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Research

Research on Devices for Handling Whole Slide Images on Pathology Workstations. An Ergonomic Outlook

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Abstract

Background: Digital Pathology represents a technological innovation that introduces changes in the traditional tasks of pathologists. In this regard, an important issue that has not been enough emphasized is the image handling from an ergonomic point of view to avoid work-related musculoskeletal disorders (MSD). The aim of this study was to investigate a proper input device for digital pathology.

Material & Methods: Research was conducted in two phases: (1). A comparative study to find out an optimal external controller. Eight medical students analyzed 11 input devices: keyboard (Hewlett Packard, HP), conventional mouse (HP), vertical mouse (CLS), touchpad (Logitech), 3 trackballs (Logitech, Kensington Expert and Ulove), Rollermouse (Contour), Ergopointer (Märzhäuser Sensotech), gamepad (Logitech) and a touchless device (Leap Motion Controller), using them with the Image Viewer software (Ventana). The web-based Fitts´ law test (UC Berkeley) was used to objectify the accuracy of each used device, randomly. 12 items were included in the questionnaire: comfort, technical aspects (cursor movement and objective achievement), prospects, overall satisfaction, prior experience, and others. (2). Evaluation by two experienced pathologists of the best rated input device on the previous experiment and its comparison with a voice recognition system (Invox Medical Dictation, Vocali) using a

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headset microphone (Plantronics). Perceived workload was scored using the NASA Task Load Index on 28 whole slide images visualized on the Digital Image Hub (Leica) platform with a 4 MegaPixel display (Barco). Data were processed with SPSS 21.0.

Results: Correlation between technical aspects of the evaluated devices and accuracy (Fitts´ law test), and comfort with overall satisfaction, was demonstrated (p<0.05). Comparative analysis of the 11 input devices concluded that vertical mouse was the best rated input device. However, on the second phase of the study, we find a slightly higher perceived workload using this device than using the voice recognition system, which was the best controller in digital pathology from an ergonomic point of view in this study.

Conclusions: We describe a methodology that can study and compare input devices for future workstations in digital pathology. Pathologists should be involved in this process trying to find ergonomic devices that prevent MSD. Voice recognition can function as a good handsfree device for digital pathology and could be considered in physical disability situations. Further studies using electromyography, accelerometry and 3D reconstruction analysis could provide additional ergonomic information.

Keywords: Digital Pathology; Input Device; Ergonomics.

Introduction

Digital Pathology (DP) represents a technological innovation in the field of Pathology [1-2] that introduces changes in the traditional tasks of pathologists, as happened decades ago with our fellow radiologists. There have been numerous studies published in recent years that state technical and clinical implementation recommendations [3]. Nevertheless, there is no consensus, regarding the most appropriate device (human interface device) for handling or moving the scanned images, an important and essential aspect for achieving similar results to those achieved with the conventional microscope, since only isolated studies have been conducted [4-6]. We have carried out a comparative study in order to identify as precise and ergonomic a device as possible while trying to avoid possible symptoms or musculoskeletal disorders (MSD) associated with continuous work on computer [7] and specifically using whole slide images.

Material & Methods

The study was conducted in two phases. The first was the assessment of 11 input devices <Figure 1> by eight fourth year medicine students from the University of Murcia, Spain. Such devices were:

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- Conventional Mouse (Hewlett Packard, HP)[a]: This device was known by all study subjects and is characterized by its single handed use, involving large muscle groups and requiring forearm supination/pronation movements, wrist flexion/extension, and postural shoulder movements (with trapeze and deltoid use, among others). Its continued use has been associated with musculoskeletal problems [8].

- Trackball: Three devices were included, which differ significantly in design and usability. Trackball 1 (Logitech)[b] is characterized by the use of the thumb to move the cursor, while the elbow and shoulder are not needed, given the device's fixed position, preventing the mobilization of associated muscle groups. Trackball 2 (Ulove)[c], given its portability (cordless) and ergonomics, can be gripped and positioned neutrally, with the muscles of the hand and thumb most affected, which is also responsible for the movement of the cursor. Trackball 3 (Kensington)[d] where different fingers can manipulate the device due to the size of a large central button responsible for the movement of the cursor, without movement in the elbow or shoulder.

- Vertical Mouse (CLS)[e]: This device is of relatively recent emergence and similar characteristics to the conventional mouse, but with a better design adapted to the concavity of the hand, avoiding excessive pronation [9], with a more neutral arrangement of the forearm muscle groups.

- Rollermouse (Contour)[f]: This new device is characterized by a neutral body position [10], with a centered arrangement and can be used with different fingers or even with different hands (many devices are designed only for right-handed individuals).

- ErgoPointer (MärzhäuserSensotech)[g]: This device, halfway between a microscope and a digital device, allows for easy adaptation by the hypothetical microscope handler since it has been designed exclusively for this type of user.

- Gamepad (Logitech)[h]: Ergonomically designed, this device is widely used for video games and one of the few input devices whose application in digital pathology has been studied [4]. We have managed to adapt the functionality of its main buttons for this study.

- Keyboard (HP)[i]: With its obvious limitations given the lack of a scroll function or a joystick, this device has also been set up for the basic features of this study.

- Touch Pad (Logitech)[j]: The tactile character of its central portion, combined with buttons, allows to use either hand or different fingers.

- Leap Motion Controller (Leap Motion)[k]: This contact free motion capture device tracks the position of the hand, wrist and forearm and presents a clear differentiation from other devices [11], but it has not yet been compared to others in digital pathology.

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The devices were presented to students randomly, and they were allowed a period of training on whole slide imaging (WSI) using Image Viewer Software (Ventana).

Figure 1: Conventional Mouse (a), Trackballs 1 (b), 2 (c) and 3 (d), Vertical Mouse (e), Rollermouse (f), ErgoPointer (g), Gamepad (h), Keyboard (i), Touch Pad (j), Leap Motion Controller (k).

For evaluation, the following 12 criteria were presented in a questionnaire that should be rated on a scale of 1 to 5: design; comfort (grip and posture); accuracy aspects (cursor movement and objective achievement); prospects; button layout; adaptation time; versatility; portability; use of additional pedal; and overall satisfaction. Previous experience with each device, whole slide images and other aspects (e.g. dominant hand) were recorded as well. Level of accuracy achieved by each participant was also recorded using the online application of K. Goldberg *et al* [12] based on Fitts' Law (http://automation.berkeley.edu/fitts/). Fitts' law is probably the most frequently used theoretical framework to describe and compare user performance for different input devices [13] and can be used as a model to predict the time to move the cursor to a precise point presented on the screen and to click on it. To develop his theory Paul Fitts studied the expected time required for a human motor system to reach an object from a starting point and he realized that the time to reach the target depended on the distance to the object and on the width of the object (in a 1D model) that is represented with the following equation,

$$T = a + b \log_2 (A+W)/W$$

in which A is the distance to the target and W is the width. Parameters a and b depend on the environment, and the pointing device and can be determined experimentally.

This equation means that the time required to move the cursor to a target increases logarithmically with distance, *ie* growing slowly because humans tend to move the cursor faster if there is more distance to cover. Similarly, it decreases with increases in the size of the target.

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In the web-based test, the user repeatedly clicks different sized pairs of rectangular and round shapes located at different distances from each other in order to complete the exercise and calculate an average time <Figure 2>. Clearly, the shorter the distance and the wider the target object the less time will be needed.

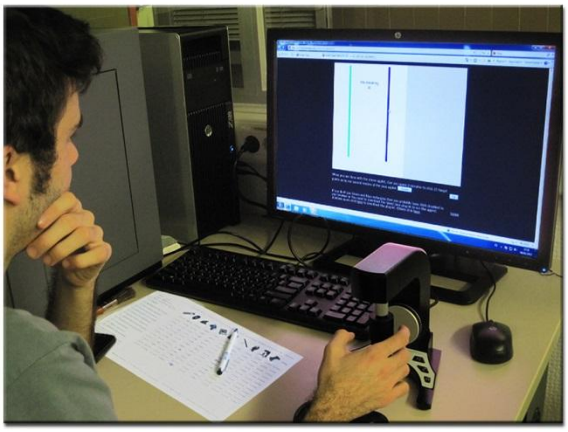

Figure 2: Phase 1 of the study.

The second phase of the study consisted of a comparison between the input device most highly ranked by the students and a new system for handling images: a voice recognition system called INVOX Medical Dictation (Vocali) through a headset microphone (Plantronics). In this case, the systems were tested and evaluated by two experienced pathologists (P1=55 years and P2=50 years) using Digital Image Hub (Leica), the Web application that showed the best performance for this study, based on appropriated keyboard shortcuts for linking voice commands, with a 4 megapixel, high resolution monitor (Barco MDCC-4130) and an HP computer with an Intel^{R} Core^{TM} i7 CPU with 8GB of RAM configured with Windows 7 Professional operating system and a 100 mbps fiber optic broadband connection <Figure 3>. The voice commands used to move the images were, "right", "left", "up", "down", "zoom" (in) and (zoom) "out". Twenty-eight whole slide images were shown to each pathologist in two separate rounds of cases: a first round for making diagnosis and a second round to locate the findings in the image that led to the diagnosis. The times were recorded, and the method used for comparison was the NASA Task Load Index (NASA-TLX), a widely used, subjective, multidimensional assessment tool that rates perceived workload [5; 14-16]. It assesses workload based on six criteria: mental demand, physical demand, temporal demand, performance, effort and frustration with a 20-point visual analogue scale, weighting the domains after explaining the exercise but prior to the completion there of, by letting the subjects compare them pairwise based on their perceived importance. This requires the user to choose which measurement is more relevant to workload. The number of times each is chosen is the weighted score. This is multiplied by the scale score for each dimension and then divided by 15 to get a workload score from 0 to 100.

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The statistical software SPSS 21.0 for Windows (SPSS Inc.) was used for statistical analysis.

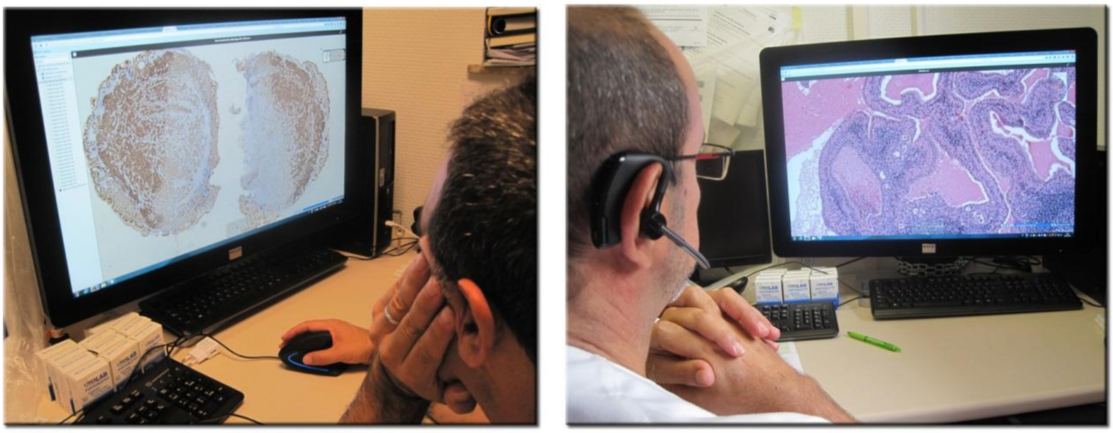

Figure 3: Phase 2 of the study.

Results

After concluding the first phase of the study, the overall rating (an average of the 12 criteria evaluated) showed the vertical mouse to be the highest rated, followed by the conventional mouse, the Rollermouse, Trackball 2, Trackball 1, the ErgoPointer, Trackball 3, the Gamepad, the Touchpad, the Leap Motion Controller, and the keyboard. Other classifications based on overall comfort (grip and posture), precision (including cursor movement and achieving goals) and the Fitts' test results were recorded <Table 1>.

For correlations studies, given the small sample size, we performed first a normalization test (Kolmogorov-Smirnov test) necessary for the reliability of the analysis results. As the p-value obtained was *>0.05* we did not reject the hypothesis of normality. This allowed us the performance of parametric tests to study correlation, such as the Chi-Squared test and the Pearson correlation coefficient, where we obtained a p-value <0.05, so we reject the null hypothesis of independence. There is significant evidence of an inverse linear correlation between the Fitts' test and the precision valued aspects (cursor movement and achieving goals), with a correlation coefficient of -0.95 (95% confidence), finding that the higher scores obtained on the technical assessment, correlated with lower scores in the average duration of the Fitts' test. Similarly, a direct linear relationship was between overall satisfaction and comfort, as well as with other aspects of precision. No correlation was observed between the assessment of design and the overall satisfaction.

On the second phase, in which experienced pathologists compared two devices, the vertical mouse and, the voice recognition system, both quantified through the NASA-TLX method, results showed that the voice recognition system required a discrete lower workload than the vertical mouse (P1: 20 vs 20.6 and P2: 22.7 vs 23.3, respectively), coinciding both pathologists

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in zero physical workload, but a poorer performance for the voice recognition system <Graph 1>, and requiring more time for the movements (P1: 27 minutes 53 seconds, P2: 23 minutes 25 seconds) than the vertical mouse (P1: 25 minutes 48 seconds, P2: 21 minutes 51 seconds).

	Overall Rating	Global Comfort	Accuracy Aspects	Fitts´ Test Results
	1st 4.78	2nd 4.63	2nd 4.9	2nd 986 ms
	2nd 4.71	3rd 4.44	1st 5	1st 811 ms
	3rd 4.38	4th 4.38	3rd 4.37	3rd 999 ms
	4th 3.98	1st 4.81	4th 3.5	4th 1505 ms
	5th 3.67	5th 4.06	5th 3.75	5th 1221 ms
	6th 3.38	9th 2.75	6th 3.67	6th 1699 ms
	7th 3.27	6th 3.50	7th 3.5	7th 1147 ms
	8th 3.23	7th 3.45	8th 3	8th 1899 ms
	9th 3.15	8th 3.06	9th 3.5	9th 1360 ms
	10th 2.75	10th 2.31	10th 2.68	10th 1973 ms
	11th 1.58	11th 2.31	11th 1.19	11th 2599 ms

Table 1: Results: input devices ranking (phase 1). Ranking/score.

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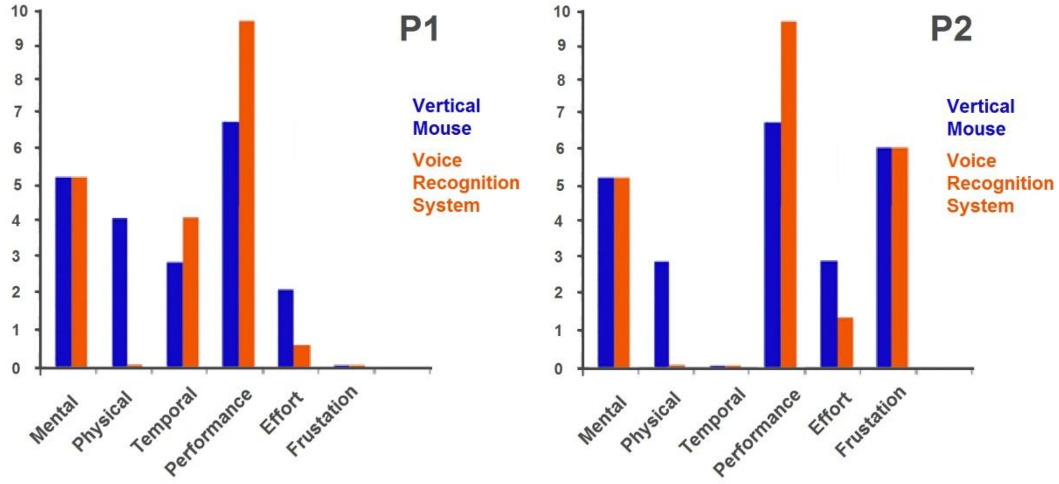

Graph 1: NASA TLX results: pathologist 1 (left) and 2 (right).

Discussion

With the advent of Whole-Slide Imaging, the field of digital pathology has exploded and is currently regarded as one promising technical improvement of diagnostic pathology, along with the traceability of tissue samples and the reports management [17], trying not to obviate the possibilities in resource optimization, given the high costs with its implementation [18]. Exploring the slide on the computer monitor represents an alternative to the classic view of glass slides under the microscope that demands a different methodology for moving and focusing the microscopic image. Use of traditional mouse produces pathologists discomfort because it leaves the hand in a non-ergonomic position, which can lead to pain and discomfort. As digital pathology is incorporated into the routine work of pathologists, workstations should be inspected in order to be suitable as though they were airplane cockpits [19], and comfort aspects are essential for preventing symptoms and musculoskeletal problems traditionally suffered by pathologists (mainly in the neck, upper back, lower back, shoulder, and upper extremities) as a result of their position over the microscope, as demonstrated by various surveys and studies over the years [20-24]. Mere digitization has shown improvement in symptoms, as Thorstenson *et al* [25] have shown, albeit in an isolated study. However, intensive and continuous work with computers (repetitive strain injury, RSI) has also shown a tendency to generate musculoskeletal problems, which are only attenuated through action regarding habits both during working hours (breaks, stretching, etc.) and in regards to furniture (armrest, seat lumbar support, height adjustable monitor, etc.) as well as other elements, such as input devices [26-31]. That is why this process of change requires a careful study of ergonomics at pathologists' workstations. Involving pathologists proactively in these early stages of digitization can minimize these problems through intervention on the

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workstations. Otherwise, problems will arise such as has already occurred in the case of radiology specialists, who have also studied preemptory interventions [32-34]. It is obvious that these conditions cause a reduction in professional performance and generate personnel losses; therefore, such aspects that traditionally have been given less attention must be given the importance they deserve.

We describe a methodology that can study and compare input devices for future digital pathology workstations. We have included in this study previously ignored parameters that evaluate ergonomic aspects trying to avoid possible symptoms or musculoskeletal problems associated with continuous work on computers [7] and specifically with scanned images. Using this methodology and through the analysis of all parameters our study shows that vertical mouse is a user-friendly solution that reached the highest score of all tested devices. This seems to be associated with the combination of its high precision and the ergonomic aspects that have participated in its design, with a more neutral body and upper limb position than other devices.

Evaluation of a voice recognition system to move the microscopic images can function as a good hands-free really ergonomic system for digital pathology and could be considered in physical disability situations [35]. However the voice recognition system produced slow movements of the microscopic images, needing more time to report cases.

In conclusion, use of the methodology that we describe permits the comparison of input devices for digital pathology workstations to evaluate several aspects of their reliability and ergonomy. Further studies using electromyography, accelerometry and 3D reconstruction analysis could provide additional ergonomic information [36-37].

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