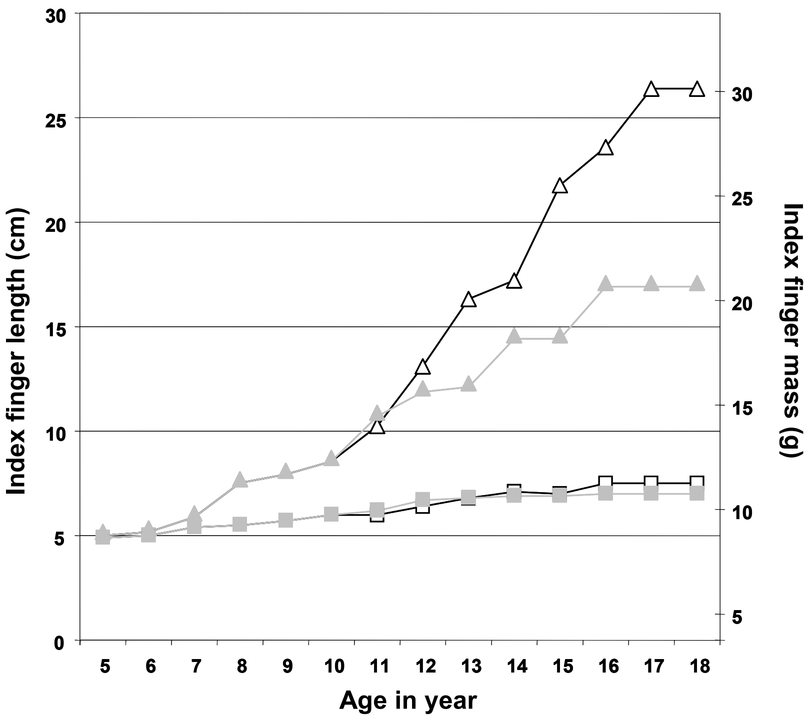

Figure 4. Changes in index finger mass in grams (triangles) and length in centimeters (squares) by gender and as a function of age for the 50th percentile of males (black lines) and females (gray lines), data from CHILDATA (24). The length and mass data were normalized to show size changes from age 5 years to adulthood.

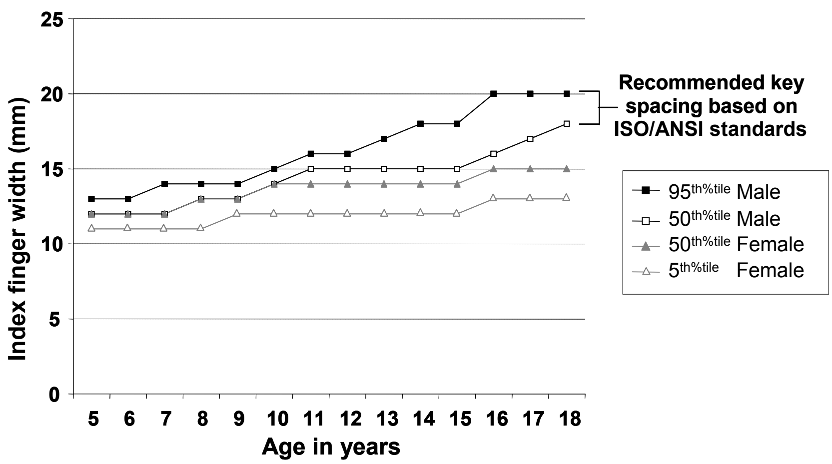

Figure 5. Index finger width by gender and size percentile as a function of age, data from CHILDATA (24). Both ANSI (28) and ISO (29) standards recommend that keys on keyboards have 19±1 mm spacing, which corresponds to the index finger width approximating the 50th to 95th percentile of adult Western males.

built-in numeric keypad. In addition, due to their small hand size relative to the adults, the children in our study could not anchor their wrist on or near the back of the mouse and easily reach or readily operate the mouse buttons. As a result, the children tended to anchor and position their wrist on the left side of the mouse, forcing them into ulnar deviation in order to reach and operate the buttons.

The second key finding of this study was that computer mouse size also influences muscular loads. Both the children and adults had lower muscle activity when operating the small mouse; however, the reduction in muscular load was greater for the children. This finding was not necessarily expected since the smaller mouse had a higher button activation force (0.85 N versus 0.65 N). When the small mouse was used, at least part of the reduction in muscular load in children may be due to the decrease in ulnar deviation. This occurrence may be due in part to the fact that the finger muscles were in close proximity to the muscles responsible for maintaining wrist posture. It is likely that crosstalk from the wrist postural muscles contributed to the measured finger muscle activity. Another possible reason for the difference in muscle activity could have been due to the lower mass of the small mouse (47 grams) relative to that of the standard mouse (86 grams). Compared with the adults, the children did have lower muscle activity, but the adults performed the tasks faster. Therefore, the faster productivity of the adults may partially explain why they had higher muscle activity levels relative to those of the children. In summary, when the children used the smaller-size mouse, there was a significant reduction in ulnar deviation and muscle activity and an increase in the speed at which they could move the mouse between targets.

The last key finding of this study is that fairly substantial anthropometric differences exist between adults and children, and even between adult males and adult females. Disproportionately sized computer input devices may lead to greater postural exposures and higher levels of muscle activity in children and adult females. These demonstrated size disparities may put added stress on the soft tissue of smaller persons and ultimately lead to higher or earlier susceptibility to musculoskeletal disorders. Finger mass and strength are likely critical in determining the activation forces of input devices, and differences in anthropometric measures of length are likely to be important for determining appropriate device sizes. According to CHILDDATA anthropometric data (24), there was roughly a threefold difference in finger mass between 5-year-old children and adults and even a 30% difference between adult males and adult females. The activation forces of computer input devices are in part chosen to be at a level high enough so that computer operators can rest their fingers on the buttons or keys without fear of accidental or unintentional activation. To fall within the range of forces recommended by ANSI (28) and ISO (29, 30) standards, most keyboards and mice have activation forces between 0.6 N and 0.8 N. Activation forces between 0.6 N and 0.8 N are roughly twice the mass of an adult male's index finger. It is likely that these force activation levels provide a safety factor that prevents accidental activation.

Given the large proportionality differences in finger masses between adult males and adult females and children, it is likely that children and adult females may benefit from computer input devices with proportionally lower activation forces. In addition, the relative differences in finger lengths between adult males, adult females, and children are much smaller than the relative differences in finger mass. For computer input devices to be child- or gender-proportional, not only should the devices be proportionally sized, but, perhaps even more critically, the activation forces should be proportionally scaled due to the greater range of differences in finger mass.

In conclusion, with women and with children between 5 and 14 years of age, representing 60% of the world population (20), the results of this study indicate that the current "one-size-fits-all" paradigm for the design of computer input devices is unlikely to meet the needs of a large percentage of the computer-using population. In order for computer-related health risks to be reduced among women and children, we recommend that researchers and companies manufacturing computers and computer input devices work together to determine the appropriate range and size offerings for computer input devices.

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