










A Usability Study of an Application to Configure Virtual Reality Training Environments for Wheelchair Users

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Abstract. Return to work (RTW) for a person with a disability can be complicated. The Rientr@ project aims to promote the recovery of autonomy in daily life and RTW of novice wheelchair users (WUs). It proposed a virtual-reality-based wheelchair simulator to help WUs become familiar with their new condition. Three virtual environments were created, and a configuration application was developed to let therapists customize the training to patients' characteristics and residual physical skills. The present work describes the usability evaluation of such an application, named Rientr@ Configurator (RC). The assessment was performed with 7 end-users; task analysis and a think-aloud protocol were used; performance and qualitative data were collected. The RC application was rated easy to use. Therapists suggested a few changes that have been implemented to increase usability and speed up the configuration procedure.

Keywords: usability, wheelchair simulator, task analysis, training virtual environment.

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1 INTRODUCTION

Return to Work (RTW) represents a significant milestone for people with disability, and several studies have demonstrated that the benefits of RTW go beyond the economic remuneration [6], [22]. Having a paid employment is associated with improved psychological well-being and self-

efficacy [8], higher social participation [1], lower mortality [12], [19], and, generally, a better Quality of Life (QoL) [3], [14]. This is particularly valid for wheelchair users (WUs), for which QoL appears to be more linked to social and environmental factors and participation in the community rather than the impairment extent.

Despite this evidence, only a limited percentage of WUs return to work. Studies have estimated that the employment rate among individuals with spinal cord injury is between 11% and 75% [7].

In this context, the Rientr@ project, funded by the Italian Institute for Insurance against Accidents at Work, aims to promote the RTW of novice WUs by means of a wheelchair simulator [2]. Such a simulator allows the WUs to experience several activities of daily living in a safe and controllable environment, thus increasing the awareness of the WUs regarding their residual abilities and possibilities for the future.

The simulator includes three training environments: an outdoor scenario, a house, and an office. All include obstacles, activities, and challenges that the therapist can customize according to the abilities of the WU and the characteristics of the wheelchair s/he drives. The customization occurs via the Rientr@ Configurator (RC), a PC-based application dedicated to therapists. The RC generates a basic configuration created on the scores obtained in the Wheelchair Skill Test (WST) [11], previously taken by the WU, and allows the operator to modify it if necessary. In this way, therapists can configure the training environments with reduced time and effort while obtaining a training scenario compatible with the specific skills of different wheelchair users. The RC application must be functional and intuitive in order to make the configuration process fast, effortless and effective.

Given this premise, it was necessary to evaluate the usability of RC application. The aim was (1) to determine whether RC represents a functional and user-friendly tool and (2) to identify which elements could possibly be improved to favor a more intuitive interaction. Usability is defined by the International Organization for Standardization (ISO) as the extent to which a tool or product achieves objectives of effectiveness, efficiency, and satisfaction [5]. It is important to note that the concept of usability refers to the process of interacting with a tool and not to its intrinsic quality, although over time, we have commonly come to speak of a "usable tool" or "non-usable tool". A good usability is necessary for a positive interaction experience and for good results, obviously declinable according to the context: a good system, among other things, increases efficiency and productivity, and reduces errors and the need for training [17].

The paper is organized as follows. First, a description of the whole Rientr@ platform and the RC application are provided. Then, the usability study procedure and results are presented. The next section describes the modifications applied to the RC application based on the gathered feedback. Finally, the conclusions are drawn.

2 RIENTR@ PLATFORM

The Rientr@ simulator consists of a parallel kinematics platform [20] on which an ad-hoc designed wheelchair is anchored. Such a wheelchair allows regulating the width, height, and tilt of the seat and the seatback using pins; moreover, it foresees the use of vacuum cushions to accommodate the user. The simulator allows the simulation of both powered and manual wheelchairs, i.e., it can be maneuvered using a hand- or a chin-joystick or by pushing the handrims. Thus, it can also help the operators in prescribing and setting up the appropriate wheelchair according to each user's needs, abilities and preferences.

The training virtual environments was developed with Unity [21] and deployed for the HTC Vive Pro headset [7]. The interaction with virtual objects occurs via Manus VR data-gloves [15], on which HTC Trackers [8] were mounted to determine the 3D position and orientation in the space of the user's hands. The virtual environments communicate with the kinematic platform to provide vestibular feedback. The real wheels are sensorized with encoders and actuated to effectively transfer the motion to the virtual wheelchair and to return the appropriate force feedback to the user, respectively. During the training, the WU sees the virtual environment (outdoor, house, or

office) through the VR headset. The therapist sees both the user's view and an ad-hoc panel through which s/he controls the training session, as represented in Figure 1. The virtual environment is configured in terms of the level of difficulty (e.g., ramp slope, obstacles to avoid, etc.) and tasks to accomplish (e.g., answering a phone call, preparing the meal) based on the configuration generated with the RC application.

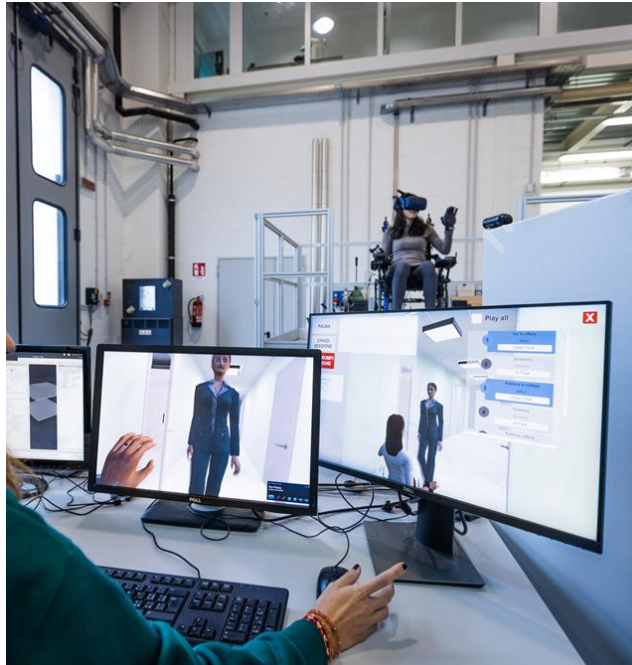


Figure 1: The Rientr@ simulator.

2.1 The Rientr@ Configurator

RC was also developed with Unity and deployed for Windows operating system. As mentioned, to ease the configuration process, RC proposes to the therapist a predefined arrangement of both the environment and the tasks to accomplish based on the Wheelchair Skill Test (WST, version 5.0) results. WST is a comprehensive and generic instrument for assessing the abilities in maneuvering the wheelchair and interacting with the environment (e.g., picking an object from the floor or at 1.5 meters) [11]. Each skill can be scored with values ranging from 0 (i.e., task incomplete or unsafe) to 3 (i.e., advanced pass; the WU carries out the skill in a highly proficient or advanced manner). It has two versions depending on whether the wheelchair is powered or manual.

The RC application workflow is represented in Figure 2. When launching the application, the therapist, through the Graphical User Interface (GUI), can either decide to create a new user or load an existing profile. When creating a new user, an interface for inserting WU data (i.e., patient ID, height, weight) and wheelchair characteristics (i.e., type [manual/powered], weight, height, width, length) is displayed. After filling in this information, a second panel allows to insert WST results as part of the creation of a new WU profile; the list of skills shown matches the selection of a manual or a powered wheelchair.

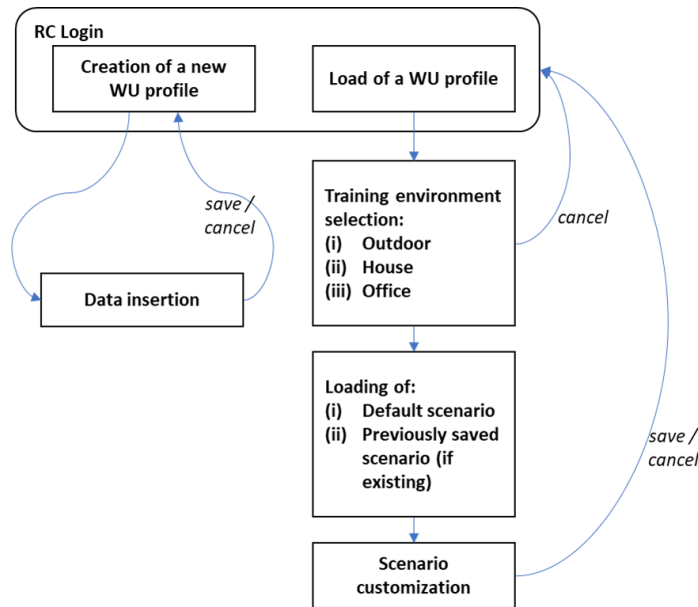


Figure 2: A scheme representing the workflow of the Rientr@ Configurator application.

After the profile creation, the therapist can decide which training environment s/he wants to customize. The environment is loaded with the settings that better fit the WST result. A specific section of the GUI allows the therapist to visualize these settings, both on a menu and directly in the virtual scene, and to modify them if needed. When the therapist considers the environment ready for the training, s/he can save the current setting and either close RC or configure other training environments. When reloading a WU profile that has been already customized, the therapist is asked if s/he wants to modify the WU's profile or further customize the environment. In this second case, s/he can load the default configuration (i.e., the one suggested according to WST) or the previously modified and saved one.

3 USABILITY STUDY

The usability study was carried out at "Associazione La Nostra Famiglia - IRCCS Eugenio Medea" in Bosisio Parini (Lecco, Italy) and at the INAIL prosthesis center in Budrio (Bologna, Italy). Seven operators with experience in wheelchair users' assistance and training (e.g., physiotherapists, assistive-device experts) and employed in the two aforementioned centers participated in our study.

The information collected during the evaluation was intended to provide feedback to modify and improve the GUI of RC and to create a user manual with all the information necessary to complete the configuration of the virtual environments in a correct and efficient way.

To prevent the operators from influencing each other, no one attended the evaluations of the colleagues, and exchanges of opinion between them were avoided until the evaluation of all participants was completed.

3.1 Measures

Objective and subjective data on the usability of the RC were collected. To do this, we used task analysis and the think-aloud protocol.

Task analysis refers to the analysis of how an activity is performed [4]. During this procedure, the general task is divided into simpler sub-tasks. The number of attempts, the time needed to complete each task, and the number of errors were collected to evaluate performance. Doubts and difficulties in completing a specific task and the perceived effort to complete the task were considered too as subjective data. In this way, it was possible to identify, quantify and prioritize the problems faced when using the application.

Furthermore, information about users' mental activity and their subjective experience was collected using the think-aloud protocol. Nielsen defines this method as "window on the soul" [16], because participants who are using the system simply verbalize their thoughts as they move through the GUI. This methodology allows to collect data on the participant's cognitive processes, noting difficulties and, therefore, problems in usability [13]. This tool is inexpensive and allows the researcher to understand the user's thinking, or at least what s/he wants to emerge. In this assessment, the operators' spontaneous comments were transcribed by the researcher supervising the whole experience.

3.2 Protocol

To carry out the test, operators were provided with: a portable PC, on which an executable version of the RC application was previously installed, a patient paper card containing the anthropometric measures and the wheelchair characteristics, and the results of the patient's WST in a written form version. All patients' data used were fictitious. One researcher was sitting near the operator, declaring the tasks to be done.

The execution of the test involved the following phases:

1. Presentation of Rientr@ project and explanation of the importance of evaluating the usability of RC with task analysis. In addition, each operator was given a brief explanation of the application's features: it was explained that the application provides a 'default' configuration based on the scores obtained in the WST for each specific WU and that this configuration could be freely modified according to their experience or their personal evaluation on the patient's status. For example, if the patient has a low score in a specific wheelchair skill or s/he is tired, the complexity of the tasks requiring that skill can be reduced.
2. Explanation of the evaluation methodology; the researcher requested participants to freely express thoughts, emotions, and comments related to the interaction, particularly to the task and the GUI.
3. The task analysis, consisting of three main tasks to be completed.
 - a) Insert a new patient profile. The end-user was asked to create a new patient profile by entering - through the appropriate GUI - the patient's weight and height, measurements of the wheelchair used for training, and the results of the WST (see Figure 3), as reported on the paper sheet. In this last step, the items stored on the computer do not fully fit with those in the WST paper format because not all of them contribute to the definition of the difficulty of the tasks presented in the training environments (see Figure 5.b).
 - b) Load the outdoor environment and modify it. The operator was asked to load the outdoor environment and change some of its features. For each variable, for example, "house ramp", the user was asked to visually check the changes using the appropriate button. Furthermore, during this task, it was proposed to navigate (with keyboard control) in the environment, approaching certain obstacles (e.g., a bump). At the end of the task, the user was asked to save the configuration and exit.
 - c) Edit the patient profile. The operator was asked to change some parameters of the "WST" section of the patient profile. Subsequently, the operator was asked to load the configured environment based on the data entered in the new patient profile.

During the execution of each task, the following data were recorded:

- a. number of mistakes made;

- b. doubts and difficulties in completing a specific task, which emerged from spontaneous comments;
- c. the time needed to carry out each task.

At the end of each task, the operator evaluated the perceived difficulty experienced during the interaction by answering the following question: "In your opinion, rate how much did you find easy to complete this task on a scale of 1 to 5, where 1 means 'extremely difficult' and 5 'extremely easy'?"

At the end of the whole task, operators answered:

- a. one open question about suggestions or changes that the operator would make to the GUI;
- b. one open question about problems encountered to complete the task, in addition to those already emerged during the task analysis.

4 RESULTS

Seven participants were included, which is above the minimum number of participants required for the usability evaluation (equal to 5, as reported in [18]).

Overall, the RC application was rated easy to use, obtaining an average ease of use score of 4.09 ± 0.58 (on a scale of 1 to 5). The results divided for each main task are reported below.

4.1 Task 1: Insert a New Patient Profile

- Errors: one operator entered the WST scores incorrectly without noticing that the skills reported on the patient's card were more than the ones displayed (Figure 3). The RC application, in fact, included only those skills considered meaningful for the configuration of the virtual environment. The other operators did not make any mistakes.

Wheelchair user	Skills (WST)	Save	X	
1	Rolls forward short distance	0 1 2 3	13 Descends steep incline	0 1 2 3
2	Rolls backward short distance	0 1 2 3	14 Ascends steep incline	0 1 2 3
3	Stops on command	0 1 2 3	15 Rolls across side-slope	0 1 2 3
4	Turns in place	0 1 2 3	16 Rolls on soft surface	0 1 2 3
5	Turns while moving forward	0 1 2 3	17 Gets over obstacle	0 1 2 3
6	Turns while moving backward	0 1 2 3	18 Gets over gap	0 1 2 3
7	Maneuvers sideways	0 1 2 3	19 Ascends low curb	0 1 2 3
8	Picks objects from floor	0 1 2 3	20 Descends low curb	0 1 2 3
9	Gets through hinged door	0 1 2 3	21 Ascends high curb	0 1 2 3
10	Rolls longer distance	0 1 2 3	22 Descends high curb	0 1 2 3
11	Ascends slight incline	0 1 2 3	23 Avoids moving obstacles	0 1 2 3
12	Descends slight incline	0 1 2 3	24 Reaches 1.5 m high object	0 1 2 3

Figure 3: The screen for entering the WST results.

- Doubts and difficulties: a widespread difficulty (N=4) was found in understanding how to switch from the measurement sheet to the WST sheet. Furthermore, all participants (N=7) did not understand at first sight that not all WST entries were to be included in the digital card. An operator reported that it must be clarified whether the voice "seat's height" includes a cushion or not and whether it refers to the front or rear seat (i.e., the backrest). Furthermore, 2 operators underlined that the total height of the seat is not relevant while the height of the person who is sitting is the most important information.
- Average time needed to complete the task: 4 minutes and 25 seconds (265 seconds).
- Perceived ease of the task: 4.

4.2 Task 2: Load the Outdoor Environment and Modify It

- Errors: 3 operators did not remember which button to press to make the command interface reappear (M key). At the end of the configuration, 1 operator pressed the Escape button to return to the initial screen, while another one did not save the changes made at the end of the configuration operation.
- Doubts and difficulties: 1 operator did not find intuitive the "go and see" button, and he thought that once the parameter to be changed (e.g., bump) was highlighted, the application would automatically lead to this parameter. 1 operator could not exit the configuration section of the outdoor environment because he expected to find a "back" button. Finally, 1 operator noted that in some configuration options, the unit of measurement was missing ("Does 5 refer to degrees of inclination or to centimeters?").
- Average time needed to complete the task: 2 minutes and 59 seconds (179 seconds).
- Perceived ease of the task: 4.71.

4.3 Task 3: Edit the Patient File

- Errors: 2 operators made a mistake in selecting the box by pressing the "configure outdoor" option instead of "edit patient profile". This error made it possible to highlight that there is no option to go back when a mistake is made, but it is necessary to exit the entire application (Figure 4). 5 operators chose the previously saved outdoor configuration instead of the one based on the new WST. One operator pressed the "Close" button with the intention of returning to the previous screen, but this action made him exit from the application.
- Doubts and difficulties: all 7 operators found difficult to associate the two labels "default configuration" and "saved configuration" to the related concepts; in fact, everyone thought that the default configuration referred to a static configuration, not based on the WST scores (although it was explained to them at the beginning of the evaluation).
- Average time needed to complete the task: 1 minute and 35 seconds (95seconds).
- Perceived ease of the task: 3.57.

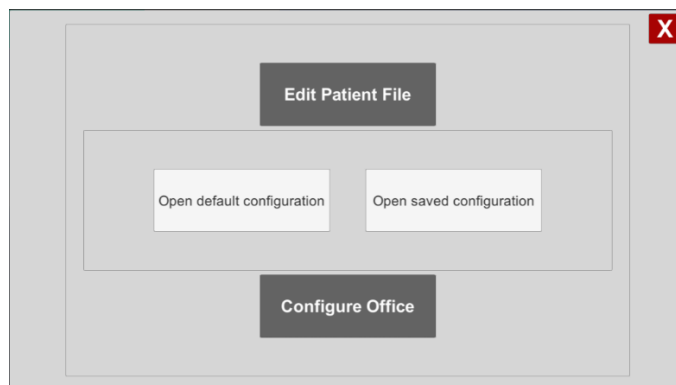


Figure 4: The screen for loading the configuration based on WST (default) or the previously saved one.

4.4 Suggestions From End-Users

Operators have proposed several changes that could facilitate the operator and speed up the configuration procedure. The suggestions are the following:

- Clarify how to switch from the measurement entry form to the WST index entry form. In this case, it has been proposed to insert a "save" button that automatically leads from the first to the second section.

- Items of the WST in written form must correspond to the ones of the digital WST. It has been proposed to keep all the entries in the "WST" tab and reduce the size, change the color (gray instead of black), and make inactive the entries that are not relevant to RC.
- Insert a button in place of the M key to make the configuration screen appear.
- Keep the patient ID always visible during the interaction.
- Insert the measurement units of some characteristics of the environment near the related numbers (e.g., "Park ramp slope" are 0, 5, or 10 degrees).
- The label for choosing the outdoor environment based on the WST must be more intuitive; it was proposed to call it "configuration based on WST" instead of "default configuration".
- The label that indicates the previously modified outdoor environment must be more intuitive; it was proposed to call it "last saved configuration" instead of "saved configuration".
- One button, in all the steps, is needed to allow operators to return to the previous screen. In this way, it would be possible to go back and correct errors.

5 MODIFICATIONS MADE TO THE RIENTR@ CONFIGURATION APPLICATION

Starting from the issues that emerged during the test and the suggestions of participants, a set of changes was implemented with the aim of improving the quality and usability of the GUI.

- Insertion of a "next" button (one arrow) that automatically leads from the first to the second screen: a "next" button was inserted to allow the operator to continue entering the WST scores after completing the entry of WU and wheelchair information.
- Change of the "total height" label: the label was modified in "height of the seated user" (figure 5): this information will be used in the training environments to define the height of the viewpoint with respect to the ground. Tooltips will further specify what value to insert in each field.

Figure 5(a) shows the 'User' configuration screen. It has two main sections: 'User' and 'Wheelchair'. The 'User' section includes fields for ID, Weight [kg], and Height [cm]. The 'Wheelchair' section includes radio buttons for 'Manual' and 'Powered', and input fields for Weight [kg], Seat's width [cm], Seat's height [cm], Tot length [cm], Tot width [cm], and Height of the seated user [cm]. A green arrow button is located at the bottom right of the screen.

Figure 5(b) shows the 'Skills (WST)' configuration screen. It displays a list of 27 skills, each with a corresponding score button (0, 1, 2, 3). The skills are: 1. Positions and operates controller, 2. Operates body positioning options, 3. Rolls forward short distance, 4. Rolls backward short distance, 5. Stops on command, 6. Turns in place, 7. Turns while moving forward, 8. Turns while moving backward, 9. Maneuvers sideways, 10. Picks objects from floor, 11. Relieves weight from buttocks, 12. Performs level transfers, 13. Gets through hinged door, 14. Rolls longer distance, 15. Ascends slight incline, 16. Descends slight incline, 17. Ascends steep incline, 18. Descends steep incline, 19. Rolls across side-slope, 20. Rolls on soft surface, 21. Gets over obstacle, 22. Gets over gap, 23. Ascends low curb, 24. Descends low curb, 25. Performs wheelchair-ground transfers, 26. Avoids moving obstacles, 27. Reaches 1.5 m high object. A 'Save' button is located at the top right of the screen.

Figure 5: (a) The "Next" button was included (the arrow at the bottom right of the screen) and "total height" was replaced with "height of the seated user" for clarity, (b) The new interface for entering WST scores.

- Correspondence between the items of the WST-written version and WST-digital version: the items not used by the application were shown in the GUI dedicated to entering the WST scores. To avoid making the operator fill in these codes unnecessarily, the unused items were grayed out, and the corresponding buttons were disabled (Figure 5).
- Insertion of a button to bring up the configuration sheet (in addition to the M key): as can be seen in Figure 6, a button ("Show interface") has been inserted to make the interface appear when it is hidden.
- Always keep the patient ID in evidence: as can be seen from Figures 6 (left) and 7, the patient ID that is being configured now is visible on all screens.



Figure 6: A button has been added to make the configuration screen reappear. Conversely, when the interface is active, the button is hidden.

- Insertion of the measurement units: the word "degrees" was added for each configurable element related to the ramps.
- More intuitive labels: the labels of the two buttons that open the environment based on an existent configuration were changed in order to facilitate the operator's choice: i) the previous label "default configuration" was changed in "open configuration based on WST"; ii) the previous label "saved configuration" was changed in "open last saved configuration" (Figure 7).
- Add the possibility to go back to the previous step: as shown in Figure 7, a "close" button (identified by the symbol X) has been added to each window to close it.



Figure 7: The new interface. It is now possible to close each window separately and easily return to the previous step. The labels on the buttons make the interaction more intuitive.

6 CONCLUSION

The present work is part of the Rientr@ project aimed at developing a wheelchair simulator to train novice wheelchair users who, for the first time, have to learn to use a wheelchair. The Rientr@ simulator is mainly composed of a mechatronic platform and three virtual reality environments that can be configured to adapt the difficulty and to train specific skills. In particular, this work describes the evaluation of the usability of an application (RC) for the customization of the virtual environments; in particular, the evaluation concerned the configuration of the outdoor virtual environment. The validation concludes that RC is perceived easy-to-use by end-users, i.e. therapists.

Nonetheless, the interface was modified according to the collected feedback to improve even more clarity and usability.

One second assessment of this application has to be conducted to evaluate if modifications that have been introduced would enhance RC's usability. This activity will be performed in future works that also validate the whole Rientr@ simulator with both healthy individuals and wheelchair users, considering the user experience and the effectiveness of the system for the acquisition of wheelchair skills.

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