A monitoring tool of workers’ activity at Video Display Terminals for investigating VDT-related risk of musculoskeletal disorders

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ABSTRACT

Today the risk factors related to the use of Video Display Terminals (VDT) are assessed by investigating the actual activities at the VDT through subjective questionnaires and/or quantitative measurements. Questionnaire outcomes are quite imprecise and seldom objective. Quantitative measurements (EMG recordings, electrogoniometers, motion analysis systems) mostly prevent subjects from moving freely while working at the VDT. The paper presents an automatic tool for the monitoring of activity at VDTs, using a quantitative, objective approach. The suitability of the proposed tool was fully tested in the laboratory, both in terms of functionalities, accuracy of the tool, and acceptance by the subjects involved. The outcomes show that the tool allows for a detailed analysis of VDT activities and may be used to improve VDT-related risk analysis with high accuracy and good acceptance by workers.

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1. Introduction

To date different studies assert the existence of health problems in computer workers [1–5], in particular, low back pain and musculoskeletal disorders of the upper extremities, neck, shoulders. The studies based on questionnaires [6–10] sometimes report poorly objective results. In fact, acquiring epidemiological evidence of the relationship between computer work and user’s disorders (e.g., carpal tunnel syndrome) through the workers’ imprecise description of their exposure, via qualitative questionnaires or interviews, may reduce outcome significance [5]. Conversely, quantitative studies of VDT work-related musculoskeletal disorders have been done by measuring muscle activity in computerized typing and mousing tasks [11,12] or fingers/hand/wrist kinematics [13] through methodologies mostly interfering with workers’ activity, such as EMG recordings [11,14,15], electrogoniometers [15–17], and motion analysis systems [12,13,18,19]. However, studies on the validity of the functional assessment of the worker’s disorders [20] and VDT-associated risks [21] demonstrate that there is the need to develop methodologies for a more accurate assessment of damage, for today the work at VDTs is regulated by national and international laws [22–26].

As for the normative principles for ensuring health and safety at the workplace, those regarding workplaces equipped with video-terminals regulate the use of the VDT in terms of exposure, i.e., the time spent at the terminal. Ergonomic principles have also been introduced in workplaces and they are now regulated by technical norms [27–31]. Related guidelines

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are continuously revised and complemented with suggestions arising from the industry, universities and trade unions. Different studies have been devoted to health issues associated with the use of the VDT, until a so-called VDT-related health hazard has been defined, and specific norms set the minimum requirements for VDT equipment [22-25]. Numerous ergonomic products have been developed, that involve the entire workplace, from chair and desk to the display of the VDT, to keyboard and mouse, which optimize hand and forearm posture in order to avoid the risk of neuromusculoskeletal pathologies (from the injury of the fingers’ tendons to low back pain).

Most studies investigating VDT-related risks for the neuromusculoskeletal system have monitored computer work (via questionnaires or by measuring forearm activity), without automatically recording the actual activity on the computer input devices (keyboard and mouse).

Starting from the above consideration and on the basis of a quantitative and objective approach, we designed and constructed an automatic tool to monitor VDT activity, within the research project “Fattori di rischio per patologie neuromuscolo scheletriche in operatori a videoterminali” (Risk factors for neuro-musculoskeletal pathologies in VDT operators), funded by the Italian Ministry of the Health, and coordinated by the IRCCS “S. Maria Nascente”, Fondazione Don Carlo Gnocchi Onlus, Milan, Italy.

This tool automatically records the actual activity on keyboard and mouse without weighing down on VDT activity. It is a low-cost, portable system suitable for any VDT station, whether at the workplace or in the laboratory. It may therefore be considered a valid tool for long-term epidemiological studies on a large number of subjects. The solution herein proposed is an alternative to more expensive tools or to those only meant for laboratory use, such as optoelectronic ones.

The paper describes the VDT activity monitoring tool and illustrates the obtained outcomes.

2. Tool description

Designed on a client-server architecture, the tool has been developed on the graphical programming environment LabVIEW 2009 (National Instruments, Austin, Texas, USA, http://www.ni.com). The application consists of:

1. a ‘VDT client program’, the program running on different workplaces - the clients for monitoring the workers’ activity at the VDT
2. a ‘VDT server program’, the program running on a dedicated computer - the server for collecting and processing the data sent over a dedicated LAN or public network (i.e. Internet).

The ‘VDT client program’ has the following functionalities:

- keyboard monitoring (activity on the keys)
- mouse monitoring (activity with the pointer and on the buttons)
- interface display by which the user manages the program (start/stop/pause the working activity) and gets feedback of his/her activity at the VDT
- VDT activity recording in text files
- data transmission to the server

The ‘VDT server program’ has the following functionalities:

- data collection from client PCs
- database set up
- data processing and classification

The VDT client program records the workers’ movements on the mouse and the keyboard: an interface (Fig. 1a and b) manages the recordings and constitutes a direct feedback to the VDT workers. At the end of each work session (work shift or the execution of a computerized task), the data file is automatically sent to the server PC. A feedback for pauses is delivered via alert messages that appear on the screen at programmable time points: a first alert message stops the recording for a predefined time and indicates pause length; at the end of the pause, a second alert message appears, presenting an ‘OK’ button to restart the recording of the VDT activity. Each work shift is considered as a ‘work session’ by the VDT client program. If pauses are scheduled during the work session, the session shall be split in different ‘session parts’. As an example, a screen shot of the data file, organized in session parts, is shown in Fig. 2.

The VDT server program consists of different SW modules, each of them in charge of a specific function. The VDT server program creates a customized database from the incoming files (by mail), and processes the data according to the different needs. Databases can be created for a cluster of VDT workers grouped by job, office, or by given features of the collected data.

2.1. Monitoring techniques

The tool measures the time spent at the computer and the time spent at keyboard and mouse only when the worker is actively working with these input devices (‘keyboard time’ and ‘mouse time’ hereafter).

Some studies deal with wrist/hand/fingers kinematics for investigating the potential risk factors associated with keyboard use [12]; others report on the testing of keyboard ergonomics to prevent or reduce arm pain or disorders [13]. The measurement of wrist/hand/fingers kinematics is usually carried out by means of optical three-dimensional motion capture systems during keyboard use. It would be useful to know in detail typing speed; overall speed and that of each hand. The herein proposed tool computes these and other parameters that may be used in in-depth studies of discomfort or musculoskeletal disorders in expert typists.

In several jobs which call for the intense use of the mouse, as with CAD or in painting/graphic works, the study of wrist kinetics (both kinematics and fatigue) is relevant for assessing risk factors; in particular, standardized computer mouse tasks are used to investigate the patho-physiological mechanisms behind musculoskeletal disorders [19]. For this type of investigation, it is useful to know in detail the typical mouse activities, such as moving, clicking, and scrolling. These
activities can be assessed with the proposed tool by tracking the mouse pointer trajectories on the screen, and by designing the time profile of the scrolling activity and the clicking activity.

In this study the following parameters of VDT activity were measured:

1. the time spent on the keyboard (‘keyboard time’) with the right and left hand (‘keyboard right hand time’ and ‘keyboard left hand time’)
2. the time spent on the mouse (‘mouse time’)
3. the number of key pressing occurrences and mean typing time
4. the trajectories of the mouse pointer on the screen (for mouse moving estimation)
5. ‘mouse buttons activity’ (clicking and scrolling).

2.1.1. Keyboard time and number of key pressing occurrences

Keyboard time was computed as the sum all ‘key time’ values, i.e., the time spent in pressing a given key. Key time was computed as the time elapsed between pressing two successive keys. In the case of pressing two keys simultaneously, key...
time was the same for both, but for keyboard time computation only one occurrence was considered. Key time values greater than 500 ms were considered equal to 500 ms, because this is the set value in the computer we used.

For the computation of ‘keyboard right hand time’ and ‘keyboard left hand time’, the conventional typing method was considered in computing the total time assigned to the right and left hand. Since the tool cannot discriminate which thumb pressed the space key, only the total time spent on this key was computed. A standard Italian keyboard was used in this task. The total number of key occurrences was computed and mean typing time for each calculated.

### 2.1.2. Mouse time

The sample rate of the mouse was set at 100 Hz. By means of its driver the mouse furnishes various data about its status to the host computer every 10 ms: the horizontal and vertical position of the mouse pointer on the monitor, the status of the buttons (pressed/non pressed), the number of elementary rotations of the mouse wheel (i.e., the scrolling button).

Mouse time was computed as the sum of the time spent in the different recorded mouse activities: moving, clicking and scrolling.

The tool continuously recorded the entire VDT activity in keyboard and mouse every 20-ms time intervals. Specifically, mouse pointer coordinates were recorded only when the mouse moved, i.e., when the pointer moved between two coordinates. The sample time of the event was also recorded: each movement was considered a basic mouse displacement lasting 20 ms. Therefore the time spent in moving the mouse was the number of the basic mouse displacements, i.e., the number of the recorded sample times, multiplied by 20 ms.

As for clicking with all the mouse buttons, it is possible to compute the duration of each single mouse click, i.e., the...
time elapsed between the mouse pressing and mouse releasing events in a click. The computation of this time was not implemented in the proposed tool, but since the time for interpreting a double click was set at 500 ms, in this work we estimated the upper limit of click duration was equal to 500 ms, in all types of clicks (left click, right click, scrolling click). Thus, the time spent in all mouse clicking activities was computed as the total number of clicks on all buttons multiplied by 500 ms.

When the mouse wheel rotates, the mouse provides scrolling values that are proportional to the amount of wheel rotation in time, and thus to the scrolling angular speed. These values are both negative and positive (when the mouse wheel is rotated clockwise for scrolling down and counterclockwise for scrolling up, respectively), and multiples of a minimum value. The minimum value corresponds to the amplitude of one basic rotation of the wheel in the time unit: basic rotation stands for the rotation between two adjacent ticks of the wheel, and the time unit is the sample time of the mouse, set at 10 ms in this case. If within the time unit two basic rotations occur, the corresponding scrolling value is twice the minimum value, and so on. The minimum value and the range of scrolling values depend on the type of mouse (the number of wheel ticks differs from mouse to mouse). For the mouse used in this work, the minimum scrolling value was 120, and the range [−2760; +2760]. Since the duration of a basic rotation of the mouse wheel depends on the specific mouse and owing to the difficulty in determining scroll velocity the mouse time spent in the scrolling activity was an estimation of the ‘scrolling time’ associated to a scrolling event of whichever rotation amplitude. The ‘scrolling time’ was thus estimated by “calibrating” the scrolling activity on 16 subjects, i.e., by recording a continuous scrolling activity for 10 min, and computing the mean value of the scrolling times associated to the relative scrolling events. The mean scrolling time was 50 ms. In this way, total scrolling time was the number of recorded scrolling values multiplied by 50 ms.

2.1.3 Trajectories of the mouse pointer
The trajectories of the mouse pointer were derived by recording the vertical and horizontal coordinates of the mouse pointer on the screen. To quantify the amount of mouse movement, the length of the trajectory of the mouse pointer was computed as sum of the distances of all the contiguous positions of the mouse pointer on the screen, after transforming in metric units the mouse pointer position which is acquired in pixel units. The resolution of the screen we used was 1280 × 1024 pixels.

2.1.4 Mouse buttons activity
It seems that some repetitive activities carried out with the mouse, especially left clicking and scrolling, are fatiguing for the index finger, in particular for the proximal and distal interphalangeal joints. For this reason we monitored mouse buttons activity, accounting for the following: number of clicks on the left and right button (‘L-click’, ‘R-click’), number of double clicks on the left button (‘D-click’), number of clicks on the scrolling button (‘Sc-click’), number of recorded values when the scrolling button is rotated clockwise (‘scroll-down’) and counterclockwise (‘scroll-up’).

2.2 Protocol and testing
The tool has been laboratory tested to highlight functionalities, accuracy and acceptance. We performed:

- A ‘Test of functionality’ to illustrate tool functionalities in all possible work-environments.
- A ‘Test of accuracy’ on 16 subjects to assess the accuracy of the methodology by comparing the tool with questionnaire-based surveys (reference methodology).
- A ‘Test of acceptance’ to investigate subjects’ satisfaction regarding the two methodologies (automatic tool, questionnaire).
- All the tests were submitted at the same time of the day, between the 9.00 a.m. and 11.30 a.m., in order to have comparable conditions.
- A bench test was also performed before the test of accuracy to investigate the timing associated with the various VDT activities that the tool provides.
- A statistical analysis was designed around the study.

2.2.1 Test of functionality
The test was performed by one subject and consisted in three different PC tasks involving keyboard and mouse. The subject was given thirty minutes to execute each task. The chosen tasks cover all potential types of VDT activity that entail the use of both keyboard and mouse in an intensive and repetitive manner.

- Task 1: word-processing in English language
  The task involves the keyboard almost entirely with sporadic use of the mouse. The fingers and the wrist do most of the activity, and the effort depends on keyboard design and hand posture.
  Task 1 consisted in writing an English text under dictation, executed by a non-expert typist.
- Task 2: graphical programming language (LabVIEW)
  The task was done in a LabVIEW graphical programming environment (LabVIEW 2009, National Instruments, Austin, Texas, USA). The official LabVIEW web page offers the following description: (1) "using intuitive graphical icons and wires that resemble a flowchart"; (2) "program with drag-and-drop, graphical function blocks instead of writing lines of text". Thus the LabVIEW task entails an intensive use of the mouse, with a lot of repetitive actions and a moderate use of the keyboard (editing of textboxes and specific combinations of keys to accomplish some typical actions of the LabVIEW environment).
  Task 2 consisted in building a portion of the program developed for the VDT monitoring tool presented in this paper, executed by an expert LabVIEW programmer.
- Task 3: drawing/painting
  The literature shows that among the risk factors for computer work-related musculoskeletal disorders, the extensive use of the computer mouse appears as the most significant [18], and the use of the mouse in painting activities seems suitable to study the perception of muscle fatigue and motor
control [19]. In consideration of this, a drawing/painting task was chosen for Task 3, which was carried out with Microsoft Paint, version 5.1. It entails the almost exclusive use of the mouse for both drawing and painting, without keyboard involvement.

Task 3 consisted in drawing/painting polygons sets, executed by a non-expert graphic designer. The subject was asked to draw and paint four sets of polygons on the screen with the mouse, in four areas of the screen. The entire area for drawing was of 1152x768 pixels, and was divided in four equal quadrants. Each polygon set consisted of 1 rectangle, 1 circle and 1 triangle. The subject was asked to draw the three figures of each set in a free order and with any dimension and position in the quadrants.

All the tasks were done at a workstation with a chair with no armrests, with the programs opened to full screen on a 19-inch LCD screen at 1280 × 1024 pixels resolution.

2.2.2. Test of accuracy
The test was performed by 16 healthy subjects, all university students familiar with the use of the most common software packages for VDT. The time they usually spent at the VDT was in the range 0–3 h/day. ‘Age’ was expressed in decimal form to account for month and day of the month at the date of the test; ‘time at the VDT’ was also expressed in decimal form to account for hours and minutes (‘age’: mean = 22.67 years, std = 2.63, range 20.25–30.10 years; ‘time at VDT’: mean = 1.78 h, std = 0.70, range 0.30–2.90 h).

For the role of ‘test givers’, another 16 subjects were recruited among university students familiar with the use of the most common software packages for personal computers with a time usually spent at the VDT in the range 0–3 h/day (‘age’: mean = 24.68 years, std = 2.21, range 20.17–28.92 years; ‘time at the VDT’: mean = 1.88 h, std = 0.73, range 0.30–3.00 h). The tasks of this group were to:

1. assess the correctness of the execution of the test without interacting with the environment of the test itself
2. check the correct functionalities of the tool under test
3. perform, together with the subjects of the group taking the test, the test of acceptance described below in order to assess their own acceptance perceived as external observers.

The two parameters ‘age’ and ‘time at the VDT’ followed the normal distribution with p > 0.05 for both groups as tested by means of the chi-square normality test. We used the Student t-test to investigate the differences between the two groups. In consideration of their different roles in the study (while one group was performing the test at the VDT, the other was acting as observer) we chose the confidence level of 99% in the Student t-test (among the three most commonly used values 90%, 95%, 99%). The two groups were not statistically different for ‘age’ (p = 0.026) and for ‘time at the VDT’ (p = 0.677).

The two groups were trained in an identical manner both in the use of the tool and the compilation of the questionnaire.

The test consisted in two tasks which were repeated 15 times each:

**Task A.** 1800 s of word-processing in English language, with 3 random interruptions of 120 s. A sound alert indicated pause start and end. The subjects were asked to record in a questionnaire the time at which they stopped and resumed typing.

**Task B.** The subjects were asked to move the mouse along the six 1-cm-wide trajectories indicated in Fig. 3. The trajectories were sequentially displayed at the center of the monitor in an area covering 2/3 monitor width × 2/3 monitor height. Again, a sound alert indicated the subject when to begin the trials.

In both tasks the timing of the activity was measured with the two methods under comparison: automatically with the VDT tool, and self-reportedly by the subjects performing the test with the standard questionnaire. In both tasks the subjects had to write down in the specific questionnaire the timing of their tasks as they perceived it.

2.2.3. Test of acceptance
The subjects and the test-givers supporting the Test of Accuracy were asked to compile a questionnaire of satisfaction about the following issues: (a) ease-of-use; (b) not hampering with working activity; (c) speed of operation, i.e., time spent in managing the measurement instrument (VDT tool vs. questionnaire). For each item, the subject and the questionnaire-giver assigned a score on a scale of 1–4 (1: minimum; 4: maximum).

2.2.4. Preliminary performance timing bench tests
Before considering as reference the timing associated with the various VDT activities that the tool provides, we performed two preliminary performance timing bench tests.

For the first *performance timing bench* test we connected the probes of an oscilloscope TDS2014 (Tektronics) 5 × 10⁻⁶ s time resolution, with the cables of mouse and keyboard to compare the time duration of a burst of activity as measured by the tool and the oscilloscope.
For the second performance timing benchmark test we produced a log file with the timing of the PC plus the timing produced by the tool during VDT activities in order to assess the absolute time of activity, i.e. the starting time point of a task. This test allowed a comparison between the time recorded by PC and the time recorded by the tool. As soon as a burst of activity with keyboard or mouse occurred, in the log file a string appears with the PC-recorded time and the tool-recorded time.

Both performance timing tests were successful: the first one showed that for bursts of keyboard and mouse activity of 5 s and 1800 s, the error was always lower than $2 \times 10^{-2}$ s; the second one showed, as expected, that the tool was synchronized with PC time and no latency was detected.

2.2.5. Parameters and statistics

One of the basic parameters to be investigated for the neuromuscular and skeleton system is the actual time a subject dedicates to a working activity at VDT, i.e. the time of exposure of the neuromuscular and skeleton system to the VDT (obviously there are other types of exposure to the VDT, e.g., eye exposure, but is not the focus in this study). In order to assess this exposure time we should quantify:

(a) The time a subject is assigned to an activity at the VDT
and
(b) The actual time the subject spends in doing such an activity at the VDT.

From these two values it is thus possible to assess
(c) the percentage of time the subject is exposed to the VDT.

The VDT tool provides for (see Section 2.2.4) an automatic and objective assessment of such percentage of time (in (c)).

On the contrary, the methodology based on questionnaires (commonly used in workplaces) is subjective and thus affected by human error when calculating this percentage of time.

We focused on the percentages of time as measured by the two methods (automatic and subjective-by-questionnaire) and the relevant difference which for the sake of clarity has been expressed as $\Delta T\%$. We then designed the statistical approach around it. For each subject we calculated the means over 15 repetitions. To test normality we applied Anderson Darling Normality Test (ADNT) [32] to the obtained data. ADNT test $p$-value indicates that there is no evidence that the data do not follow a normal distribution. Data may be thus described by the mean and the standard deviation. The significance of the ADNT test was high for both tasks: $p > 0.05$ for the Task A and for all the trials of Task B. Furthermore, we also showed that the $\Delta T\%$ value was significant by means of the One Way ANOVA (OWA) test ($p < 0.005$). Table 2a reports the outcome of the two statistical tests.

3. Results

3.1. Outcome of the test of functionality

Table 1 summarizes VDT activity time characteristics for each executed task.

The use of the mouse is predominant in Tasks 2 and 3; whereas the keyboard is mostly used in Task 1, but not at all in Task 3.

Fig. 4 shows the number of key occurrences in Tasks 1 and 2.

As expected typing is absent throughout Task 3. Fig. 4a concerns the most typed keys in the word-processing task; Fig. 4b, the less used keys in such a task. In Task 2, typing on the computer keyboard is quite sporadic and only some keys, depending on the program, are consistently pressed.

Mean typing time values were computed every 60 s and the trend in time is shown in Fig. 5, for all three tasks.

Fig. 5 shows also the mean, standard deviation and coefficient of variation in percent values (CV%) computed on the overall time of the task. Unsurprisingly Fig. 5 shows that typing time was almost constant throughout the word-processing task, whereas it slightly increased towards the end as a result of fatigue. Conversely the typing time of the LabVIEW task is characterized by long intervals of inactivity and short intervals of activity on the keyboard. In Task 3 the typing activity is absent.

In a more detailed analysis of the word-processing task, the tiredness of the subject could be evaluated by the typing time trend which accounts for the decrease in key typing speed, but also by analyzing the VDT data file that shows the repetitive use of the ‘Backspace’ and ‘Cancel’ keys, denoting an increment of errors.

Fig. 6 shows mouse movement, i.e. the trajectories of the pointer on the screen for Tasks 1 and 2. The trajectories and coordinates in time of the pointer for Task 3 are shown in Fig. 7a and b, respectively.

The greatest amount of mouse movement was recorded for tasks involving graphic elements, i.e., programming languages and drawing/painting activities. The length of the trajectories was: 16.14 m for Task 1, 128.05 m for Task 2, and 101.12 m for Task 3. In Tasks 2 and 3 the pointer trajectories on the screen are more densely drawn than in Task 1, and more concentrated in the central area of the screen, indicating that the mouse moving activity is restricted to a temporary region of activity. Conversely, in the word-processing task, the trajectories are less condensed with a considerable spread towards the upper left side of the screen, denoting that mouse moving is more intermittent and mainly takes place in the region where the commands of the menu bar are displayed. The shorter length of the trajectory in Task 3 with respect to Task 2 indicates that drawing/painting activities are more concentrated in small areas, which entails short displacements of the mouse pointer. Fig. 7b is the chart of the horizontal and vertical mouse pointer coordinates in time, where the intensive and repetitive mouse painting activity is clearly visible in those segments of the chart presenting short displacements of the horizontal and vertical coordinates.

Mouse buttons activities are reported in Fig. 8 for the three tasks.

Fig. 8a shows the number of occurrences of the mouse buttons activities: the number of clicking on the left and right button (‘L-click’, ‘R-click’), the number of double clicking on the left button (‘D-click’), the number of clickings on the scrolling button (‘Sc-click’), the number of recorded values when the scrolling button is clockwise rotated (‘scroll-down’) or counterclockwise (‘scroll-up’).
Table 1 – Time characteristics of VDT activity in the three 30-min tasks.

<table>
<thead>
<tr>
<th>Use of the computer input devices (min)</th>
<th>Task 1</th>
<th>Task 2</th>
<th>Task 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keyboard total time (min)</td>
<td>17.476</td>
<td>1.709</td>
<td>–</td>
</tr>
<tr>
<td>Keyboard right hand time (min)</td>
<td>7.655</td>
<td>0.945</td>
<td>–</td>
</tr>
<tr>
<td>Keyboard left hand time (min)</td>
<td>8.031</td>
<td>0.764</td>
<td>–</td>
</tr>
<tr>
<td>Space key time (min)</td>
<td>1.790</td>
<td>0.000</td>
<td>–</td>
</tr>
<tr>
<td>Mouse total time (min)</td>
<td>1.650</td>
<td>25.444</td>
<td>26.116</td>
</tr>
<tr>
<td>Mouse moving time (min)</td>
<td>0.936</td>
<td>17.380</td>
<td>23.816</td>
</tr>
<tr>
<td>Mouse clicking time (min)</td>
<td>0.700</td>
<td>7.592</td>
<td>2.300</td>
</tr>
<tr>
<td>Mouse scrolling time (min)</td>
<td>0.013</td>
<td>0.473</td>
<td>0.000</td>
</tr>
</tbody>
</table>

The bold values represent the “total amount of time” respectively spent on the keyboard and on the mouse.

As with mouse moving, in the word-processing task the mouse buttons activity was sporadic (Fig. 8a). Clicking on the left button was the most recurrent mouse button activity in all three tasks. Fig. 8b shows the left button clicking frequency (number of clicking events per minute) vs. the bin of frequency. Fig. 8c shows the left button clicking occurrences in time computed over 2-min intervals: this activity was more intense in Tasks 2 and 3 as compared to Task 1. Fig. 8d reports the mouse scrolling values (related to the amount of wheel rotation) in

3.2. Outcome of the test of accuracy

Table 2 shows the outcome of the statistical analysis. We adopted the STATA software (Stata Corporation, College

Fig. 4 – Number of occurrences of the typed keys in Tasks 1 and 2: (a) number of occurrences of the most typically typed keys in a word-processing task. No occurrences in Task 3; (b) number of occurrences of the least used keys in a word-processing task. No occurrences in Task 3.
Station, Texas, USA, [http://www.stata.com](http://www.stata.com) which embeds the software primitives used for ADNT and OWA tests [32].

In both the two tasks the subjects had to annotate in the specific questionnaire the timing of their task as perceived by themselves.

### 3.2.1. Task A

Upon comparing tool-recorded and self-recorded times in the word-processing activity, it was clear that the latter was affected by human errors and in particular, but not exhaustively:

**Fig. 6** – Trajectories of the mouse pointer on the screen during the tasks: (a) Task 1 – word-processing (Microsoft WORD); (b) Task 2 – graphical programming language (LabVIEW).
3.2.2. Task B

The recorded data of the mouse movements in terms of x and y coordinates as function of time furnished the timing of each assigned trial from the beginning to the end of the trajectory.

Again, the self-recorded time was affected by human errors.

<table>
<thead>
<tr>
<th>Trial</th>
<th>ΔT% mean</th>
<th>ΔT% max</th>
<th>ΔT% std-dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Anderson darling normality test  &gt;0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>One way ANOVA &lt;0.005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keyboard trial</td>
<td>1.4</td>
<td>2.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Mouse trial</td>
<td>9.2</td>
<td>12.6</td>
<td>1.7</td>
</tr>
<tr>
<td>Trial Fig. 3A</td>
<td>9.5</td>
<td>12.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Trial Fig. 3B</td>
<td>12.4</td>
<td>13.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Trial Fig. 3C</td>
<td>10.3</td>
<td>11.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Trial Fig. 3D</td>
<td>10.4</td>
<td>11.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Trial Fig. 3E</td>
<td>9.2</td>
<td>10.9</td>
<td>1.1</td>
</tr>
<tr>
<td>Task B</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 7 – Activity of the mouse pointer during Task 3 (drawing/painting polygons): (a) trajectories of the mouse pointer on the screen; (b) time chart of the coordinates of the mouse pointer.
Fig. 8 – Mouse buttons activity: (a) occurrence of mouse buttons; (b) left button clicking frequency vs. classes of frequency; (c) Number of L-click in 2-min intervals; (d) time chart of mouse scrolling activity (no mouse scrolling activity in Task 3).

<table>
<thead>
<tr>
<th></th>
<th>VDT tool</th>
<th>Questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Subjects</td>
<td>Test-givers</td>
</tr>
<tr>
<td>Ease-of-use</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.9</td>
<td>3.7</td>
</tr>
<tr>
<td>Not hampering with working activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.2</td>
<td>3.1</td>
</tr>
<tr>
<td>Speed of operation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.4</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Scoring (4 = max 1 = min).
Table 4: VDT activity index values for the three 30-min tasks.

<table>
<thead>
<tr>
<th>Index</th>
<th>Task 1</th>
<th>Task 2</th>
<th>Task 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_{i\text{TASKI}}$ (% mouse moving time in TASKI/total time of TASKI)</td>
<td>3.121</td>
<td>57.932</td>
<td>79.388</td>
</tr>
<tr>
<td>$A_{i\text{TASKI}}$ (% mouse clicking time in TASKI/total time of TASKI)</td>
<td>2.333</td>
<td>25.306</td>
<td>7.667</td>
</tr>
<tr>
<td>$A_{i\text{TASKI}}$ (% mouse scrolling time in TASKI/total time of TASKI)</td>
<td>0.044</td>
<td>1.575</td>
<td>0.000</td>
</tr>
</tbody>
</table>

3.3. Outcome of the test of acceptance

Table 3 illustrates the acceptance of the methodology considering the following issues: (a) ease-of-use; (b) not hampering with working activity; (c) speed of operations to manage the measurement tool. Results show the high degree of acceptance of the automatic tool as compared with the questionnaire for 16 workers and 16 test-givers.

4. Discussion and conclusions

The here by described tool allows for the assessment of exposure to VDT in terms of activity on input devices (mouse, keyboard), and on a specific function of the device (for example an area of the keyboard, a specific key of the mouse), parameters that are very difficult or impossible to investigate through questionnaires.

Different exposure parameters can be measured, that may be used in multi-factorial VDT-related risk analysis. In this sense, the tool can also be useful for investigating claims by workers: selected exposure parameters will furnish objective data to support or confute the worker’s complaints. An immediate potentiality is the clustering of workers in terms of time of activity. In consideration of its potentialities as a tool for testing, we should consider that it only needs to be initialized by the worker. The automatic tool for monitoring the activities at Video Display Terminals is intended for use during the daily activities at the PC.

The focus of the tool is to monitor VDT activity of workers that start from the same conditions (good posture and ergonomics). This is a critical factor, because the activity at VDT has a strong correlation with musculoskeletal disorders. The parameters acquired by the tool allow for:

1. The generation of a database of daily reports of activity-related parameters (time, type and intensity of an activity).
2. The clustering of workers on the basis of time, type and intensity of activity.
3. The generation of a database of medical knowledge after a properly designed data-mining useful for risk-pathology correlation.

As an example of item (3) – certainly a non-exhaustive one – for a planned investigation of VDT work-related risk factors, suitable risk indexes can be built to be used in epidemiological studies, measuring the specific VDT activity. For example the following index could be proposed and easily computed from the recorded data, for epidemiological studies on muscle–skeletal symptoms in computer workers:

$$A_{i\text{TASKI}}(\%) = \frac{\text{Time of the activity } A_i \text{ in TASK } i}{\text{Total time of TASK } i}$$  (1)

where TASKI (i=1, 2, 3) is one of the three proposed tasks in the Test of Functionality and $A_{i\text{TASKI}}$ is a specific activity within the task (e.g. typing, mouse moving, mouse scrolling, etc.). For instance, the numerical values reported in Table 4 have been obtained with the proposed index from the results in Table 1. Indexes derived, for example, from the measured activity of the involved anatomical body segments (e.g., finger, wrist, forearm), could be useful to understand the involvement of different VDT tasks in musculoskeletal disorders, and eventually create suitable hazard clusters, especially for some intensive tasks. For example, in the LabVIEW task (Task 2), quite a bit of time is spent in constantly pressing the left mouse button with the index finger to shift the wires either horizontally or vertically on the screen. The same holds for mouse scrolling, a repetitive task of flexion and extension of the medial and distal interphalangeal joints of the index finger. A suitable set of indexes could thus be designed to compute the potential risk for VDT-exposed workers, to quantitatively approach medical–legal advice.

To investigate the suitability of the proposed architecture and user’s acceptance, the tool was fully tested in the laboratory.

The test of functionality was designed to highlight the functionalities of the tool in three typical environments of work as future scenarios of application: word processing, graphical programming language, and drawing/painting. The test showed that in all three environments it was possible to assess a multitude of parameters by which it is possible to assess the type and intensity of a specific VDT activity with mouse/keyboard. The parameters the tool furnishes are useful, for example, in the following fields of work:

1. **word-processing**, where the predominant activity is keyboard typing, as for VDT-workers involved in data-entry.
2. **graphical programming** language, where the predominant activity is mouse moving, mostly by clicking and scrolling keys, as for VDT-workers involved in the design of object-oriented-software-programs.
3. **drawing/painting**, where the predominant activity entails the use of the mouse, with particular care to mouse kinematics, as for example for VDT-workers involved in Computer Aided Design.

The Tests of Accuracy and Acceptance were performed on group of subjects familiar with. Software packages of personal computers. These tests showed the advantages of the
methodology in terms of accuracy, and the high degree of acceptance especially when compared with methodologies based on questionnaires. In particular the test of accuracy clearly showed that the questionnaires are not adequate to assess timing. This is in agreement with Homan MM and Armstrong TJ [33] who showed through different methodologies that automatic PC-based solutions should be preferred to methods based on purely subjective questionnaires.

The study will continue to further investigate VDT-related risks. For this purpose the tool kit will be integrated with other functionalities and adapted for clinical use:

- Integration with sensors to allow for motion analysis as well. The tool will be integrated with fix sensors solid with mouse, keyboard, chair, and wearable sensors placed on some anatomical body segments involved in VDT activity (i.e. finger, wrist, forearm, shoulders, neck, trunk), for example, force-sensing resistors, wearable triaxial accelerometers and/or gyroscopes [34].

- Integration with electromyography equipment to perform fatigue tests.

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REFERENCES


[24] Italian Legislative Decree no. 626/1994 (Decreto Legislativo n. 626 del 19/09/94). Attuazione delle direttive 89/391/CEE,


