Digital tools for medical education amidst the COVID-19 pandemic: challenges, solutions and the CHERRIES on top

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Digital tools for medical education amidst the COVID-19 pandemic: challenges, solutions and the CHERRIES on top

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by

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Summary

The COVID-19 pandemic has caused disruptions in many aspects of daily life. Healthcare workers and students were particularly affected since they had to face a yet-unknown lethal disease without being able to attend regular and continuous education sessions. This Privat-Docent thesis is based on five studies assessing the impact of innovative and highly interactive web-based or blended education interventions on knowledge and skill acquisition, and, when relevant, on infection prevention behavior. All these trials were designed according to the checklist for reporting results of internet e-surveys, better known as its acronym, CHERRIES. Since all but one of these trials were randomized, the eHealth extension of the consolidated standards of reporting trials was consistently used and methods and results reported accordingly. Several perspectives can be drawn from these five trials and are detailed at the end of this thesis, including the importance of a collaborative, interprofessional and trans-departmental approach.

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Introduction

Before presenting the articles selected for this Privat-Docent thesis, this introduction will summarize the elements necessary to understand their rationale. First, the general background which led to the design of these studies, and sometimes to the development of specific educational interventions, will be presented. Then, the concepts of electronic learning (e-learning), gamification and serious game design will be described. The final chapter of this introduction will cover the elements one should consider when designing online trials.

Background

During the last few decades, most viral epidemics were contained and mainly had regional impacts. Thus, several viruses, such as the Middle East Respiratory Syndrome (MERS), were named according to the impacted zone [1]. While these regions implemented local lockdowns and travel restrictions, Europe, including Switzerland, was mostly spared [2]. The worst consequences the Old Continent had to face were those linked to seasonal influenza pandemics [3,4]. Thus, European countries were little prepared to face the repercussions of the viral pandemic caused by the yet-unknown strain of an otherwise widely spread respiratory virus, the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [5,6].

The authorities had to manage a host of unanticipated consequence which disrupted almost every aspect of daily life [7–9]. In addition to the issues faced by all citizens, many healthcare workers were required to learn or refresh seldom-used infection prevention and control (IPC) skills and procedures [10,11]. However, social distancing prevented regular continuing education interventions and alternative methods of teaching the required knowledge and skills had to be devised [12,13]. Furthermore, medical professionals and public health specialists faced an unprecedented resistance to IPC recommendations. This was the result of rapidly evolving and often contradicting guidelines [10], distrust in the authorities [14,15], and conspiracy theories [16–18].

The undergraduate medical curriculum was also disrupted by the pandemic [19]. Clinical rotations were interrupted, and many students were therefore unable to assess patients presenting common yet time-critical conditions such as stroke and myocardial infarction even though their incidence was higher during the pandemic [20]. Since many senior medical students were on the verge of graduating and some were even fast-tracked to help manage the surge of COVID-19 cases [21], providing these future professionals with alternative means of acquiring the necessary clinical knowledge regarding these critical pathologies was essential.

Electronic learning (e-learning)

Electronic learning, or e-learning, refers to the provision of an educational intervention using electronic devices [22,23]. Thus, e-learning does not refer to a specific type of intervention but rather covers a very broad range of educational tools. It is therefore unsurprising that studies report contradicting results regarding the impact of e-learning interventions since they do not actually compare similar educational tools [22,23]. Very few e-learning interventions can be considered as almost identical, but researchers carrying out meta-analyses must resort to categorization to pool data.

There are many ways in which e-learning tools can be classified. A rather common way of categorizing these interventions is to differentiate those which can be used at any time (asynchronous interventions) from those which must be followed at a certain time (synchronous interventions). For instance, webinars are synchronous e-learning interventions and participants must follow them at a given time except if they are recorded. Conversely, educational videos hosted on an electronic device or on the web represent a common example of asynchronous interventions. However, this categorization fails to take participant engagement into account. Indeed, learner involvement vastly differs from one e-learning modality to another, and some interventions require little or no user interaction while others require frequent learner inputs to be completed. Since engagement can improve knowledge acquisition [24,25], it may be more appropriate to categorize e-learning interventions as either static (no interactivity) or dynamic (any level of interactivity) [26]. Table 1 describes some of the modalities belonging to these categories but does not provide a comprehensive list of all specific interventions and hybrid interventions developed over time.

The fifth article included in this Privat-Docent thesis describes the impact of a highly interactive e-learning module developed to teach the National Institutes of Health Stroke Scale (NIHSS) on senior medical students in comparison with the conventional educational video created by Patrick Lyden [27]. This dynamic module is freely available online: https://nihss-study.ch/e-learning.

Category	**Type of intervention**	**Comment / description**
Static	Digital texts or images	Almost any textbook or image can be digitized and made available on an electronic platform. These electronic versions are hardly more interactive than a standard textbook.
	Powerpoint-like presentations	Any presentation requiring the user to click either on the same button or on the slide to go to the next slide, without engaging the user in other interactions
	Digital audio recordings	While video podcasts have also emerged, these interventions are often referred to as "podcasts". These audio recordings do not allow any form of interactivity (other than leaving comments that may or may not be answered by the author or by other users).
	Videos	A regular video displayed on an electronic device, whether online or offline. Youtube videos and vlogs (video blogs) belong to this category.
Dynamic	PowerPoint-like presentations with embedded questions	These modalities are often used to present case scenarios and challenge the user with questions. They are often linear, and the scenario usually does not adapt to the users' answers.
	Adaptive case scenarios	These modules act in a way similar to gamebooks, with scenarios evolving in different ways according to the users' answers or actions.
	Interactive simulations	These can sometimes be considered as serious games (see next subsection). The simulation adapts to almost each user action providing learners with the highest level of interactivity.

Table 1. Examples of static and dynamic e-learning modalities.

Gamification and serious games

Increasing learner engagement can be achieved through gamification. Before going over gamification techniques and frameworks, it is important to understand that there are significant differences between gamification and serious games [28]: while serious games are full-fledged games designed for a purpose other than pure entertainment, gamification refers to the use of game elements in educational interventions other than actual games [29]. For instance, awarding badges for completing e-learning modules such as online videos or quizzes or unblocking content after successfully answering a quiz are common gamification components. Serious games require more than the inclusion of gamification components and must include game mechanics and game dynamics. Figure 1, which is adapted from the updated version of *For the Win* [30], gives a hierarchical view and several examples of these elements.

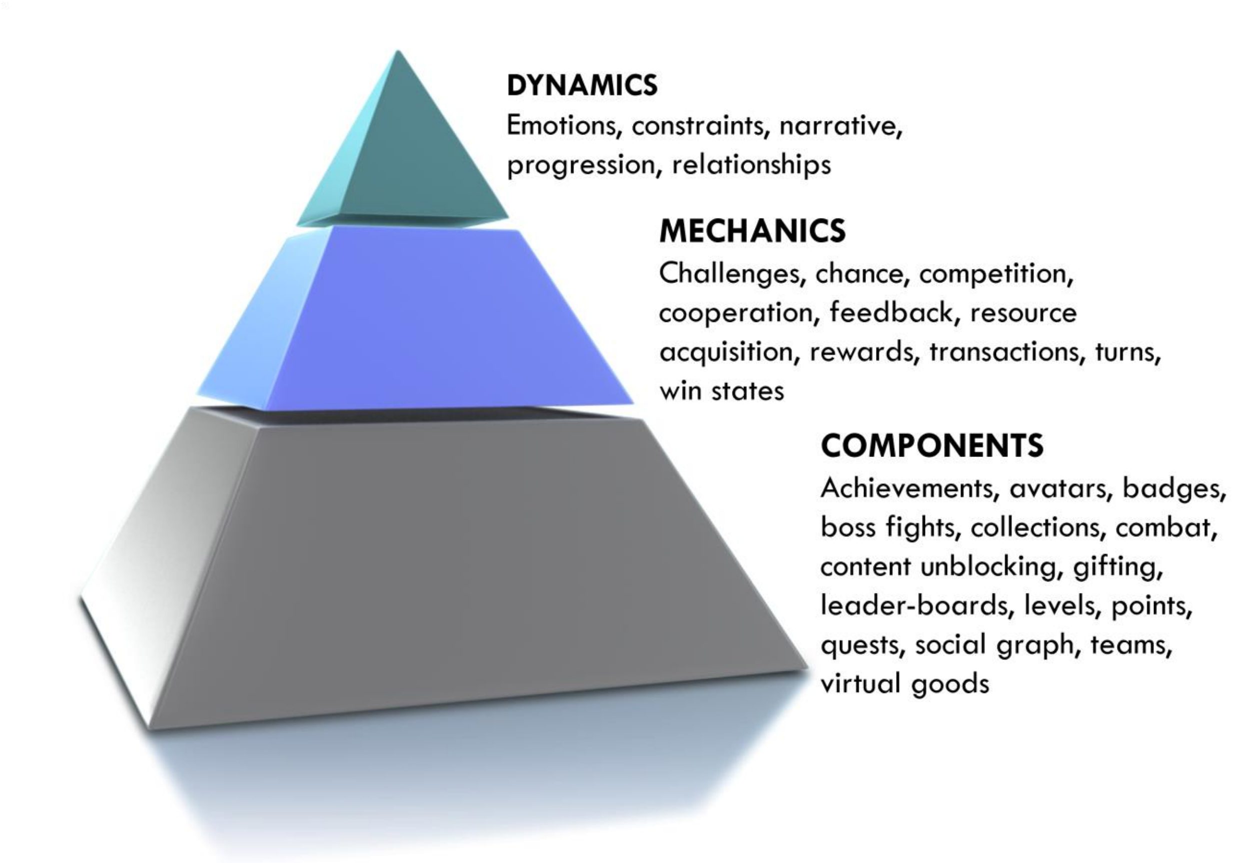

Figure 1. Hierarchy of game elements, adapted from Werbach K & Hunter D, *For the win*, 2020 [30].

A potential misconception would be to believe that serious games are necessarily computer-based and thus necessarily e-learning interventions. Indeed, apart from serious board games [31], other gaming modalities have been used to design to create immersive educational interventions [32]. Some researchers have even developed escape games akin to those which now flourish in most major cities of the world [33].

The impact of gamification and serious games varies widely [34]. Some games are unable to achieve their goal (such as knowledge acquisition or skill acquisition) by failing to link learning objectives to game objectives, and game objectives to game mechanics [35]. There are many ways to avoid this shortcoming, and using an appropriate framework can have a major impact on the game's effectiveness. The SERES framework [36,37], which can be used to develop both gamified e-learning modules and serious games [38,39], is adaptable and ensures that the developments are evidence based and theory driven. There are five stages to this framework, each of which may require multiple iterations before being completed. In the first stage, scientific foundations, the target audience, theoretical bases and outcomes are defined. It is only after completing this stage that design foundations (i.e., the second stage) are decided. Design requirements and game mechanics are also defined during this second stage, and development (stage 3) can only begin once this stage has been completed. The game or educational intervention is actually completed once the third stage is over. Indeed, the fourth stage consists in clinical validation studies, while the fifth stage is the rollout and dissemination of the intervention. While this framework has many advantages, it still lacks important elements, such as considering the use of the game as part of a pedagogical scenario, defining learning incentives, or describing the game's structure and progression prior to the development phase. Other frameworks take such elements into account [40–42], but usually fail to consider the importance of an evidence based, theory driven and collaborative development.

Although the SERES framework natively embedded all the elements required to develop the gamified e-learning module the effect of which is described in two of the articles included in this thesis [38,39,43], it lacked some key elements a serious game should include. Thus, the development of the "Escape COVID-19" serious game required the use of an additional tool to complement the SERES framework and improve the games' probability of success [44]. The tool selected for this purpose was Scott Nicholson's RECIPE for meaningful gamification. RECIPE stands for Reflection, Engagement, Choice, Information, Play and Exposition. These six elements are detailed in Table 2.

Element	**Definition**
Reflection	The first element of the mnemonic is also the last described in Nicholson's original publication [45]. Reflection is intended to increase participants' engagement by allowing them to link the gamified materials with personal experiences (past or present). To achieve reflection, participants should be given the opportunity to "step back" from the gamified learning materials to connect the gamified experience to their own personal stories.
Engagement	Many elements of the RECIPE mnemonic refer to the participant's engagement in the game. According to Nicholson, this item specifically refers to mechanisms designed to transfer the participant's engagement in the game to the real world. This can be achieved by many different mechanisms, including the integration of social components within the gamified learning material.
Choice	Choice directly relates to the participant's empowerment. By making meaningful choices which affect the course of the game/story, learners' engagement is increased. According to Nicholson, choosing not to play should also be an option for the participant, who should then be given the opportunity to access other learning materials containing the same information.
Information	While most other elements of Nicholson's RECIPE relate to gamification and game mechanisms, information is directly linked to the learning objectives. Information should be unbiased and, if possible, evidence based. Reliable information will increase the participant's engagement, and the learner/player should understand "why" it is important to engage with the gamified learning material [46].
Play	This element appears before all others in Nicholson's original publication [45]. It refers to the freedom which should be given to the learner. According to Nicholson, the possibility to explore the game's universe increases the participant's engagement. This is increased even further by including constraints or boundaries: in other word, the player/learner should be able to fail (both on purpose and involuntarily).
Exposition	Exposition links game and learning elements to the real world, allowing players to understand, sometimes even unconsciously at first, the important challenges tackled by the gamified instrument they are using. Ideally, learners should be able to create their own story based on the one told by the gamified material. Therefore, exposition relates to the creation of a meaningful narrative.

Table 2. Nicholson's RECIPE for meaningful gamification, adapted from Nicholson S, *A RECIPE for Meaningful Gamification*, 2015 [45].

Three different educational interventions are presented in the articles included in this Privat-Docent thesis: the most basic is the aforementioned dynamic, highly-interactive e-learning module used to teach the NIHSS [47]. It should not be considered as a gamified tool since no game elements were included in its development. Second, a gamified e-learning module, developed according to Arnab's model [35], represents an intermediate step between a dynamic e-learning module and a true serious game [43]. Finally, "Escape COVID-19" is a full-fledged serious game the impact and uptake of which are described through two articles [48,49]. The distinction between gamified e-learning modules and true serious games can however be difficult to ascertain, and interventions are sometimes mislabeled. To avoid confusion, Wen Tan and Zary recently described 18 diagnostic markers of serious games [50]. These markers are equally divided into three categories: user experience, play, and learning. To be considered as a serious game, an intervention must possess at least four markers of each category. Table 3 shows the criterion met by the gamified e-learning module and by Escape COVID-19.

Category	**Markers**	**Gamified e-learning module**	**Escape COVID-19**
User Experience	Limits	The module is linear (the player is constrained)	The game is linear (the player is constrained)
	Feedback	Actions taken by the player lead to different outcomes	Actions taken by the player lead to different outcomes
	Scaffolding	Game mechanics are not used throughout the module	Gradual increase in the intensity of game mechanics
	Affordance	The actions available to the player are clear	The actions available to the player are clear
	Transparency	The options available to the player are self-explanatory	The options available to the player are self-explanatory
	Consistency	Interactions are consistent and outcomes are predictable	Interactions are consistent and outcomes are predictable

Table 3. Serious game markers of the gamified e-learning module and of Escape COVID-19. Adapted from Tan JW, Zary N, Diagnostic Markers of User Experience, Play, and Learning for Digital Serious Games: A Conceptual Framework Study [50].

Play	Relevance	The theme is professionally relevant to the target audience	The theme is professionally relevant to the target audience
	Objectives	There are no game objectives, only learning objectives	The purpose of the game is clear (avoid infection)
	Possibility	More substance is added as the learner progresses	More substance is added as the player progresses
	Consistency	Not applicable since only a few elements are gamified	Game mechanics are consistent throughout the game
	Scaffolding	The cognitive effort does not increase throughout the module	The cognitive effort gradually increases over four levels
	Error Friendliness	Learners cannot fail interactions	The "game over" screen allows players to trade points (thumbs up) or to restart the current level.
Learning	Target Outcomes	The objectives of the module are clearly stated	The goal of the game and of each level are clearly stated
	Knowledge	The knowledge provided is consistent with the objectives	The knowledge provided is consistent with the objectives
	Relevance	The knowledge and skill levels are appropriate to the intended audience	The knowledge and skill levels are appropriate to the intended audience
	Cognitive Load Management	Not considered as part of the module development	The game allows for progressive knowledge intake
	Expectation Defying	Not considered as part of the module development	The game avoids monotonous or predictable interactions
	Assessment	There is no such system embedded within the module	There is a total score (thumbs up vs virii) which allows for auto-assessment

Table 3 (continued). Serious game markers of the gamified e-learning module and of Escape COVID-19. Adapted from Tan JW, Zary N, Diagnostic Markers of User Experience, Play, and Learning for Digital Serious Games: A Conceptual Framework Study [50].

The differences between the gamified e-learning module and the serious game can be seen in Figures 2 and 3 below.

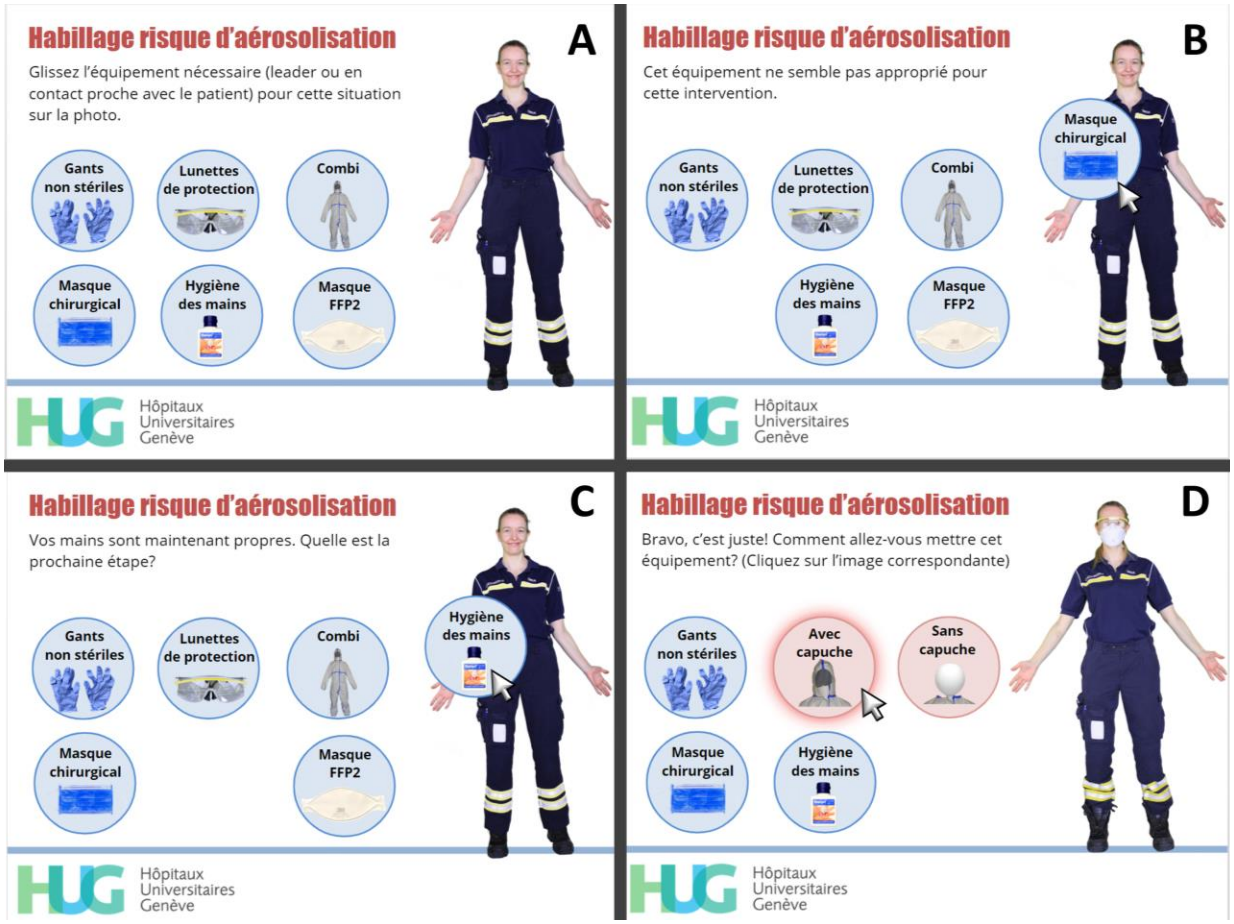

Figure 2. Gamified e-learning module. A: initial state with general instructions about the interaction. B: the participant has dragged the wrong item over the prehospital physician: immediate feedback is displayed to prompt a rethink. C: the right item has been dragged and the module now asks the participant to consider the next step. D: positive reinforcement feedback asking the participant to make a meaningful choice.

The gamified e-learning module is freely accessible here: https://anesth.ch/covid-19

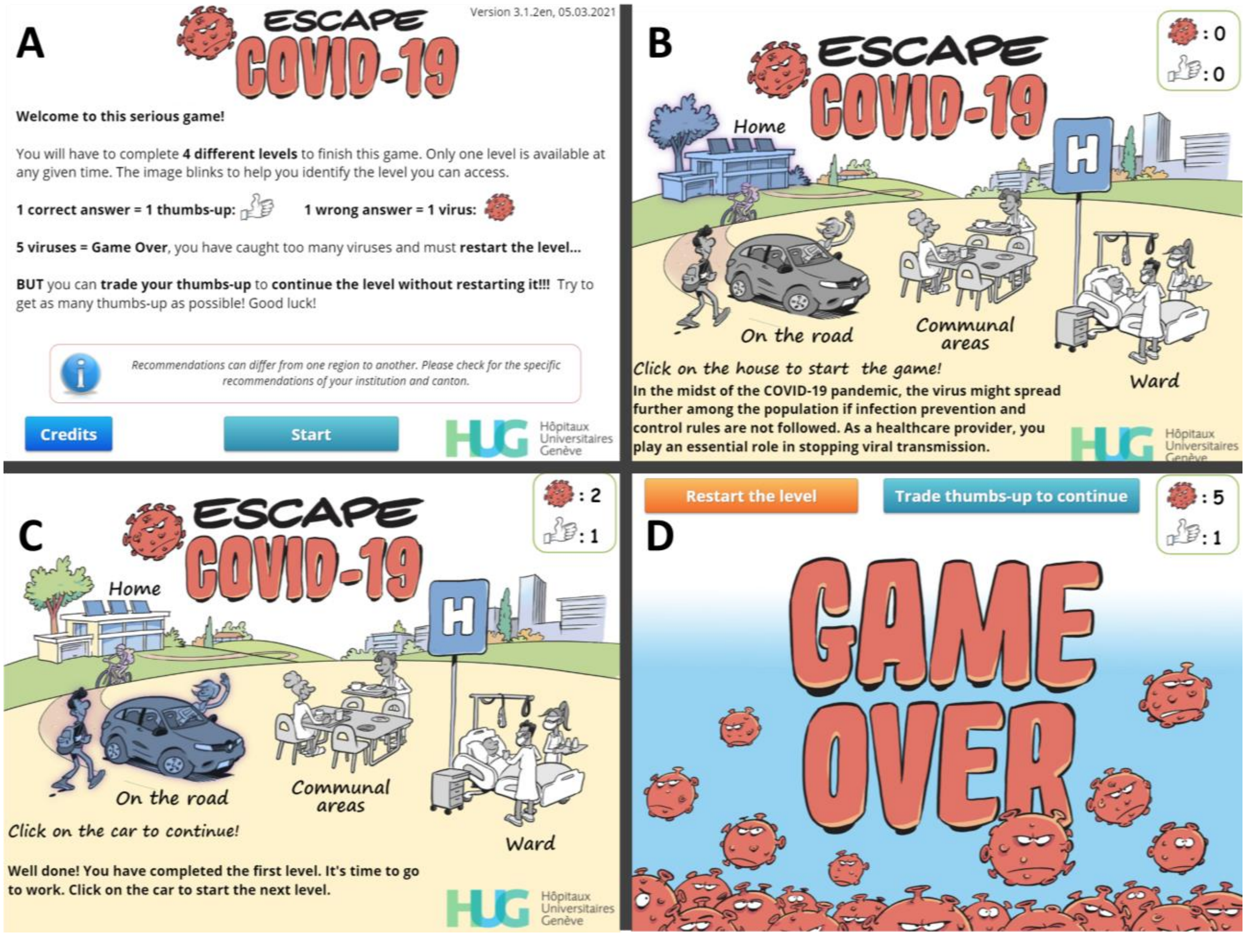

Figure 3. Escape COVID-19 serious game. A: the initial screen displays the rules of the game. B: after clicking on start, the game board with the four levels and the initial context is shown. C: the first level has been completed by the participant, and the score has changed (top right); the participant is congratulated and is now told they must go to work (and click on the "on the road" image). D: the participant has gathered five viruses and is shown the "game over" screen; they can trade their thumbs-up to continue or restart the current level.

The Escape COVID-19 serious game is freely available in both French and English: https://escape-covid19.ch/

Design and implementation of web-based trials

Rationale

Scientifically sound studies are necessary to determine the impact of learning tools on knowledge and skills acquisition and retention. The need for physical distancing notwithstanding, assessing web-based tools through web-based studies is only logical. Such studies must be carefully planned and require a considerable amount of pre-testing to avoid bugs putting potential participants off.

Web-based questionnaires

Since questionnaires are almost always necessary, even if only to gather demographical data, ensuring the quality and validity of the data obtained through web-based questionnaires essential. This was acknowledged by Gunther Eysenbach, founder and Editor-in-Chief of the Journal of Medical Internet Research, who created and published the Checklist for Reporting Results of Internet E-Surveys (CHERRIES) in 2004 [51]. In addition to regular items common to all questionnaires, this checklist covers many important aspects specific to web-based platforms:

- Pre-testing
- Question randomization and adaptive questioning
- Completeness check and review step
- Electronic participant identification, including cookies and internet protocol address check.

In Eysenbach's original publication [51], pre-testing refers to "the usability and technical functionality of the electronic questionnaire". While this is of course necessary, it does not take a critical element into account: checking the data extraction mechanisms. Such mechanisms must indeed be tested prior to study inception to ensure that data is adequately recorded and can easily be exported. In addition, data must also be secured. Securing data should be considered in two separate ways: first, data should be backed up to avoid any preventable loss in case of hardware failure; second, data should only be accessible to authorized research investigators, particularly if identifying information is collected. In this latter case, participants should be able to access their data and request their deletion. Even though Switzerland is not part of the European Union, it would be unrealistic to believe that the General Data Protection Regulation (GDPR) would not apply to any participant. Therefore, web-based studies gathering identifying information should enable participants to review and erase their data at will.

Attrition

Another important, common, and often overlooked element should also be taken into account when designing web-based studies: attrition [52–54]. While attrition is expected in longitudinal studies, it is less watched for in one-shot web-based studies. Nevertheless, many elements may lead to significant attrition: questionnaires may be too long [55], participants may find the material uninteresting, or there may be a compatibility problem with the device used to access the web-based material. All these elements should be considered prior to study inception and monitored during the study.

Web-based randomized trials

To avoid some preventable biases, randomization should also be strongly considered when carrying out web-based studies. While the regular Consolidated Standards of Reporting Trials (CONSORT) guidelines can be used [56], many aspects specific to web-based trials are not covered by the original statement. Acknowledging the challenges and features specific to web-based trials, Eysenbach published, in 2011, an extension of the CONSORT statement dubbed CONSORT-EHEALTH (Consolidated Standards of Reporting Trials of Electronic and Mobile HEalth Applications and onLine TeleHealth). There have been several revisions of this extension over time, with the latest version (1.6) available online as a Google Form. While this extension enables researchers carrying out web-based trials to report their studies in a comprehensive and systematic way, it is not devoid of flaws and further iterations (and possibly forks) should be considered.

Practical aspects

Besides all the critical considerations exposed above, three main aspects must be considered:

1. Site hosting: not all web hosts are equivalent. Particular attention must be paid to data protection and backup. The operating system, hardware, storage space and available bandwidth should also be considered before selecting a host.
2. Development environment: most current websites rely on content management systems (CMS), such as Wordpress, Joomla, or Drupal. Many are open source and free to use, even for commercial purposes. However, none of them can be used for research purposes out of the box and additional, often expensive extensions may be necessary.
3. Coding abilities: in line with the previous point, research-specific features may be desirable or even necessary but may not be available, even through commercial extensions. Therefore, at least one team member should be proficient in computer coding, particularly in programming languages used for web development such as HTML5 (HyperText Markup Language 5), PHP (Hypertext Preprocessor), CSS (Cascading Style Sheets) and Javascript.

The Joomla CMS was used in all the studies described in this Privat-Docent thesis. This CMS natively embeds a feature called “access control list”, which allows administrators and super users to define user groups and restrict access to certain parts of the website. This facilitates attrition monitoring and ensures that participants will follow the study’s steps in the order intended by the investigators.

All study sites were hosted in Switzerland (Kreativmedia GmbH, Zürich). Apart from automated daily backups, this host and its location ensured one of the highest level of data protection currently available. In addition, the recent and powerful servers used ensured that there would be virtually no attrition because of server unavailability or sluggishness.

These elements are systematically reported in the methods of all the studies included in this Privat-Docent thesis, along with the extensions used to perform specific tasks. In addition, the first four studies refer to the articles describing the development of the gamified e-learning module and of the serious game. These articles have been published open access and are freely available on the internet:

- The development of the gamified e-learning module was published in June 2020 in JMIR Serious Games. The article was called *Teaching Adequate Prehospital Use of Personal Protective Equipment During the COVID-19 Pandemic: Development of a Gamified e-Learning Module*.

Reference: Suppan M, Gartner B, Golay E, Stuby L, White M, Cottet P, Abbas M, Iten A, Harbarth S, Suppan L. *Teaching Adequate Prehospital Use of Personal Protective Equipment During the COVID-19 Pandemic: Development of a Gamified e-Learning Module.* JMIR Serious Games. 2020 Jun 12;8(2):e20173. doi: 10.2196/20173. PMID: 32516115; PMCID: PMC7295001 [43].

- The development of the Escape COVID-19 serious game was published in the same journal in December 2020: *A Serious Game Designed to Promote Safe Behaviors Among Health Care Workers During the COVID-19 Pandemic: Development of "Escape COVID-19"*.

Reference: Suppan M, Catho G, Robalo Nunes T, Sauvan V, Perez M, Graf C, Pittet D, Harbarth S, Abbas M, Suppan L. *A Serious Game Designed to Promote Safe Behaviors Among Health Care Workers During the COVID-19 Pandemic: Development of "Escape COVID-19"*. JMIR Serious Games. 2020 Dec 3;8(4):e24986. doi: 10.2196/24986. PMID: 33242312; PMCID: PMC7717924 [44].

Original articles

Effect of an E-Learning Module on Personal Protective Equipment Proficiency Among Prehospital Personnel: Web-Based Randomized Controlled Trial

This article describes a web-based, quadruple-blind randomized controlled trial designed to assess whether a lightly gamified e-learning module could improve knowledge acquisition regarding prehospital personal protective equipment (PPE) use in comparison with standard guidelines [38]. The e-learning module used as experiment was the result of a collaborative, interprofessional and trans-departmental development carried out at the Geneva University Hospitals [43]. All professional prehospital providers working in Geneva were invited to participate and represented a convenience sample. The participation rate was high (176/291, 60.5%) and both interventions significantly improved the rate of adequate PPE choice. The e-learning module was not more effective at improving correct PPE choice than standard guidelines but increased the participants' confidence in their ability to use this equipment. This lack of statistically significant difference was thought to spawn from the already high baseline knowledge in this population rather than from a lack of effect of the e-learning module.

Reference: Suppan L, Abbas M, Stuby L, Cottet P, Larribau R, Golay E, Iten A, Harbarth S, Gartner B, Suppan M. *Effect of an E-Learning Module on Personal Protective Equipment Proficiency Among Prehospital Personnel: Web-Based Randomized Controlled Trial.* J Med Internet Res. 2020 Aug 21;22(8):e21265. doi: 10.2196/21265. PMID: 32747329; PMCID: PMC7446759 [38].

Original Paper

Effect of an E-Learning Module on Personal Protective Equipment Proficiency Among Prehospital Personnel: Web-Based Randomized Controlled Trial

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Abstract

Background: To avoid misuse of personal protective equipment (PPE), ensure health care workers' safety, and avoid shortages, effective communication of up-to-date infection control guidelines is essential. As prehospital teams are particularly at risk of contamination given their challenging work environment, a specific gamified electronic learning (e-learning) module targeting this audience might provide significant advantages as it requires neither the presence of learners nor the repetitive use of equipment for demonstration.

Objective: The aim of this study was to evaluate whether a gamified e-learning module could improve the rate of adequate PPE choice by prehospital personnel in the context of the coronavirus disease (COVID-19) pandemic.

Methods: This was an individual-level randomized, controlled, quadruple-blind (investigators, participants, outcome assessors, and data analysts) closed web-based trial. All emergency prehospital personnel working in Geneva, Switzerland, were eligible for inclusion, and were invited to participate by email in April 2020. Participants were informed that the study aim was to assess their knowledge regarding PPE, and that they would be presented with both the guidelines and the e-learning module, though they were unaware that there were two different study paths. All participants first answered a preintervention quiz designed to establish their profile and baseline knowledge. The control group then accessed the guidelines before answering a second set of questions, and were then granted access to the e-learning module. The e-learning group was shown the e-learning module right after the guidelines and before answering the second set of questions.

Results: Of the 291 randomized participants, 176 (60.5%) completed the trial. There was no significant difference in baseline knowledge between groups. Though the baseline proportion of adequate PPE choice was high (75%, IQR 50%-75%), participants' description of the donning sequence was in most cases incorrect. After either intervention, adequate choice of PPE increased significantly in both groups ($P<.001$). Though the median of the difference in the proportion of correct answers was slightly higher in the e-learning group (17%, IQR 8%-33% versus 8%, IQR 8%-33%), the difference was not statistically significant ($P=.27$). Confidence in the ability to use PPE was maintained in the e-learning group ($P=.27$) but significantly decreased in the control group ($P=.04$).

Conclusions: Among prehospital personnel with an already relatively high knowledge of and experience with PPE use, both web-based study paths increased the rate of adequate choice of PPE. There was no major added value of the gamified e-learning module apart from preserving participants' confidence in their ability to correctly use PPE.

(J Med Internet Res 2020;22(8):e21265) doi: 10.2196/21265

KEYWORDS

personal protective equipment; COVID-19; electronic learning; prehospital; randomized controlled trial; protection; equipment; safety; gamified; online learning; communication

Introduction

Background and Importance

Adequate use of personal protective equipment (PPE) is of paramount importance to ensure health care workers' safety and to avoid shortages of such equipment in the context of the coronavirus disease (COVID-19) pandemic [1,2]. Protection guidelines against severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection have rapidly evolved following publication of new evidence regarding its mode of transmission, making prompt adaptation of the guidelines both frequent and necessary [3-5]. Prehospital personnel is particularly at risk of contamination as they usually work in a challenging environment and have to stay next to their patients in the narrow space of the ambulance for extended periods of time. This risk is further increased when high-risk procedures such as endotracheal intubation have to be performed [6-8].

To avoid misuse of PPE, effective communication of the corresponding guidelines to frontline health care workers is necessary [9]. However, continuous education has been massively disrupted due to the cancellation of continuous education sessions to limit disease transmission [10]. In this challenging context, electronic learning (e-learning) might provide significant advantages as it requires neither the presence of learners nor the repetitive use of equipment for demonstration as could be the case for live simulation [11,12].

Goal of This Investigation

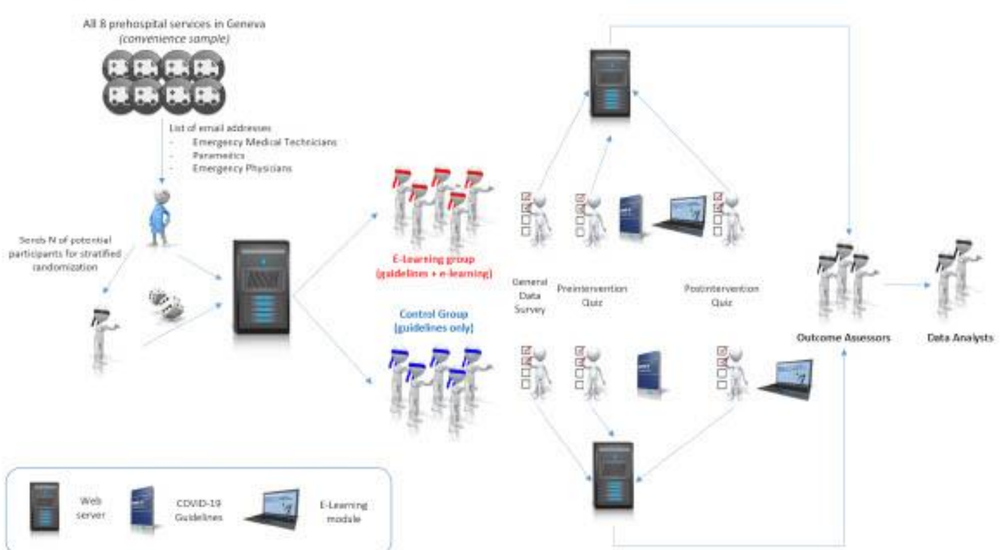
The purpose of this study was to evaluate whether a specifically designed gamified e-learning module [13] could improve the rate of adequate PPE choice by prehospital personnel in the context of the COVID-19 pandemic. Our hypothesis was that knowledge of PPE guidelines would be inconsistent between prehospital personnel, and that an e-learning module may increase and standardize knowledge regarding the use of PPE. This could help limit both underuse and overuse of such equipment.

Methods

Study Design

This was an individual-level, stratified, randomized, controlled, quadruple-blind (investigators, participants, outcome assessors, and data analysts) closed web-based trial (Figure 1) designed following the CONSORT-EHEALTH (Consolidated Standards of Reporting Trials of Electronic and Mobile HEalth Applications and onLine TeleHealth) guidelines [14,15] and incorporating relevant elements from the CHERRIES (Checklist for Reporting Results of Internet E-Surveys) statement [16].

Figure 1. Study design.



Enrolment and Consent

Individual emails that were identical for all participants except for the unique links that pointed to one of the two study paths were sent on April 13, 2020 (Multimedia Appendices 1 and 2). These unique links were automatically created by the survey component but were not recorded in the mailing component other than in generic form (there was no way the individual tokens could be linked to the email addresses). The webmaster could therefore only know whether the email had been opened and the survey started, but was prevented from reconciling the email address with the survey answers, thereby guaranteeing user anonymization. Using unique links served two purposes: they allowed the participants to resume the course in case they were interrupted and also avoided double entries. Given the current circumstances, and as the vast majority of prehospital professionals had had their holidays cancelled and were therefore at work, participants were only given 12 days to complete the study, with email reminders sent on days 3, 7, and 10.

Apart from the survey link, the emails contained information regarding the study length and objectives as well as a short data protection statement. Participants were informed that they would be presented with the most recent version of the prehospital COVID-19 guidelines as well as with an e-learning module, though the order in which these materials would be shown was not explained. They were informed that, by clicking on the survey link, they consented to participate in the study and were provided with the names and electronic addresses of five investigators (BG, EG, L Stuby, L Suppan, and PC), whom they could contact at any time. As collected data were irreversibly anonymized, it was impossible for users to ask for their own answers to be deleted once the survey had been completed.

To improve the response rate, the chief ambulance and medical officers of all companies were asked to encourage their paramedics, EMTs, and emergency physicians to participate in the study. Participation reminders were also sent to all prehospital personnel along with a daily COVID-19 information newsletter.

Participation was not mandatory. No monetary incentive or prize was offered to the survey participants. As the e-learning module was akin to a continuous education session, participants were informed before beginning the survey that they would be able to print a continuous education certificate upon completion. As the certificate component was independent from both the mailing and the survey components, participants were ensured they could generate the certificate without their identity being disclosed.

Study Sequence

After clicking on the survey link, a welcome screen containing detailed information about the study was displayed. This welcome screen was identical for both groups and, similarly to the email messages, did not convey any information regarding the study sequence to ensure the participants were adequately blinded.

After clicking on the start button, participants were asked a series of questions designed to gather demographic-related data. Adaptive questioning was used in this section to avoid displaying irrelevant questions. Participants were then asked a series of general questions related to SARS-CoV-2 and the COVID-19 pandemic.

The control group was then shown the prehospital COVID-19 guidelines. They were then asked to answer a second set of questions before being prompted to evaluate the learning path up to this point. Only then could they access the e-learning module and download their certificate.

The e-learning group followed the same path at first, but accessed the e-learning module immediately after being shown the guidelines. This group then completed the same second set of questions, was asked to evaluate the learning path (which in this case included the e-learning module), and was finally allowed to download the completion certificate.

Outcomes

The main outcome was defined as the difference in the proportion of correct choice of PPE before and after the course, assessed by means of short clinical scenarios.

Secondary outcomes were stratification of the main outcome by profession and by personal history of COVID-19 (whether or not the participant had been infected), accuracy of donning and doffing sequences reconstitutions, differences in the rates of overuse and underuse of PPE, confidence in one's ability to use PPE, perceived usefulness of the course, and satisfaction regarding the course. The latter three outcomes were assessed by means of a 5-point Likert scale.

Data Collection

Data was electronically recorded and securely stored in an encrypted MariaDB database (Version 5.5.5; MariaDB Foundation). At the end of the study, all data was extracted to CSV format by the only investigator who had access (L Suppan). No personally identifiable data (including name, date of birth, email, or IP address) was ever asked for or recorded.

Data Curation and Availability

The extracted data were imported into Stata (StataCorp LLC). Variables were renamed to facilitate their understanding by the blinded data analysts. All data that could have enabled data analysts to identify group allocation were removed, and data fields were sorted accordingly. Incomplete questionnaires were excluded at this stage. The control and e-learning groups were renamed using city names (Moscow and Nairobi), and all relevant data were exported by L Suppan to a Stata .dta file and sent to L Stuby and MA for analysis.

Sample Size

As guidelines differ from region to region, we decided to only include prehospital staff working in the Geneva emergency medical system, thereby using a convenience sample rather than performing a sample size calculation.

Outcomes Assessment

Though most outcomes were electronically recorded and their interpretation therefore was generally independent of subjective human evaluation, comments had to be assessed by outcome

The regional ethics committee issued a "Declaration of no objection" (Req-2020-00374) as the population studied was not considered vulnerable according to the Swiss federal law on human research [17]. As the purpose of the study was to examine the effect of two different study paths only on providers' knowledge and attitude toward PPE, registration of the trial was not performed as it is not deemed necessary by the International Committee of Medical Journal Editors [18].

Setting

The study took place in April 2020 in Geneva, Switzerland; the detailed organization of local prehospital emergency services has already been described elsewhere [19]. There are five levels of increasing expertise working in the prehospital field. Ambulance drivers all have a basic life support certificate but are never called upon to deal with emergency situations. Emergency medical technicians (EMTs) are certified after 1 year of training, and can either transport stable patients on their own, or team up with a paramedic to deal with more difficult prehospital situations. The highest level of nonphysician care is provided by paramedics, who complete a 3-year curriculum. Whenever a potentially life-threatening emergency is identified by emergency dispatchers, paramedics are sent in teams of two. A medical reinforcement by way of a light vehicle, Service Mobile d'Urgence et de Réanimation (SMUR), staffed by a paramedic and an emergency physician can either be dispatched at the same time as the ambulance or be called upon by paramedics if specialized medical care is required on site. Emergency physicians are either senior residents or fellows working in one of the following departments: emergency medicine, anesthesiology, or general internal medicine. They can be supervised, either by call or on-site, by a senior specialist emergency physician, which represents the highest level of prehospital care in this setting.

Apart from the physician-staffed prehospital medical service, there are seven different ambulance companies in Geneva, two of which belong to public organizations while the remaining five are privately owned. As each company has its own continuous education structure as well as its own equipment, medical devices, and protocols, one cannot expect all paramedics to share the same knowledge level regarding all aspects of prehospital emergencies.

Online Platform

An online platform [20] developed under the Joomla! 3.9 content management system (Open Source Matters) was created specifically for the purpose of this study. A mailing management component (AcyMailing 5.10, Acyba), a survey component (Community Surveys Pro 5.4.0, CoreJoomla), and a form builder component used to issue completion certificates (BreezingForms Pro 1.9.0, Crosstec) were installed on the website. L Suppan was the only author with access to the platform's administration console. No maintenance or update was planned on the server, platform, or content during the study period.

Study Material

A previously described gamified e-learning module created under Storyline 3 (Articulate Global) was used in this study [13]. The module contains 19 sections and embeds 7 video sequences. Within the module, trigger mechanisms are used to check that the user had accessed and completed all required steps before being allowed to proceed to the following section. The e-learning package is available on the study website where it can be viewed and downloaded freely. The comprehensive prehospital COVID-19 guidelines from the Geneva University Hospitals, version 1.11, was also used in this study [21].

Two quizzes were created by BG and L Suppan: a preintervention quiz designed to establish the participants' baseline knowledge regarding PPE, their use and indication, and a postintervention quiz to assess whether these parameters had changed. Both quizzes contained 10 closed questions, either multiple choice or multiple answer. Questions designed to assess PPE choice were preceded by short clinical scenarios. Each quiz was displayed over 5 pages. The number of questions was limited to reduce attrition. These quizzes were tested and validated by all coinvestigators.

Consistency of specific "free-text" questions, such as age, was checked by means of regular expression ("regex") rules. All answers were automatically checked for completeness by the system before participants were allowed to proceed to the next page. Custom validation messages were displayed to inform users who had not answered a question. Participants were not allowed to correct or review their answers once a page had been completed.

Subjects and Inclusion and Exclusion Criteria

Chief ambulance officers of all services were asked to provide one of the investigators (L Suppan) with a list of all the professional email addresses of their EMTs, paramedics, and emergency physicians. All the email addresses received from these officers were included.

Email addresses of ambulance drivers were excluded as these drivers usually only deal with interhospital transfers and almost never don PPE. Senior specialist emergency physicians were also excluded, as they are few in number and are usually involved in the writing of the guidelines or in the creation of the learning material; in addition, some of them are authors of this study. Finally, the email addresses of the paramedics who participated in the creation of this study or the learning material were also excluded.

Randomization and Allocation Concealment

Before performing a 1:1 randomization, stratification was achieved according to professional status (EMTs, paramedics, and emergency physicians). Email addresses were then sorted according to alphabetical order, and an investigator (MS) who did not have access to the email addresses database was given the number of participants by category and performed the randomization using a computer-generated table. The randomization key was then combined with the list of email addresses and entered in the mailing component by the only investigator who had access to the system (L Suppan). As the list of email addresses and allocations were solely present in an encrypted database, all other investigators were blinded as to group allocation.

assessors. Two assessors (L Stuby and PC), blinded as to group allocation, were asked to independently assess all comments. The nature of comments were to be rated as "positive," "negative," or "neutral" regarding the study, and as to whether they challenged Infection Prevention and Control (IPC) guidelines (binary, yes versus no). Disagreements were solved by sending the unclear comments to a third outcome assessor (BG), who was blinded to the previous assessments.

Statistical Analysis

Statistical analysis was performed using Stata 15. Continuous independent outcomes were assessed using the Student *t* test or the Mann-Whitney rank-sum test depending on normality. Categorical outcomes were assessed using Fisher exact test. A two-sided $P<.05$ was considered significant. Normality of distribution was first assessed graphically. In case of doubt, the Shapiro-Wilk test was applied.

Continuous paired data were assessed using either the paired Student *t* test or the Wilcoxon matched-pairs signed-rank test depending on normality. The sign test for matched pair was used if symmetry could not be proven. Categorical paired data were analyzed using asymptotic symmetry and marginal homogeneity tests. Binomial paired data were assessed using the McNemar test.

Stratification was defined a priori based on expertise level (EMTs, paramedics, or physicians) and COVID-19 status (negative; confirmed, quarantined; confirmed, cured or unknown). Two post hoc sensitivity analyses were conducted.

Data Availability

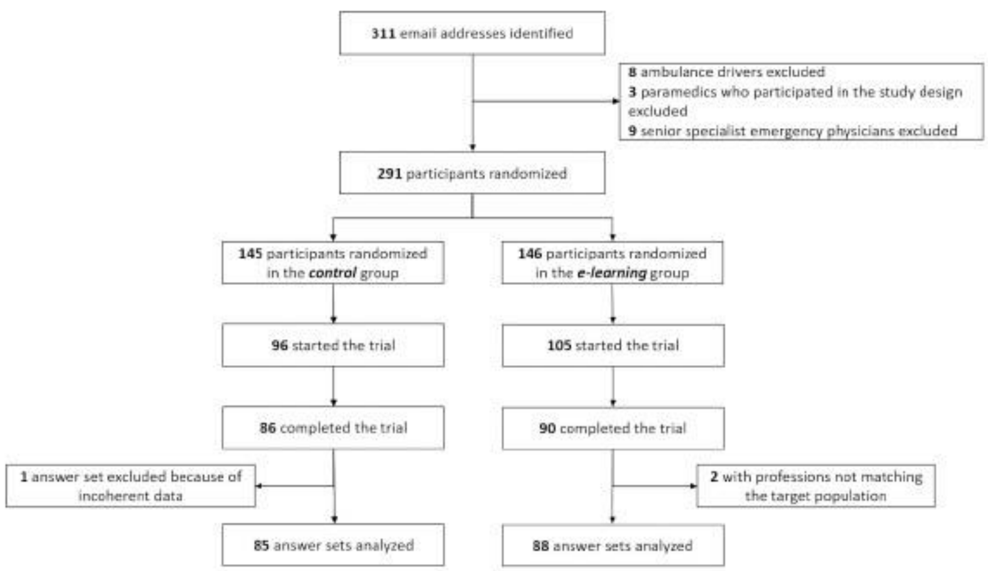
The original data has been deposited to Mendeley Data [22].

Results

Characteristics of Study Subjects

Of the 291 randomized participants, 176 (60.5%) completed the trial (Figure 2). No change was made to the web platform after the first batch of emails was sent. There was no significant downtime (the server was available more than 99% of the time throughout the study period). Just three participants were unable to complete the trial owing to technical problems, the exact nature of which could not be determined: two were not able to access the e-learning module, and one could not access the guideline (in PDF format). The study path was completed in one session by 82.7% of the participants (143/173).

Figure 2. Study flowchart.



The blinded data analysts (L Stuby and MA) excluded two surveys from the e-learning group as the participants' professions did not match the target population (one "ambulance driver" and one "other"). They also excluded one survey from the control group because of incoherent answers (Multimedia Appendix 3). Participant characteristics are described in Table 1.

Figure 3. Change in proportion (%) of adequate choice of personal protective equipment.

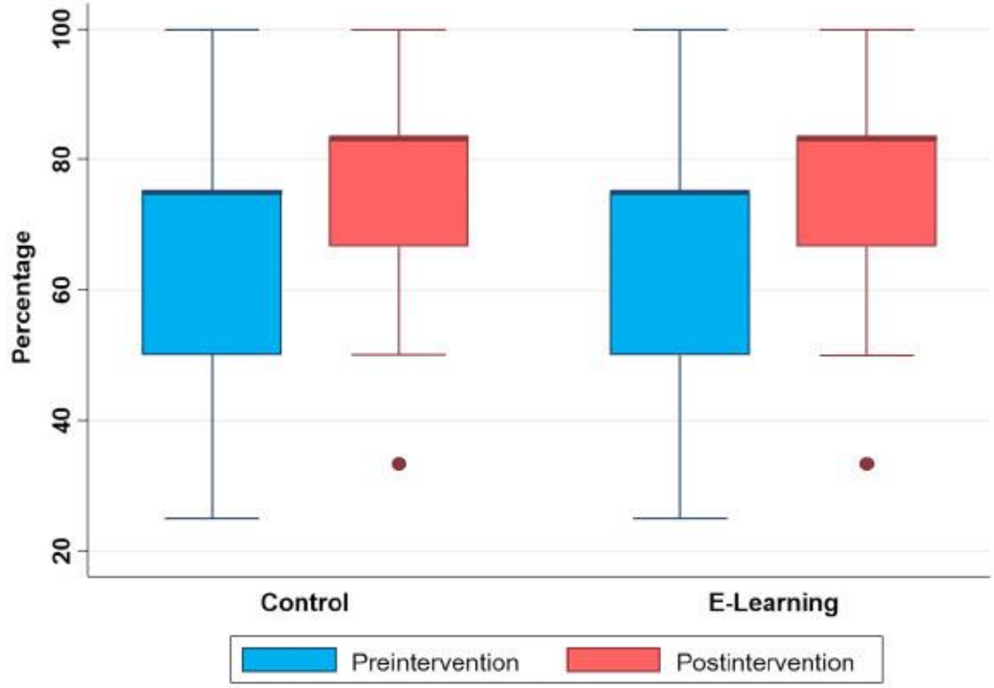


Table 2. Adequate choice of personal protective equipment (main outcome).

Outcomes	Control (n=85)	E-learning (n=88)	*P* value
Main outcome: difference in percentage of correct answers, median (Q1-Q3)	8 (8 to 33)	17 (8 to 33)	.27
Main outcome by profession (%), median (Q1-Q3)			
Paramedic	8 (0 to 25)	17 (8 to 33)	.15
Paramedic student	25 (8 to 33)	29 (25 to 33)	.49
Emergency medical technician	25 (8 to 33)	8 (–8 to 33)	.88
Physician	25 (13 to 38)	13 (–8 to 42)	.30
Main outcome by coronavirus disease status (%), median (Q1-Q3)			
Negative for coronavirus disease	8 (8 to 33)	25 (8 to 33)	.20
Positive for coronavirus disease	8 (–8 to 33)	0 (–8 to 17)	.37

Confidence in the ability of using PPE was identical before and after the course in the e-learning group (P=.27), but was significantly lower after the course in the control group (P=.04).

While most participants found the course useful (68.5%, 95% CI 61.5%-75.3%), the proportion of participants finding the course "very useful" was significantly higher (P=.01) in the e-learning group (33.0%, 95% CI 23.2%-42.8% versus 11.8%, 95% CI 4.9%-18.7%). Participants were generally satisfied regarding the course (60.0%, 95% CI 49.6%-70.4% for the e-learning group versus 62.5%, 95% CI 52.4%-72.6%; P=.28; Figure 4).

Table 1. Participant characteristics[a].

Characteristics	Control (n=85)	E-learning (n=88)
Profession, n (%)		
Student paramedic	5 (5.9)	10 (11.4)
Emergency medical technician	11 (12.9)	12 (13.6)
Paramedic	61 (71.8)	60 (68.2)
Physician	8 (9.4)	6 (6.8)
Gender, female, n (%)	32 (37.6)	28 (31.8)
Age (years), median (Q1-Q3)	35 (30-42)	34 (28-40)
Professional experience (years), median (Q1-Q3)	9 (3-15)	7 (2-12)
Prior infection prevention and control course, n (%)		
No/does not remember	73 (85.1)	70 (79.6)
Yes	12 (14.1)	18 (20.4)
Coronavirus disease status, positive, n (%)	7 (8.3)	6 (6.8)
Local guideline seen, yes, n (%)	79 (92.9)	84 (95.4)
Last time guideline seen (days), median (Q1-Q3)	5 (3-10)	5 (2-8)
Specific coronavirus disease course followed, yes, n (%)	28 (32.9)	32 (36.4)

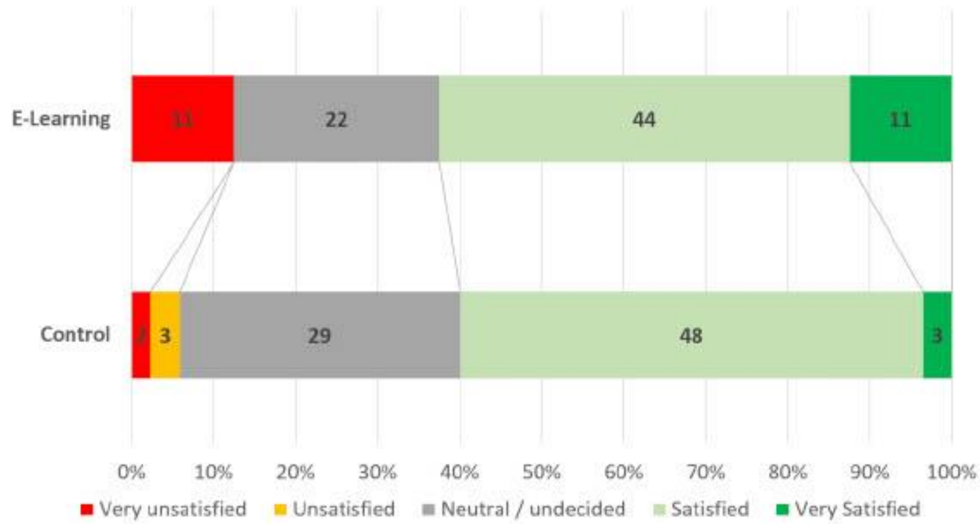
[a]Totals may not equal to 100% due to rounding.

Main Results

There was no significant difference in baseline knowledge between groups. Though the baseline proportion of adequate PPE choice was high (75%, IQR 50%-75%), description of the donning sequence (assessed preintervention) was in most cases incorrect, as only 7 (4%) of the participants were able to reconstitute it accurately, with a similar proportion between groups. The donning sequence initially displayed in the survey was left unchanged by 7% of the participants (12/173, 6 per group).

Adequate choice of PPE was significantly increased in both groups after the intervention (*P*<.001; Figure 3). Though the median of the difference was higher in the e-learning group (17%, IQR 8%-33% versus 8%, IQR 8%-33%), it did not reach statistical significance (*P*=.27). This difference was similar regardless of stratification by profession or history of COVID-19 (Table 2). No participant was able to describe the correct doffing sequence, which was assessed postintervention. The doffing sequence originally displayed in the survey was left unchanged by 8% of the participants (14/173, 7 per group).

Figure 4. Participant satisfaction.



The proportion of positive comments was similar between groups (14%, 95% CI 7%-21% in the e-learning group versus 19%, 95% CI 11%-27%; P=.16). Participants who expressed disagreements with IPC recommendations were also evenly divided (5.7%, 95% CI 3.2%-8.2% in the e-learning group versus 4.7%, 95% CI 0.2%-9.2%; P>0.99).

Two post hoc sensitivity analyses were performed. The first was achieved by excluding all participants who answered they were either "very unsatisfied" or "unsatisfied" with the course. The second was performed by excluding participants whose compliance regarding COVID-19–specific IPC guidelines could be doubted; this included those who did not answer "systematic wearing of a double pair of gloves" to the question "Which of these measures is NOT one of the infection prevention measures?" (40 [45%] in the e-learning group versus 35 [41%]). These analyses did not demonstrate a significant change regarding the main outcome (P=.89 and P=.29, respectively).

Discussion

Main Results

In this study, the proportion of those making an adequate choice regarding PPE increased significantly after prehospital personnel followed either web-based study path. Though the median of the increase was twice that of the e-learning group, this difference was not statistically significant.

Failure to reach significance might be explained by many different factors. The high baseline proportion of adequate choice of PPE in both groups may have dampened any relative impact of the intervention as there was little room left for improvement. Although this result might seem counterintuitive given the high rate of participants who responded that they did not attend (or did not recall attending) an IPC course prior to this study, more than 90% declared they had consulted the local guidelines recently. Most participants were therefore aware of the local recommendations, and the anxiety generated by the COVID-19 pandemic probably acted as a catalyst regarding their interest in such guidelines [23].

Another factor that might partly explain the lack of a significant difference is the sample size, which limited the power to detect small differences. Nevertheless, as PPE guidelines vary not only between countries, but also between Swiss cantons, it might have been inadequate to draw conclusions from a pooled group of paramedics working in different cantons with different guidelines [24]. Moreover, though increasing the sample size would increase the chances of finding a significant difference, too small an increase would not be clinically relevant regardless of the P value obtained [25]. Lack of significance might therefore also be consecutive to lack of effect of the e-learning module regarding knowledge acquisition in this particular population.

Though necessary to assess participants' knowledge and attitudes regarding PPE prior to the interventions, the first set of questions, along with the study title, might have acted as a primer and focused the participants' attention on the specific contents that would be tested postintervention [26]. This effect might have further dampened the potential impact of the e-learning module.

The relatively low level of satisfaction displayed by the participants should also be taken into account. Though e-learning modules and serious games usually increase participant satisfaction when compared to more traditional methods [27,28], such an effect could not be found in this study. Disagreement with IPC guidelines might, at least in part, explain why some participants were dissatisfied [5,29,30]. Indeed, the vast majority of paramedics working in Geneva have had some prior training regarding the use of PPE in situations other than the COVID-19 pandemic. Preparations for high-risk transfers during the 2014 Ebola epidemic [31] and practical exercises in the context of simulated major incidents involving the presence of hazardous materials [32] have presented paramedics with many different PPE guidelines and protocols over the last few years. As the latter situations require more stringent donning and doffing procedures than those described in the COVID-19 context, some paramedics seem to feel that IPC recommendations do not go far enough. There is however a delicate balance between underprotection and overuse of scarcely available resources that must be maintained [33,34]. Moreover, it can hardly be expected to have all paramedics don maximal PPE for all interventions. This would not only considerably increase intervention time, but also make delicate interventions more difficult given the bulk of the PPE and lead to more difficult communications. It could also increase fatigue as such equipment has been shown to be quite uncomfortable [35].

Secondary Outcomes

Though confidence in the ability to use PPE was maintained in the e-learning group, it significantly decreased after reviewing the guidelines in the control group. Participants who initially felt confident in their knowledge might have felt it was challenged after being asked specific questions [36,37]. The e-learning module probably helped restore their altered confidence, as interactive presentations, as well as gamification, have been shown to increase this feeling [38,39]. Nevertheless, most participants were unable, regardless of their assigned intervention, to reconstruct either the donning (assessed preintervention) or the doffing (assessed postintervention) sequences. This potential limitation has already been highlighted in the paper describing the development of the gamified e-learning module used in this study [13], though cut scenes were embedded to provide direct demonstration [40,41].

Though incorrect answers regarding the donning sequence are easily understandable as they might primarily result from a lack of knowledge, an inability to correctly rebuild the doffing sequence is questioning. No less than four different broad categories of causes could be involved: ineffectiveness of the teaching material, inadequate sequence, flawed means of assessing the participants' knowledge, or disagreement with the procedure outlined in the guidelines and in the e-learning module. As this result was unforeseen, the method used in this study was unfortunately ill-suited to the evaluation of the underlying causes. Nevertheless, with less than 10% of participants having left the initially displayed sequences unchanged, a technical flaw can reasonably be ruled out.

Limitations

Apart from the abovementioned limitations, the ever-increasing knowledge regarding SARS-CoV-2 and COVID-19 might render both the guideline and the gamified e-learning module used in this study obsolete. However, current technological tools might mitigate this effect as they allow for a quick adaptation, even of highly interactive content [42].

Another limitation is the relatively small number of questions asked pre- and postintervention. Keeping the total number of questions and the time required to complete either study path relatively low was necessary to limit attrition [16,43]. This strategy was altogether successful as dropouts amounted to less than 15% in either group, a rather lower proportion than generally reported [44]. Attrition was further limited thanks to the use of unique identifiers, which allowed as many as 30 participants (17.3%) to complete their assigned study path in more than one session.

Despite its limitations, this study also has some strengths, among which the quadruple-blind design and the relatively high response rate should be acknowledged. Moreover, as all answers were electronically recorded, there was no risk of an outcome assessment bias. Finally, as neither the control nor the e-learning path requires the physical presence of either participants or instructors, the framework used in this study could serve as the building ground for courses in the context of an epidemic or a pandemic such as the current COVID-19 situation.

Perspectives

The larger impact such a web-based study might have had, regardless of the effect of a specific intervention such as the gamified e-learning module, should be assessed, as a possible change in PPE consumption or infection rate among prehospital providers could ensue.

The potential impact of this gamified e-learning module on less experienced and less primed participants should also be evaluated to confirm (or refute) the theories outlined in this discussion. The gamified e-learning module can thus be freely downloaded from the study website in both a web (HTML5 with Flash fallback) and SCORM (Shareable Content Object Reference Model) format.

Conclusions

Among prehospital personnel with an already relatively high knowledge and experience regarding PPE use, both web-based study paths increased the rate of adequate choice of PPE. There was no major added value of the gamified e-learning module apart from preserving participants' confidence in their ability to correctly use PPE.

Acknowledgments

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Conflicts of Interest

Most of the authors participated in the development of the gamified e-learning module tested in this trial. Nevertheless, as this module is freely available, the authors deny any financial conflict of interest.

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Editorial Notice

This randomized study was not prospectively registered. As the purpose of the study was to examine the effect of two different study paths only on providers' knowledge and attitude toward PPE, registration of the trial was not performed as it is not deemed necessary by the International Committee of Medical Journal Editors. The editor is therefore following the guidelines suggested by the ICMJE and not mandating prospective registration of this randomized trial. However, readers are advised to carefully assess the validity of any potential explicit or implicit claims related to primary outcomes or effectiveness, as retrospective registration does not prevent authors from changing their outcome measures retrospectively.

Multimedia Appendix 1

First email sent to participants belonging to the control group.
[PDF File (Adobe PDF File), 45 KB-Multimedia Appendix 1]

Multimedia Appendix 2

First email sent to participants belonging to the e-learning group.
[PDF File (Adobe PDF File), 45 KB-Multimedia Appendix 2]

Multimedia Appendix 3

Details of the answer set excluded by the blinded data analysts.
[PDF File (Adobe PDF File), 126 KB-Multimedia Appendix 3]

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Abbreviations

CHERRIES: Checklist for Reporting Results of Internet E-Surveys
CONSORT-EHEALTH: Consolidated Standards of Reporting Trials of Electronic and Mobile HEalth Applications and onLine TeleHealth
COVID-19: coronavirus disease
E-learning: electronic learning
EMT: emergency medical technician
IPC: infection prevention and control
PPE: personal protective equipment
SARS-CoV-2: severe acute respiratory syndrome coronavirus 2
SCORM: Shareable Content Object Reference Model
SMUR: Service Mobile d'Urgences et de Réanimation

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Impact of Face-to-Face Teaching in Addition to Electronic Learning on Personal Protective Equipment Doffing Proficiency in Student Paramedics: Randomized Controlled Trial

The two randomized controlled trials testing the effect of the gamified e-learning module designed to enhance prehospital PPE use were effective at improving correct PPE choice [38,57]. However, both these studies revealed that most participants were unable to correctly rebuild the donning and, more importantly still, the doffing sequence. Indeed, inadvertent contamination usually happens during the doffing phase [58]. Since e-learning alone was not effective at teaching complex PPE donning and doffing skills [38,57], it was thought that adding a face-to-face teaching intervention could improve both skill acquisition and retention. After developing a protocol designed to test this blended learning modality [59], this multicentric randomized controlled trial was carried out [39]. Its results confirm that a blended learning intervention improves PPE doffing skills acquisition and retention. This is particularly important since viral pandemics are unpredictable and may recur at any time. Efficient teaching interventions must therefore be readily available to help healthcare professionals who have little or even no experience in PPE use acquire the necessary knowledge and skills to protect their patients, their loved ones, and of course themselves.

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Article

Impact of Face-to-Face Teaching in Addition to Electronic Learning on Personal Protective Equipment Doffing Proficiency in Student Paramedics: Randomized Controlled Trial

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Abstract: Personal protective equipment doffing is a complex procedure that needs to be adequately performed to prevent health care worker contamination. During the COVID-19 pandemic, junior health care workers and students of different health care professions who had not been trained to carry out such procedures were often called upon to take care of infected patients. To limit direct contact, distance teaching interventions were used, but different trials found that their impact was rather limited. We therefore designed and carried out a randomized controlled trial assessing the impact of adding a face-to-face intervention using Peyton's four-step approach to a gamified e-learning module. Sixty-five student paramedics participated in this study. The proportion of doffing sequences correctly performed was higher in the blended learning group (33.3% (95%CI 18.0 to 51.8) versus 9.7% (95%CI 2.0 to 25.8), $p = 0.03$). Moreover, knowledge and skill retention four to eight weeks after the teaching intervention were also higher in this group. Even though this study supports the use of a blended learning approach to teach doffing sequences, the low number of student paramedics able to adequately perform this procedure supports the need for iterative training sessions. Further studies should determine how often such sessions should be carried out.

Keywords: personal protective equipment; electronic learning; prehospital; student paramedics; infection prevention; face-to-face learning; randomized controlled trial; Peyton's approach; blended learning

1. Introduction

1.1. Background and Importance

The COVID-19 pandemic has highlighted the key role of personal protective equipment (PPE) and revealed that many HCWs lack both knowledge and training regarding this equipment [1,2]. Efficient and adequate PPE use is, however, of paramount importance to avoid contaminating both patients and HCWs [3,4]. While correctly donning PPE is of critical importance, many studies have shown that contamination usually occurs during the doffing phase [5–10]. In addition, donning and doffing PPE in non-dedicated spaces with time constraints increase the contamination risk even further [11,12].

Training HCWs is an efficient way of decreasing self-contamination during PPE doffing [13–17]. A recent systematic review concluded to the superiority of face-to-face training over passive training only (i.e., text documents or video) regarding PPE doffing procedure compliance [18]. However, the evidence retrieved was considered to be of rather low quality; thus, the authors highlighted the need of further clinical trials for comparing training methods.

A gamified e-learning module tailored to the needs of prehospital providers was previously developed [19]. The impact of this intervention was however limited [20,21]. While distance learning was strongly promoted during the first wave of the COVID-19 pandemic [22,23], complex skills undoubtedly require a blended learning approach, combining workshops and other teaching interventions [24–26]. Such workshops could rely on Peyton's four-step educational approach [27], which has been shown to be more efficient at teaching procedural skills to HCWs than a standard teaching approach [28]. Our hypothesis was that using a blended learning strategy by adding a workshop using Peyton's approach to an interactive, gamified e-learning module would increase knowledge and skill acquisition and retention regarding PPE doffing procedures in student paramedics. Adhering to Peyton's approach was thought to be of particular interest since this method is also used during continuous training sessions followed by paramedics in Switzerland [29,30].

1.2. Objectives

The goal of this randomized clinical trial (RCT) was to determine whether adding a face-to-face teaching intervention (following Peyton's approach) to a gamified e-learning module could improve correct doffing sequences' skills and knowledge and retention in student paramedics.

2. Materials and Methods

2.1. Study Design and Setting

This was a parallel-group, randomized, triple-blind (participants, instructors, and outcome assessors) controlled superiority trial prospectively registered (International Registered Report Identifier PRR1-10.2196/26927) (Figure 1). The protocol has been previously published [31]. It is reported according to the Consolidated Standards of Reporting Trials (CONSORT)-EHEALTH checklist [32] and includes relevant elements from the Checklist for Reporting Results of Internet E-Surveys (CHERRIES) since online questionnaires were used in this study [33]. The regional ethics committee delivered a declaration of non-objection as to conducting this RCT (Req-2020-01340).

All first-year students ($n = 65$) from the Colleges of Higher Education in Ambulance Care located in Bern and Geneva, Switzerland, were invited to participate in this study. To allow the first-year German-speaking students to participate in the study, the study material including the e-learning module was translated in German. There were no exclusion criteria. No incentive was provided.

Instructors, recruited for study purposes, were informed that the objective was to teach the non-contaminating doffing of PPE to first-year students during two training sessions. They were not aware of the study design, and were therefore blinded to the existence of two different training paths. The instructors received a detailed PPE doffing procedure and a summary sheet of the Peyton's approach steps as a reminder during the sessions. They were previously trained by investigators about the doffing procedure and Peyton's pedagogical approach. The instructor:learner ratio was planned to range from 1:1 to 1:3 as such ratios have been shown to be particularly effective [28].

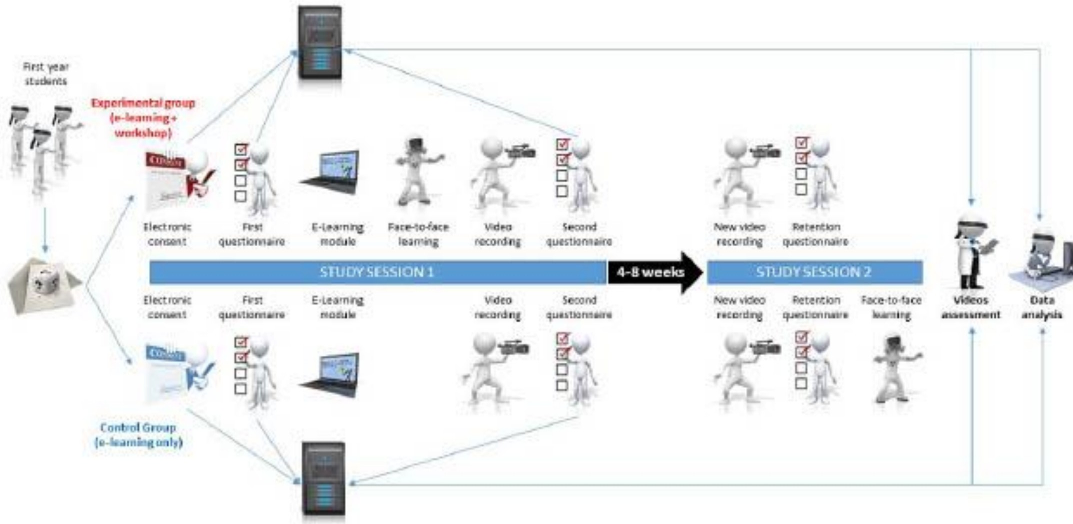

Figure 1. Study design, adapted from Stuby et al., 2021 [31].

2.2. Online Platform

An online platform [34] running under the Joomla! 3.9 content management system (Open Source Matters) was developed by LSu for the study's purpose and thoroughly tested by 3 other authors.

2.3. Randomization and Concealment of Allocation

An investigator (MS), who did not know the participants and had no contact with them, created unique study accounts, which were then randomized into two groups according to a computer-generated list [35] with a 1:1 allocation ratio and stratification by school and language. Opaque, sealed envelopes containing individual login information were created and transmitted to local investigators. Given the utter lack of risk for the participants, there was no unblinding procedure, no data monitoring, and no interim analysis. Participants were randomly divided between the instructors by an investigator (LSt or LC) using an online team generator [36].

2.4. Enrolment and Consent

Prior to the beginning of the study, an email containing information about the study was sent to the participants. Prior to logging in, the learning objectives and a data security statement were displayed on the website home screen. Consent was obtained electronically.

2.5. Study Sequence

After clicking the start button, a first questionnaire designed to collect demographic data and assess learning differences according to the VARK (visual, aural, reading/writing, or kinesthetic) modalities was displayed. Both groups were then invited to follow an interactive, gamified e-learning module [19].

After completing the module, participants belonging to the control group were asked to don the following PPE: protective glasses, N95 respirator mask, coverall with hood, and gloves. They were then asked to perform individually the doffing sequence, which was recorded on video. After completing this procedure, participants were asked to return to the online platform to electronically rebuild the doffing sequence.

Analyzing the proportion of correct hand disinfection was decided as some investigators quickly noticed that, during the study sessions, some of the hand disinfection procedures were incorrect. As this action was not specifically taught in either group, it was decided to consider that the doffing procedure was correct if the hand disinfection procedure was performed at the correct time point, even if it was poorly executed. The entire PPE doffing procedure, which was validated by IPC experts, is detailed in Table S1. However, as hand disinfection is a critical IPC procedure, it was decided to assess it separately. Adequate friction time and proper disinfection of all hand's areas were assessed subjectively.

The number of errors was added as secondary outcome because it allows a more precise assessment of the overall performance than a binary outcome. Furthermore, the risk of contamination is probably not binary and would be expected to increase as the number of errors increases.

2.10. Blinded Data Collection and Assessment

Some outcomes were recorded electronically allowing their assessment to be independent from subjective human assessment. For the other outcomes, assessors were blinded to participants' allocation. In case of disagreements, we chose to ask MS to review the recordings in order to reach a consensus.

2.11. Data Availability

All investigators were able to access the curated and coded data set. The database is available as Supplementary File S3. The video recordings were used only for the purpose of this study and were destroyed after analysis.

2.12. Sample Size

In two previous studies, no participant was able to electronically rebuild the correct doffing sequence after following the gamified e-learning module used in the present study [20,21]. However, the practical reality (skill) could be dissociated from the theoretical responses (knowledge) collected on the online platform, which made it necessary to set up a control group in this study.

It was calculated that 46 participants would be needed to have a 90% chance of detecting, at the 5% significance level, an increase in the primary outcome from 10% in the control group to 50% in the experimental group; additional participants were accepted as the training was part of their curriculum.

2.13. Statistical Analysis

Data analysis was performed using Stata 15.1 (StataCorp. 2017. Stata Statistical Software: Release 15. StataCorp LLC, College Station, TX, USA). Due to the small sample size, only non-parametric tests were used. Fisher's exact test was used for dichotomous variables and the Mann–Whitney U test for continuous variables. The computerized doffing sequence accuracy was analyzed as a whole, and according to the respective doffing zones (contaminated and noncontaminated zones). The Likert scales were described graphically, and statistical comparison performed using Fisher's exact test. Conversely to what was stated in the statistical analysis plan of the protocol, they were not dichotomized for statistical analysis (specified before statistical analysis, due to important loss of information). The results were described as a percentage with 95% CI for the proportions and according to the median (Q1;Q3) for the continuous variables. A p value < 0.05 was considered significant. A prespecified subgroup analysis by working status (actively working in an ambulance service or not) was carried out as an increased rate in adequate choice of PPE has been shown in this subgroup [20]. Working status was assessed through the first questionnaire. There were no missing data.

Two post hoc analyses were decided: the estimation of the correlation between the time needed to perform the procedure and the number of errors made, and the search for an association between the VARK scores and the performance and experience (satisfaction

Instead of immediately donning and doffing PPE after completing the e-learning module, participants in the experimental group were randomly assigned to one of the instructors to follow face-to-face learning according to Peyton's 4-step approach. After this workshop, these participants resumed the same path as their peers from the control group by moving on to the recording of the doffing sequence on video and were then asked to rebuild the doffing sequence on the online platform.

Four to eight weeks after this initial intervention, depending on the schools' schedules, participants were invited to a second session. Both groups first repeated the video recording of the PPE doffing sequence, then logged into the platform to electronically rebuild the doffing sequence. The experimental group was then considered as having completed the study path, while the control group attended a face-to-face learning session to ensure that all participants had ultimately been given the same level of training regardless of their initial allocation.

2.6. *Gamified E-Learning Module*

The development of the infection prevention and control (IPC) gamified e-learning module used in the present study has already been described [19]. Briefly, this module was developed following the theory-driven approach of the SERES framework [37,38]. It includes several learning objectives and provides general knowledge regarding SARS-CoV-2 (definition, incubation time, transmission routes, and symptoms), PPE items, and donning and doffing sequences. Gamification mechanisms were used to facilitate knowledge acquisition regarding donning and doffing sequences. This gamified module was also used to describe and detail the concept of "contaminated" and "noncontaminated" zones, thus separating the doffing procedure in two specific phases. The specific doffing steps occurring in each zone are detailed in Table S1 in Supplementary File S1.

2.7. *Face-to-Face Learning*

Face-to-face teaching was based on Peyton's approach [27] and followed these steps:

(1) The instructor performed a complete doffing sequence without giving any comments;
(2) The instructor performed a doffing sequence accompanied by step-by-step explanations (description of key points);
(3) Learners were asked to guide the instructor through the doffing sequence, step by step;
(4) Learners were asked to perform the complete doffing sequence before receiving individualized feedback. Each participant performed this step only once.

2.8. *Primary Outcome*

The primary outcome was the proportion of doffing sequences correctly performed after knowledge acquisition during the first study session. The adequacy of the procedure was individually assessed by two investigators (one of whom is an IPC specialist and the other an emergency medicine physician). These investigators, who were blinded as to group allocation, viewed the videos and completed a checklist (Table S2 in Supplementary File S2). In case of disagreement, the study protocol stated that a consensus would be reached by discussion. However, due to logistic reasons, disagreements were solved by asking a third investigator (MS) to individually review the recordings. This investigator was not provided with the ratings given by the other investigators. Her assessments allowed us to address all disagreements as all the ratings were binary (either correct or incorrect).

2.9. *Secondary Outcomes*

Nine secondary outcomes were assessed. Seven of them were prespecified in the study protocol: time required to teach the technique, time required to perform the doffing procedure, learner satisfaction, proportion of correct computer sequences, confidence in using PPE, and knowledge and skill retention. The last two were decided during study sessions and before the constitution of the database: proportion of correct hand disinfection, and number of errors (procedure deviations and/or contaminations) during the procedure.

and confidence) of the participants. For the first, after graphical description, the Pearson correlation coefficient was used. For the second, the association was sought using logistic and linear regression models with the VARK scores as predictive and adjustment variables and the performance (correct/incorrect sequence, and number of errors, respectively).

2.14. Protocol Deviations

The protocol deviations were the following: addition of two secondary outcomes (hand disinfection and number of errors in the doffing procedure); way to reach consensus slightly modified; unblinded statistical analysis due to sending of an unblinded data set to statistical analyst (all data had however been entirely acquired); non-dichotomization of Likert scales (decided before statistical analysis due to loss of information); use of a teacher rather than third-year students for the face-to-face teaching due to headmaster's decision leading to the addition of a sensitivity analysis of primary outcome; face-to-face teaching ratio higher than 1:3 once, due to availability of only one German-speaking instructor during the session.

3. Results

Sixty-five participants were enrolled in the study. One was excluded after missing the first study session (Figure 2). Their characteristics are detailed in Table 1. All sessions but one (17/18) were conducted with an instructor:learner ratio of 1:1 to 1:3, with one exception of 1:4.

Table 1. Participants' characteristics.

	E-Learning (n = 31)	Blended Learning (n = 33)
Age, in years, median (Q1;Q3)	24 (22;26)	27 (23;28)
Gender, n (%)		
Male	13 (41.9)	13 (39.4)
Female	18 (58.1)	20 (60.6)
Other	0 (0.0)	0 (0.0)
Location, n (%)		
Geneva	8 (25.8)	10 (30.3)
Bern (French-speaking)	5 (16.1)	5 (15.2)
Bern (German-speaking)	18 (58.1)	18 (54.6)
Actively working in an ambulance service, n (%)	24 (77.4)	24 (72.7)
Canton of practice of those currently working, n (%)		
Aargau	4 (16.7)	1 (4.2)
Basel	0 (0.0)	3 (12.5)
Bern	13 (54.2)	12 (50.0)
Fribourg	0 (0.0)	2 (8.3)
Geneva	1 (4.2)	0 (0.0)
Neuchâtel	1 (4.2)	1 (4.2)
Solothurn	1 (4.2)	2 (8.3)
Vaud	2 (8.3)	2 (8.3)
Valais	2 (8.3)	1 (4.2)
VARK scores, median (Q1;Q3)		
visual	7 (5;9)	6 (4;7)
aural	8 (5;11)	8 (6;11)
read	5 (3;6)	5 (3;7)
kinesthetic	9 (7;11)	9 (8;10)

Total may be over 100% due to rounding.

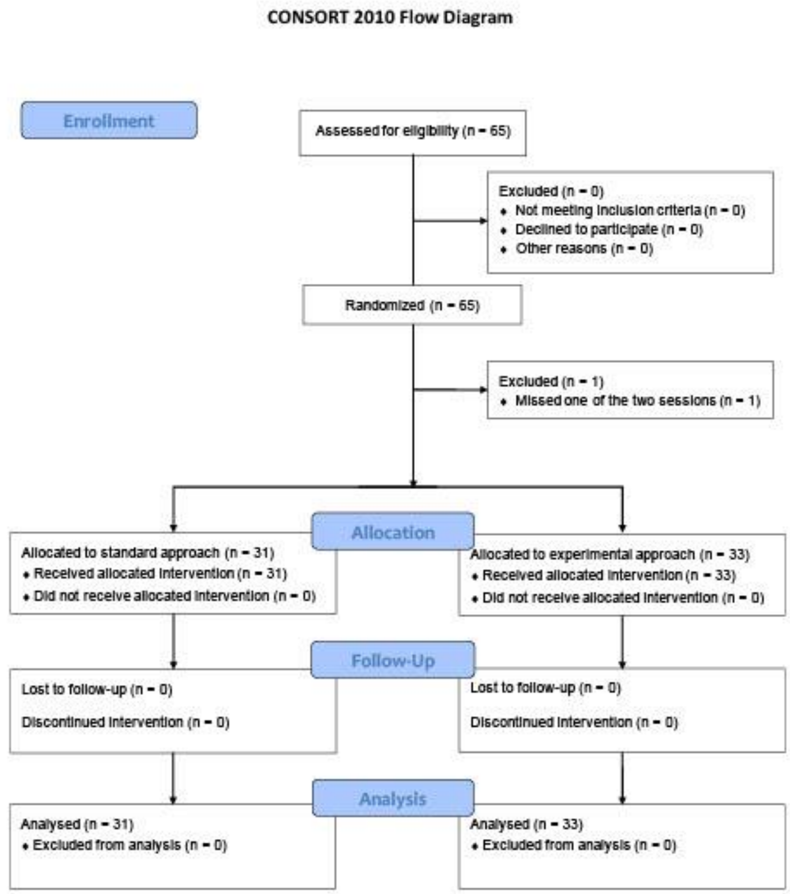

Figure 2. Study flowchart.

The proportion of doffing sequences correctly performed was higher in the group who followed the blended learning compared to the one who followed only the e-learning (33.3% (95%CI 18.0 to 51.8) versus 9.7% (95%CI 2.0 to 25.8), $p = 0.03$). The pre-specified subgroup analysis did not change the direction, nor the magnitude of effect (Table 2).

Table 2. Subgroup analysis of primary outcome by working status.

	E-Learning (n = 31)	Blended Learning (n = 33)	*p*-Value
Correct sequence among participants actively working, % (95%CI)	8.3% (1.0 to 27.0)	29.2% (12.6 to 51.1)	0.14
Correct sequence among participants not actively working, % (95%CI)	14.3% (0.3 to 57.9)	44.4% (13.7 to 78.8)	0.31

For the face-to-face teaching, the additional median (Q1;Q3) time required was 22 (19;25) minutes. There was no significant difference, either in the time required to perform the doffing procedure, nor in the knowledge at acquisition (independently of the zones) (Table 3). Knowledge retention and doffing skills in the contaminated zone were significantly higher in the blended learning group (Table 3).

Table 3. Secondary outcomes.

	E-Learning (n = 31)	Blended Learning (n = 33)	*p*-Value
Time required to perform the doffing procedure at first session, in seconds, median (Q1;Q3)	133 (107;151)	129 (118;164)	0.59
Time required to perform the doffing procedure remotely, in seconds, median (Q1;Q3)	113 (93;135)	124 (113;144)	0.08
Correct computerized sequence at first session in contaminated zone (knowledge at acquisition), % (95%CI)	80.6% (62.5 to 92.5)	90.9% (75.0 to 98.1)	0.30
Correct computerized sequence at first session in non-contaminated zone (knowledge at acquisition), % (95%CI)	77.4% (58.9 to 90.4)	72.7% (54.7 to 86.7)	0.78
Correct computerized full sequence at first session (knowledge at acquisition), % (95%CI)	64.5% (45.4 to 80.8)	66.7% (48.2 to 82.0)	1.00
Correct computerized sequence remotely in contaminated zone at second session (knowledge retention), % (95%CI)	38.7% (21.8 to 57.8)	66.7% (48.2 to 82.0)	0.04
Correct computerized sequence at second session in non-contaminated zone (knowledge retention), % (95%CI)	64.5% (45.4 to 80.8)	75.7% (57.7 to 88.9)	0.42
Correct computerized full sequence at second session (knowledge retention), % (95%CI)	35.5% (19.2 to 54.6)	48.5% (30.8 to 66.4)	0.32
Doffing sequences correctly performed remotely at second session (skill retention), % (95%CI)	3.2% (0.1 to 16.8)	24.2% (11.1 to 42.3)	0.03

The number of errors was significantly lower in the experimental group (Figure 3, Table 4). A weak correlation (first session, $r = -0.31$, $p = 0.012$, second session, $r = -0.33$, $p = 0.007$) was found between the time needed to perform the procedure and the number of errors made (Figure 4). There was a 0.74 error per minute decrease (95%CI 0.17 to 1.32, $p = 0.012$) during the first sessions and a 1.41 error per minute decrease (95%CI 0.40 to 2.42, $p = 0.007$) during the second sessions. The predictivity of this model is however very low (r squared = 0.1 for both sessions).

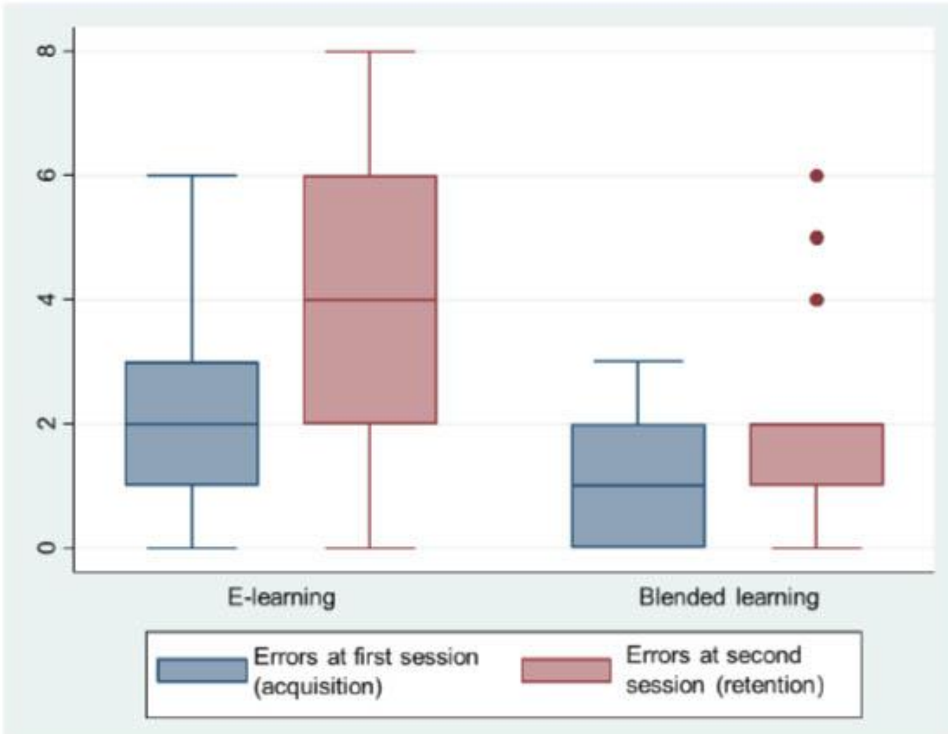

Figure 3. Number of errors by session.

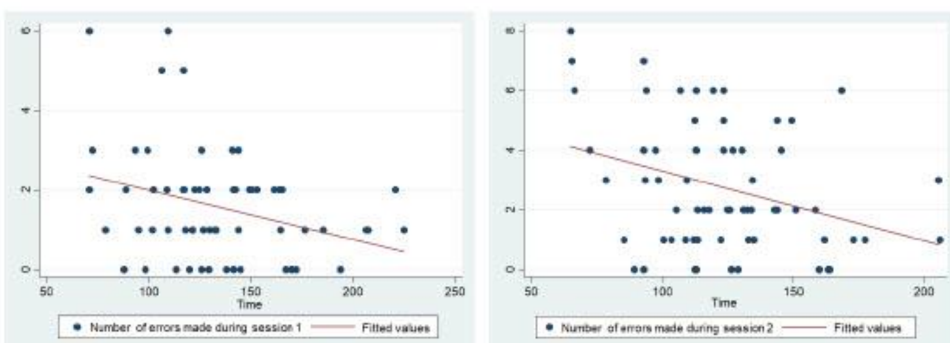

Figure 4. Correlation between time required to perform the doffing procedure and number of errors made.

A common error concerned hand disinfection with 45.3% of overall participants performing it incorrectly during the first session, and 50.0% at the second session, with less errors in the experimental group (not statistically different) (Table 4).

Satisfaction (Figure 5) and confidence in using PPE (Figure 6) were significantly different between groups ($p = 0.016$ and $p < 0.001$, respectively).

Table 4. Number of errors by session and hand disinfection.

	E-Learning (n = 31)	Blended Learning (n = 33)	p-Value
Number of errors in the procedure at acquisition, median (Q1;Q3)	2 (1;3)	1 (0;2)	<0.001
Number of errors in the procedure at retention, median (Q1;Q3)	4 (2;6)	2 (1;2)	<0.001
Correct hand disinfection at acquisition, % (95%CI)	45.2% (27.3 to 64.0)	63.6% (45.1 to 79.6)	0.21
Correct hand disinfection at retention, % (95%CI)	41.9% (24.5 to 60.9)	57.6% (39.2 to 74.5)	0.32

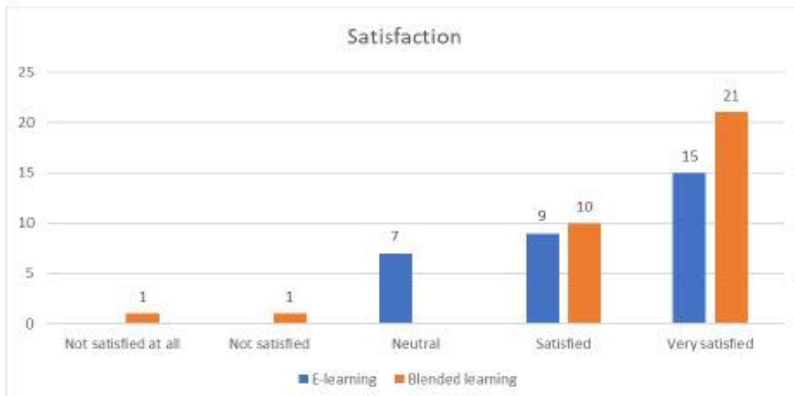

Figure 5. Participant satisfaction.

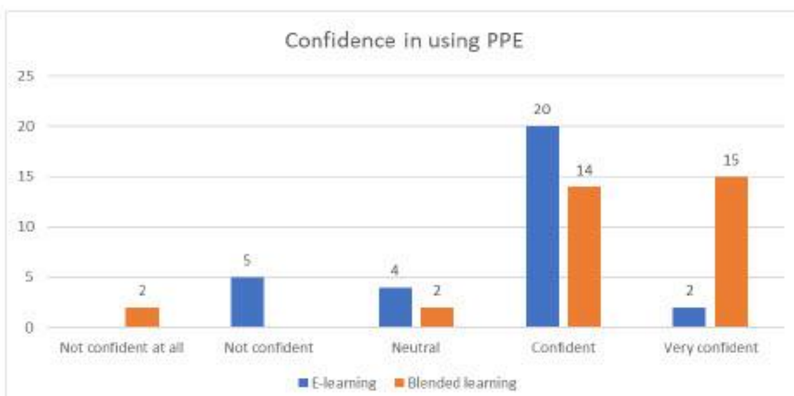

Figure 6. Participant confidence in using personal protective equipment.

By analyzing the primary outcome stratified according to language/type of instructor, there was no change in the direction of the effect, which was, however, only statistically significant in the French-speaking subgroup despite its smaller sample size (Table 5).

Table 5. Sensitivity analysis of primary outcome (correct doffing procedure) depending on language and type of instructor.

	E-Learning (n = 31)	Blended Learning (n = 33)	*p*-Value
French-speaking participants with third-year student as instructor (n = 28), % (95%CI)	7.7% (0.2 to 36.0)	46.7% (21.3 to 73.4)	0.04
German-speaking participants with teacher as instructor (n = 36), % (95%CI)	11.1% (1.4 to 34.7)	22.2% (6.4 to 47.6)	0.66

None of the VARK scores were significantly associated with the performance (regardless of binary or continuous outcome).

4. Discussion

4.1. Main Considerations

Adding a face-to-face teaching intervention following Peyton's approach to a gamified e-learning module significantly improved PPE doffing skill acquisition in student paramedics. Prior studies have shown that adding training modalities to learning paths increases HCWs compliance and decreases contamination during PPE doffing procedures [17,39–41], can help decrease both the time required to doff PPE and the number of errors [42], and can allow participants to perform complex procedures more efficiently [25,26]. In our study, the superiority of the blended learning approach could be due either to the face-to-face training itself or to the addition of a second training modality. However, there was no difference in the ability of adequately rebuilding the correct PPE doffing sequence on the web platform. This supports the theory that adequately performing a complex procedure such as PPE doffing not only depends on knowledge acquisition but also relies on practical aspects. We therefore believe that using blended learning approaches, including at least a practical skill station, is necessary to teach complex procedures such as PPE doffing. This is further supported by the fact that more students felt "very confident" after following the blended learning approach.

The proportion of student paramedics adequately performing the PPE doffing procedure was lower during the follow-up sessions. However, skill retention was still higher in student paramedics who had followed both interventions in comparison with those who had only followed the e-learning module. Once again, there was no significant difference between groups in the ability of adequately rebuilding the full PPE doffing sequence on the web platform.

During both sessions, the time required to perform the doffing procedure was similar between groups, with shorter times associated with a slightly increased number of errors. Importantly, participants who had only followed the e-learning module made twice as many errors than those who had followed the blended learning approach. Errors during the doffing procedure can lead to self-contamination and increase HCW's risk to contract or transmit diseases [9,43–45]. The more errors HCWs make, the higher the risk [43]. However, not every deviation leads to contamination [43,46], and the risk should therefore be considered according to the kind of error made by the HCW [47]. Since this outcome was not included in the present study, possible contaminations were assessed subjectively without using marking agents (phosphorescence or inactivated virus for instance) [10,43].

Almost one paramedic student out of two did not adequately disinfect hands. Since this procedure is considered as a basic skill, it was neither taught nor reminded in both study arms. Hand disinfection is nevertheless a critically important procedure, and emphasis will need to be put on the importance of adequately performing hand disinfection [48]. Given these unexpectedly low results, particularly in the context of the current pandemic, reminders should therefore be included in all future IPC teaching interventions [49,50] owing to the contamination risk associated with improper hand disinfection [46,51].

In line with prior studies [9,52,53], the participants who were not actively working in an ambulance service had higher skill acquisition and retention scores. Some authors suggest that complex procedures such as PPE doffing should be taught to HCWs before they acquire inadequate practices [13]. However, this finding could also be due to confounding biases regarding several factors. Indeed, all paramedic students are required to work actively in an Emergency Medical Service (EMS) once they are admitted to one of the two schools involved in this study (Bern's school). Since this school is the only one including German-speaking participants who were taught by a full-fledged teacher rather than by third-year students, the differences seen in our study could be, in part if not entirely, due to these differences.

4.2. Limitations and Strengths

This study has several limitations other than the protocol deviations already listed above. First, even though we strived to increase the number of participants by carrying out a multicenter study and translated the previously described e-learning module into German for this purpose, our sample size was still small. This small sample size precluded any strata analysis, and biases linked to the multicenter and multilingual aspects of our study cannot be ruled out. In addition, the planned sample size was not adequate and the post hoc analysis yields a power of 54%. Indeed, we had correctly anticipated that some student paramedics would adequately perform the PPE doffing procedure despite the fact that prior results showed that almost all participants were unable to correctly rebuild the doffing procedure on a web platform. While this supports the theory that practical reality can be dissociated from theoretical responses, we incorrectly estimated the potential increase in PPE doffing skill proficiency after following a blended learning approach. Second, even though our goal was to use only third-year student paramedics as instructors to limit teaching biases during the face-to-face sessions, we had no choice but to use a full-fledged teacher for the subgroup of German-speaking participants. Therefore, the absence of a statistically significant difference between groups in the subset of German-speaking participants could be ascribed, at least in part, to this deviation from our original protocol, even though all instructors, regardless of their professional status, received the same training regarding Peyton's approach. Third, we did not foresee that student paramedics might lack skills regarding hand disinfection. Even though this outcome was added after the first recordings had been assessed, there should be little bias as all assessors were blinded as to group allocation.

However, this study also has strengths. First, the robust, stratified randomization method allowed us to obtain well-balanced groups despite the limited sample size. Second, the electronic acquisition of data related to secondary outcomes also helped limit potential assessment biases. Another important strength is the utter lack of dropouts between the initial study session and the follow-up sessions. Finally, this is one of the few studies reporting the impact of adding a face-to-face teaching intervention to a gamified e-learning module.

4.3. Perspectives and Practical Implications

First of all, because of the differences found between theoretical responses and actual skills, future studies exploring this domain should include practical skill assessments, even if no skill station is included in the learning path. In addition, studies involving actively working HCWs should consider acquiring video recordings during actual interventions. Indeed, the number of errors in the PPE doffing procedure might actually be higher in the field because of the Hawthorne effect [54–56], narrow spaces, and time constraints.

Chemical, biological, radiological, and nuclear threats are globally increasing but most health care workers (HCWs) are insufficiently trained to face such situations [57,58]. Given the unsatisfactory skill acquisition and the even poorer retention of PPE doffing procedural skills in student paramedics even after following a blended learning approach, further studies are needed to understand how the proficiency of prehospital providers can be enhanced regarding this critical procedure. While this could potentially be achieved by adding further training modalities, it is also possible that the only way of ensuring adequate skill acquisition and retention is through the provision of regular refresher sessions. The impact of regular refresher sessions has been studied regarding basic life-support skills [59,60], and future studies could be designed to assess the impact of similar sessions regarding PPE doffing skills.

Another important element that future studies should consider is the systematic assessment of computer literacy [61,62]. Indeed, even though we considered that computer literacy should be high in our population of Swiss student paramedics since the vast majority of them are young people living in a high-income country [63], the inconsistency between their actual skills and their ability to adequately rebuild the doffing sequence on a computer platform in prior studies [20] is intriguing. Therefore, we recommend that future research in this domain should always assess computer literacy in any population studied and avoid being prejudiced by potential misconceptions regarding specific populations.

Finally, iterative assessments of PPE doffing skills should be performed and PPE doffing should, whenever possible, be systematically executed under the supervision of proficient and regularly IPC-trained personnel to avoid contamination [64].

5. Conclusions

In this study, adding face-to-face training to a gamified e-learning module increased PPE doffing proficiency among first year student paramedics and enhanced skill retention. The proportion of participants able to adequately perform the procedure was, however, rather low, and PPE doffing procedures remain complex to learn, retain, and perform. Future studies are needed to determine whether additional training modalities can enhance skill acquisition and retention, or if regular refresher sessions are the only way of ensuring PPE doffing skills proficiency.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/ijerph19053077/s1, Table S1: PPE doffing procedure for instructors; Table S2: Assessment grid; CSV file S3: Data set.

Author Contributions: Conceptualization, L.C. and L.S. (Loric Stuby); Data curation, L.C. and L.S. (Laurent Suppan); Formal analysis, L.S. (Loric Stuby); Funding acquisition, L.C.; Investigation, L.C., M.S., B.A.G., E.D., M.M., L.S. (Laurent Suppan) and L.S. (Loric Stuby); Methodology, L.C., M.S., L.S. (Laurent Suppan) and L.S. (Loric Stuby); Project administration, L.C., M.S., L.S. (Laurent Suppan) and L.S. (Loric Stuby); Resources, L.C., M.S., B.A.G., M.M., L.S. (Laurent Suppan) and L.S. (Loric Stuby); Supervision, S.H., L.S. (Laurent Suppan) and L.S. (Loric Stuby); Validation, L.C., M.S., L.S. (Laurent Suppan) and L.S. (Loric Stuby); Visualization, L.S. (Loric Stuby); Writing—original draft, L.C. and L.S. (Loric Stuby); Writing—review & editing, L.C., M.S., B.A.G., E.D., M.M., S.H., L.S. (Laurent Suppan) and L.S. (Loric Stuby). All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki. The regional ethics committee delivered a declaration of non-objection as to conducting this RCT (Req-2020-01340).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the participants to publish this paper.

Data Availability Statement: The data presented in this study are available as supplementary material.

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Conflicts of Interest: LSt, LSu, and BG occasionally receive financial compensation when serving as external teaching professional and/or exam expert for the Colleges of Higher Education in Ambulance Care in Geneva and Bern. MM is employed by the Center for Medical Education in Bern as a teacher. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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Impact of a Serious Game (Escape COVID-19) on the Intention to Change COVID-19 Control Practices Among Employees of Long-term Care Facilities: Web-Based Randomized Controlled Trial

During the first months of the COVID-19 pandemic, guidelines were frequently updated according to the rapidly increasing knowledge base regarding this new disease. This unavoidably led to the emergence of contradicting guidelines [10]. These contradictions fuelled conspiracy theories and undermined the dissemination of key infection prevention messages [14,60]. Motivated by the success of the gamified e-learning module used to improve prehospital PPE use [38,43,57], the infection prevention and control (IPC) team of the Geneva University Hospitals suggested the idea of creating a serious game to improve IPC behaviour. This game, "Escape COVID-19", was successfully developed by virtue of a trans-departmental and interprofessional collaboration [44]. In 2022, it was featured as a World Health Organization case study [61].

Since an intervention can be visually appealing without being actually effective, a randomized trial designed to assess whether "Escape COVID-19" could improve IPC behaviour was planned [62]. The original article "*Impact of a Serious Game (Escape COVID-19) on the Intention to Change COVID-19 Control Practices Among Employees of Long-term Care Facilities: Web-Based Randomized Controlled Trial*" describes its thrilling results: in a population of long-term care facility workers, participants were more than three time more likely to change their IPC behaviour after playing "Escape COVID-19" than after being presented with the official guidelines.

Reference: Suppan M, Abbas M, Catho G, Stuby L, Regard S, Achab S, Harbarth S, Suppan L. *Impact of a Serious Game (Escape COVID-19) on the Intention to Change COVID-19 Control Practices Among Employees of Long-term Care Facilities: Web-Based Randomized Controlled Trial*. J Med Internet Res. 2021 Mar 25;23(3):e27443. doi: 10.2196/27443. PMID: 33685854; PMCID: PMC7996198 [48].

Original Paper

Impact of a Serious Game (Escape COVID-19) on the Intention to Change COVID-19 Control Practices Among Employees of Long-term Care Facilities: Web-Based Randomized Controlled Trial

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Abstract

Background: Most residents of long-term care facilities (LTCFs) are at high risk of complications and death following SARS-CoV-2 infection. In these facilities, viral transmission can be facilitated by shortages of human and material resources, which can lead to suboptimal application of infection prevention and control (IPC) procedures. To improve the dissemination of COVID-19 IPC guidelines, we developed a serious game called "Escape COVID-19" using Nicholson's RECIPE for meaningful gamification, as engaging serious games have the potential to induce behavioral change.

Objective: As the probability of executing an action is strongly linked to the intention of performing it, the objective of this study was to determine whether LTCF employees were willing to change their IPC practices after playing "Escape COVID-19."

Methods: This was a web-based, triple-blind, randomized controlled trial, which took place between November 5 and December 4, 2020. The health authorities of Geneva, Switzerland, asked the managers of all LTCFs under their jurisdiction to forward information regarding the study to all their employees, regardless of professional status. Participants were unaware that they would be randomly allocated to one of two different study paths upon registration. In the control group, participants filled in a first questionnaire designed to gather demographic data and assess baseline knowledge before accessing regular online IPC guidelines. They then answered a second questionnaire, which assessed their willingness to change their IPC practices and identified the reasons underlying their decision. They were then granted access to the serious game. Conversely, the serious game group played "Escape COVID-19" after answering the first questionnaire but before answering the second one. This group accessed the control material after answering the second set of questions. There was no time limit. The primary outcome was the proportion of LTCF employees willing to change their IPC practices. Secondary outcomes included the factors underlying participants' decisions, the domains these changes would affect, changes in the use of protective equipment items, and attrition at each stage of the study.

Results: A total of 295 answer sets were analyzed. Willingness to change behavior was higher in the serious game group (82% [119/145] versus 56% [84/150]; P<.001), with an odds ratio of 3.86 (95% CI 2.18-6.81; P<.001) after adjusting for professional category and baseline knowledge, using a mixed effects logistic regression model with LTCF as a random effect. For more than two-thirds (142/203) of the participants, the feeling of playing an important role against the epidemic was the most important factor explaining their willingness to change behavior. Most of the participants unwilling to change their behavior answered that they were already applying all the guidelines.

Conclusions: The serious game "Escape COVID-19" was more successful than standard IPC material in convincing LTCF employees to adopt COVID-19–safe IPC behavior.

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KEYWORDS

COVID-19; transmission; serious game; infection prevention; health care worker; SARS-CoV-2; nursing homes; randomized controlled trial; long-term care facilities; impact; game; intention; control; elderly

Introduction

Background and Importance

Long-term care facilities (LTCFs) have been hit hard by the COVID-19 pandemic [1-4]. Although most LTCF residents are either old or frail and therefore more prone to complications and death following SARS-CoV-2 infection [5,6], other factors, such as shortages of human resources [7-9], must also be taken into account. This lack of resources can lead to suboptimal application of infection prevention and control (IPC) procedures [10], thus facilitating viral transmission. As even a single LTCF employee can contaminate a great number of colleagues and residents [11], and as rapid viral transmission between residents has been reported [12], it is essential to support LTCF employees [13] and ultimately help them adhere to IPC guidelines [14].

Even though most LTCF employees recognize the importance of preventing SARS-CoV-2 transmission, their motivation to act according to their awareness might be hampered by overwork [8,15], by too often updated and sometimes contradicting guidelines [16,17], and by mistrust in health care authorities [18]. Moreover, in spite of well-established evidence regarding specific IPC practices such as hand hygiene and use of personal protective equipment (PPE) [19], most health care workers (HCWs), including LTCF employees, only seldom apply them perfectly [20-22]. The current need for physical distance and the disruption of the regular continuing medical education courses has deteriorated this situation even further [23].

To enhance the communication of appropriate IPC guidelines and improve their application by HCWs and related staff who are regularly in contact with patients, we developed a web-based serious game called "Escape COVID-19" [24] using Nicholson's RECIPE for meaningful gamification [25]. Although electronic learning (e-learning) interventions might be ineffective in teaching complex technical procedures ([17,26]; Stuby et al, unpublished data, 2021), they are nevertheless useful in increasing knowledge and their use is generally associated with a high level of learner satisfaction [27-29]. As the probability of executing an action is strongly linked to the intention of performing it (according to the theory of planned behavior [30,31]), an engaging serious game could enhance the dissemination of essential IPC guidelines and encourage LTCF employees to change their behavior regarding IPC practices [29,32,33].

Objective

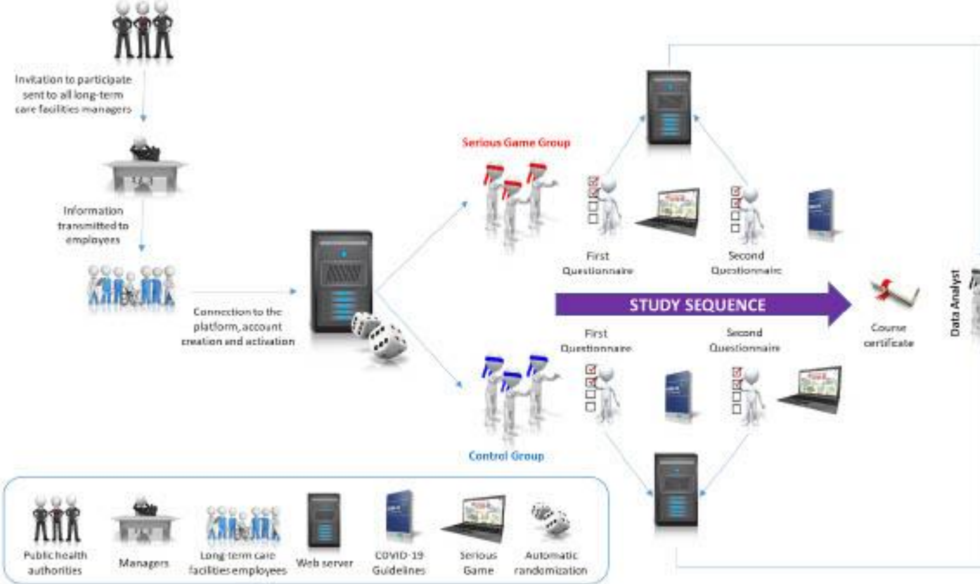
Our main objective was to assess the impact of "Escape COVID-19," a web-based serious game, on the intention of LTCF employees to change their IPC practices. Our secondary objective was to determine the reasons underlying the potential willingness to change IPC practices or lack thereof.

Methods

Study Design and Setting

This was a web-based, triple-blind (investigator, participants, data analyst), randomized controlled trial, which took place between November 5 and December 4, 2020. Its design has been published previously [34] and is summarized in Figure 1. A declaration of no objection was issued by our regional ethics committee (Req-2020-01262) as such projects do not fall within the scope of the Swiss federal law on human research [35]. This study was designed according to the CONSORT-EHEALTH (Consolidated Standards of Reporting Trials) guidelines [36] and incorporates relevant elements from the CHERRIES (Checklist for Reporting Results of Internet E-Surveys) checklist [37].

Figure 1. Study design.

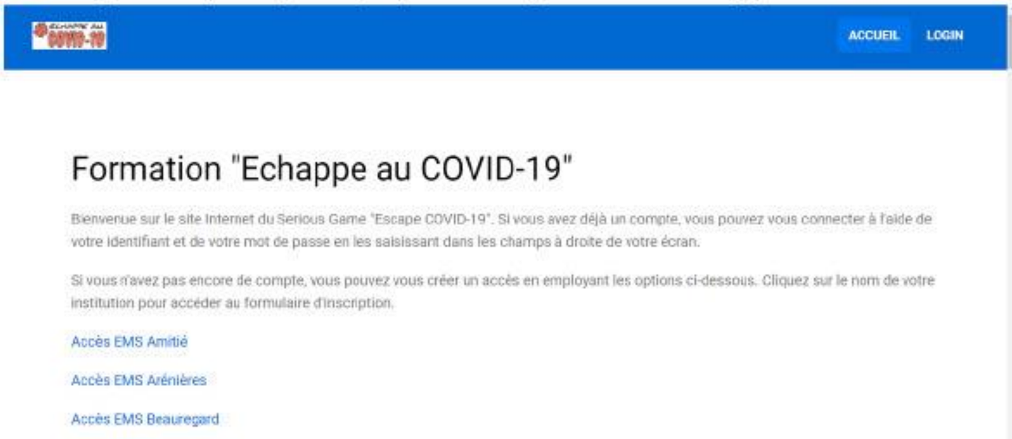


Having been informed by IPC specialists from the Geneva University Hospitals of the development of "Escape COVID-19," the public health authorities of Geneva, Switzerland, were interested in giving the employees of all LTCFs under their jurisdiction access to this serious game. They therefore provided us with a comprehensive list of all such facilities, but insisted on liaising with LTCF managers themselves. As LTCF employees other than HCWs can often be in contact with residents, we informed the representatives of the health care authorities that, for methodological and clinical relevance, all LTCF employees should be invited to participate, regardless of their professional status. We therefore provided them with an email template that described the objective of this study and the target population, and gave information regarding data protection (Multimedia Appendix 1). This template was sent by the public health authorities to all LTCF managers following a regular LTCF coordination meeting during which the characteristics of the study and the serious game were detailed. Participants, including LTCF managers, were unaware that they would be allocated to one of two different study arms but were required to provide consent (see below) and were given the approximate time required to complete the whole path (30 minutes). An email address that could be used to contact the investigators was also provided. The only incentive that participants were given was the promise of acquiring a course completion certificate at the end of the study path.

Online Platform

A specific web-based platform [38], hosted on a Swiss server, was created under the Joomla 3.9 content management system [39]. Only two authors (MS and L Suppan) had access to the administration console and data, which were stored on an encrypted MySQL-compatible database (MariaDB 5.5.5, MariaDB Foundation). Daily backups were performed throughout the study period. They were triggered by a cron job script and uploaded on a physically separate server through an encrypted connection. The front page displayed a comprehensive list of all LTCFs under Geneva health authorities' jurisdiction (Figure 2).

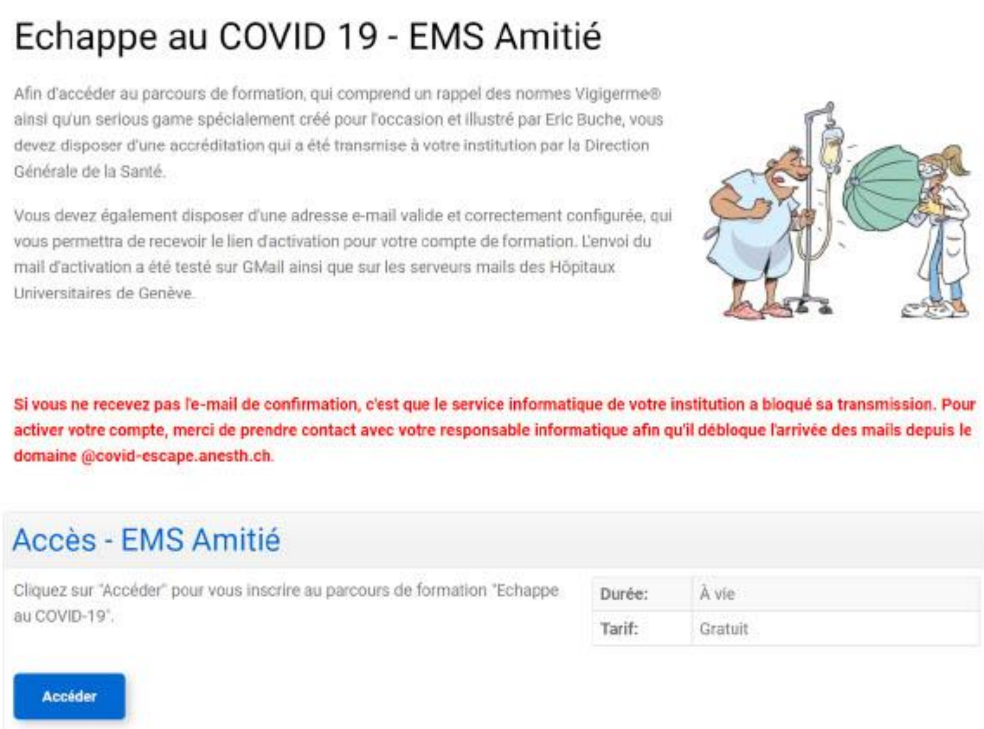
Figure 2. Front page of the study website (in French). Only the first three long-term care facilities are displayed.



Stratification was achieved by having LTCF employees click on a link specific to their institution. When they clicked on this link, participants were automatically randomized to one of the two study paths by GegaByte's Random Article module (GegaByte Technologies) [40]. This process was invisible to the end user and there was no way either participants or investigators could influence group allocation.

General information regarding the study, the need to register with a valid email address, and the need to allow the reception of emails coming from the website's domain was then displayed (Figure 3).

Figure 3. General information displayed (in French) before accessing the registration form.



After clicking on the "Access" button, a registration form, identical for both groups, was shown (Figure 4). This form was created using Membership Pro (Joomdonation) as this component enabled us to allocate users to specific groups, to create specific fields, and to disable the "Name" field [41]. Therefore, participants were only asked to enter their email address; they were not asked for any other personal information and were not required to give their first and last names.

Figure 4. Registration form (in French).

To avoid having LTCF employees registering under the wrong institution, LTCF-specific accreditations were created for each facility (Figure 4, "Accréditation" field). The full list of accreditations was sent to the public health authorities, who were informed they were to adapt our email template accordingly for each LTCF.

After filling in the registration form, participants were asked to activate their account using a specific link sent to the email address they had entered. This email also contained a reminder regarding data handling and security (Multimedia Appendix 2). Participants were informed that clicking on the activation link was considered as consent to participate in the study. After activating their account, participants were able to log in to the platform. Upon login, they were redirected to the first questionnaire (Multimedia Appendix 3) by the Redirect-on-Login 4.6 component (Pages-and-Items) [42].

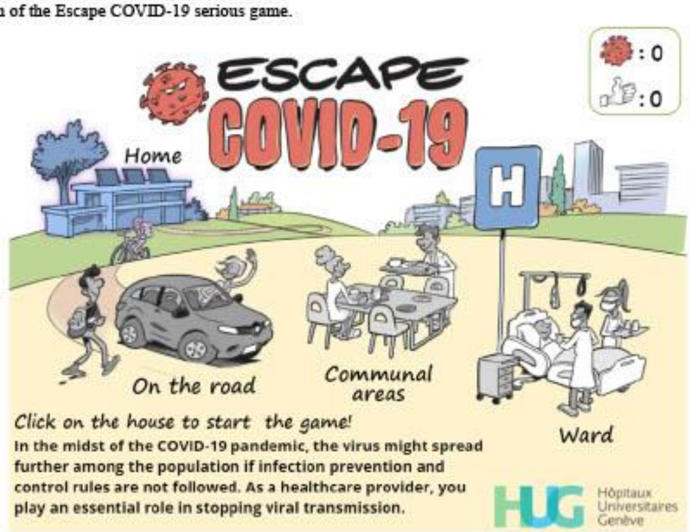
This first questionnaire (Multimedia Appendix 3) was designed to assess the participants' baseline knowledge and to gather demographic data. It was developed using Community Surveys Pro (Corejoomla) [43], which enables a completeness check and allows for the use of branching logic. The number of initial questions was kept to a minimum and branching logic was used to try to limit attrition [44-47]. All multiple-choice and multiple-answer questions were mandatory and had to be answered before participants could move on to the next step. The answers could not be changed once a page had been completed.

After completing this first questionnaire, participants in the control group were shown a quick reminder of the most recent national guidelines published by the Federal Office of Public Health of the Swiss Confederation [48]. They were also given links to local IPC guidelines for health care professionals (Vigigerme) provided by the Geneva University Hospitals (Figure 5). After reviewing these guidelines, which are freely available on the internet [49], these participants were asked to complete the second questionnaire (Multimedia Appendix 4).

Figure 5. Control material (in French). The model was displayed for 10 seconds before providing links to infection prevention and control guidelines.

Conversely, "Escape COVID-19" (version 2.1.1) was launched once participants in the serious game group had completed the first questionnaire. The development of this serious game has previously been described [24]. Briefly, "Escape COVID-19" was first developed in French under Articulate Storyline 3 (Articulate Global) through multiple iterations by using the first three steps of the SERES framework [23,50,51] and Nicholson's RECIPE for meaningful gamification [25]. Graphical elements were designed by Eric Buche [52] to lend a unique aspect to the game (Figures 6 and 7). The game has been fully translated in English and can be freely accessed on the internet [53]. The first and last author can be contacted to obtain Shareable Content Object Reference Model (SCORM) packages, which can be reused freely for research and educational purposes. Although the screen captures are presented in English to enhance their comprehension by an international readership, the original (French) versions can be seen in Multimedia Appendix 5.

Figure 6. Welcome screen of the Escape COVID-19 serious game.



This serious game includes four different levels, which create a meaningful narrative [25] by presenting recurrent and critical standard situations encountered by HCWs, including community and hospital exposures. Feedback is systematically given [54] to reinforce the expected behavior. Desirable behaviors and correct answers are rewarded by awarding a "thumbs-up," while viruses are accumulated whenever a wrong answer is given or an unwished-for behavior is performed. A "game over" screen is displayed (Figure 7) if the player gathers a total of 5 viruses. The player can then either restart the level or spend their thumbs-up to decrease the virus count (1:1).

Figure 7. "Game over" screen of the Escape COVID-19 serious game.

After completing all four levels, participants were shown a link that enabled them to access the second questionnaire (Figure 8). This ensured that this questionnaire could only be answered by participants who had actually completed the game.

This second and last questionnaire was designed to assess whether the participants intended to change their IPC practices after completing their allocated set of learning materials. It was also developed using Community Surveys Pro, with branching logic used to try to limit attrition and completeness checks enabled to avoid missing data. After completing this last questionnaire, participants in the control group were granted access to the serious game, while those who belonged to the serious game group were shown the control materials. All participants could then access a certificate generation module that enabled them to obtain a course completion certificate. No time limit was set for either of the two questionnaires or for completing the serious game.

Figure 8. The only way participants could access the second questionnaire was by clicking on the "Exit the game" button.

During the whole study path, participants were allocated to specific user groups according to their progression. This was carried out by using Joomla's native Access Control List feature (PHP functions JUserHelper::addUserToGroup and JUserHelper::removeUserFromGroup, embedded using Sourcerer by Regular Labs [55]), and served two purposes. First, it allowed us to determine precisely at which step some participants elected to abandon the study. Second, it allowed participants who had been interrupted to be immediately redirected to the next incomplete step of the study when resuming.

Outcomes

The primary outcome was the proportion of LTCF employees who answered they were willing to change their IPC practices after seeing either the serious game or the control material. The secondary outcomes were the identification of factors associated with participant willingness to change their behavior, the reasons given by participants opposed to changing theirs [56], and the potential motivators which could have led them to change. Attrition was evaluated at each stage of the study.

We also assessed the IPC domains affected in participants who answered they were willing to change their IPC behavior, and whether these participants would modify their use of specific PPE items. In total, 13 questions were used to assess these latter outcomes. Therefore, conversely to the previous outcomes, answering questions related to IPC domains and PPE items were not compulsory to limit attrition.

Participants and Sample Size

Regardless of their professional status, all LTCF employees working in Geneva, Switzerland, who received the invitation and elected to participate were included in this study and represented a convenience sample. As the number of eligible employees was estimated to be approximately 4000 people, we hoped for a participation rate of around 20%. This would have allowed us to detect a difference of 10% at the .05 significance level with a power of 80% as we had calculated that 388 participants would have been needed in each group to detect such a difference.

Answer sets that had not been marked as completed by the computer system and those filled by participants other than LTCF employees (ie, government employees or employees of other institutions) were excluded.

Data Curation and Statistical Analysis

Data was exported by L Suppan in Microsoft Excel (Microsoft Corp; XLSX) and in comma-separated value (CSV) formats depending on the components before being imported, appended, and merged under Stata (StataCorp LLC). The groups were renamed using neutral names ("Atreides" and "Corrino"), the fields that could have led to the unblinding of the data analyst were removed, and the curated DTA file was transmitted to L Stuby, who used Stata (version 15.1) for statistical analysis. This investigator was not part of the serious game development team and did not coauthor the original publication, as we wanted to avoid any potential conflict of interest.

Univariable and multivariable logistic regression were used to assess the primary outcome, with adjustment performed according to prior knowledge (expressed as the percentage of correct answers), professional status, and facility. The log-linearity assumption was checked graphically and the goodness-of-fit was tested using the Hosmer-Lemeshow test. As randomization was stratified by center, we adjusted for this in the analysis by employing a random effects logistic regression model, using LTCF as a random effect. We tested the null hypothesis of absence of random effect using a chi-bar-square test. We calculated the intraclass correlation coefficient (ICC) to quantify to what extent responses in a single LTCF were correlated.

Secondary outcomes were analyzed by assigning numerical values to the answers gathered through the use of Likert scales. As the domains potentially affected by a change in behavior were assessed using Likert scales ranging from 1 (not at all) to 6 (very much), the same values (ie, a score ranging from 1 to 6) were assigned to each item. The composite outcome was the sum of these 9 questions and was analyzed through univariable linear regression then adjusted by employing a mixed effects model, using LTCF as a random effect and the same adjustment variables as for the primary outcome.

The changes in the use of specific PPE items were assessed using 5-point Likert scales, ranging from "much less" to "much more." An odd number was decided upon to allow participants to give a neutral answer. Values ranging from –2 to +2 were therefore assigned to each answer, with positive values attributed to changes enhancing IPC behavior. A composite outcome was generated by summing up these values. We used the same statistical method as for the prior composite outcome. When computing composite outcomes, the same weight was applied to all questions. As a reduction in the use of N95 respirators can also be considered as desirable depending on the setting, a sensitivity analysis was performed by analyzing the composite outcome with and without this particular item. Each individual question based on a Likert scale was also analyzed separately and the results are presented graphically, either in the manuscript or in multimedia appendices. No imputation technique was used.

Descriptive statistics were used to describe the factors associated with willingness or refusal to change behavior. The chi-square test or—if the expected frequencies assumption was not met—the Fisher exact test were used to assess differences between groups.

The curated data file (with the groups renamed as "Control" and "Serious Game") is available on the Mendeley Data repository [57].

Results

During the course of the study, the public health authorities of Geneva requested that we create specific accesses for other institutions whose members were not part of the target population. A total of 652 accounts were created, out of which 569 (87.3%) were activated. After exclusion of accounts that had not completed the second questionnaire and of those belonging to institutions other than LTCFs, 295 answer sets were analyzed (Figure 9). Participant characteristics are detailed in Table 1.

Figure 9. Study flowchart.

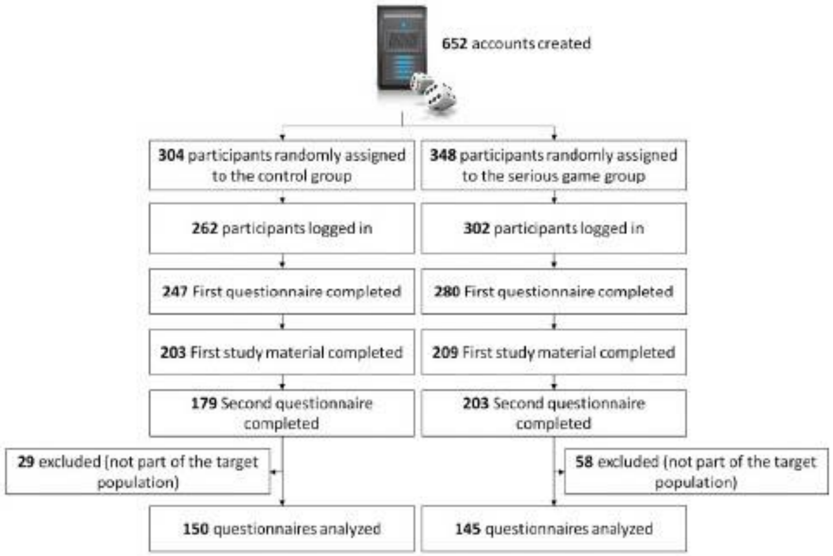


Table 1. Participant characteristics from 36 long-term care facilities in Geneva, Switzerland. Totals may not equal 100% due to rounding.

Participant characteristics	Control (n=150)	Serious game (n=145)
Gender, female, n (%)	118 (78.7)	111 (76.6)
Age (years), median (Q1-Q3)	45 (39-51)	43 (34-52)
Professional group, n (%)		
Nursing staff	83 (55.3)	83 (57.2)
Administrative/support staff	30 (20.0)	24 (16.6)
Physicians	3 (2.0)	3 (2.1)
Other	34 (22.7)	35 (24.1)
Detailed nursing staff status, n (%)		
Nurse	32 (38.6)	35 (41.2)
Health care assistant	36 (43.4)	34 (40.0)
Nurse assistant	5 (6.0)	11 (12.9)
Other	10 (12.1)	5 (5.9)
Non–health care professionals, n (%)		
Hospitality/catering	20 (58.8)	14 (40.0)
Animation	11 (32.4)	12 (34.3)
Other	3 (8.8)	9 (25.7)
Self-assessed frequency of patient contact for non–health care professionals, n (%)		
Very often	25 (39.1)	25 (41.0)
Quite often	19 (29.7)	12 (19.7)
Infrequently	15 (23.4)	22 (36.1)
Almost never	5 (7.8)	2 (3.3)
Years active in the health sector, median (Q1-Q3)	11 (6-22)	12 (4-21)
Baseline knowledge (percentage of correct answers), median (Q1-Q3)	40 (20-60)	40 (20-80)

Out of 36 LTCFs, only 8 provided 10 or more full answer sets, totaling 178 (60.3%) of all analyzed answers. Furthermore, one-third (n=12) of all LTCFs provided less than 5 full answer sets.

The willingness to change behavior was higher in the serious game group (82% [119/145], 95% CI 76%-88% versus 56% [84/150], 95% CI 48%-64%; *P*<.001), with an unadjusted odds ratio of 3.60 (95% CI 2.11-6.13; *P*<.001). After adjusting for professional category and baseline knowledge, using a random effects logistic regression model with LTCF as a random effect, the magnitude of the effect increased slightly, with an odds ratio of 3.86 (95% CI 2.18-6.81; *P*<.001). The effect was not significantly affected by professional category (*P*=.46) or baseline knowledge (*P*=.52). The ICC of 0.07 (95% CI 0.01-0.33) suggests little correlation of responses within individual LTCFs, although the chi-bar-square test showed that there was good evidence against the null hypothesis of no random effects (*P*=.046). A sensitivity analysis performed by excluding answers coming from LTCFs with <10 answers yielded an unadjusted odds ratio of 2.42 (95% CI 1.25-4.68; *P*=.009) and an adjusted odds ratio of 2.54 (95% CI 1.25-5.13; *P*=.01).

The factors underlying the willingness or lack thereof to change IPC behavior are detailed in Tables 2 and 3. The factors that could have led participants to change their behavior can be found in Table 4.

Table 2. Factors underlying the willingness to change infection prevention and control behavior.

Factors	Control (n=84), n (%)	Serious game (n=119), n (%)
The feeling of playing an important role in the common effort against the epidemic	60 (71.4)	82 (68.9)
The information given in the training material	55 (65.5)	74 (62.2)
The probability of infecting a relative	42 (50.0)	58 (48.7)
One should follow the procedures	38 (45.2)	57 (47.9)
Other	1 (1.2)	3 (2.5)

Table 3. Factors underlying the lack of willingness to change infection prevention and control behavior.

Factors	Control (n=66), n (%)	Serious game (n=26), n (%)
I already apply all these guidelines	62 (93.9)	23 (88.5)
This material was not in line with my situation	6 (9.1)	4 (15.4)
The material I have just seen was not helpful	0 (0.0)	0 (0.0)
I do not believe these measures to be useful	0 (0.0)	0 (0.0)
I disagree with these measures	0 (0.0)	0 (0.0)
Other	3 (4.6)	3 (11.5)

Table 4. Factors that could have brought about a change in infection prevention and control behavior.

Factors	Control (n=66), n (%)	Serious game (n=26), n (%)
A better understanding of the reasons underlying the recommendations	19 (28.8)	7 (26.9)
A greater probability of infecting a relative	12 (18.2)	8 (30.8)
The feeling of having an important role in the common effort against the epidemic	28 (42.4)	12 (46.2)
Another reason	19 (28.8)	5 (19.2)
Nothing—I could not have been convinced by any argument	2 (3.0)	2 (7.7)

Among the participants who answered that they were willing to change their IPC behavior after following the learning material, those in the control group exhibited a higher intensity in their willingness to adopt the recommended behaviors (4.88, 95% CI 0.56-9.22; *P*=.03). Adjustment for baseline knowledge, professional status, and LTCF slightly increased the effect, which did not change direction and remained statistically significant (4.98, 95% CI 0.85-9.10; *P*=.02). When analyzed separately, there were no significant differences between the control and intervention group in six IPC domains: not going to work if symptomatic (*P*=.07), protection from both colleagues and patients (*P*=.09), donning sequences with and without risk of aerosolization (*P*=.54 and *P*=.72, respectively), more frequently changing gloves (*P*=.26), and practicing hand hygiene (*P*=.33; Multimedia Appendix 6). However, participants in the control group felt significantly more concerned regarding workplace disinfection (*P*=.002; Figure 10), handling of the face mask (*P*=.02; Figure 11), and protecting themselves from asymptomatic people (*P*=.04) than participants in the intervention group (Figure 12).

Figure 10. Magnitude of the willingness to change workplace disinfection behavior.

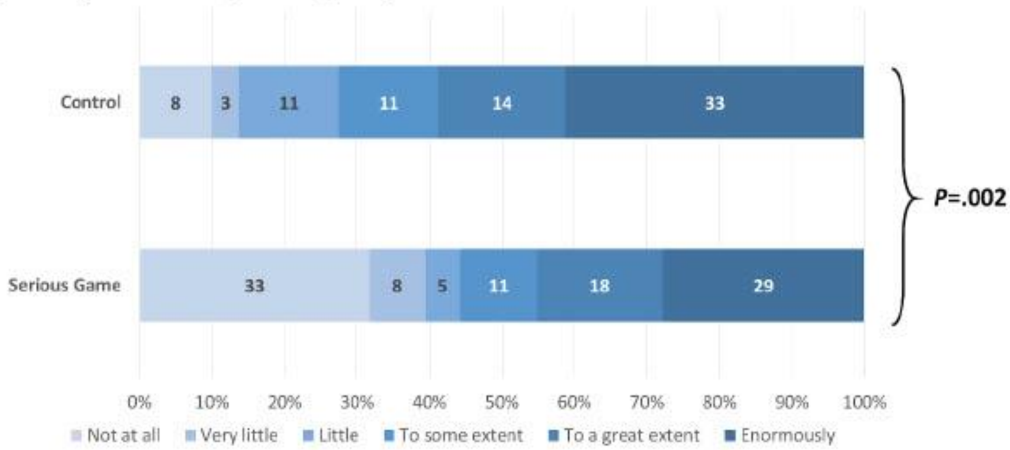


Figure 11. Magnitude of the willingness to change face mask handling behavior.

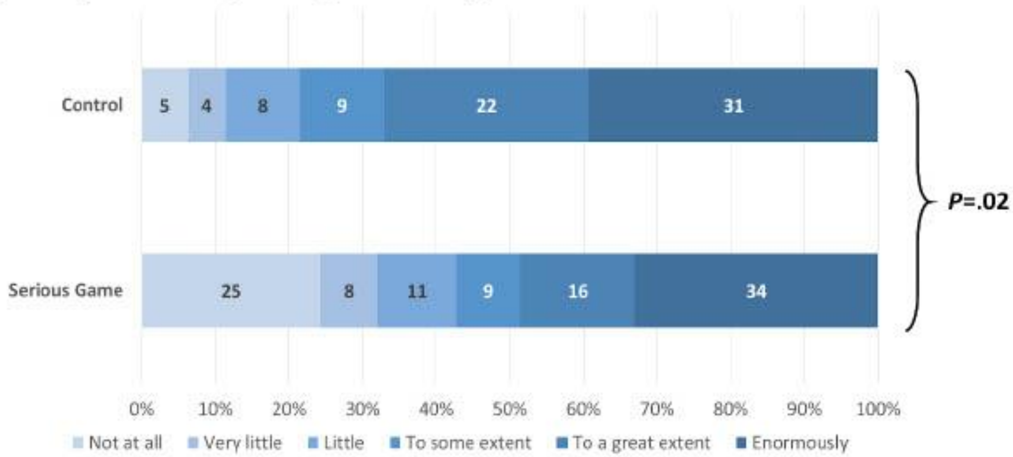
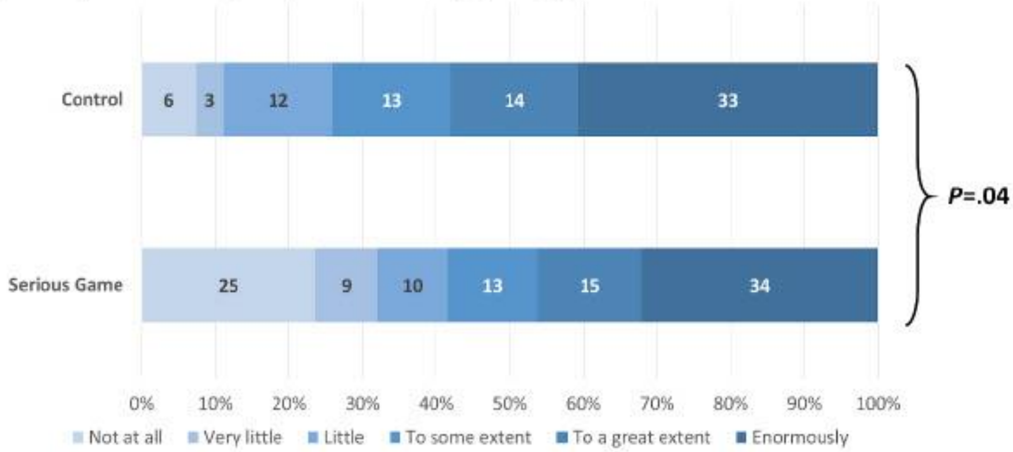


Figure 12. Magnitude of the willingness to protect oneself from asymptomatic people.



There was no overall difference between the groups in the intention of participants to change their use of specific PPE items after studying the IPC material (0.56, 95% CI –0.36 to 1.48; P=.23). Discarding the question about the use of N95 respirators did not affect this result (0.45, 95% CI –0.24 to 1.14; P=.20). There was no significant difference when PPE items were analyzed separately (surgical masks, P=.18; N95 respirators, P=.42; ocular protections, P=.22; gloves, P=.47; Multimedia Appendix 7).

Discussion

Principal Results

After following an online learning path, most participants reported that they were willing to change their IPC behavior. The serious game "Escape COVID-19" was, however, significantly more successful at inducing that change than the simple presentation of IPC guidelines. As this game was created through a theory-driven development process [24,25,50], its success at achieving the intended outcome reinforces the conclusions made by Gentry et al [29] in their recent systematic review, in which they called for further research using such methods.

Factors underlying the willingness to change IPC behavior were very similar between groups, with the feeling of playing an important role against the epidemic being most prominent, superseding even the information given in the training material. This could explain, at least in part, the success of the serious game over the standard IPC guidelines. Indeed, the "exposition" and "engagement" elements of Nicholson's RECIPE for meaningful gamification [25] were extensively used in the development of "Escape COVID-19" [24]. The exposition element is related to the creation of a meaningful narrative in the serious game. This was achieved by having the player go through steps they would usually encounter during the course of a regular work day, including informal times such as breaks or meals. The engagement element is two tiered, the first tier being linked to social engagement and the second to the concept of "flow." This latter concept relates to a progressive increase in the game's difficulty to avoid disinterest [58]. The former, social engagement, is usually achieved by the creation of multiplayer modes. Although "Escape COVID-19" lacks such a mode, it nevertheless takes this element into account by having the player make decisions that would, in real life, affect other people. To further strengthen the importance of these elements, analyzing the factors that could have motivated a change in IPC behavior revealed that the feeling of having an important role in the common effort against the epidemic was the leading factor that could have convinced participants to adapt their practices. This finding is in line with the driving force of the personal locus of control and the receptiveness to learning about and engaging in new behavior in the health care field [59].

The factors underlying the lack of willingness to change IPC behavior were also similar between groups. The vast majority of participants unwilling to change answered that they were already applying all the guidelines they had been presented with. As the serious game contained little material other than that presented in the standard IPC guidelines, it might therefore be surmised that the serious game was also more successful in conveying key IPC messages. Nevertheless, the magnitude of the intention to change IPC practices was significantly higher for some specific aspects in the fewer participants who were willing to change their IPC practices after following the control materials. Our hypothesis is that these participants might have been looking for information regarding some specific IPC aspects and were from the start highly motivated to change their practices according to relevant and up-to-date IPC guidelines, regardless of the way the information was presented. Another explanation is that, even though the serious game was more engaging, it was not designed to give in-depth explanations regarding specific IPC measures. This might have contributed to this difference, even though the proportion of participants answering that "a better understanding of the reasons underlying the recommendations" would have made them more willing to change their IPC practices was similar between groups.

No participant answered that they disagreed with the IPC guidelines or that they did not believe such measures to be useful. Given the current inclination for fake news [60-62] and conspiracy theories [63-65], this is rather reassuring, even more so as some participants were not HCWs but members of administrative, catering, and hospitality staff. More reassuring still is that the analysis of the factors that could have brought about a change in IPC behavior showed that only very few participants answered that they could not have been convinced by any argument.

Limitations and Strengths

This study has several limitations. First, even though the probability of executing an action is strongly linked to the intention of performing it, one can hardly be certain that LTCF employees claiming they are willing to change their IPC behavior will actually change it. Field observations would be necessary to ascertain this aspect, along with a different study design as both groups ultimately accessed the serious game in this study. Another important limitation is that we did not reach the sample size we had expected [34]. Indeed, while we had hoped for at least 800 participants, the actual number of accounts activated by LTCF employees was rather lower. This low figure raises many questions and hypotheses. Indeed, while at least a complete answer set was obtained for each individual LTCF, less than 10 complete answer sets were given by more than three-quarters (28/36) of all LTCFs under the jurisdiction of the public health authorities of Geneva, with almost half of those (12/28) giving less than 5 complete answer sets. It might therefore be assumed that, while all LTCF managers received the information regarding the study, many decided not to forward it to their employees. This was an unexpected finding; however, this study was not designed to assess the reasons underlying this decision. Hypotheses can however be drawn, some of which are more concerning than others. Among the least concerning, fear of overloading already overworked LTCF employees with information, an insufficient number of reminders, or the simple lack of regularly updated mailing lists could partly explain the low participation rate witnessed in many LTCFs. Moreover, some managers might have felt that the material, which originated from a university hospital, was not in line with their situation. However, this hypothesis is challenged by the fact that this impression, though asked for, was reported by 10 participants only. Lack of eHealth literacy is probably not to blame for the lack of participation. Indeed, LTCF employees increasingly use digital devices in the course of their work [66], and recent surveys have shown that eHealth literacy was rather high in HCWs [67]. Among the most disturbing hypotheses, a low level of concern of some LTCF managers, a potential mistrust of health authorities or the institution authoring the game, or even of IPC guidelines, cannot be ruled out. The will to avoid spreading information that could lead to an increase in the use of PPE items and, therefore, to an increase in material costs, seems unlikely. Regardless of the reason, the ability of health authorities to successfully convey critical messages by efficient vectors to LTCF employees should be assessed specifically to solve potential communication issues. The creation of IPC focal points in each LTCF is a path that could be explored.

Despite these limitations, this study also has some strengths, among which the fully automated randomization process, the triple-blinding, and the originality of the material could be mentioned. Finally, despite the lower-than-expected participation rate, the presence of a control group has enabled us to limit certain biases, as one could also hypothesize that only the most motivated LTCF employees would have participated, thereby creating a selection bias and limiting the interpretation of our findings.

Perspectives

This serious game might not be equally effective in all populations, and IPC messages might differ from one region to another. By virtue of its flexible design, "Escape COVID-19" can be updated rather easily and should now be tested on other populations. It has been fully translated into English and is in the process of being translated into German and Italian to allow its deployment at the Swiss national level. To enhance its visibility, publicizing actions similar to those used to promote another recently developed serious game ("COVID-19 – Did You Know?) should be considered [68]. Currently, "Escape COVID-19" is freely available to play online [53], and the corresponding author can be contacted at any time to obtain a SCORM package in either French or English, while translation into other languages is pending.

Conclusion

Among LTCF employees, the serious game "Escape COVID-19" was more successful than standard IPC material in inspiring the willingness to adopt COVID-19–safe IPC behavior.

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Conflicts of Interest

None declared.

Multimedia Appendix 1

Email template.
[PDF File (Adobe PDF File), 57 KB-Multimedia Appendix 1]

Multimedia Appendix 2

Email received upon account creation.
[PNG File , 268 KB-Multimedia Appendix 2]

Multimedia Appendix 3

First questionnaire.
[PDF File (Adobe PDF File), 132 KB-Multimedia Appendix 3]

Multimedia Appendix 4

Second questionnaire.
[PDF File (Adobe PDF File), 105 KB-Multimedia Appendix 4]

Multimedia Appendix 5

Original versions of the screen captures, in French.
[PDF File (Adobe PDF File), 553 KB-Multimedia Appendix 5]

Multimedia Appendix 6

Graphical results of questions regarding infection prevention and control domains (based on the 6-point Likert scale).
[PDF File (Adobe PDF File), 533 KB-Multimedia Appendix 6]

Multimedia Appendix 7

Graphical results of questions regarding specific personal protective equipment items (based on the 5-point Likert scale).
[PDF File (Adobe PDF File), 509 KB-Multimedia Appendix 7]

Multimedia Appendix 8

CONSORT-EHEALTH checklist (V 1.6.1).
[PDF File (Adobe PDF File), 1214 KB-Multimedia Appendix 8]

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Abbreviations

CHERRIES: Checklist for Reporting Results of Internet E-Surveys
CONSORT: Consolidated Standards of Reporting Trials
HCW: health care worker
ICC: intraclass correlation coefficient
IPC: infection prevention and control
LTCF: long-term care facility
PPE: personal protective equipment
SCORM: Shareable Content Object Reference Model

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Nationwide Deployment of a Serious Game Designed to Improve COVID-19 Infection Prevention Practices in Switzerland: Prospective Web-Based Study

The successful deployment of "Escape COVID-19" was promptly followed by several requests for further dissemination, one of which came from members of the Swiss National Science Foundation's (SNSF) National Research Program 78 ("COVID-19"). The SNSF supported the nationwide dissemination of "Escape COVID-19" by funding its translation in German and in Italian (an English translation was already underway by its developers). The SNSF also supported the creation of versions adapted to lay people, since the original game specifically targeted healthcare workers. In addition, the SNSF funded a part-time position promote the endorsement of "Escape COVID-19" by authoritative organizations and to inform the managers of health care facilities that this game was freely available online.

This wide-scale deployment allowed the gathering of a huge quantity of data, and this publication details the factors impeding or facilitating the adoption of adequate IPC behaviour. It also describes the effect of cultural and professional background on the uptake of IPC messages and suggests solutions for future improvement.

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Original Paper

Nationwide Deployment of a Serious Game Designed to Improve COVID-19 Infection Prevention Practices in Switzerland: Prospective Web-Based Study

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Abstract

Background: Lassitude and a rather high degree of mistrust toward the authorities can make regular or overly constraining COVID-19 infection prevention and control campaigns inefficient and even counterproductive. Serious games provide an original, engaging, and potentially effective way of disseminating COVID-19 infection prevention and control guidelines. *Escape COVID-19* is a serious game for teaching COVID-19 infection prevention and control practices that has previously been validated in a population of nursing home personnel.

Objective: We aimed to identify factors learned from playing the serious game Escape COVID-19 that facilitate or impede intentions of changing infection prevention and control behavior in a large and heterogeneous Swiss population.

Methods: This fully automated, prospective web-based study, compliant with the Checklist for Reporting Results of Internet E-Surveys (CHERRIES), was conducted in all 3 main language regions of Switzerland. After creating an account on the platform, participants were asked to complete a short demographic questionnaire before accessing the serious game. The only incentive given to the potential participants was a course completion certificate, which participants obtained after completing the postgame questionnaire. The primary outcome was the proportion of participants who reported that they were willing to change their infection prevention and control behavior. Secondary outcomes were the infection prevention and control areas affected by this willingness and the presumed evolution in the use of specific personal protective equipment items. The elements associated with intention to change infection prevention and control behavior, or lack thereof, were also assessed. Other secondary outcomes were the subjective perceptions regarding length, difficulty, meaningfulness, and usefulness of the serious game; impression of engagement and boredom while playing the serious game; and willingness to recommend its use to friends or colleagues.

Results: From March 9 to June 9, 2021, a total of 3227 accounts were created on the platform, and 1104 participants (34.2%) completed the postgame questionnaire. Of the 1104 respondents, 509 respondents (46.1%) answered that they intended to change their infection prevention and control behavior after playing the game. Among the respondents who answered that they did not intend to change their behavior, 86.1% (512/595) answered that they already apply these guidelines. Participants who followed the German version were less likely to intend to change their infection prevention and control behavior (odds ratio [OR] 0.48, 95% CI 0.24-0.96; P=.04) and found the game less engaging (P<.001). Conversely, participants aged 53 years or older had stronger intentions of changing infection prevention and control behavior (OR 2.07, 95% CI 1.44-2.97; P<.001).

Conclusions: Escape COVID-19 is a useful tool to enhance correct infection prevention and control measures on a national scale, even after 2 COVID-19 pandemic waves; however, the serious game's impact was affected by language, age category, and previous educational training, and the game should be adapted to enhance its impact on specific populations.

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KEYWORDS

COVID-19; serious game; infection prevention; SARS-CoV-2; prospective; web-based; deployment; prevention; gaming; public health; dissemination; health information; behavior; survey

Introduction

Background and Importance

Vaccination campaigns against SARS-CoV-2 have been gathering momentum, but most countries remain months away from reaching group immunity [1-4], provided that such immunity can be attained [5,6]. The almost incessant emergence of new variants is concerning [7]—all the more so as some variants have been shown to evade the immune response acquired by vaccination or by prior infection [8,9]. Viral dissemination may even be facilitated, if normal social interactions are restored and social distancing measures are eliminated, as countries face ever increasing social and economic pressures [10-12]. Moreover, many people experience a rather intense state of tiredness [13-15] coupled with a rather high degree of mistrust toward public health authorities [2,16-18], which can result in a rapidly progressive slackening of infection prevention and control procedures [19-21] and which may even affect health care workers [22]. Switzerland is no exception, and conspiracy theories also thrive in this country [23]. Strengthening infection prevention and control messages and promoting adequate behavior is, therefore, more important than ever; however, regular or aggressive information campaigns might prove counterproductive [21]. These latter strategies were intensively used during the early waves of the pandemic; however, new methods of communication should be considered to increase adherence to infection prevention and control guidelines.

To disseminate COVID-19 prevention messages in an original and engaging way, a transdepartmental and multidisciplinary development team created Escape COVID-19 [24], a serious game based on Nicholson's concept for meaningful gamification [25]. By increasing the players' engagement, serious games, which also enhance knowledge, satisfaction, and skills [26], can help promote adequate behaviors [27,28]. The impact of Escape COVID-19 was assessed in a population of nursing home employees [29]: In a triple-blind controlled trial, the self-reported likelihood of changing infection prevention and control practices was almost 4 times higher in the group of participants who had followed the serious game [29]. However, Escape COVID-19 was only available in French at the time of this prior study, and the population in which it was tested did not allow us to determine whether socioeconomic status or cultural differences influenced its uptake. We hypothesized that receptiveness to messages promoting COVID-19 infection prevention and control behaviors might depend on socioeconomic status and cultural specificities [30].

Objective

The objective of this study was to identify factors learned from playing Escape COVID-19 that favor or impede intentions of changing infection prevention and control behavior in a larger and more heterogeneous population than that used in the previous study [29].

Methods

The Escape COVID-19 Serious Game

The development and features of the Escape COVID-19 serious game have been described previously [24,29]. Briefly, this game was created using Storyline 3 (Articulate Global LLC) and developed using the SERES framework [31], an iterative development approach, to ensure that scientific and design foundations were evidence-based and adapted to the target audience. The different types of players described by Bartle [32] were taken into consideration during the development of Escape COVID-19; therefore, some graphics, game mechanics, and narratives were developed to target achievers, explorers, and socializers.

There is little consensus on what actually defines a serious game; however, according to the conceptual framework created by Tan and Zary [33], Escape COVID-19 fits the definition of a serious game. This framework [33], which describes the criteria required to determine whether a specific material is indeed a serious game, comprises 3 clusters: user experience, play, and learning. Each of these clusters includes 6 base markers, and a minimum of 4 markers per cluster is required to declare that the material under consideration is indeed a serious game. Escape COVID-19 complies with all 18 markers.

Escape COVID-19 contains 4 different levels and takes approximately 15 minutes to complete. Each level represents settings that health care workers typically encounter during a work day (at home, on the road, in communal areas, and in the ward). Players are faced with meaningful choices and are consistently provided with customized, relevant feedback [34]. Adequate infection prevention and control behaviors are rewarded (by an increase in their "thumbs-up" count), while dangerous behaviors lead to an increase in the viral count (Figure 1).

If the virus count reaches a value of 5, a game over screen is displayed (Figure 2). The player can then choose to restart the level or to exchange their thumbs-up count for an equivalent reduction in virus count.

An abridged version, in which the fourth and hardest level (the ward—Figure 3) was not available to players, was also developed (at the request of the Swiss National Science Foundation).

Figure 1. Screenshot showing an example—the player has given a wrong answer, and their viral count rose accordingly.

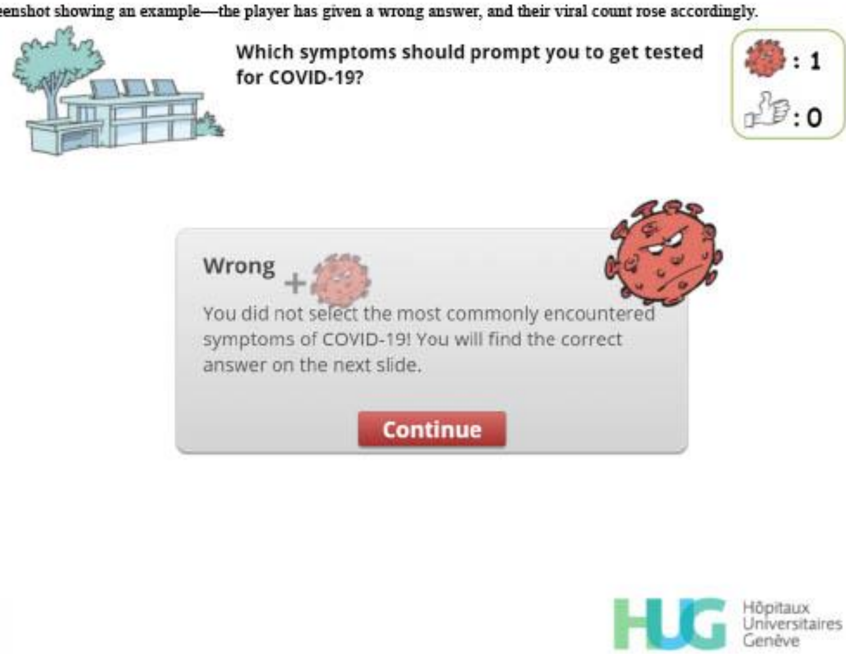
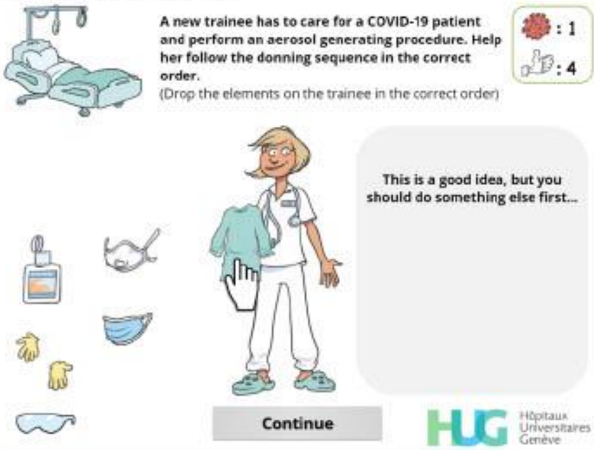


Figure 2. Game over screenshot.

Figure 3. In the donning sequence interaction, the player is asked to drag and drop the appropriate personal protective equipment items in the correct order, and live feedback is displayed in the grey area on the right.



Study Design, Setting, and Participants

We conducted a web-based, fully-automated prospective cohort study in accordance with the Checklist for Reporting Results of Internet E-Surveys (Figure 4) [35]. A declaration of *no objection* was issued by the regional research ethics committee (Req-2021-00600) as this project did not fall within the scope of the Swiss Act on Research involving Human Beings [36]. A disclaimer containing a data policy statement was displayed on the registration form. Data were collected between March and June 2021.

Switzerland is a federal country composed of 26 cantons. There are 4 official languages in Switzerland: German and Swiss German, which are usually grouped as one (62.1%), French (22.8%), Italian (8.0%), and Romansh (0.5%). English is the main language for 5.7% of the permanent resident population [37]. We developed the original version of the Escape COVID-19 serious game in French [24], which we then translated into English. Translations in German and Italian were requested and paid for by the Swiss National Science Foundation (National Research Program 78 framework [38]). A separate translation in Romansh was not requested because Romansh-speaking people in Switzerland generally also speak either German or Italian.

While health care workers were the primary target of this serious game [24], because many of its infection prevention and control messages also apply, we included non–health care workers in this study.

To recruit participants, the Swiss National Science Foundation financed the dissemination of the link to the Escape COVID-19 website [39]. Public and private health care organizations in Switzerland were contacted, and managers were asked to spread the link by different means (such as by email and newsletters). Ten organizations, including the Swiss Red Cross and the Swiss Society for Public Health, decided to endorse the game and allow their logo to be displayed on the website and on the course completion certificate. To enhance participation even further, the Geneva University Hospitals published a press release [40], which was relayed by *Agence France-Presse* [41].

Figure 4. Study design. The European Union flag (on the left at the account creation step) signifies that account and data management were in compliance with the General Data Protection Regulation.

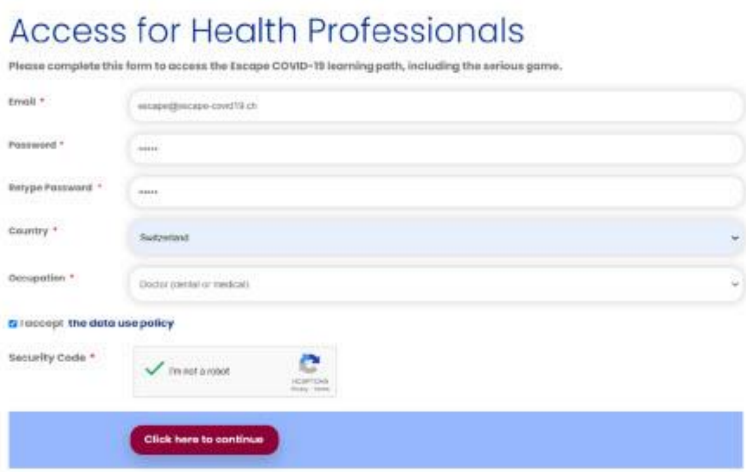
Web Platform and Study Sequence

A multilingual website [39] was developed using a content management system (Joomla!, version 3.9; Open Source Matters Inc). The front page displayed a disclaimer to address concerns regarding potentially contradicting guidelines immediately above the language-specific links used for account creation (Figure 5). Dedicated links were available to allow non–health care workers to create specific accounts.

Participants registered using Joom Donation MembershipPro (version 2.1; Joomla Extensions by JoomDonation), which allows an extensive customization of the registration fields and the addition of specific fields. For instance, the occupation field differed for those who were health care workers and those who were not health care workers. In addition, respondents who were not health care workers were asked to select the highest degree or level of school that they had completed. All fields, including CAPTCHA (Completely Automated Public Turing test to tell Computers and Humans Apart) and a checkbox to accept the data use policy, were required before participants were automatically logged in (Figure 6).

Figure 5. Front page of the website.

Figure 6. Registration form example.



Participants were immediately redirected to a demographic questionnaire (gender, age, and COVID status). All questionnaires were created using Community Surveys (version 5.5; Bulasikku Technologies Pvt Ltd), which allows for the use of branching logic. Regular expressions were used to avoid invalid entries. Respondents who were not health care workers were asked whether they wanted to follow the full or abridged version of the Escape COVID-19 serious game.

After completing the demographic questionnaire, participants were able to launch and play Escape COVID-19. After completing the game, a second questionnaire was displayed (Table 1).

Table 1. Second questionnaire.

Questions, response options, and response-dependent questions
After playing this serious game, are you going to change any of your infection prevention practices?
Yes
What areas will these changes affect?[a]
Not going to work if you have symptoms compatible with COVID-19
Protecting yourself from both your colleagues and your patients[b]
The donning sequence[c] when dealing with procedures CARRYING a risk of aerosolization[b]
The donning sequence when dealing with procedures NOT CARRYING a risk of aerosolization[b]
Changing nonsterile gloves more frequently[b]
Practicing hand hygiene more frequently
Disinfecting your workplace
Handling the face mask more carefully
Protecting yourself from asymptomatic people as well as from symptomatic ones
You are now going to use:[d]
Face masks
N95 respirator masks
Eye protection[b]
Nonsterile gloves[b]
Which of these elements greatly contributed to your intention to modify your practices?[e]
The information given in the serious game
The feeling of playing an important role in the common effort against the epidemic
The probability of infecting a relative
One should follow the procedures
Another reason[f]
No
Why will your practices not change?[d]
I already apply all these guidelines
The information given in this serious game does not apply to my situation
The information given in the serious game was not helpful
I do not believe these measures to be useful
I disagree with these measures
Another reason[f]
What could have motivated you to change your practices?[e]
Better understand the reasons behind the recommendations
A greater probability of infecting a relative
The feeling of having an important role in the common effort against the epidemic
Nothing—I could not have been convinced by any argument
Other[f]
Difficulty of the serious game[g]
Please rate the following items from 1 (strongly disagree) to 5 (strongly agree):

Questions, response options, and response-dependent questions
This serious game is engaging
This serious game is meaningful
This serious game is useful
This serious game is boring
I will recommend this serious game to my friends and relatives
I will recommend this serious game to my colleagues
Duration of the serious game[h]
Do you have any further comments to make regarding this serious game?

[a]Response options were in the form of a 5-point Likert scale from 1 (not at all) to 5 (very much).

[b]This option was not shown to non–health care workers who had elected to follow the abridged version of the serious game.

[c]The *donning sequence* refers to the order in which the personal protective equipment items should be put on.

[d]Response options were in the form of a 5-point Likert scale from 1 (much less) to 5 (much more).

[e]Multiple choice question (more than one possible answer).

[f]A free-text field was displayed when this option was selected.

[g]Response options were in the form of a 5-point Likert scale from 1 (too easy) to 5 (too difficult).

[h]Response options were in the form of a 5-point Likert scale from 1 (much too short) to 5 (much too long).

Participants were unable to bypass any step of the study path by virtue of the Access Control List feature in Joomla!. Sourcerer (version 8, Regular Labs) was used to embed the appropriate PHP (Hypertext Preprocessor) functions (JUserHelper::removeUserFromGroup and JUserHelper::addUserToGroup) to ensure that participants were redirected to the appropriate step when resuming the study path. The Conditional Content component (version 3, Regular Labs) was used to display text and links allowing participants to easily resume the study path.

Data Collection

All data were automatically stored on an encrypted MySQL-compatible database (MariaDB, version 5.5.5; MariaDB Corporation Ab) located on a Swiss server. Participants were able to access and delete their accounts and data at any time. Data from all the participants who created an account on the study platform between March 9 and June 9, 2021 were included regardless of their professional status. Participants were allowed to delete their accounts after playing the game, in which case all data associated with their account were automatically removed from the database and could, therefore, be neither retrieved nor included in analysis.

Given the design of this study, there was no predetermined sample size, and no sampling scheme was used. Therefore, the participants who did not delete their accounts represented a convenience sample.

Outcomes

The primary outcome was the proportion of participants reporting that they were willing to change their infection prevention and control behavior (ie, by answering "Yes" to the first question of the second questionnaire). Some secondary outcomes depended on the participants' willingness to change infection prevention and control behavior: In participants willing to change behavior, secondary outcomes were the infection prevention and control areas affected and the intensity of the participants' willingness to change. The presumed evolution in the use of specific personal protective equipment items was also assessed, as were the elements motivating this willingness to change behavior. In participants unwilling to change infection prevention and control behavior, secondary outcomes were assessment of the reasons for refusing to change and of the potential motivators which could have induced a willingness to change. Other secondary outcomes such as length, difficulty, and willingness to recommend the serious game to either friends or colleagues were assessed regardless of the participants' intention to change behavior. Perceived meaningfulness and usefulness of the game and impression of engagement and boredom while playing the serious game were also assessed in the whole sample.

Data Curation and Statistical Analysis

Data were extracted from the database and imported into Stata (version 15; StataCorp LLC) for data curation. Records of participants who did not complete the first questionnaire were excluded. The curated DTA file is available in Multimedia Appendix 1. Descriptive statistics (frequency, relative percentage, mean, and standard deviation) were used when appropriate. As the serious game has already proven its usefulness in health care workers [29], the primary outcome, intention of changing infection prevention and control behavior, was first analyzed using univariate logistic regression according to professional status (health care workers versus non–health care workers). Multivariable logistic regression was then performed to further adjust for gender, COVID status, language, and age. The assumption of log-linearity of age was assessed graphically. As age was not log-linear, it was categorized according to its quartiles. Goodness of fit was checked using the Hosmer-Lemeshow test. Among non–health care workers, univariate and multivariable logistic regression were performed to determine whether language or other specific factors such as gender, age category, occupation, level of education, or playing the abridged version of the serious game rather than the full game were associated with answering the second questionnaire after completing the serious game. The actual values, from 1 (not at all) to 5 (very much) based on Likert scales, were first used to compute the secondary outcomes. No weighting was applied. For these outcomes, inconsistent answers (ie, those from participants who gave either the minimum or maximum rating for both boredom and engagement) were excluded.

The likelihood ratio test was used to determine whether the parallel lines or proportional odds assumption was met. When met, multivariable ordered logistic regression was used to search for an association between participants' characteristics and secondary outcomes related to the perception of the serious game (engagement and meaningfulness). Because the aforementioned assumption was not met, 2 generalized ordered logistic models were generated using 2 different secondary outcomes as dependent variables: boredom and usefulness. Willingness to change, language, gender, age category, COVID status, occupation, and level of education were used as predictive variables in these models.

Results

From March 9 to June 9, 2021, a total of 3227 accounts were created on the platform: 37 participants chose to delete their accounts, and 325 were excluded as they did not complete the first questionnaire (Figure 7). The characteristics of the 2865 participants included in the analysis are described in Tables 2 and 3.

Most health care workers were nurses (53.0%, 967/1823). Physicians accounted for 11.9% of participants (216/1823), and nursing assistants accounted for 8.1% (148/1823). Other health care professions accounted for 27.0% of the health care worker population.

Figure 7. Study flowchart.

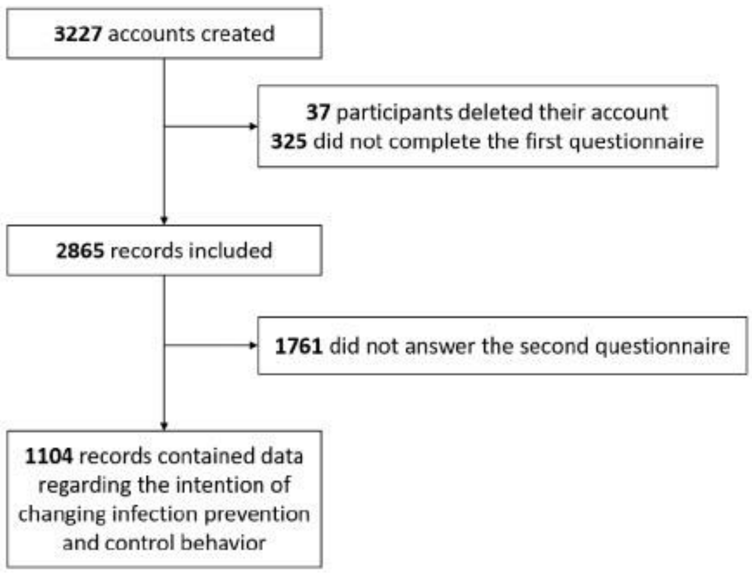


Table 2. Participant characteristics.

Characteristic	Non–health care worker (n=1042)	Health care worker (n=1823)
Language, n (%)[a]		
English	86 (8.3)	83 (4.6)
French	515 (49.4)	646 (35.4)
German	415 (39.8)	1064 (58.4)
Italian	26 (2.5)	30 (1.7)
Gender, n (%)		
Male	395 (37.9)	404 (22.2)
Female	630 (60.5)	1404 (77.0)
Other	17 (1.6)	13 (0.7)
Missing	0 (0)	2 (0.1)
Age, mean (SD)	40.9 (13.8)	41.6 (13.6)[b]
COVID status, n (%)[a]		
Negative or not tested	905 (86.9)	1447 (79.4)
Positive or isolated	3 (0.3)	6 (0.3)
Cured	84 (8.1)	232 (12.7)
Refused to answer	50 (4.8)	136 (7.5)
Missing	0 (0)	2 (0.1)

[a]Percentage totals may exceed 100% due to rounding.
[b]n=2 values were missing.

Table 3. Additional characteristics of non–health care workers.

Characteristic	Non–health care workers, n (%)
Occupation	
Health or social	251 (24.1)
Business	49 (4.7)
Hospitality	20 (1.9)
Manufacturing	35 (3.4)
Public sector or education	252 (24.2)
Transport or retail	28 (2.7)
Other	335 (32.1)
Missing	72 (6.9)
Degree of education	
Mandatory school	49 (4.7)
Secondary education	39 (3.7)
Professional diploma	289 (27.7)
High school graduate	149 (14.3)
University graduate	430 (41.3)
Other	60 (5.8)
Missing	26 (2.5)
Version played	
Abridged	576 (55.3)
Full	466 (44.7)

Of the 2865 participants included in the analysis, 1104 (38.5%) provided information regarding their intentions of changing infection prevention and control behavior, and 1061 fully completed the second questionnaire. Of those, 477 (45.0%) generated a course completion certificate.

Among non–health care workers, the only factor associated with the probability of answering the second questionnaire was having completed the abridged version, which was significant after adjusting for playing the abridged version rather than the full one and for gender, age, occupation, and level of education (odds ratio [OR] 1.96, 95% CI 1.48-2.59). In health care workers, an association between language and the probability of answering the questionnaire was present after univariate analysis ($P<.001$) and remained after adjusting for gender, age category, profession, and COVID status ($P=.002$). In this group, participants who refused to detail their COVID status were less likely to answer this questionnaire (OR 0.49, 95% CI 0.32-0.75).

Among participants who answered the second questionnaire, less than half (509/1104, 46.1%) intended to change their infection prevention and control behavior after playing the game. However, among those who did not intend to change their infection prevention and control behavior, the vast majority answered that they already apply these guidelines (Table 4). Few participants (13/595, 2.2%) answered that they disagreed with these measures or that they did not believe such measures to be useful.

Participants intending to change infection prevention and control behavior were generally radical in their willingness to change certain aspects of the practices (not at all: 1003/4085 answers, 24.6%; very much: 1795/4085 answers, 43.9%).

Most of them were not likely to change their use of specific personal protective equipment items, the only exception being related to the use of protective goggles (156/383, 40.7% answered that they would use goggles more or much more after playing the serious game).

Participants who answered that they intended to change their infection prevention and control behavior were mostly motivated by the information contained in the serious game and by the feeling of playing an important role in the common effort against the epidemic (Table 5).

Table 4. Reasons given for not changing infection prevention and control behavior.

Reason	Non–health care worker (n=309), n (%)[a]	Health care worker (n=286), n (%)[a]
Already applies these guidelines	288 (93.2)	224 (78.3)
The information given in the serious game did not apply to the participant's situation	33 (10.7)	78 (27.3)
Disagrees with these measures	3 (1.0)	10 (3.5)
The information given in the serious game was not considered helpful	5 (1.6)	2 (0.7)
Did not believe these measures to be useful	2 (0.6)	2 (0.7)
Another reason	6 (1.9)	19 (6.6)

[a]Multiple responses are possible; therefore, percentages do not add to 100%.

Table 5. Reasons associated with the willingness of changing infection prevention and control behavior.

Reason	Non–health care worker (n=124), n (%)[a]	Health care worker (n=385), n (%)[a]
The information given in the serious game	70 (56.5)	208 (54.0)
The feeling of playing an important role in the common effort against the epidemic	76 (61.3)	200 (51.9)
One should follow the procedures	43 (34.7)	144 (37.4)
The probability of infecting a relative	57 (46.0)	129 (33.5)
Another reason	3 (2.4)	8 (2.1)

[a]Multiple responses are possible; therefore, percentages do not add to 100%.

Univariate logistic regression showed that, compared to non–health care workers, health care workers were more likely to intend to change their infection prevention and control behavior (OR 3.35, 95% CI 2.59-4.34). This association was reinforced after adjusting for age category, gender, language, and COVID status (OR 3.88, 95% CI 2.94-5.13). The 2 elements with significant associations were German language (OR 0.48, 95% CI 0.24-0.96) compared to reference category (English) and being aged 53 years or older (OR 2.07, 95% CI 1.44-2.97) compared to reference category (11-30 years).

Among non–health care workers, belonging to the highest age category (53 years or older: OR 3.33, 95% CI 1.66-6.68) and playing the full rather than the abridged version of the serious game (OR 4.45, 95% CI 2.63-7.55) were associated with a more significant willingness to change infection prevention and control behavior. There was no significant difference in this outcome related to either occupation (P=.42) or educational status (P=.11).

Thirty-three records (33/1061, 3.1%) were excluded because they contained either minimal or maximal ratings for both the engagement and boredom items. The serious game was generally considered engaging (mean 3.9, SD 1.0), meaningful (mean 4.4, SD 0.9), and useful (mean 4.3, SD 0.9). Boredom was rated rather low (mean 1.9, SD 1.1).

Perceived meaningfulness was affected by 4 different factors. Non–health care workers who intended to change their infection prevention and control behavior were more likely to find the game meaningful (OR 2.40, 95% CI 1.44-3.99). Those who had chosen to play the full version of the game were also more likely to find the game meaningful (OR 1.74, 95% CI 1.05-2.88). Participants who did not identify themselves as belonging to the male or female gender found the game to be less meaningful (OR 0.14, 95% CI 0.03-0.68).

Likewise, non–health care workers who intended to change their infection prevention and control behavior, and those who had chosen to play the full version of the game were more likely to find it engaging (OR 2.73, 95% CI 1.71-4.33 and OR 2.24 95% CI 1.39-3.60, respectively). Non–health care workers who identified themselves as belonging to the female gender also found the game more engaging (OR 1.58, 95% CI 1.02-2.45), while participants who did not identify themselves as either male or female found it less engaging (OR 0.19, 95% CI 0.05-0.76). Participants who played the German version of the game also found it less engaging (OR 0.15, 95% CI 0.06-0.40).

Health care workers were more likely than non–health care workers to recommend this serious game to their colleagues (OR 1.87, 95% CI 1.49-2.35). They were also more likely to recommend it to their relatives than non–health care workers were (OR 1.43, 95% CI 1.14-1.79). Regarding difficulty, Escape COVID-19 was considered to be well balanced by 71.3% (756/1061), and more health care workers (534/655, 81.5%) to found it to be well balanced (P<.001), with 13.6% (89/655) finding it either easy or too easy, versus 54.7% of non–health care workers (222/406), with 39.4% (160/406) finding it either easy or too easy. Regarding length, the serious game was considered as well balanced by 89.4% of participants (health care workers: 597/655, 91.1%; non–health care workers: 351/406, 86.5%; P=.002).

Given the differences observed in the uptake of the French and German versions, we carried out a posthoc qualitative analysis of the final comments recorded by participants to determine whether translation problems could be involved. There were 158 comments, 81 of which (51.3%) were recorded by participants who played the German version of Escape COVID-19. Of these, 8 (9.9%) were linked with translation issues. Two examples can be found below:

> *The game is very good, so please refrain from using unnecessary anglicisms that are hard to understand for anyone who is not a native English speaker...*
>
> *Please pay attention to correct gendering. The job title "Krankenschwester" is wrong...*

All original comments are included in the curated data file (Multimedia Appendix 1).

Discussion

Principal Results

This nationwide campaign based on an innovative educational tool shows that giving players the impression of having an important role in the fight against the pandemic is a potent motivator for enhancing intentions of changing infection prevention and control behavior. Future serious games could use this element to promote vaccination.

Slightly less than half (509/1104, 46.1%) of participants who provided information on their intentions responded that they intended to change their infection prevention and control behavior after playing Escape COVID-19. While this figure might seem rather low at first glance, the vast majority of those not willing to change behavior answered that they already apply the guidelines outlined in the serious game. Even more reassuringly, the proportion of participants who did not believe infection prevention and control measures to be useful was extremely low. These findings must, however, be mitigated by a probably important selection bias, which is further detailed below.

The only element associated with a lesser probability of answering the second questionnaire for non–health care worker participants was choosing to play the full rather than the abridged version of the serious game. Two hypotheses might explain this finding. First, the full version of the game is longer and is much more difficult because it includes the fourth level (the ward), and non–health care workers are neither used to this setting nor to the specific personal protective equipment items and procedures depicted there. Some participants might, therefore, have chosen to abandon the game without completing this level. As the serious game was not embedded in a learning management system, we were unable to define the exact moment at which participants chose to drop out, and we were unable to gather information related to specific questions or to record the final score obtained by participants. Second, some of the participants who completed this full version of the game might have felt ill at ease completing the second questionnaire and might have thought that only health care workers were actually qualified to answer it. Nevertheless, findings from a recent study [42] strengthen support for the importance of including non–health care workers in the target population. Indeed, a secondary analysis of quantitative data collected in Ghana showed that nonclinical staff, midwives and pharmacists demonstrated lower adherence to infection prevention and control guidelines than that demonstrated by other health care workers [42]. Thus, designing infection prevention and control promotion materials that can reach many different professions, including non–health care workers in regular contact with vulnerable populations, is essential to limit viral transmission.

Older participants reported that they were more likely to change their infection prevention and control behavior after following the serious game. Three theories could explain this association. First, older age is associated with an increased risk of complications after SARS-CoV-2 infection [43], and older individuals might therefore be wary of such complications. Second, regular information material such as flyers, posters, or other text documents might be too dull and too hard to grasp [44]. A more engaging and unambiguous way of providing information might, therefore, be more appropriate to convey critical messages to this population. Indeed, even though there might be a tendency to think that games are only for young individuals, factual data bely this somewhat prejudiced impression [45-48]. Third, an effect that is linked to different digital generations (ie, X, Y and Z) could also be present. Indeed, entering an e-learning process has been found to be linked to the strongest level of contextualization of learned web-based content in generation X (individuals born between 1965 and 1979) [49].

As a federal and multilinguistic country, Switzerland represents a unique challenge. In this nationwide study, the probability of gathering health care worker data regarding the intention of changing infection prevention and control behavior and concerning perceptions about the serious game depended on language, gender, and COVID status. This last fact is hardly surprising, as it can be hypothesized that participants unwilling to detail their COVID status before playing the game might already have been skeptical regarding its content. Indeed, it does not seem unrealistic to assume that these participants did not trust the investigators and the data protection policy displayed on the website or that they were simply unwilling to provide any useful data. Though not conclusive, an element supporting this hypothesis was found in a randomized controlled trial [50] that assessed the effect of an e-learning module on attitude and knowledge regarding personal protective equipment, in which an inconsistent answer set had to be excluded and was the only one in which the respondent answered that they were unwilling to disclose their COVID status.

This study was carried out after the peak of the second pandemic wave had been reached in Switzerland, and most health care workers had already accessed a wide array of infection prevention and control educational tools, thereby substantially decreasing the number of potentially naïve participants. While gender has already been shown to influence engagement in video game activities [51], the impact of language on messages conveyed by serious game has scarcely been studied and deserves attention. Indeed, apart from the lesser probability of answering the second questionnaire, playing the game in a specific language was associated with a different probability of changing infection prevention and control behavior. One aspect of this issue is that the German and Italian translations were performed by third parties who did not take into account the multidisciplinary aspect which had driven the creation of the serious game [24]. Taking learners' profiles into account is, however, essential [52] and might have enhanced message uptake, and one participant commented on the fact that an outdated word was used to identify nurses (ie, *Krankenschwester* rather than *Pflegefachperson*).

Many studies [53,54] have already explored the adherence of particular subsets of health care workers to specific COVID-19 transmission-reducing behaviors. Recently, a web-based survey carried out in Saudi Arabia showed that respiratory therapists were more likely to adhere to infection prevention and control guidelines at home than at work [53]. Thus, behavioral change should be promoted not only in the professional setting but also in the private sphere, and motivation appears to be a key factor to promote such change. Strengthening this message even further, a systematic review [54] assessed the impact of interventions aimed at promoting eHealth capability or motivation among health care professionals, reported that most interventions aimed to promote capability rather than increasing motivation, and concluded that evidence-based developments should be carried out to enhance this last factor. Escape COVID-19, which was generated by virtue of a theory-driven process, seems to provide adequate messages, if our results are to be trusted. In addition, this serious game also helps health care workers reflect on their infection prevention and control behavior outside of the hospital environment through its first 2 levels (at home and on the road).

Cultural differences and perceptions regarding serious games, their graphics, player and nonplayer characters, and the game environment might also affect the impact of serious games. In this study, the participants who followed the German version of Escape COVID-19 were less likely to find it engaging. The reasons underlying this difference could not be thoroughly assessed, and further data should be gathered to determine how this version should be modified to increase engagement. This is critical, as the probability of actually carrying out an action relies upon this parameter [55]. In any case, including native speakers and ensuring the quality and validity of the translation is essential.

In addition, cultural and regional differences can alter whether a specific material should be considered a game, and the boundaries between serious games and gamification are often unclear [56]. However, using McCallum's [57] definition, there is little doubt that Escape COVID-19 is indeed a serious game as it is the result of the "creation of a whole new experience to achieve some change in the player."

Obtaining a course completion certificate might have convinced some participants to complete the second questionnaire, even though more than half of those who completed it chose not to generate a certificate. Many reasons could explain this fact. First, in Switzerland, some health care workers are not required to obtain continuing medical education credits. This decreases the potential impact of the incentive of obtaining a course completion certificate. Second, official federal organizations are less used to issuing continuing medical education credits for web-based courses, particularly serious games. This prevented us from granting official continuing medical education credits to participants, which further decreased the value of this particular incentive.

Limitations

The main limitation of this study was the use of convenience sampling, which led to a 2-tiered selection bias. First, it is to be expected that the participants who decided to register to play the game were already interested in COVID-19 protective procedures and were probably motivated to enhance their infection prevention and control behavior. Second, even after registering and playing the game, the only incentive to complete the second questionnaire was the possibility of acquiring a course completion certificate. This incentive was rather limited, as this certificate did not grant any continuing medical education credits, and many Swiss health care workers are not required to attend continuous education. In addition, this study took place after the peak of the second pandemic wave in Switzerland, which potentially decreased the interest some might have had in playing such a game. Furthermore, we were not able to determine the reasons that prevented a rather high proportion of participants from completing the second questionnaire. Attrition is to be expected in such studies [58,59], and we, therefore, strove to keep all questionnaires as short and straightforward as possible [60]. Despite our efforts, the second questionnaire might, nevertheless, have been considered too long by participants who dropped out. It is also possible that some participants who dropped out found the game ill-suited to their particular situation, unnecessary, or even boring. The high level of satisfaction among respondents is, however, relatively reassuring in this matter.

As an abridged version of the game had not been considered during the initial development process and because it was urgently requested, considerations specific to non–health care workers were neither sought nor taken into account. Therefore, even though infection prevention and control procedures are simpler and easier to follow for non–health care workers, this lack of customization might explain, at least in part, the lower willingness to change infection prevention and control behavior observed in non-health care workers. Rather than modifying Escape COVID-19 even further, the use of other serious games, such as "COVID-19-Did You Know?," which was designed to target non–health care workers from inception, should be considered [61].

Perspectives

The cultural differences in message uptake identified in this study are intriguing. Even though such differences have already been identified [62], the extent of these differences was quite surprising, and their causes should now be studied in order to be able to adapt future serious games to these cultural characteristics. While the original, French version of Escape COVID-19 was developed taking feedback from potential end users into account [24], the translated versions were not.

Therefore, in line with the co.LAB framework, which recommends identifying learners' profiles and adapting the game accordingly [52], we are considering carrying out focus groups to determine the shortcomings of the current version of this game and the elements that could make Escape COVID-19 more engaging. Different focus groups would be required to take into consideration elements specific to particular social, cultural, and linguistic backgrounds. In addition, such focus groups could be used to determine whether a new level or a new module could help promote vaccination. The main issues such a development must address should be explored during these sessions, which might also shed light on cultural differences regarding vaccine hesitancy [1,2,63,64].

Conclusion

Despite the incentive of obtaining a course completion certificate, the postgame questionnaire was completed by less than half of all participants. Even though more than half of those who filled in this questionnaire reported that they were not going to change their infection prevention and control behavior, they attributed this answer to the fact that they already apply the infection prevention and control guidelines presented in the serious game. The impact of Escape COVID-19 on participants who intended to change their infection prevention and control behavior after playing was, however, substantial as these users were generally radical in their willingness to alter their practice. They reported that their willingness to change their infection prevention and control behavior was equally motivated by the feeling of playing an important role in the common effort against the pandemic and by the information contained in the serious game.

In this study, older age was associated with the intention of changing infection prevention and control behavior. Conversely, playing the German version of the game decreased the likelihood of intending to change behavior. Different hypotheses could explain these findings and should now be explored to help adapt the game and enhance the uptake of infection prevention and control messages.

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Conflicts of Interest

None declared.

Multimedia Appendix 1

Curated data file in CSV and DTA formats.
[ZIP File (Zip Archive), 248 KB-Multimedia Appendix 1]

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Asynchronous Distance Learning of the National Institutes of Health Stroke Scale During the COVID-19 Pandemic (E-Learning vs Video): Randomized Controlled Trial

This last article describes a randomized controlled trial designed to evaluate the effect of a dynamic, highly interactive e-learning module on NIHSS knowledge acquisition in senior medical students in comparison with Patrick Lyden's original video. Assessing whether this module was effective in this population of soon-to-be physicians was deemed particularly important since the medical students who participated in the study had been unable to participate in the usual clinical rotations which are part of the regular medical curriculum. Thus, these future professionals had not had the occasion to clinically assess stroke victims even though many of them would have to face patients presenting this time-critical pathology during their first year of residency. The module used in this study was an improved version of the module tested in a prior study [63].

Reference: Suppan M, Stuby L, Carrera E, Cottet P, Koka A, Assal F, Savoldelli GL, Suppan L. *Asynchronous Distance Learning of the National Institutes of Health Stroke Scale During the COVID-19 Pandemic (E-Learning vs Video): Randomized Controlled Trial*. J Med Internet Res. 2021 Jan 15;23(1):e23594. doi: 10.2196/23594. PMID: 33428581; PMCID: PMC7812917 [47].

Original Paper

Asynchronous Distance Learning of the National Institutes of Health Stroke Scale During the COVID-19 Pandemic (E-Learning vs Video): Randomized Controlled Trial

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Abstract

Background: The COVID-19 pandemic has considerably altered the regular medical education curriculum while increasing the need for health care professionals. Senior medical students are being incrementally deployed to the front line to address the shortage of certified physicians. These students, some of whom will be fast-tracked as physicians, may lack knowledge regarding the initial management of time-critical emergencies such as stroke.

Objective: Our aim was to determine whether an e-learning module could improve asynchronous distance knowledge acquisition of the National Institutes of Health Stroke Scale (NIHSS) in senior medical students compared to the traditional didactic video.

Methods: A randomized, data analyst–blinded web-based trial was conducted at the University of Geneva Faculty of Medicine between April and June 2020. Fifth year medical students followed a distance learning path designed to teach the NIHSS. The control group followed the traditional didactic video created by Patrick Lyden, while the e-learning group followed the updated version of a previously tested, highly interactive e-learning module. The main outcome was the score on a 50-question quiz displayed upon completion of the learning material. The difference in the proportion of correct answers for each specific NIHSS item was also assessed.

Results: Out of 158 potential participants, 88 started their allocated learning path and 75 completed the trial. Participants who followed the e-learning module performed better than those who followed the video (38 correct answers, 95% CI 37-39, vs 35 correct answers, 95% CI 34-36, $P<.001$). Participants in the e-learning group scored better on five elements than the video group: key NIHSS concepts ($P=.02$), the consciousness – global item ($P<.001$), the facial palsy item ($P=.04$), the ataxia item ($P=.03$), and the sensory item ($P=.04$).

Conclusions: Compared to the traditional didactic video, a highly interactive e-learning module enhances asynchronous distance learning and NIHSS knowledge acquisition in senior medical students.

(J Med Internet Res 2021;23(1):e23594) doi: 10.2196/23594

KEYWORDS

stroke; COVID-19; e-learning; medical student; medical education; online learning; randomized controlled trial; video

Introduction

The swift strengthening of public health policies in the context of the COVID-19 crisis has wrought deep changes in the regular medical education curricula of many countries [1-4] while also increasing the need for health care professionals, including physicians. Senior medical students are being incrementally used on the front lines to address the shortage of these professionals [5,6], and other students may soon be required to follow suit [7]. Accelerated graduation procedures have also been described in some regions [8]. Senior medical students as well as some of these fast-tracked physicians may lack knowledge regarding the initial management of specific emergencies such as stroke. Stroke is a time-critical emergency that must be treated swiftly to improve functional and vital prognoses [9]; however, disruptions in acute stroke pathways have been described in the wake of the COVID-19 pandemic [10]. The National Institutes of Health Stroke Scale (NIHSS) is widely used to assess stroke victims [11], and senior medical students as well as junior residents should be familiar with its application.

Traditional classroom or bedside teaching can be difficult to conduct in certain situations, such as a pandemic [12-14]. Many universities have strived to increase distance learning capabilities, thereby highlighting the potential benefits of electronic learning (e-learning) [15-17]. E-learning is a generic term that includes many types of technologically enhanced learning materials [18-20]. Asynchronous distance learning using these methods has yielded mixed results, probably due to differences in the quality of the content and the mode of delivery [21].

Since the release of Patrick Lyden's didactic video in 1994 [22], the development of NIHSS teaching material has been rather limited. We have recently shown that compared to this didactic video, a highly interactive e-learning module improved NIHSS knowledge acquisition in paramedics [23]. We defined this module as "highly interactive" because it uses multiple learning mechanics to promote interaction and engagement. Among these mechanics, preventing content skipping [24] and providing feedback tailored to the user's answer were the most prominent [25]. Branching logic was extensively used to create this feedback.

This first study was performed with the participants present at the study site; therefore, they could immediately access technical support if needed. Moreover, although most results favored the use of the e-learning module, the control group was better at scoring the ataxia element than the e-learning group. Although video extracts were used within the e-learning module to demonstrate the assessment of almost all NIHSS items, the chapter regarding the ataxia element did not contain any video extracts. We therefore hypothesized that systematically embedding videos could improve NIHSS learning acquisition, and we updated the module accordingly.

Given the need for social distancing during the COVID-19 pandemic, our goal was to compare medical students' asynchronous distance learning of the NIHSS using two different teaching tools: the gold standard didactic video and the updated version of our e-learning module.

Methods

Study Design and Setting

We performed a randomized, controlled, data analyst–blinded, web-based trial following the CONSORT-EHEALTH guidelines and incorporating relevant elements from the Checklist for Reporting Results of Internet E-Surveys (CHERRIES) checklist [26,27]. The study took place between April 28 and June 8, 2020, in Geneva, Switzerland. Fifth year medical students at the University of Geneva Faculty of Medicine (UGFM) were invited to take part in this trial on a voluntary basis.

Standard Protocol Approvals, Registrations, and Participant Consent

Because the study included no patients and as no health outcomes were recorded, trial registration was not required according to the International Committee of Medical Journal Editors guidelines. Although the participants were not part of a vulnerable group according to Swiss federal law on human research [28], we filed a jurisdictional enquiry, and the regional ethics committee issued a "Declaration of no objection" (Req 2020-00474). The study was also approved by the Board of the Teaching Committee of the UGFM. Informed consent was gathered electronically.

Enrollment

After gathering the necessary authorizations, the UGFM students' secretary transmitted the exact number of fifth year medical students to MS, who performed a 1:1 computer assisted randomization without having access to any other data regarding the students. MS then created specific identifiers that were transmitted back to the UGFM along with a mailing template Multimedia Appendix 1. The UGFM staff were therefore unable to determine the students' allocations or results. In addition, we were prevented from determining the students' identities.

The students were informed of the goals of the investigation, were given information regarding data security and anonymization procedures, and were supplied with the email addresses of three investigators to allow them to ask further questions. Students who elected to browse the website were provided with additional information as well as with a link to a full 4-page consent form in PDF format that they could either print or save. Using their identifiers to log into the site was considered as acceptance to participate in the study. All participants were free to withdraw at any time. No financial incentive was provided.

Web-Based Platform and Learning Material

We created a specific web-based platform under the Joomla 3.9 content management system (Open Source Matters) [29]. The control was Patrick Lyden's original video, which was subtitled in French [22]. The experiment used version 21 of our e-learning module, which was developed using Articulate Storyline 3 (Articulate Global). This software enables the creation of many types of interactive content, including gamified modules and serious games [30,31], which can be accessed on regular computers as well as on smartphones and tablets.

The e-learning module contains 16 independent chapters. The first chapter is the introduction, which is automatically displayed when the module is launched. Prevention of content skipping is the first learning mechanic used in the module, and it already appears in the introductory slides (Figures 1-3) [24].

A table of contents is displayed as soon as the user has completed the introduction. The user can then choose to review the introduction or to access any other chapter apart from the summary (Figure 4).

Figure 1. Prevention of content skipping. The user cannot click on the *Cliquez ici pour continuer* (Click here to continue) button until both blue buttons have been clicked.

Figure 2. The user has clicked on one of the two buttons, and the learning content is now displayed in a lightbox. The *Cliquez ici pour continuer* (Click here to continue) button, which is slightly visible in the background, is still grey; therefore, it is inactive.

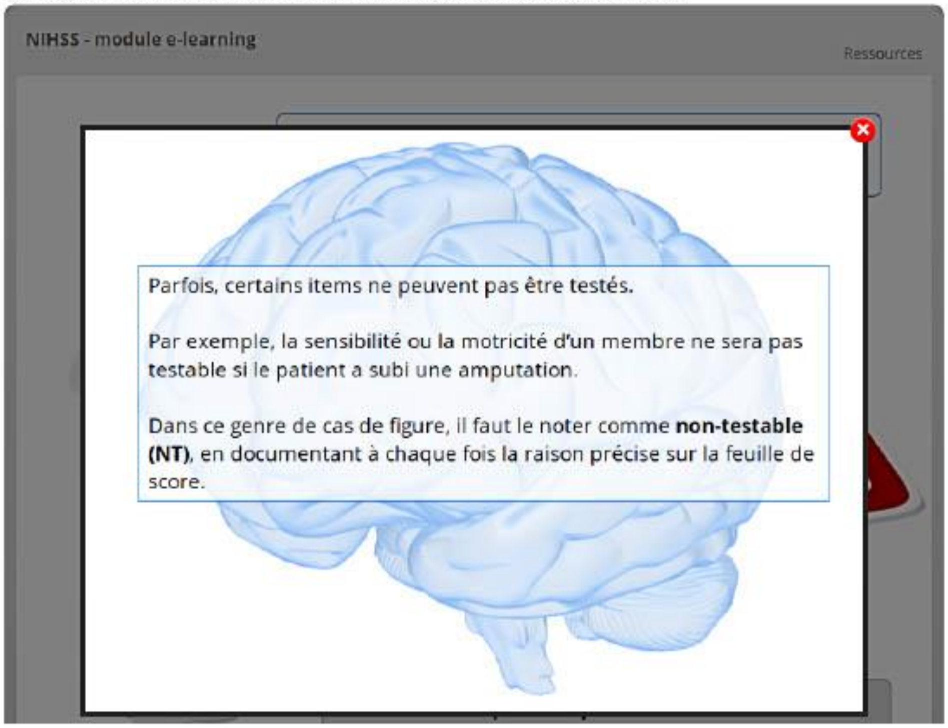


Figure 3. Both buttons have been clicked, and the user has seen both lightboxed slides. The *Cliquez ici pour continuer* (Click here to continue) button has thus been activated and is now colored blue.

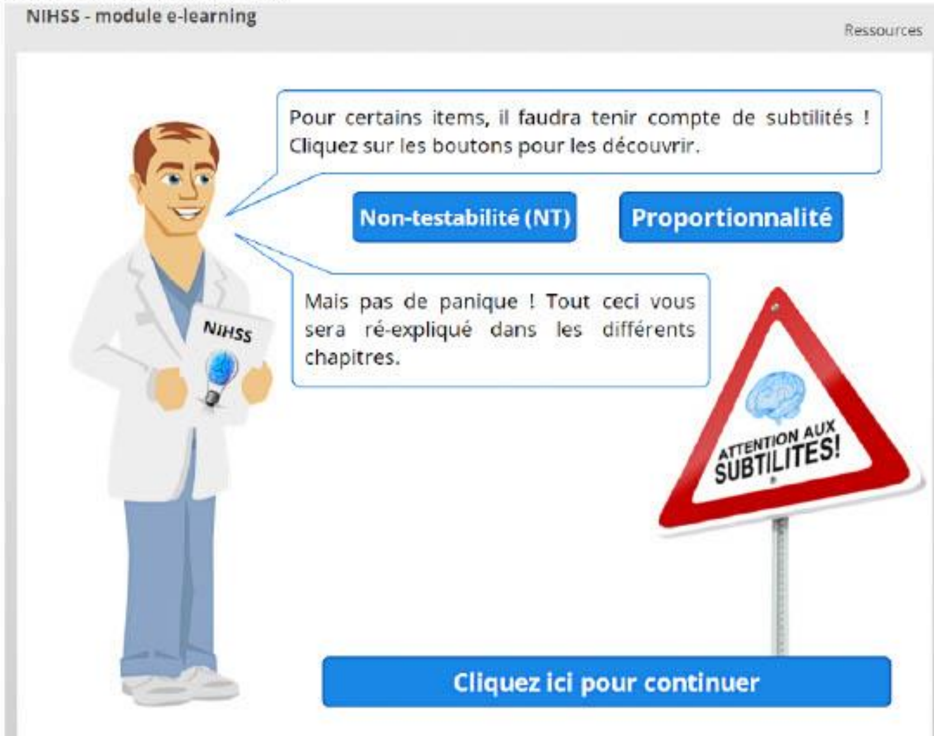


Figure 4. Table of contents of the e-learning module. The *Résumé* (Summary) can only be accessed once all the other chapters have been completed.

Thirteen chapters are used to explain each specific NIHSS item (3 chapters are used to cover the first item, "consciousness," which is divided into 3 elements). Although the chapters are numbered consecutively according to the NIHSS scoring logic, the user can freely elect the order in which to follow the chapters.

All chapters include at least two learning mechanics. First, each chapter begins by displaying the NIHSS score specific to the scoring item, and users are once again prevented from skipping content, as they must click on each numbered button to discover the score (Figure 5).

The second learning mechanic is linked to the use of subtitled videos. Video extracts are shown to the user, who must correctly score the NIHSS item (Figure 6). This version of the module contains video extracts in all chapters, including for the items related to dysarthria, level of consciousness – global, and level of consciousness – questions. In the previously studied version of our module (version 20), there were no video extracts for these items [23].

Feedback is provided for each question [25]: if the answer is incorrect, a clue is given (Figure 7), and the user has the opportunity to review the NIHSS item scoring.

If the answer was correct, feedback is also given to reinforce the message (Figure 8).

Specific interactions were designed to further illustrate particular elements, such as visual field deficits (Figure 9) or extinction and inattention (Figure 10).

Figure 5. Prevention of content skipping. The user cannot click on the *Continuer* (Continue) button until all the blue buttons have been clicked.

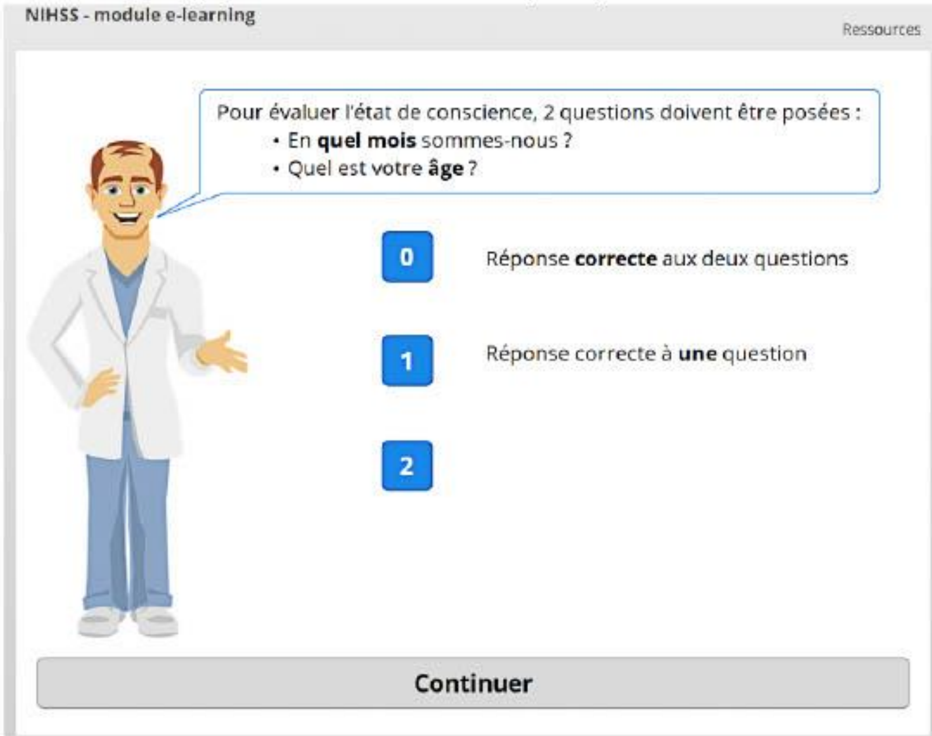


Figure 6. Video-based question. The user must choose the correct score for the patient displayed in the video before clicking on *Valider la réponse* (Validate the answer).

Figure 7. Wrong answer feedback and clue. The user can choose either to try again (*Réessayer*) or to review the scoring specific to this item by clicking *Cliquez ici pour afficher l'échelle* (Click here to display the scale).

Figure 8. Positive feedback after a correct answer.

Figure 9. Interactive explanation of visual field deficit.

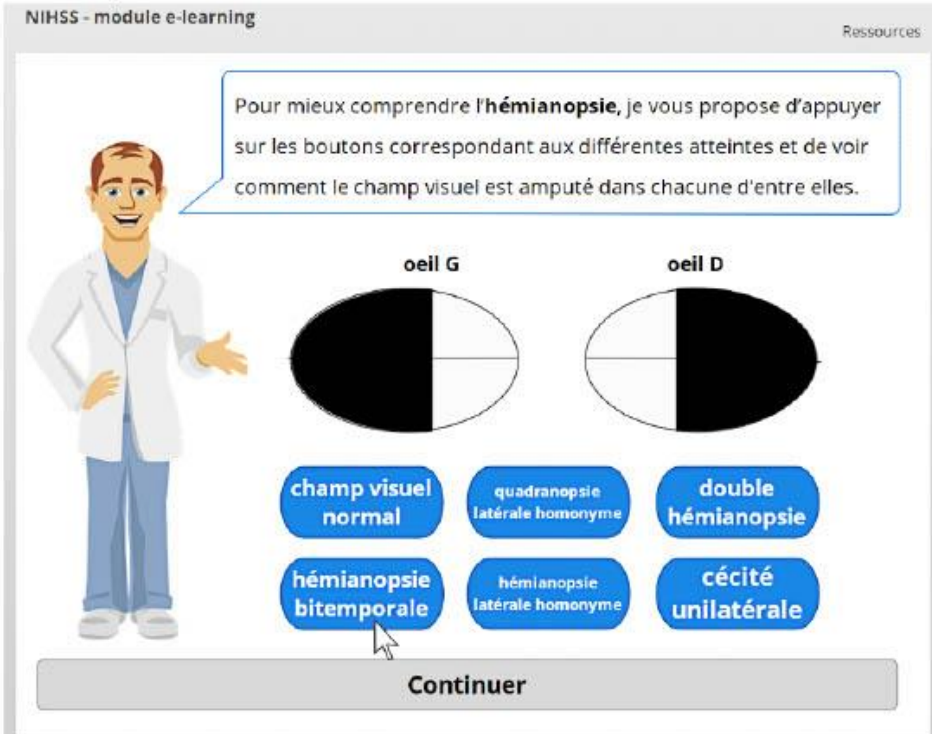
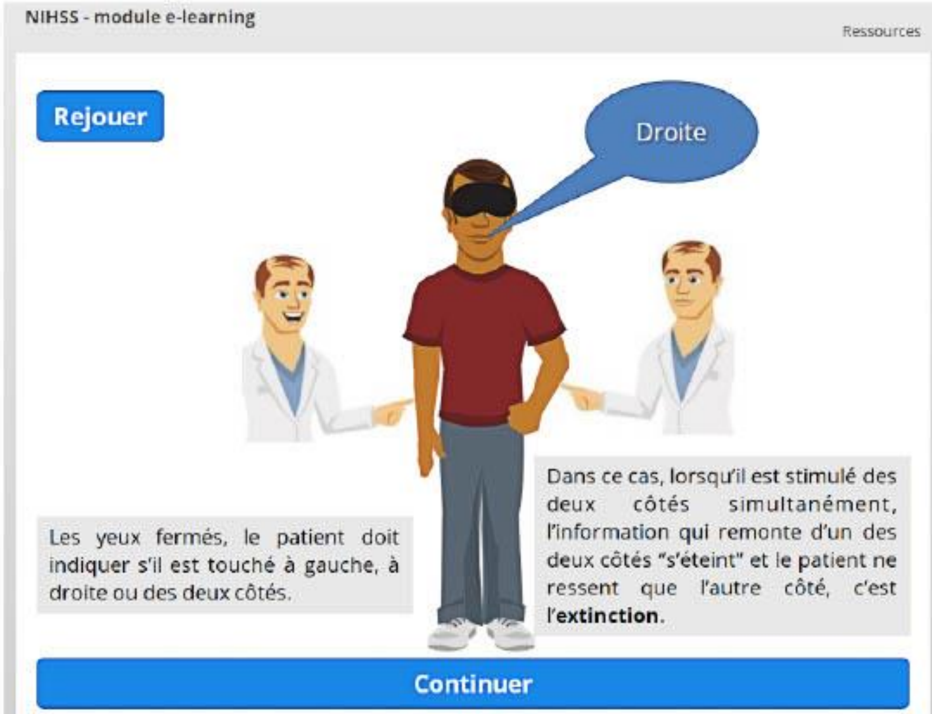


Figure 10. Animation used to explain extinction and inattention.



The user can choose to exit the module at any time, as a prompt will be shown to allow the user to either resume the module or reset it. Before the summary chapter can be activated, users must complete a 14th chapter, which details the "coma score."

This e-learning module, along with its previously studied iteration, can be accessed freely on the internet [32].

Study Sequence

Immediately after login, the medical students learned which group they had been allocated to and were asked a first set of 6 questions displayed over a single page. Upon answering these questions, they could then access the learning material. No time limit was applied apart from the study end date (June 8, 2020). Once the learning material was completed, students were allowed to proceed to a 50-question quiz. This quiz was identical for all participants and contained five questions related to basic NIHSS concepts, followed by the clinical evaluation of 3 patients taken from Patrick Lyden's certification videos. The NIHSS elements were displayed and scored in sequence according to the NIHSS scoring logic. After finalizing the quiz, participants were given their overall score as well as the possibility to review all questions at will and were shown their answers along with the correct answers. Then, 4 questions, based on a 5-point Likert scale, were asked to assess secondary outcomes, such as satisfaction. Students were finally given access to both the video and the e-learning module to discover the other teaching modality and/or to review the one they had just followed.

Outcomes

The primary outcome of the study was the proportion of correct answers to the 50-question quiz. Secondary outcomes were the proportion of correct answers for each specific NIHSS item, user satisfaction, perceived adequacy of the time needed to complete the course, perceived difficulty of the course, probability that the participant would recommend the course, and whether the learning path had been completed over multiple days.

Data Collection and Curation

Data were securely stored on an encrypted MariaDB 5.5.5 database (MariaDB Foundation) located on a Swiss server before being extracted in comma-separated values (CSV) format. We used STATA (StataCorp) for data curation and anonymization.

Statistical Analysis

STATA 15.1 was used by L Stuby for statistical analysis. Incomplete answers to the 50-question quiz were not analyzed.

Normality was assessed by graphical evaluation and, if in doubt, we used the Shapiro-Wilk test. We applied the Fisher exact test to categorical variables and the Student *t* test or the Mann-Whitney U test to continuous variables according to normality. We considered a 2-sided *P* value <.05 as significant.

We used a convenience sample and calculated the power post hoc. We defined 4 sensitivity analyses a priori according to whether the participant had prior knowledge of the NIHSS, had already followed a specific NIHSS course, had worked in either an intensive care unit or in a neurology or neurosurgery ward for more than 3 months, or had completed the learning path over multiple days. This was defined as more than 12 hours elapsed between initiation and completion of the course.

Finally, we performed univariate followed by multivariable linear regression to look for possible confounding factors.

Data Availability

Our curated data file is available on Mendeley Data [33].

Results

Out of 158 potential participants, 75 (47.5%) completed the trial (Figure 11). Table 1 details their characteristics.

After the first mailing (April 28, 2020), 21 students completed the trial. The first reminder (May 11, 2020) led 29 more students to complete the course, while another 25 participated after the second and last reminder (May 18, 2020).

Figure 11. Study flowchart.

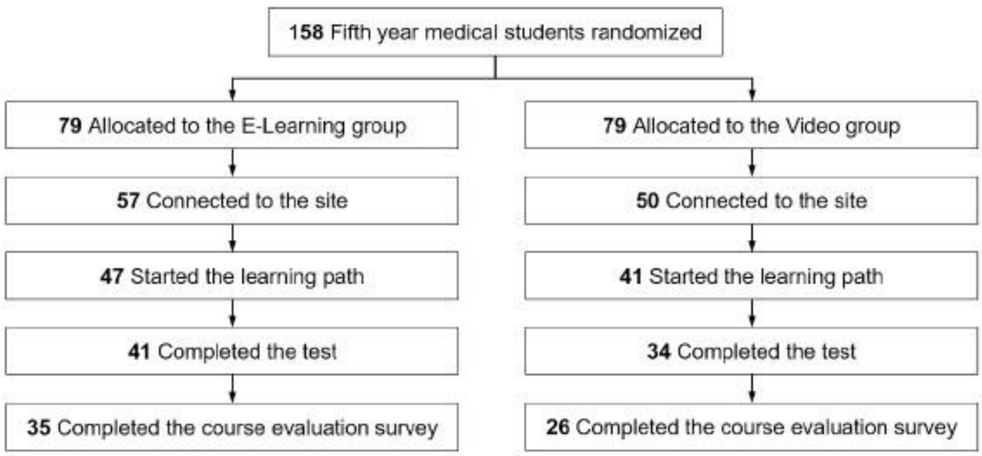


Table 1. Participant data (N=75).

Characteristic	Value	
	Video group (n=34)	E-Learning group (n=41)
Age, median (Q1-Q3)	24 (23-25)	24 (23-24)
Prior knowledge of NIHSS[a] application, n (%)	3 (9)	3 (7)
Specific NIHSS course followed, n (%)	4 (12)	2 (5)
E-learning NIHSS course followed, n (%)	0 (0)	0 (0)
Had worked in intensive care unit or neurology ward, n (%)	0 (0)	1 (2)
Missing data, n (%)	2 (6)	2 (5)

[a]NIHSS: National Institutes of Health Stroke Scale.

Participants who followed the e-learning module performed better than those who followed the video (38 correct answers, 95% CI 37-39, vs 35, 95% CI 34-36, $P<.001$). Participants in the e-learning group scored better on five elements than the video group: key NIHSS concepts ($P=.02$), the consciousness – global item ($P<.001$), the facial palsy item ($P=.04$), the ataxia item ($P=.03$) and the sensory item ($P=.04$). There was no such effect in the video group. Detailed results are shown in Table 2.

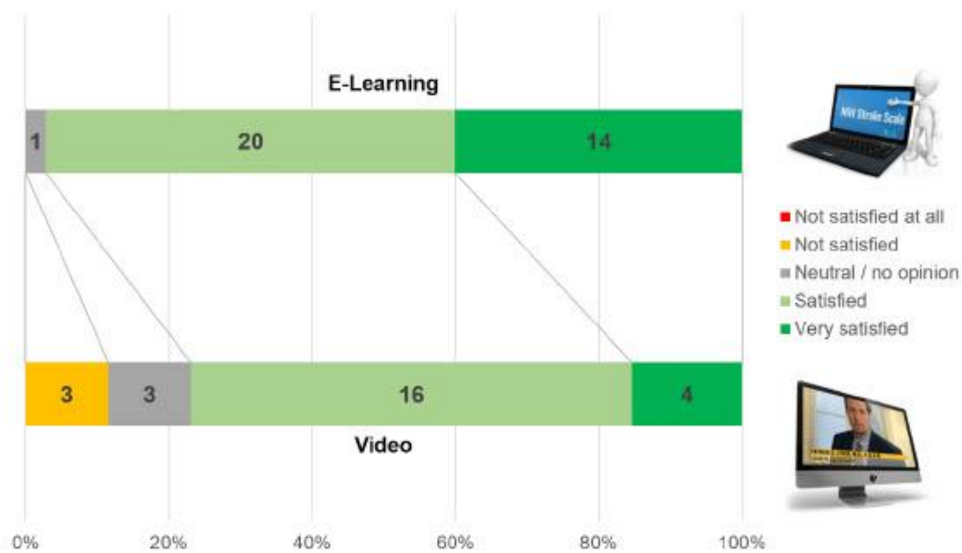
The rate of "very satisfied" participants was higher in the e-learning group (14/35, 40%; 95% CI 24%-56%) versus the video group (4/26, 15%; 95% CI 5%-25%, $P=.02$) (Figure 12).

Table 2. Quiz results.

Item	Video group (n=34)	E-Learning group (n=41)	*P* value
Overall score, mean (SD)	35 (3)	38 (3)	<.001
Overall score, 95% CI	34-36	37-39	N/A[a]
Detailed results by item, median (Q1-Q3)			
Key NIHSS[b] concepts	5 (4-5)	5 (5-5)	.02
Consciousness – Global	2 (2-2)	3 (2-3)	<.001
Consciousness – Questions	3 (2-3)	3 (3-3)	.70
Consciousness – Commands	2 (2-3)	3 (2-3)	.06
Gaze	2 (2-3)	3 (2-3)	.34
Visual	2 (2-2)	2 (2-2)	.23
Facial Palsy	1 (0-2)	2 (1-2)	.04
Motor arm	4 (4-5)	5 (4-5)	.17
Motor leg	5 (4-6)	5 (4-5)	.23
Ataxia	1 (1-1)	1 (1-2)	.03
Sensory	3 (2-3)	3 (3-3)	.04
Language	1 (1-2)	1 (1-1)	.63
Dysarthria	2 (2-2)	2 (2-2)	.07
Extinction and inattention	2 (2-3)	2 (2-3)	.14

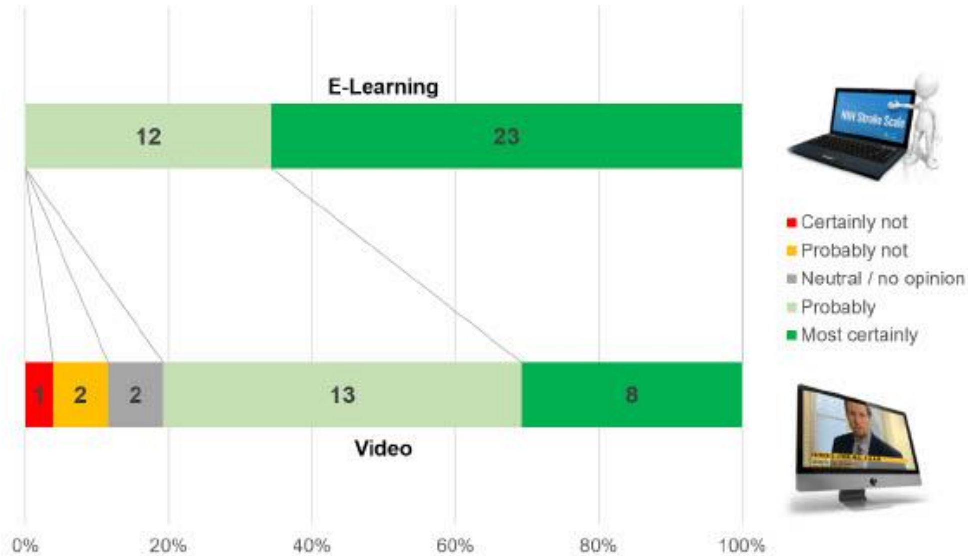
[a]N/A: not applicable.
[b]NIHSS: National Institutes of Health Stroke Scale.

Figure 12. Satisfaction of the participants in the e-learning and video groups regarding the learning method.



Although the precise total learning time dedicated to either method could not be assessed due to the study design, no statistical difference regarding the perceived duration of the course was identified (80% (28/35) adequate in the e-learning group, 95% CI 67%-93%, vs 65% (17/26) 95% CI 47%-83%, *P*=.25). There was no significant difference regarding the perceived difficulty of the course, as 84% (16/19) (95% CI 68%-100%) found it "easy or very easy" in the e-learning group versus 53% (8/15) (95% CI 28%-78%) in the video group (*P*=.07). Participants who followed the e-learning method were more likely to recommend it to a colleague; 23/35 participants (66%) answered "Yes, most certainly" (95% CI 50%-82%), versus 8/26 (31%; 95% CI 13%-49%) in the video group, *P*=.007 (Figure 13). The proportions of participants in the two groups who followed the course over less than 12 hours were similar (58% (14/24) in the e-learning group, 95% CI 38%-78%, versus 52% (17/33) in the video group, 95% CI 35 to 69, *P*=.79).

Figure 13. Likelihood that the participants in the e-learning and video groups would recommend the course.



The post hoc calculation showed a power of 97%. None of the 4 preplanned sensitivity analyses showed any major changes in the direction of the effect. The multivariable linear regression only showed a minor change in the coefficient (<15%), confirming these results.

Discussion

Principal Findings

In this study, asynchronous distance learning using a highly interactive e-learning module yielded better results than following the traditional didactic video on the web. The superiority of a previous version of this module has already been established in Swiss paramedics following an onsite computer-based course [23]. The present study confirms the generalizability of these findings when using this method for asynchronous distance learning in a different population of learners, namely, fifth year medical students. Indeed, although paramedics follow a 3-year curriculum focusing on critical emergencies, baseline knowledge and understanding of neurosciences should be higher in students on the verge of obtaining their master of medicine degree [34]. This assumption is supported by the median score of the control group, which was higher by two points in this study than it was in paramedics [23].

The shortcomings we had identified in the previous iteration of the e-learning module seem to have been addressed, as embedding cutscenes from the original video into every chapter of the module improved the impact of the module on knowledge acquisition. The use of short videos associated with active learning activities such as guiding questions or interactive elements has been shown to enhance knowledge acquisition and retention [35]. Interactivity itself is also known to improve both engagement and performance in medical students [36,37].

Slightly less than half of all potential participants completed their allocated learning path. Considering that the learning material was optional and that students' summative assessments of this semester were replaced by formative assessments, the participation rate is rather encouraging given the global lack of incentive. More encouraging still is the proportion of students who would recommend the course to their peers, as such mechanisms may increase students' involvement [38]. As many medical students actively helped on the front lines during the crisis, some of them may have been prevented from participating in this study owing to their high workload [39].

The quiz shown to the participants upon completion of the learning material included not only the full evaluation of 3 different stroke patients, but also 5 general questions we had designed Multimedia Appendix 2. While this could be considered as a potential bias in the study design, these questions were solely linked to key elements and basic principles of the NIHSS, and their understanding is essential to the correct application of the scale Multimedia Appendix 2. Our aim was indeed to evaluate whether knowledge acquisition was different when presenting similar content in different learning formats.

As the overall score regarding these questions was high in both groups, and as other significant results favored the e-learning method, there is little probability that these 5 initial questions induced a bias.

In many hospitals, the NIHSS is commonly used to triage stroke victims and help reduce both door-to-CT (CT: computed tomography) and door-to-needle times [9]. Decreasing these times is associated with better neurocognitive and functional outcomes [40]. Moreover, the adoption of a common scale between different specialists seems necessary to improve reproducibility and avoid the misinterpretation that can result from the use of different scores [41]. Swift acquisition and mastery of the NIHSS is therefore an essential skill for medical students, as most will be required to take care of stroke patients during their residency while working in the emergency department or in the neurology department. This is further strengthened by the fact that medical students often perceive neurology as the most difficult medical discipline, and the development of negative perceptions toward this specialty could lead to avoidance mechanisms when considering a career or treating a patient [42]. We might therefore assume that any kind of stroke-directed educational program could help raise awareness in non-neurologist physicians and thus increase the rate of correct treatment while decreasing door-to-needle time.

Limitations and Strengths

This study has limitations that must be acknowledged. The main limitation is that we only measured immediate knowledge acquisition; we were unable to assess knowledge retention due to the study design and the limited timeframe. As this latter parameter is critical to the clinical application of the NIHSS, further studies will be needed to assess whether the e-learning method improves retention and leads to more accurate application of the scale. Moreover, the precise time taken to complete either learning method was not evaluated in this study. While it can be argued that dedicating more time to learning given content should yield better results, studies have shown that engagement is the most important factor regarding knowledge acquisition [43]. Although time to learning material completion is an interesting outcome, we chose not to record these data for two main reasons: risk of unblinding and technical limitations. As the time required to watch the video is fixed unless the participants elect to use the video commands, and as most of them chose not to use this option in a previous study [23], we thought it better not to risk unnecessarily unblinding the data analyst. The technical aspect was linked to the web-based learning management system and to the mode of delivery of the teaching material. As access to the university premises was barred during the study period, participants followed the learning material from many different locations. Interruptions in the learning process may therefore have occurred; however, we had no means of recording recurrent short breaks in the group that followed the e-learning module, as pauses may also have resulted from taking notes, mulling over the content, or simply rereading some of the written paragraphs to better understand them. To mitigate this limitation, a sensitivity analysis comparing participants who completed the study path in less and more than 12 hours was performed. Reassuringly, no difference was noted.

Despite these limitations, this study also has several strengths, including the randomization, the blinding mechanisms, the electronic data acquisition, the originality of the learning method and its mode of delivery in the context of the COVID-19 pandemic.

Conclusion

Compared to the traditional didactic video, a highly interactive e-learning module enhances distant NIHSS knowledge acquisition in medical students.

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Conflicts of Interest

None declared.

Editorial Notice

This randomized study was not registered. The authors explained that their study included no patients and no health outcomes were recorded. According to the ICMJE rules, if the purpose is to examine the effect only on the providers rather than patients, then registration is not necessary. However, readers are advised to carefully assess the validity of any potential explicit or implicit claims related to primary outcomes or effectiveness.

Multimedia Appendix 1

Mailing template.
[PDF File (Adobe PDF File), 224 KB-Multimedia Appendix 1]

Multimedia Appendix 2

Original questions used in the 50-question quiz.
[PDF File (Adobe PDF File), 276 KB-Multimedia Appendix 2]

Multimedia Appendix 3

CONSORT-eHEALTH checklist (V 1.6.1).
[PDF File (Adobe PDF File), 2197 KB-Multimedia Appendix 3]

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Abbreviations

CHERRIES: Checklist for Reporting Results of Internet E-Surveys
CSV: comma-separated values
CT: computed tomography
NIHSS: National Institutes of Health Stroke Scale
UGFM: University of Geneva Faculty of Medicine

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Discussion, perspectives and conclusion

Discussion

The five articles described in this Privat-Docent thesis highlight several important aspects of web-based trials. First, although all these studies were carried out and published in a rather short time frame, most were randomized and all complied with the high-quality standards detailed in authoritative international guidelines [51,64]. In a 2022 systematic review carried out by Nyberg et al., the first publication described in this thesis (Effect of an E-Learning Module on Personal Protective Equipment Proficiency Among Prehospital Personnel: Web-Based Randomized Controlled Trial [38]) was the only quantitative study assessing interventions to change the work environment for which the overall quality was rated as "high" [65]. Therefore, and despite the importance of quickly increasing evidence in case of a rapidly evolving pandemic, taking the time to carefully plan and carry out high-quality studies is both desirable and feasible. Many Editors and publishers have strived to decrease their turnaround times for articles linked to the crisis at hand. It was thus even possible to submit study protocols for publication, thus enhancing research quality and enabling investigators to benefit from useful feedbacks provided by peer reviewers. Such a protocol was published prior to the assessment of "Escape COVID-19" among employees of long-term care facilities [62]. This protocol, which was published in JMIR Research Protocols, was accepted less than a month after its initial submission (submitted November 10, peer review reports December 2nd, accepted December 8th).

Collaboration is also a critical aspect of the studies presented as part of this thesis. Indeed, all these studies represent the fourth (or even fifth [49]) stage of the SERES framework and would have been impossible to carry out if the prior stages had not been completed [36]. These first stages could not have been completed without a strong interprofessional and trans-departmental collaboration: the early inclusion of IPC specialists in the development process was unquestionably required to validate the scientific foundations and theoretical bases of the learning materials [43,44]. Of course, collaboration is not limited to content validation by specialists of the subject matter: without graphical artists, beta testers, statisticians, software developers and web platform designers, considering such studies would be challenging if not impossible.

The fifth stage of the SERES framework, which consists in the rollout and dissemination of the intervention, was mostly tackled in *Nationwide Deployment of a Serious Game Designed to Improve COVID-19 Infection Prevention Practices in Switzerland: Prospective Web-Based Study* [49]. While figures may seem rather high with more than 3'000 accounts created on the platform, they are hardly satisfactory for a nationwide deployment. This rather limited uptake is even more surprising given the high level of support provided by the Swiss National Science Foundation, which financed a part-time position to help disseminate the game, and by the Federal Office of Public Health which added a link to the game on its official platform and on its regular COVID-19 newsletter. In addition, Escape COVID-19 was endorsed by more than 10 different organizations, including the Swiss Society for Public Health and the Conference of Cantonal Health Directors. Since even the most effective intervention is ultimately ineffectual if not used, understanding the factors facilitating and impeding the dissemination of critical information is of the utmost importance. Therefore, a post-hoc analysis was carried out to understand the yield of different communication channels on account creation [66]. In this instance, a press release by the Geneva University Hospitals was shown to be significantly more effective than the official communication from the Swiss Federal Office of Public Health. While this may of course vary from one country or region to another, exploring the most efficient ways of conveying information is necessary to help manage future crises.

Perspectives

Three main perspectives can be drawn from this Privat-Docent thesis: (1) development of generic, adaptable infection prevention teaching interventions; (2) further testing and development of the NIHSS e-learning module; and (3) CHERRIES topping i.e., suggestions for adaptating Eysenbach's original checklist [51].

Development of generic, adaptable infection prevention teaching interventions

The gamified e-learning module and the serious game "Escape COVID-19" are now ailed by the very disease they tried to prevent [44]: the information they contain is markedly outdated and neither tool can currently be used to teach and promote infection prevention practices. Nevertheless, both tools have proven useful and the development of similar materials should be considered to anticipate future epidemics or even pandemics [67]. Since PPE requirements will vary depending on the pathogen, these teaching materials should be easily and quickly adaptable. Other elements should also be considered, including global accessibility: indeed, Internet bandwidth and outdated devices may prevent people living in low or middle-income countries from accessing these materials [68]. Furthermore, our experience shows that cultural specificities and linguistic particularities strongly influence message uptake [49]. To avoid omitting any important element when designing IPC teaching materials, the use of an appropriate development framework should be considered. A recently created framework called co.LAB could be particularly useful in this regard as it acknowledged the importance of interprofessional collaboration [69]. This framework is made of 23 building blocks sorted into five categories:

1. Context and objectives (context, learning goals, game outline)
2. Learning design (learners' profiles, learning functions, learning objectives, learning foundations, pedagogical scenario, knowledge foundation)
3. Mechanics (learning mechanics, game mechanics, learning incentives & rewards, game incentive & rewards, learning interaction, game interaction)
4. Game design (goals & rules, game universe, fidelity and simulation model, interfaces and user experience, game structure, narrative)
5. Assessment (learning assessment, game assessment)

This framework can be used and read in many different ways since the blocks and categories to which they belong can be rearranged at will. Since it natively embeds not only a collaborative dimension but also assessment elements, it appears particularly well-suited for the purpose of developing a generic and highly adaptable serious game which could be deployed in case of a new pandemic.

Further testing and development of the NIHSS e-learning module

Version 21c of the e-learning module designed to teach the NIHSS was used in *Asynchronous Distance Learning of the National Institutes of Health Stroke Scale During the COVID-19 Pandemic (E-Learning vs Video): Randomized Controlled Trial* [47]. This version was an improved iteration of the module used in a prior publication (version 20e) [70]. The improvements were based on the observation that knowledge acquisition (or at least adequate scoring using the test NIHSS videos) was lower in participants who had followed the e-learning module regarding one element, dysarthria. For this particular element, no video extract had been included in this version of the e-learning module. It was therefore theorized that including video extracts could significantly influence knowledge acquisition, and version 21c of the e-learning embedded video extracts for all NIHSS items. The hypothesis held true and version 21c of the e-learning module was either equal or superior to the traditional didactic video regarding knowledge acquisition [47]. Nevertheless, this module cannot be considered as the pinnacle of NIHSS teaching and deserves further improvements. Indeed, a perfect module should allow participants to achieve higher scores than those reported in this study [47]. Many improvements could be considered, including the addition of gamification elements. Although gamification could serve to further enhance learner engagement, it must however be acknowledged that it would not improve other aspects which directly influence patient assessment. A potential solution could be to include three-dimensional models which could allow learners to refine their physical examination [71]. The yield of such models is however rather inconsistent and iterative assessments and improvements will be necessary to progressively enhance the module [72].

In the meantime, the current version of the NIHSS e-learning module can serve further purposes. Indeed, while this module has now been tested on paramedics and on medical students [47,70], its impact on other healthcare professionals remains to be determined. Since NIHSS knowledge may decline even among professionals who use this scale on a daily basis [73], a randomized trial is underway to determine if this e-learning module can restore NIHSS knowledge more effectively than the traditional didactic video in a population of nurses and physicians who are regularly confronted with stroke patients [74]. Knowledge retention will also be assessed through this study, which will also provide data regarding baseline NIHSS knowledge in this population.

CHERRIES topping

The very fast and often unpredictable technological evolutions require frequent adaptations in the design, methodology, and reporting of web-based studies. It would be preposterous to pretend covering all potential types of currently conceivable web-based studies, and this section will therefore focus on the improvements which could be considered regarding CHERRIES [51].

Many evolutions regarding web-based surveys have taken recently taken place. In light of these changes, the inclusion of the following elements in CHERRIES could be considered:

Full description of the survey tool

There are many different tools available to administer online questionnaires. Many different features can prove useful regarding a particular survey, including question randomization, conditional (branching) logic, specific question types (hotspots, ranking, selection of single or multiple images, etc.) [75], embedded calculators (to provide participants with their personal score), personalized messages according to the answers provided, etc. Survey tools or platforms can also be used to manage participants by sending invitation emails, handling automatic reminders for non-responders and partial responders by sending email or even text messages [76], and acknowledging participation by generating certificates. Other innovative features will also be developed, and there is a virtually endless number of potential combinations which make it worth describing the whole tool to allow other researchers to replicate the methods.

Data protection and GDPR compliance

There are growing concerns regarding personal data protection and the GDPR sets strict and comprehensive rules in this regard [77]. Researchers should strive to abide to such rules and participants should be able to access their personal data, modify it or even erase it. This is of course only possible if participation is not anonymized. Regardless of the mode of participation, data protection and GDPR compliance should be clearly acknowledged, both on the study's website and in the manuscript.

Data access and encryption

In line with the previous item, data should only be accessible by authorized personnel. Researchers are however unlikely to self-host their internet servers and employees of the hosting company may easily access unencrypted data present on the servers they manage. To prevent unauthorized access on shared or non-self-hosted servers, data encryption should be considered and reported accordingly [78].

Data back-up and extraction

On the other end of the spectrum of data protection stands the problematic of data conservation and accessibility. Web server components can break down unexpectedly, including hard drives and other storage mechanisms. To avoid losing critical data, mechanisms should be set up to ensure that frequent back-ups are performed and minimize potential data loss [79]. In addition, while data should of course be protected from prying eyes, it should nevertheless be easily accessible to authorized personnel. Data should be easily extractible to formats compatible with most major statistical software (e.g., tab or comma separated values formats).

Data availability

The FAIR (findability, accessibility, interoperability, and reuse) principles should be considered whenever designing a web-based questionnaire study [80]. Therefore, data availability statements should be mandatory for such studies and easily discoverable and searchable repositories should be used. Participants should be informed that their responses, not their personal data, will be made publicly available for scientific purposes.

Spin-off applications

The techniques developed and presented in this Privat-Docent thesis can serve other purposes than the development of e-learning modules, gamified interventions, and serious games, and several spin-off projects based on these foundations are already underway. For instance, an innovative way of ensuring participant anonymity while allowing for targeted reminders has already been developed. To achieve this, accounts are created using randomized usernames and passwords on a Joomla platform specifically created for this purpose. These credentials are imported along with the actual email addresses of participants, who are then invited to participate using a mailing component installed on the CMS platform. Those who agree to participate click on a link included in the invitation email, which automatically logs them in using a PHP "GET" request. This mechanism should help prevent attrition since participants are not required to enter or even to copy-paste credentials. In this particular study, participants are required to fill three questionnaires, and Joomla's access control list is used to monitor participant progression. Thus, specific reminders can be sent to people who have started, but not completed the study. Once the last questionnaire has been completed, the participant's email address is automatically removed from the system using a custom coded PHP script. This ensures absolute and irreversible anonymization.

Conclusion

The constraints imposed by the COVID-19 pandemic have led to the development of many tools designed to overcome these limitations. While all IPC measures regarding this pandemic have now been lifted, the knowledge gathered through this crisis remains and should be built upon to anticipate future, potentially similar crises. Recent technological developments have enabled clinicians, policy makers, and public health and IPC specialists to quickly and efficiently spread critical information.

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Abbreviations

CHERRIES	Checklist for Reporting Results of Internet E-Surveys
CMS	Content Management System
CONSORT	Consolidated Standards of Reporting Trials
CONSORT-EHEALTH	Consolidated Standards of Reporting Trials of Electronic and Mobile HEalth Applications and onLine TeleHealth
COVID-19	COronaVIrus Disease 2019
CSS	Cascading Style Sheets
E-learning	Electronic learning
FAIR	Findability, Accessibility, Interoperability, and Reuse
GDPR	General Data Protection Regulation
HTML5	HyperText Markup Language 5
IPC	Infection Prevention and Control
MERS	Middle East Respiratory Syndrome
NIHSS	National Institutes of Health Stroke Scale
PHP	Hypertext Preprocessor
PPE	Personal Protective Equipment
RECIPE	Reflection, Engagement, Choice, Information, Play and Exposition
SARS-CoV-2	Severe Acute Respiratory Syndrome - CoronaVirus 2
SNSF	Swiss National Science Foundation

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