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Laboratory Investigation

LABORATORY INVESTIGATION

Comparative usability of modern anaesthesia ventilators: a human factors study

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Abstract

Background. The anaesthesia ventilator represents the key equipment for intraoperative respiratory care. Improper operation of this device may threaten a patient's health. A self-explanatory interface facilitates handling and decreases the risk of operating errors. This study systematically evaluates the usability of user interfaces in four modern anaesthesia ventilators.
Methods. Twenty naïve operators were asked to execute 20 tasks on each of four different anaesthesia ventilators (Avance CS^{2TM}, GE Healthcare; Flow-i^{TM}, Maquet; and Perseus^{TM} and Primus^{TM}, Dräger) in a randomized order. The success of task execution, frequency of requests for assistance, and processing times were recorded. During the tasks, the operators' visual focus was measured via eye-tracking. Additionally, subjective assessments of usability were evaluated by a standardized questionnaire. For comparison, six experienced operators undertook the same protocol.
Results. The overall rate of falsely executed tasks was low. Naïve operators requested assistance least when using the Perseus (26). Pooled processing times were shortest for the Perseus (222 s), followed by the Primus (223 s), the Avance (238 s), and the Flow-i (353 s). Task-specific processing times differed considerably between the devices. Eye-tracking analyses revealed associated interface issues that impeded the operators' performance. Operators rated usability best for the Perseus [mean (SD): 67 (17) arbitrary units] and worst for the Flow-i [50 (16) arbitrary units]. Results from experienced operators support these findings by trend.
Conclusions. The usability of modern anaesthesia ventilators differs considerably. Interface issues of specific tasks impair the operator's efficiency. Eliminating the specific usability issues might improve the operator's performance and, as a consequence, the patient's safety.

Key words: patient safety; ventilators, mechanical

Operating an anaesthesia ventilator means acting in a complex working environment, comprising the patient, the operator, and the machine.[1] These individual components determine the system's performance, but the strengths and weaknesses of the ventilator's interface also play a part.[2] Large efforts have been made to evaluate the performance of anaesthesia ventilators.[3–5] In contrast, little is known about the interaction between ventilators and users. With increasing functionality, the operational complexity of ventilators has increased, and usability has become more important.[6] The amount of errors attributed to poor design is noteworthy.[7 8] A study analysing safety-reporting databases in the USA found that up to 49% of ventilator-related adverse events were caused by human factor issues.[9]

A simple and self-explanatory design might lead to a significant increase in patient safety.[6 10 11] In this regard, an anaesthesia ventilator that is self-explanatory to operate represents a

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Editor's key points

- The authors examined the usability of modern ventilators used in anaesthetic practice using a battery of tests, including gaze-tracking.
- They found significant variability in metrics of ease of use, although the incidence of wrongly executed tasks was low.

key component to efficient and safe patient treatment. We hypothesized that modern anaesthesia ventilators differ in usability with regard to the varying designs of their user interface.

Methods

Anaesthesia ventilators

Four modern anaesthesia ventilators from three different manufacturers were studied: Avance CS^{2TM}, GE Healthcare, Chalfont St Giles, Great Britain; Flow-i^{TM}, Maquet, Rastatt, Germany; AND Perseus^{TM} and Primus^{TM}, both Dräger Medical, Lübeck, Germany. All ventilators were put into operation within the same room but separate cabins to achieve a comparable and quiet testbed. At the beginning of each examination day, the ventilators' semi-automated self-tests were executed by an experienced technician, following manufacturers' instructions. Before test procedures, the ventilators were connected to a lung model (SMS Manley Lung Simulator, BC Group International Inc., St Charles, MO, USA; compliance, 50 cm H_2O ml^{-1}), and start settings were set to a defined default.

Operators

After ethical approval and written informed consent were obtained, a total of 28 volunteers were included in the study. Twenty-two participants, all medical students, were screened for eligibility. Blinded against the intention of the study, these persons indicated their experience in a questionnaire. The study group of naïve operators (NO) included only persons who had no relevant experience with any anaesthesia ventilator to avoid biasing our results by habituation or coping strategies of experienced users. Subsequently, six volunteers, all anaesthesia residents, were allocated to the study group comprising experienced operators (EO).

With respect to the psychophysical design of the study, operators were not included when they had indicated last night's sleep period as <5 h, medication with sedatives, and alcohol or drug uptake within the last 10 h. The operators' reaction time was assessed to ensure comparability, using a self-programmed visual task.

Study protocol

On the day of examination, naïve operators received a tutorial giving general instructions on technical handling of anaesthesia ventilators. This was necessary because it is not a subject in their medical education curriculum. The tutorial was about the setting of ventilation parameters and alarm limits, interpretation of display information such as ventilation curves, breathing-circuit principles, and how to switch from mechanical to manual ventilation. The teaching contents were viewed using a technical scheme, non-specific for any of the included ventilators. It was conducted by the same instructor in the same manner for each individual.

After the tutorial, operators were allowed to inspect the anaesthesia ventilators visually for a maximal period of 1 min each. Subsequently, ventilators were tested, including 20 tasks that were designed to map typical operating steps during routine use of an anaesthesia ventilator (Table 1). All ventilators were presented to each operator in a randomized order. In order to generate an alarm, the ventilators were disconnected from the lung model after having started mechanical ventilation, invisible to the operators.

Tasks were given verbally, with the operator standing in front of the respective ventilator and the investigator standing to its side. All tasks were read aloud word by word, while the operator was allowed to start to render the task at his own discretion. Some tasks included numbers to be set at the ventilator. In these tasks, the numbers varied between ventilators to avoid execution of the task ahead of time.

Operators were asked to execute the tasks quickly but with due diligence. During the task, operators were able to request assistance from the investigator up to three times before the task was rated failed. First assistances included revealing an item's label, suggesting submenu search, or pointing out the necessity of additional activation or confirmation. Second assistances included giving an item's location or identifying an item's submenu. Third assistances included activation of the requested process. If the operators faced obstacles but did not ask for assistance, assistances were given after 60, 120, and 180 s. Tasks were considered complete at the operator's decision. Measurement of processing times began at the start of vocalizing the task to the operator and ended once the task was completed. Frequencies of assistances were recorded by the investigator.

Table 1 Task formulation. Parameters to be set by the operators varied between anaesthesia ventilators. Values are given for the Primus^{TM} as an example

1.	Set volume-controlled ventilation mode
2.	Set tidal volume to 700 ml
3.	Set ventilation frequency to 9 bpm
4.	Set positive end-expiratory pressure to 6 cm H_2O
5.	Start volume-controlled ventilation
6.	Set maximal inspiratory pressure to 40 cm H_2O
7.	Set inspiratory oxygen concentration to 30%
8.	Set inspiratory-to-expiratory ratio to 1 to 1.5
9.	Set end-inspiratory pause to 20%
10.	Open alarm menu
11.	Set upper limit of minute ventilation to 11 litres min^{-1}
12.	End volume-controlled ventilation
13.	Set pressure-controlled ventilation mode
14.	Set inspiratory pressure to 20 cm H_2O
15.	Set ventilation frequency to 7 bpm
16.	Start pressure-controlled ventilation
17.	Quit alarms
18.	Switch to manual ventilation
19.	Read aloud minute ventilation
20.	Show emergency oxygen supply