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Usability characteristics assessment protocol applied to eTouch ultrasound user-defined workflow optimization tool

F. Vannetti[a], T. Atzori[a], S. Matteoli[b], K. Hartmann[c], G. Altobelli[d], R. Molino-Lova[a], L. Forzoni[d]

[a]Fondazione Don Gnocchi, Florence, Italy
[b]Department of Industrial Engineering, Università degli Studi di Firenze, 50139 Florence, Italy
[c]VenenZentrum, Freiburg, Germany
[d]Esaote S.p.A., Florence, Italy

Abstract

The Ultrasound (US) examination time reduction is an increasing compelling request in sonographer's everyday life. The increased number of patients and the cost reduction are two opposite forces, which can lead the sonographer to work faster without caring about scanning posture. The numerous repeated actions performed can easily lead to Work-related Musculoskeletal Disorders (WRMSD). The analysis of those problems has driven to the definition and implementation of eTouch tool: user-defined Macros appositively created, automatically and sequentially saved and performed in real time by pressing a button. The present work investigates ergonomics and usability performances of a portable US system (MyLabAlpha, Esaote S.p.A., Italy) by using eTouch as well as the classical manual interface in two clinical applications (Abdominal and Vascular). performed by a skilled sonographer on a healthy subject. is. Upper-body kinematic and muscle activation of the sonographer's left arm were recorded through an optoelectronic system (SmartDx400, BTS Spa, Italy) and a multi-channel Wireless Superficial Electromyography (SEMG, Freemg300, BTS Spa, Italy). The number of keystrokes used during the manual procedure was more than 3 times higher than the one with eTouch. This difference implied a reduction of US execution time when using eTouch in comparison with manual use of about 30%. Results of the upper-body kinematic showed that the arm was extended for less time intervals when using eTouch, whereas during the manual procedure there was a greater activation of the deltoid, responsible for the elevation of the shoulder and thus the extension of the arm. SEMG analysis showed that eTouch allowed a significant reduction of muscular activation, especially for the anterior deltoideus. Our findings showed that eTouch is recommendable for decreasing WRMSD risk.

Keywords: Work-related musculoskeletal disorders; Ergonomics; Macro

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Nomenclature

WRMSD   Work-Related Musculoskeletal Disorders
TS   Touch Screen
US   Ultrasound
TGC   Time Gain Compensation
AA   Abdominal Aorta
CD   Color Doppler
ROI   Region of Interest
PRF   Pulse Repetition Frequency
CCA   Common Carotid Artery
SEMG   Surface Electromyography

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1. Introduction

The Ultrasound (US) examination time reduction is an increasing compelling request in sonographer's everyday life [1]. The increased number of patients to be scanned per day and the request of cost reduction are two opposite forces which can oblige the sonographer to work faster with less consciousness for the problem of scanning posture and with numerous repeated actions with reduced time for breaks between an examination and the following, can easily lead to Work-Related Musculoskeletal Disorders (WRMSD) [2-5].

The analysis of these problems has driven to the definition and implementation of the eTouch tool for automated personalized workflow solutions. Specifically, eTouch represents a tool for the creation of a personalized, user-targeted workflow of the system. It allows the user to record sequences of key mixing functions of both Touch Screen (TS) and control panel. Each recorded sequence (macro) can be named and saved to be available as a customized button in customized TS (eTouch environment). The recording of the macro is performed during the normal use of the US system. Pressing the eTouch button) on the physical control panel, the user enters the eTouch environment on the TS (Fig. 1).

Examples of eTouch macros can be:

- *"Freeze-image-print" macro*: from Real Time (live), the activation of this macro drives the system in Freeze status, saves an image (the last image of the cine loop) and prints the image (if a printer is connected and active, the image will be printed, otherwise the macro will end with the saving of the image);
- *"CFM and line" macro*: from Real Time (live), the Color Doppler (CD) modality is activated and the Doppler line placed;
- *"Annot-measure from live" macro*: from Real Time (live), the system is forced in Freeze status, the recorded annotation is placed on the image and a generic distance measure is activated (the first caliper of the measurement is shown on screen, linked to trackball movements, but not fixed).

A practical recording example of eTouch macro can be the "High Penetration" macro, requested by the user for setting the system as maximization of the capability to scan in depth, in one single touch. The macro will allow: 1) to set the desired status of the system, for example B-Mode real-time (live) – from which the macro will start; 2) to start the eTouch macro recording; 3) to move five times the toggle corresponding to the depth toward a deeper distance, and three times the frequency toggle toward a lower frequency; 4) not to record both pointer and trackball movements; 5) to press the eTouch button to stop recording and then type the desired button related to the string name.

For any macro the eTouch environment is characterized by the TS encoders' controls (shown in the lower part of the TS) which are those ones of the basic TS page of the last activated mode (B-Mode, CD, PW, etc.).

The present work investigates both ergonomics and usability performances of a portable US system by using eTouch as well as the classical manual interface in two clinical applications in order to evaluate the of eTouch application in comparison with the manual traditional procedure.

Fig. 1. (a) eTouch button (red circle); (b) eTouch environment with three macros on the Touch Screen page layout.

2. Material and methods

Both ergonomics and usability performances [6-8] regarding the human upper limb kinematics evaluation of one US portable system (MyLabAlpha, Esaote S.p.A., Florence, Italy) were performed thank to a skilled sonographer who performed two clinical applications (Vascular and Abdomen) on a healthy 34-years-old subject.

MyLabAlpha has a touch screen-centered user interface and a limited number of physical buttons on the control panel with respect to other classic US system user interfaces. MyLabAlpha user interface is characterized by the following main aspects:

- Centrality of the re-configurable touch screen in order to be able to easily operate on it. Both buttons and encoders of the control panel, necessary for the "direct" functions, remain "physical". The modalities (B-Mode, CD, PW, M-Mode, and Continuous Wave Doppler) and their General Gains, Time Gain Compensation, Freeze, Clip/Image/Acquire, Measurements, AutoAdjust, Pointer, Menu and Archive, and Print are physical buttons present on the control panel, because they are mainly used during an examination (when the system is pre-set properly) and they have to be activated while the user looks at the main screen, where the US image is displayed. The six toggles/encoders at the base of the TS represent "physical" controls, too, even if related to re-configurable functions.
- General gains of the modalities are "physical" encoders. They can be adjusted while the user looks at the US image; it is important to check the result of the gain change without having to continuously change the eyes point of view between the control panel and the US image.
- Physical sliders of the Time Gain Compensation (TGC) in order to adjust the time gain compensation of the image on the main screen without having to look at the control panel or the TS.
- Reduced distance between the trackball (which is the center of the user interface) and all the controls (encoders and main modalities) in order to reduce the operator hand, arm and shoulder fatigue [6]
- Workflow (both regarding the trackball-pointer interaction and the general control panel-touch screen interaction) structured to avoid "long travels" of the operator's hand in order to perform even a single and simple task.
- TS (based on resistive technology - it can be operated also with surgical gloves) has been organized in such a way to have a maximum of two levels within the same environment. Regarding the US modalities (B-Mode, CD, PW, etc.) the Image Parameters Area has two levels (Basic and Advanced, Fig. 2) with the Basic level including all the most used modality adjustment controls.

Abdominal (Abdominal Aorta - AA) and Vascular applications (Common Carotid Artery - CCA) were performed by applying standard scanning manual protocols as well as eTouch.

Fig. 2. Two levels of the Image Parameters Area: (a) Basic level; (b) Advanced level.

Manual examinations (about B-Mode and CD scanning, for anatomical and blood flow evaluation, respectively, and related images and Doppler parameters optimization, as well as, vessel diameter measurement execution) were performed according to the following scanning protocols:

- Abdominal application:
  1. Probe, application and user preset selection.
  2. Start of the examination: real-time environment activation.
  3. Imaging: visualization of an abdominal scanning plane containing the AA. Adjustment of depth, frequency, general gain and TGC, in order to optimize the image quality. Image parameters such as XView (speckle reduction and image quality enhancement algorithm) and MView (spatial compound technology) have to be optimized. Image the AA, freeze the image and perform a distance generic measurement related to the width of the AA and its saving as a still frame.
  4. CD: visualize the CD signal of AA, adjust the dimensions of the CD Region of Interest (ROI) and its position, optimize the Pulse Repetition Frequency (PRF), the Doppler frequency and the Doppler general gain in order to avoid aliasing effect.
  5. Closing the exam with its archiving within the internal local Hard Disk of the system.
- Vascular application:
  1. Probe, application and user preset selection.
  2. Start of the examination: real-time environment activation.
  3. Imaging: visualization of the CCA. Adjustment of depth, frequency, general gain and TGC in order to optimize the image quality. Image parameters such as XView and MView have to be optimized. Image the CCA, freeze the image and perform a distance generic measurement related to the width of the CCA and its saving as a still frame.
  4. CD: visualize the CD signal of CCA, adjust the dimensions of the CD ROI, its position and its electronic steering (the longitudinal scanning is considered), optimize the PRF, the Doppler frequency and the Doppler general gain in order to avoid aliasing effect.
  5. Closing the exam with its archiving within the internal local Hard Disk of the system.

For the automated workflow test in Abdominal and in Vascular applications, the following macros were created and then used sequentially in real time.

- Abdominal application:
  1. eTouch automatic selection of Convex probe AC2541 (Esaote S.p.A., Florence, Italy), abdominal application and preset (note that eTouch proper performance depends on the position of the probe that has to be located in the same connector where it was connected when macro was recorded).
  2. Five eTouch macros for: 1) fat patient: increase of depth and lowered frequency; 2) thin patient: lowered depth and increased frequency (the opposite of macro number 1); 3) XView and MView enhanced structures effect: selection of XView C, XEnhancement increased up to 10, XSmoothing increased up to 3 (where

XEnhancement is a XView Technology parameter which enhances the hyper-echoic structures, while XSmooth is an XView Technology parameter which increases the image smoothness effect particularly visible on parenchyma and homogeneous tissues), MView increased up to 3; 4) come back to the original XView and MView default settings: decrease the XEnhancement to the original default value, decrease the XSmoothing to the original default value, decrease the M-View to the original default value, decrease the M-View to the original default value; 5) freeze the real-time and then start the distance generic measurement.

3. Three eTouch macros for: 1) save the image (still frame), unfreeze to come back to the real time; 2) visualization of slow flows: activate CD, decrease of PRF, increase the CD frequency and increase the CD General Gain; 3) visualization of fast flows: activate CD, increase PRF, decrease the CD frequency and increase the CD General Gain (the opposite of macro number 2).

4. One eTouch macro for saving an image and closing the exam saving it in the internal archive, and then opening the Start Exam page for a new patient.

- Vascular application:
  1. eTouch automatic selection of Linear probe (SL1543, Esaote S.p.A., Florence, Italy), vascular application and preset (note that eTouch proper performance depends on the position of probe that has to be located in the same connector where it was connected when macro was recorded).
  2. Five eTouch macros for: 1) fat patient: increase of depth and lowered frequency; 2) thin patient: lowered depth and increased frequency (the opposite of macro number 1); 3) XView and MView enhanced structures effect: selection of XView C, XEnhancement increased up to 10, XSmoothing increased up to 5, MView increased up to 3; 4) come back to the original XView and MView default settings: decrease the XEnhancement to the original default value, decrease the XSmoothing to the original default value, decrease the MView to the original default value, decrease the MView to the original default value; 5) freeze the real-time and then start the Distance Generic Measurement.
  3. Three eTouch macros for: 1) save the image (still frame), unfreeze to come back to the real time; 2) visualization of slow flows: activate CD, decrease PRF, increase the CD frequency and increase the CD General Gain; 3) visualization of fast flows: activate CD, increment of PRF, decrease the CD frequency and increase the CD General Gain (the opposite macro number 2)
  4. One eTouch macro for saving an image and closing the exam saving it in the internal archive, and then opening the Start Exam page for a new patient.

For Abdominal and Vascular automated workflow tests, TGC and B-Mode General Gain were set using AutoAdjust (Automatic parameter Adjustment function).

Despite the automatic workflows, the operator still needed to perform some actions manually because they involved the trackball or the visual alignment of the correction angle to the vessel position with respect to the probe, such as positioning the PW line of sight, positioning the PW SV, adjustment of the theta angle (θ) correction for the velocity generic measurement, performing and closing the Velocity Generic Measurement, and positioning the CD ROI and adjusting its dimensions.

All tests were performed in a simulated clinical environment (Fig. 3), focusing on the user interface workflow of the US system, only. The test setting was organized in such a way to have the system on its proper height adjustable cart (with four swiveling wheels), positioned at a height, of the trackball from the ground, of 79 cm. The chair of the operator could not be adjusted in height (fixed at 44 cm). The examined subject bed was adjusted at the height of 63 cm. The sonographer used the US system with the left hand, handling the probe with the right one during both clinical applications. US examinations were performed with the operator facing the examined subject, who was laying on the operator's right side. The presence of a prompter was considered necessary in order to remind the scheduled sequence of action as listed in the protocols.

During US examinations the upper-body kinematic and muscle strength of the sonographer were recorded through a six cameras optoelectronic system (SmartDx400, BTS Bioengineering Spa, Italy) and a Multi-channel Wireless Superficial Electromyography (SEMG, Freemg300, BTS Bioengineering Spa, Italy).
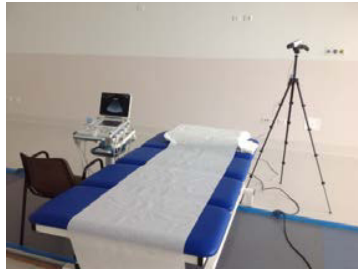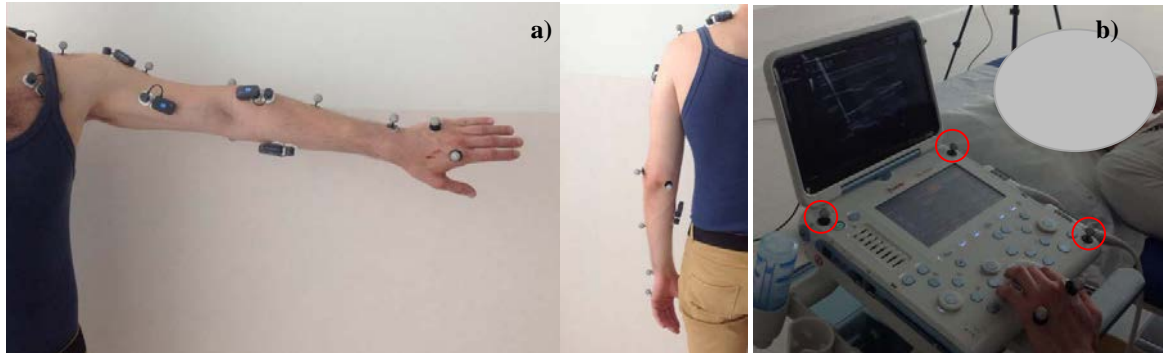
Fig. 3. Testing room.

Fig. 4. passive reflective markers placed on (a) sonographer's left arm; (b) US system.

A total of 11 passive reflective markers were placed on sonographer's left arm and US system (to define a plan and have a reference to the movements of the left upper limb) for kinematic computation (Fig. 4). Calibration procedures were carried out before starting each experimental session. Kinematic and SEMG data were processed with Matlab by using low pass filtering at 15Hz and high-pass filtering at 20Hz, respectively.

A chronometer recorded the time duration of each procedure.

3. Results

3.1. US execution time analysis

The number of key strokes used during the manual procedure was always higher than during eTouch application: 45 vs. 13 and 48 vs. 14 for Vascular and Abdomen protocol, respectively. This difference implied a reduction of US execution time when using eTouch in comparison with manual use. Specifically the execution time was 90 s and 114 s in case of eTouch procedure for Vascular and Abdominal protocol, respectively; whereas it was 131 s and 148 s in case of manual procedure for Vascular and Abdominal protocol, respectively.

3.2. Motion and SEMG analysis

Results of the upper-body kinematic showed that the arm was stretched for less time intervals when using eTouch procedure, whereas during manual procedure there was a greater SEMG activation of the deltoid, responsible for the elevation of the shoulder and thus the extension of the arm.

By measuring the trace length of the marker placed on the first metacarpal, the eTouch tool allowed a reduction of about 6% and 17% for Abdominal and Vascular protocol, respectively, in comparison with the manual procedure (Fig. 5).
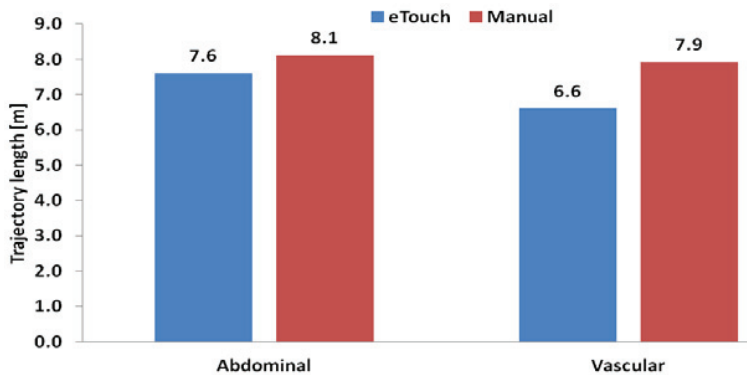
Fig. 5. Length of the trajectory of the marker placed on the first metacarpal.
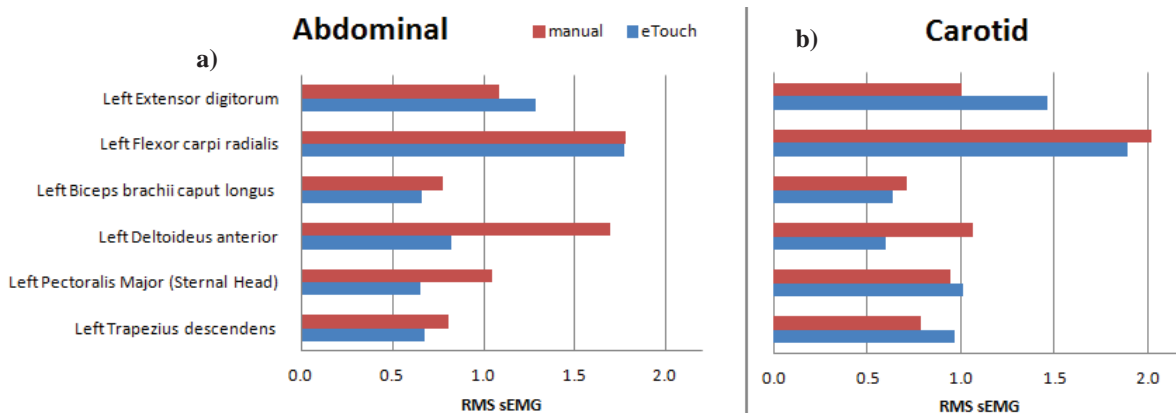

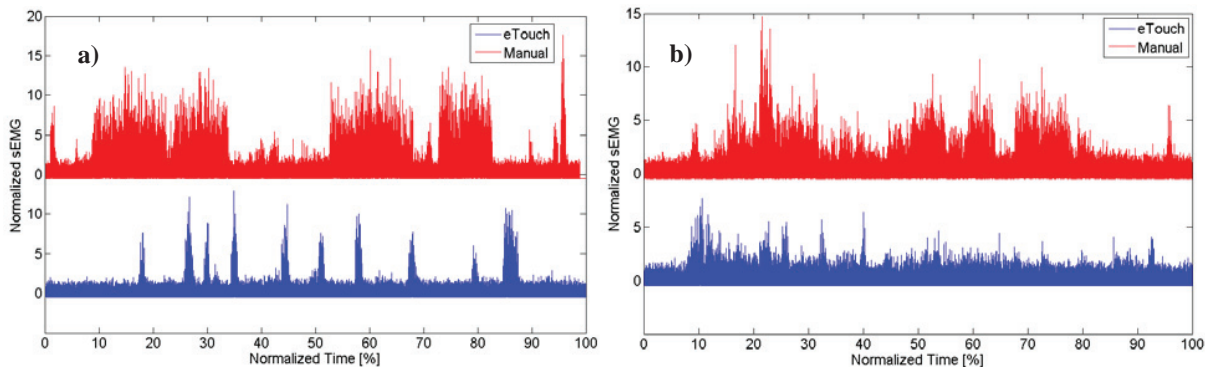Fig. 6. RMS of SEMG signal (a) Abdominal protocol; (b) Vascular protocol.

Fig. 7. SEMG of left deltoideus anterior: a) Vascular protocol; b) Abdominal protocol.

SEMG analysis showed that eTouch allowed a reduction of muscular activation during the execution of both protocols (Fig. 6), especially for the anterior deltoideus for which the reduction of the RMS (Root Mean Square) signal was about 51% and 44% for Abdominal and Vascular protocol, respectively. Figure 7 shows the SEMG amplitude, normalized to resting sEMG, of the anterior deltoideus, for both protocols.

4. Discussion and conclusion

eTouch environment represents a completely new concept used to create a personal workflow. It is a tool which allows using user-defined Macros appositively created, automatically and sequentially saved and performed in real time by pressing a button. Our findings showed that eTouch reduces the number of used keystrokes/adjustments as well as US execution time (31% and 23% less than manual for Abdominal and Vascular, respectively). Furthermore, eTouch reduces the time during which the sonographer's left arm is extended, without having any support to lay on. Nevertheless, there is an increase of the muscular activity of both trapezius descendens and extensor digitorum during Abdominal and Vascular protocol when the eTouch procedure is applied. The increase of both muscles activity is explained by kinematic measurements which showed: 1) a higher vertical position of the sonographer's left shoulder respect to the US keyboard system which implies a higher elevation of the shoulder joint due to the trapezius contraction; 2) a longer resting position of the sonographer's left wrist in extension on the US keyboard bar. The increase of muscular activity is thus completely due to the sonographer's static posture, which does not depend on the protocol/procedure applied, and can be reduced by changing the scanning posture during the US examination.

SEMG data showed a lower contraction of the anterior deltoideus and the pectoralis major which are muscles most involved in the shoulder pain and stress-related pathologies. So, eTouch tool is recommendable for decreasing WRMSD risk.

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