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Towards a knowledge-based decision support system to foster the return to work of wheelchair users

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ABSTRACT

Accidents at work may force workers to face abrupt changes in their daily life: one of the most impactful accident cases consists of the worker remaining in a wheelchair. Return To Work (RTW) of wheelchair users in their working age is still challenging, encompassing the expertise of clinical and rehabilitation personnel and social workers to match the workers' residual capabilities with job requirements. This work describes a novel and prototypical knowledge-based Decision Support System (DSS) that matches workers' residual capabilities with job requirements, thus helping vocational therapists and clinical personnel in the RTW decision-making process for WUs. The DSS leverages expert knowledge in the form of ontologies to represent the International Classification of Functioning, Disability, and Health (ICF) and the Occupational Information Network (O*NET). These taxonomies enable both workers' health conditions and job requirements formalization, which are processed to assess the suitability of a job depending on a worker's condition. Consequently, the DSS suggests a list of jobs a wheelchair user can still perform, exploiting his/her residual abilities at their best. The manuscript describes the theoretical approach and technological foundations of such DSS, illustrating its development, its output metric, and application. The developed solution was tested with real wheelchair users' health conditions provided by the Italian National Institute for Insurance against Accidents at Work. The feasibility of an approach based on objective data was thus demonstrated, providing a novel point of view in the critical process of decision-making during RTW.

1. Introduction

In 2018, EU-27 countries registered more than 3.124.828 non-fatal accidents in the workplace and 3.332 fatalities [12]. The Italian National Institute for Insurance against Accidents at Work (INAIL) in 2019 registered 561.190 accidents at work, of which 560.011 foresaw contusions (30%), fractures to upper and lower limbs (29%), damages to the spine (13%), head (13%), and trunk and internal organs (11%) [5].

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Together with physical consequences and according to the nature and magnitude of the accidents, workers may also face impairments related to the cognitive sphere. Impairments caused by such accidents may be permanent and cause the individual to change his/her job or to leave the labour force. One of the most impactful cases is when the worker remains in a wheelchair, which may cause the worker to leave the workforce. This fact has consequences at different levels: firstly, on the worker him/herself and his/her family, who have to face an abrupt change of daily routine, with potential adverse effects also on the quality of life; secondly, on the institutional stakeholders, such as the National Healthcare Systems and the National Security Systems, which have to face an increasing social and economic burden; lastly, on the companies, which may face the loss of highly-skilled workforce.

Because of all these negative effects, it is fundamental to promote the Return To Work (RTW) of wheelchair users (WUs) in their working age. Nonetheless, RTW is a challenging activity, requiring the cooperation of different health, rehabilitation, and social professionals to identify a multi-dimensional model of the employee's disability [42]. Moreover, RTW professionals have to tackle the possibility of modifying jobs (or their characteristics) to enable employees with disability to meet production targets while preserving his/her health [9]. The synergetic effort required by professionals is far from trivial, considering that different experts can have different perspectives on the same subject [13] and that European countries lack homogeneous guidelines.

In Italy, INAIL is the public entity taking care of the RTW of people injured at the workplace. The standard procedure for RTW foresees: (1) the assessment of the worker's physical, cognitive, and psychological conditions, of his/her functional abilities, and the analysis of his/her workplace (e.g., job type, physical environment, risks, social norms, the attitude of the employer and co-workers); (2) the selection and the deployment of interventions either supporting the worker (i.e., the provision of assistive devices, wheelchairs included) or modifying the workplace (i.e., removal of physical barriers) or adaptations of the tasks composing the job. The first attempt is always aimed at reintegrating the worker into the same working position he/she was occupying before the accident. In cases where this is not possible due to the worker's new conditions, the vocational personnel can suggest the RTW in the same company in a more suitable role or a new workplace that better fits the workers' physical and cognitive abilities. To carry out this process, INAIL takes advantage of a team of multidisciplinary experts ranging from clinicians, physical, occupational, and vocational therapists to psychologists, social workers, and technicians and involves the worker's family, colleagues, and employer. The identification of suitable occupations is managed locally through the network of regional and provincial social workers that collects the availability of working positions for people with disabilities.

This paper describes the efforts undertaken by INAIL to facilitate the process of WUs' RTW with the Rientr@ project [2]. Rientr@ has the aim of supporting all the professionals involved in the RTW process by providing them with a Decision Support System (DSS) that – taking as input the WU's residual capabilities – can suggest a list of possible jobs the worker can still perform exploiting his/her residual abilities at their best. The DSS leverages expert knowledge and standard classifications to help key RTW professionals identify suitable job options for WUs with physical and/or cognitive disabilities. In particular, Rientr@ DSS leverages the International Classification of Functioning, Disability, and Health (ICF) [57] to describe an individual's functioning and the Occupational Information Network (O*NET) [19] (based on the Standard Occupational Classification (SOC) system [11] to describe a job's characteristics. Rientr@ DSS exploits Semantic Web technologies – namely ontologies – to provide a formal and shared representation of a WU's health condition and to match it with a list of jobs the WU can still perform.

Rientr@'s approach novelty is that, differently from existing ontology-based solutions in the field of RTW or professions, it considers a WU's residual capacity and matches it with the effort required by a job's activities. In this way, the DSS facilitates the identification of jobs' critical aspects for a specific worker, thus actively supporting the RTW professionals during the decision-making process.

This work is organized as follows: Section 2 highlights some of the most relevant works in this field, while Section 3 introduces the materials adopted to conceptualize the problem at hand (ICF and O*NET's structures and their matching). Section 4 introduces the methods adopted in this work, i.e., the definition of criticality scores for job activities, while Section 5 describes the results – delving into: a) ICF / O*NET formal representation and the rule system developed to match them; b) the representation of the algorithm for the evaluation of job suitability. Section 5 also presents a preliminary validation conducted with experts in RTW and introduces the prototypical application and the architecture exploiting the ontology-based DSS. Section 6 discusses the outcomes of the preliminary validation and presents some limitations of the DSS. Finally, the Conclusions summarize the main contributions of this paper and draft the future research activities to be conducted on the DSS.

2. Related work

The use of Semantic Web technologies as the backbone of DSSs has been investigated in the past, and a variety of examples can be traced in the scientific literature [4]. Ontologies can support information interoperability by formalizing (domain) knowledge into computable models, which can further extend their knowledge through reasoning processes [3]. These features make ontologies particularly useful to support Artificial Intelligence-enabled systems in healthcare since ontologies can leverage expert knowledge and enable transparent reasoning processes similar to those performed by human experts [10] – thus avoiding the "black-box" bias generally associated with data-driven approaches [16].

2.1. Ontology-based approaches for DSSs in healthcare

Semantic formalization of knowledge in the healthcare domain is exploited in a wide range of medical settings [54], mostly because it presents a twofold advantage: ontologies can support data interoperability (i.e., they facilitate data interchange among applications adopting different data formats), while they provide a logic-based and semantically-enriched representation of a domain. As highlighted in a recent review by Narayanasamy et al. [31], domain ontologies in the healthcare domain can support the classification of drugs, diseases, and conditions. The most prominent examples of this are the ontologies of the International Classification of Diseases (ICD) and ICF, international standards known by all clinicians. The representation of health and biomedical domains began in the early 2000s [46] and is still ongoing. This activity aims to provideshared, accessible, and interoperable ontologies [21]. A recent literature review [52] pointed out domain ontologies' richness in representing disabilities and other conditions, illustrating that recurring to international standards (such as ICF or ICD) supports the shareability of the models and information interoperability in a clinical context.

The adoption of ontologies as backbones of DSSs is also attested in the early 2000s: the ability to perform reasoning leveraging expert knowledge is relevant for different health disciplines, ranging from clinical decision-making to rehabilitation, including chronic illnesses management [29]. The approach underlying the different ontology-based solutions consists of formalizing (a portion of) a domain – e.g., a set of particular conditions, diseases, etc. – following an ontology engineering methodology and acquiring inferred information, leveraging on reasoning processes or querying [55]. Moreover, many DSSs in healthcare require the modelling of rules to "guide" the behaviour of a DSS. However, it was recently highlighted [22] that rules development may lack interoperability since they are formalized with different languages.

2.2. Ontologies for job matching

Ontologies have been widely used in several DSSs devoted to matching individuals with professions for recruitment purposes, using education, training, working experience and/or other relevant soft skills as criteria. Villazón-Terrazas and colleagues [56] developed a semantic platform for e-employment that leverages an ontology network, formalizing candidates' CVs and job offers to foster better matches. Guo and colleagues [18] developed a system capable of extracting and formalizing relevant information about candidates' qualifications and experiences to enhance the matching between people and jobs. Kethavarapu & Saraswathi [24] developed a recommender system in which semi-automatically generated ontology provides applicants with job offers information from online portals. More recently, Kumar and colleagues [26] exploited an ontology-based crawler to search the web for technical job recommendations aimed at helping job seekers find the most appropriate position easily.

The description of jobs and their characteristics is pivotal in e-recruitment, and some examples of frameworks aimed at describing a particular aspect of jobs can be traced in the literature [1]. On a broader scale, the European Skills, Competences, Qualifications and Occupations (ESCO) ontology [43] provides a vocabulary to describe any profession with the required set of skills, knowledge, competencies, and qualifications. ESCO combines three pillars (profession, competence, qualification) to provide a three-dimensional job description and is adopted as a European standard in job definition.

2.3. Matching persons with disabilities and professions: a research gap

To the best of the authors' knowledge, only one work tackled the issue of matching workers with disabilities with jobs using ontology as enabling technology. Shishehchi and Banihashem [44] developed an ontology-based recommender system to understand whether an applicant with some impairments can fruitfully exploit specific assistive technologies and match the applicants with one or more jobs suitable for them. The matching process uses Semantic Web Rule Language (SWRL) [20].

The system proposed by Rodas-Tobar et al. [41] supports recruiters in adding workers with disabilities to the staff. Although rule-based, this system does not leverage expert knowledge (or its formal representation) to conduct inferences.

Both recommender systems are interesting for their purposes; however, they do not rely on any clinical standard or shared classification of disability to describe the applicants. In addition, the identification of the types of disability a job can accept is manually performed.

3. Materials

As mentioned in the Introduction section, the Rientr@ DSS leverages domain ontologies to represent ICF and O*NET, which are standard classifications used to describe different domains of knowledge. From a technological perspective, the DSS leverages ontologies – instruments for domain knowledge formalization and sharing that are widely adopted in many research fields, such as healthcare [27,39], rehabilitation [23], and personalization of care [8,40]. This technology allows to describe formally relevant pieces of knowledge composing a domain in a sharable model and enables reasoning processes that can elicit inexplicit pieces of knowledge. For these reasons, ontologies are often adopted as the backbone for DSS and recommender systems [4]. Rientr@ ontology takes advantage of both these aspects, as it provides a formal model of the domains involved in the project and leverages reasoning to generate inferences, with the aim of supporting RTW.

ICF and O*NET, described in the following paragraphs, constitute the basis for the creation of the proposed ontology-based DSS, which – given the WU health status coded with ICF – returns a list of possible jobs exploiting reasoning algorithms.

3.1. International classification of functioning, disability and health

The World Health Organization (WHO) standard ICF is a theoretical framework for classifying an individual's functioning and disability. It provides a basis for the definition and measurement of health and it conceptualizes human functioning as a dynamic and complex relationship between the individual health condition and contextual components, i.e., environmental and personal factors. The classification is organized into categories, each belonging to a specific component. ICF is composed of four components: *Body functions* (*b*) – describing the physiological functions of the body system; *Body structures* (*s*) – providing the means to identify anatomical parts of the body; *Activities and participation* (*d*) – listing a set of tasks or involvement in life situations; *Environmental factors* (*e*) – describing the physical, social and attitudinal environment in which a person lives. Each component is detailed into chapters by adding one digit after the letter identifying the component (e.g., b5 "*Functions of the digestive, metabolic and endocrine system*"), which are also further categorized. A three-digit code refers to the second level of the categorization (e.g., *b510 "Ingestion functions"*), while the third level is composed of four digits (e.g., *b5105 "Swallowing"*); finally, the fourth level is composed of five digits and is the most detailed level available in the ICF classification (e.g., *b51050 "Oral swallowing"*). To express the severity of an impairment, a qualifier is added after a category; a qualifier consists of a digit or a series of digits that specify the magnitude, the location, and the nature of any problem. Qualifiers are placed after the ICF code, separated by a decimal "." – or by the "+ " sign for the description of environmental facilitators (e.g., b280.1; e1550 +3). According to the component, each ICF category allows the use of one or more qualifiers (up to four [58], as detailed in Table 1).

The description of an individual's health condition and his/her functioning is given by the set of ICF categories together with associated qualifiers.

Since ICF encompasses more than 1450 categories (i.e., three, four, and five-digit codes), WHO developed Core sets to ease the adoption of ICF in clinical practice. The Core sets can be defined as a selection of ICF codes relevant for specific health conditions and healthcare contexts. Although Rientr@ DSS's ontology is not limited to the representation of Core Sets, the model leverages the Core sets dedicated to Traumatic Brain Injury (TBI), Spinal Cord Injury (SCI), Stroke (STR), and Vocational Rehabilitation (VRH) to help clinical personnel in describing a WU's health condition according to the main clinical causes that lead a person to use a wheelchair, also including those aspects that can prevent workers from engaging in employment.

3.2. Occupational information network

The Occupational Information Network (O*NET) is a comprehensive system designed to describe occupations by means of multiple descriptors and categories [37]. It employs a taxonomic approach based on SOC to classify 1016 occupations. O*NET relies on a hierarchical Content Model [38] to describe the key features of each occupation through a set of cross-jobs variables called *descriptors*. Descriptors are organized into six major domains: *Worker characteristics*, *Worker requirements*, *Experience requirements*, *Occupational requirements*, *Workforce characteristics*, *Occupation-specific information*. Each domain is further classified into specific categories, which group descriptors to provide a list of specific characteristics describing a job. An example of the O*NET hierarchical model is reported in Fig. 1.

A list of descriptors is assigned to each occupation. For the purposes pursued in this work, only two categories were considered: *Abilities* – encompassing cognitive, psychomotor, physical, and sensory abilities – and *Skills* – including basic skills and cross-functional skills with their subclasses. Abilities and Skills describe the characteristics that a worker must have or fulfill (from a physical and cognitive perspective) to perform a specific profession. The DSS exploits only the Abilities and

Table 1
Use of qualifiers according to ICF components. "Performance" describes what a person does in his/her actual environment, "Capacity" indicates what an individual does in a standardized environment; "With/without assistance" indicates whether the evaluation is performed in the presence of personal assistance and/or assistive devices (e.g., glasses, wheelchair, etc.).

ICF Category	Qualifier 1	Qualifier 2	Qualifier 3	Qualifier 4
Body structures	magnitude of the impairment (ranges from 0 – no impairment, to 4 – complete impairment. Allows 8 – other specified, 9 – other not specified)	-	-	-
Body functions	magnitude of the impairment (ranges from 0 – no impairment, to 4 – complete impairment. Allows 8 – other specified, 9 – other not specified)	nature of the impairment (ranges from 0 to 9: each number indicates a different cause of the impairment)	localization of the impairment (ranges from 0 to 9: each number indicates a different location of the impairment in the body)	-
Activities and participation	magnitude of the impairment in the *performance* with assistance (ranges from 0 – no impairment, to 4 – complete impairment. Allows 8 – not specified, 9 –not applicable)	magnitude of the impairment in the *capacity* without assistance (ranges from 0 – no impairment, to 4 – complete impairment. Allows 8 – not specified, 9 –not applicable)	magnitude of the impairment in the *capacity* with assistance (ranges from 0 – no impairment, to 4 – complete impairment. Allows 8 – not specified, 9 –not applicable)	magnitude of the impairment in the *performance* without assistance (ranges from 0 – no impairment, to 4 – complete impairment. Allows 8 – not specified, 9 –not applicable)
Environmental factors	magnitude of barriers (or, with +, magnitude of facilitators; ranges from 0 to 4. Allows 8 – not specified, 9 –not applicable)	-	-	-

Skills of O*NET (exceptexcept for the Technical Skills, which represent the user's ability to operate with technologies in specific working-related aspects of a job) because these descriptors can provide an adequate description of the cognitive and physical abilities required to perform a specific profession. The remaining O*NET domains (i.e., occupation-specific requirements, worker's previous experience, worker's personal factors, etc.) could be considered not significantly affected in case of injury and do not provide information regarding cognitive or physical abilities that contribute to the aim of the DSS.

O*NET associates each descriptor to an *importance score* (ranging from 0 to 100) that determines how much owning that descriptor influences the worker's performance in a specific job. For instance, the profession *"43–4031.01 Court Clerks"* includes 35 Skills, 11 of which with an importance score higher than 50/100 (e.g., "*Active listening*" 75/100, "*Social perceptiveness*" 53/100, etc.) and 24 scoring less than 50 (e.g., "*Negotiation*" 47/100). O*NET importance score is organized in [38], depending on the value each category gets for a specific profession. The following Table 2 depicts the four anchors for O*NET scores.

3.3. O*NET and ICF theoretical link

Although both ICF and O*NET rely on a taxonomical organization of their contents, the two classifications focused on very different domains. To make O*NET and ICF interoperable, the Linking Rules methodology developed by (Cieza et al., [7]) was adopted; the whole theoretical procedure followed to perform such a match has been described in detail in a previous work [32], and summarized in Table 3. Eventually, the linking resulted in a match between an O*NET category belonging to Skills and Abilities and at least one ICF category (second-level category or deeper).

The linking process took advantage of ICF *Body functions* and *Activities and participations* categories since they focus on the functioning of an individual while performing specific activities and can be used for describing any health condition. Furthermore, to better express the fact that WUs must be evaluated for a profession while performing an activity using their wheelchair, the Activities and participation qualifier selected is *performance with assistance* (i.e., the first qualifier for this component, as depicted in Table 1).

3.4. Rientr@ ontology and DSS languages

The Rientr@ ontology is developed following the principles and guidelines proposed in the AgiSCOnt methodology [49]; this methodology leverages close collaboration with domain experts (in this case INAIL vocational personnel) and axploits and agile and iterative approach foster stakeholders' participation in the ontology engineering phase, even if they do not have a deep knowledge of Semantic Web and its technologies [50]. In particular, AgiSCOnt is characterized by flexibility and domain analysis features that facilitate the engineering process [51].

From a language point of view, the Rientr@ ontology relies on W3C-endorsed languages Resource Description Framework (RDF), RDF Schema [28], Ontology Web Language (namely, OWL 2 DL, a practical realization of Description Logic [35]) and adopts SWRL to represent inference rules. It is developed using the Protégé ontology editor (version 5.5.0) [30]. Finally, the Rientr@ ontology is stored in a triple store (Stardog semantic repository [53]), where it can be queried with SPARQL [36].

The DSS application is developed exploiting the Java programming language Standard Edition (SE) and Maven libraries for a cross-platform user interface that is able to interact with Stardog Java API – Stardog Native API for the RDF Language (SNARL). Rientr@ ontology is hosted on the Stardog semantic repository, a triplestore that can be used to retrieve and modify RDF and OWL triples via the SPARQL query language. These APIs are just using Stardog HTTP API, and thus, all of Stardog's features are available via Java application.

4. Methods

The development of Rientr@ DSS was performed in three steps. First, an operationalization of the "level of criticality" for each specific Skill or Ability (already approached in Negri et al. [32], i.e., how much a disability impacts a specific job activity, and the computation of one (or more) value(s) allowing the operator to assess the overall job suitability for each specific user are performed (Sections 5.1 and 5.2). These two steps were performed by the same *Consensus Group,* which had performed the ICF-O*NET linking on the basis of empirical data provided by

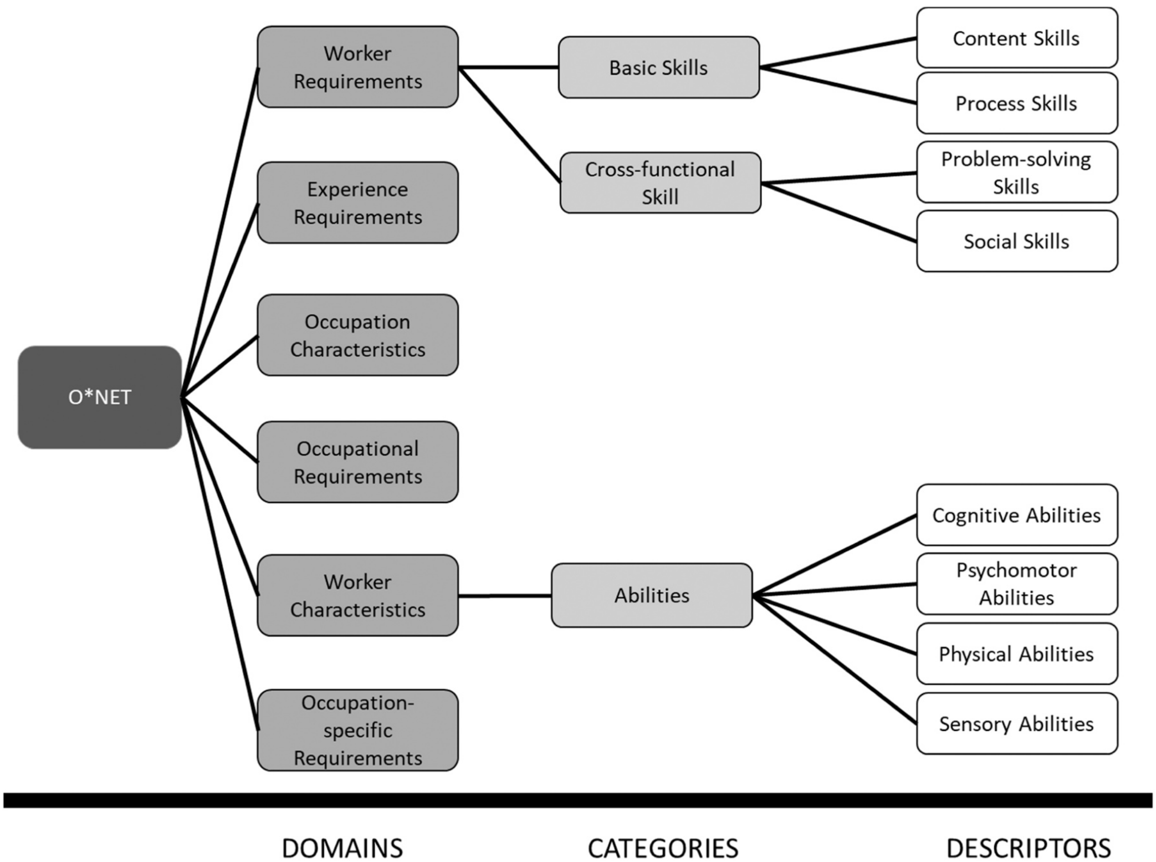


Fig. 1. An excerpt of the O*NET hierarchical content model.

Table 2
Classification of the O*NET importance score.

Anchor number	Anchor description	Score range
0	Not important	≤ 25
1	Somewhat important	$26 \leq$ score ≤ 49
2	Important	$50 \leq$ score ≤ 74
3	Very important	≥ 75

INAIL personnel. According to INAIL expertise and experience, these data were selected as representative health conditions. The three operational health conditions (opHCs) were also assessed by INAIL operators – with yearly expertise in RTW – against 10 known jobs, i.e., for each opHC and job, the operator declared it: suitable, suitable with precautions (i.e., by providing the worker with appropriate assistive devices), or not suitable. The jobs were: file clerk, carpenter, gem and diamond worker, word processor and typist, postal service clerk, landscaping and ground keeping worker, travel guide, billing-cost-rate clerk, construction worker, and receptionist. The three opHCs used for this step – and presented in detail in Appendix A – were:

- opHC1: a patient with severe right hemiplegia caused by hemorrhagic stroke (STR). From a physical perspective, her health condition is characterized by: moderate weakness in the right lower and upper limbs, slight loss of sensibility in the same areas, and slight vision-related impairments. From a cognitive perspective, moderate difficulties in language expression (both spoken and written) exist.
- opHC2: a patient with Traumatic Brain Injury (TBI) whose health condition is characterized by paraplegia and moderate coordination difficulties, as well as a slight lengthening of reaction time. Cognitively, the patient presents slight mnemonic and concentration difficulties.
- opHC3: a patient with Spinal Cord Injury (SCI) and TBI, characterized by tetraplegia, slight chronic pain, and severe weakness in upper and lower limbs. From a cognitive perspective, her condition presents mild attention deficit and mild memory loss.

The second step was the development of the DSS itself, meaning its components, the process of making them interoperable, and the implementation of the reasoning rules (Section 5.3). After the development of the DSS, it was necessary to design and implement a simple application that acts as a Graphical User Interface (GUI) to allow the users to navigate through the DSS easily even if they have limited or no background knowledge of semantic technologies and ontologies. This simple and easy-to-use GUI application connects all the modules, translates ontological data, retrieves reasoned data, and exchanges information to/from the DSS in real-time. Hence, an architecture for a large-scale DSS was designed, aiming at making the ontology-based DSS a tool capable of supporting RTW operators in Italy.

Finally, a preliminary validation of the DSS was carried out by enrolling a team of experts working in the field of vocational rehabilitation within INAIL Prostheses Centre in Budrio (BO, Italy) (Section 5.4). Four different health conditions (TestHCs) – representative of the population eligible for RTW process – were considered. INAIL provided them on the basis of four real people who, in the past, have been treated in the Prostheses Centre:

- TestHC1: a male (49 years old) suffering from TBI with complete paralysis of lower limbs; use of the wheelchair; pre-existing cognitive problems in focusing attention, sound discrimination, and using logic to solve problems – exacerbated after the accident. Mood problem (depression). Moderate impairment of muscle tone and strength.
- TestHC2: incomplete tetraplegia (resulting in complete lower limb paralysis) male patient (42 years old) after SCI. Moderate limitations

Table 3
The linking process methodology. The Table illustrates the Liking Rules for ICF and O*NET and provides some examples of their application to the case at hand.

#	Rule as defined by Cieza et al. [7]	Application of Cieza et al. rule	Example
1	Acquire good knowledge of the conceptual and taxonomical fundamentals of the ICF.	As in Cieza et al [7].; also, acquire a good knowledge of O*NET-SOC taxonomy.	
2	Identify the purpose of the information to be linked by answering the question What is this piece of information about? or What is this item about?	Define the purpose of the information to be linked, and the related core concept(s) of the Skill or of the Ability of interest.	Written Comprehension: ▪ Core concept(s): reading, understanding the information.
3	Identify any additional concepts contained in the piece of information in addition to the main concept(s) already identified in the previous step.	As in Cieza et al. [7]	Written Comprehension: ▪ Other concept(s): comprehending the literal and implied meanings of messages.
4	Identify and document the perspective taken on within a certain piece of information when linking it to the ICF.	Identify the perspective considering the end user; i.e., when doubt arises, consider that the final aim is the development of a tool to address WU's RTW.	*Explosive strength* (i.e., the ability to use short bursts of muscle force to propel oneself (as in jumping or sprinting), or to throw an object): ▪ Consider propelling oneself as on a manual wheelchair.
5	Identify and document the categorization of the response options (e.g., intensity, frequency, duration, agreement, qualitative attributes).	Identify and document the categorization of the O*NET skill or ability.	Dynamic strength: ▪ Duration. Explosive strength: ▪ Intensity.
6	Link all meaningful concepts, the most relevant and additional ones, to the most precise ICF category.	As in Cieza et al. [7]; an additional ICF category was introduced when the description with only one category was not considered complete.	Near Vision: (1) b21003 Monocular acuity of near vision; (2) b21002 Binocular acuity of near vision.
7	Use *other specified* [8] or *unspecified* [9] ICF categories as appropriate.	Use *other specified* [8] or *unspecified* [9] ICF categories if the concept cannot be described successfully or completely by one (or two) ICF category(ies).	Response Orientation: ▪ b7608 Control of voluntary movement functions, other specified.
8	If the information provided by the meaningful concept is not sufficient for making a decision about the most precise ICF category, assign the concept to *nd* (not definable).	As in Cieza et al. [7]	Learning strategy ▪ nd
9	If the meaningful concept is not contained in the ICF, but is clearly a personal factor as defined in the ICF, assign the meaningful concept to *pf* (personal factors).	n.a.	
10	If the meaningful concept is not contained in the ICF, assign this meaningful concept to *nc* (not covered).	As in Cieza et al. [7]	Technology Design ▪ nc

in the functionality of the trunk and upper limbs. The patient reports longer times for performing tasks due to cognitive issues.

- TestHC3: paraplegic female patient (34 years old) after TBI. Slight cognitive impairments in memory and language functions after the accident exist. Good trunks and upper limbs functionality.
- TestHC4: paraplegic male patient (45 years old) after SCI. Chronic pain to upper limbs (musculoskeletal), mild cognitive impairments, moderate vision-related impairments.

Each health condition was modelled with ICF (as presented in Appendix B). The four TestHCs were evaluated with the DSS against five different jobs. Then, six members of the INAIL Prosthesis Centre with yearly expertise in the field of vocational rehabilitation and RTW were asked to assess the suitability of the 5 jobs for each patient represented by the TestHCs mentioned above. Their roles were: social worker (3), orthopedic technician (2), and physiatrist (1); they well reflected the composition of a team generally performing an RTW assessment. The assessment was performed via a self-administered questionnaire, containing the ICF description of the four TestHCs. All the assessors were blinded to DSS results and to others' responses.

5. Results

5.1. Operationalization of the level of criticality

To obtain a general score for each Skill or Ability involved in a profession, we considered the level of WU's impairments (expressed with ICF qualifiers) and the level of importance that those Skills and Abilities cover in the job for which the WU is evaluated (i.e., the importance anchor). The operationalization was performed on the basis of the risk analysis approach (in which $Risk = Impact \times Probability$), which combines the two factors using multiplication. In our case, the "severity of the impairment" was associated with *Impact*, while the "importance" replaced the *Probability* (i.e., the chance that a Skill or an Ability is required for a specific job). Thresholds were then defined, having in mind to be the most conservative as possible (i.e., ≥ 7 extremely critical, ≥ 5 relevantly critical, ≥ 3 moderately critical, ≥ 1 slightly critical, otherwise not critical). The outcome is presented in Fig. 2.

Given the matrix, it is possible to combine all the levels of impairments with levels of importance. For instance, considering a WU characterized by a health condition whose highest impairment is in "b7601 Control of complex voluntary movements" (defined in ICF as "Functions

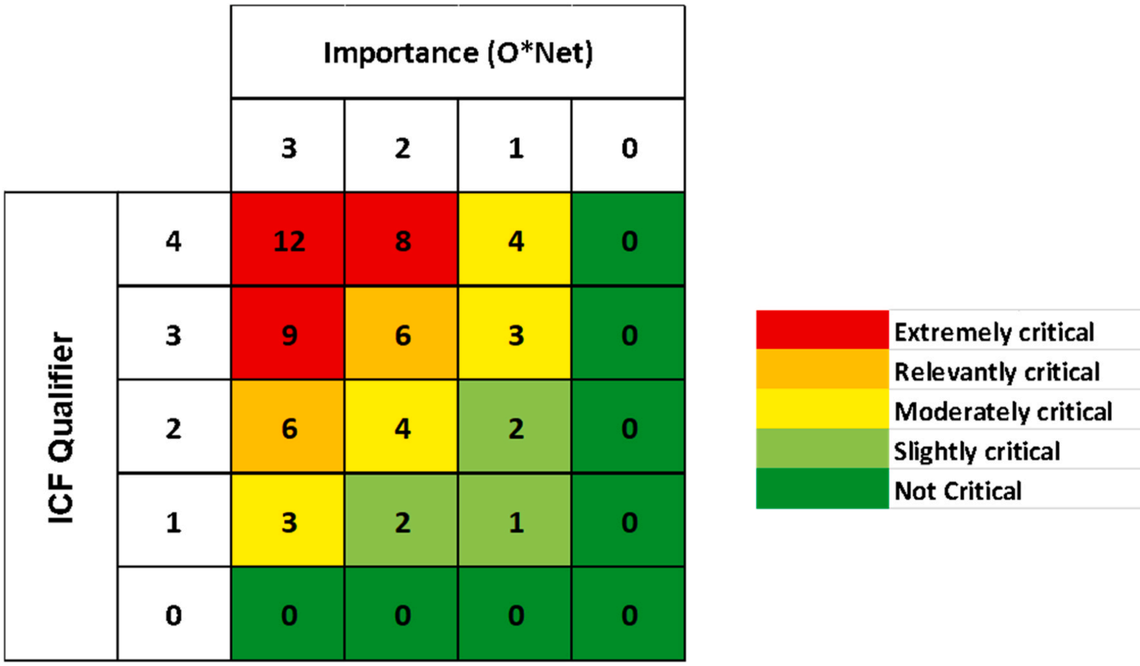


Fig. 2. A matrix combining ICF-based health characterization of a WU with the level of importance of a Skill and Ability in a profession to get an indication of the criticality a WU may face in performing certain activities.

associated with control over and coordination of complex voluntary movements"), with a qualifier equal to 3: if he/she is evaluated for working as a "Model maker with wood" (e.g., a sample builder, product carpenter), the psychomotor ability "Multi-limb coordination" (defined in O*NET as "The ability to coordinate two or more limbs –for example, two arms, two legs, or one leg and one arm while sitting, standing, or lying down; it does not involve performing the activities while the whole body is in motion" and translated in ICF with the code b7601) covers the importance of 53 (the anchor is *2 – Important*). Therefore, the WU may experience a *relevant criticality* (criticality score = 6) in performing such an ability. On the contrary, the same WU evaluated for the work of "Receptionist and Information Clerk", in which the importance of the same ability amounts to 19 (anchor *0*), would obtain an outcome of absence of criticality (Fig. 3).

5.2. Algorithm for the job overall suitability

To obtain an objective and qualitative assessment of the overall job suitability for a specific user, two indices were calculated: the General Criticality Score (GCS) and the Amount of Impaired Skills and Ability

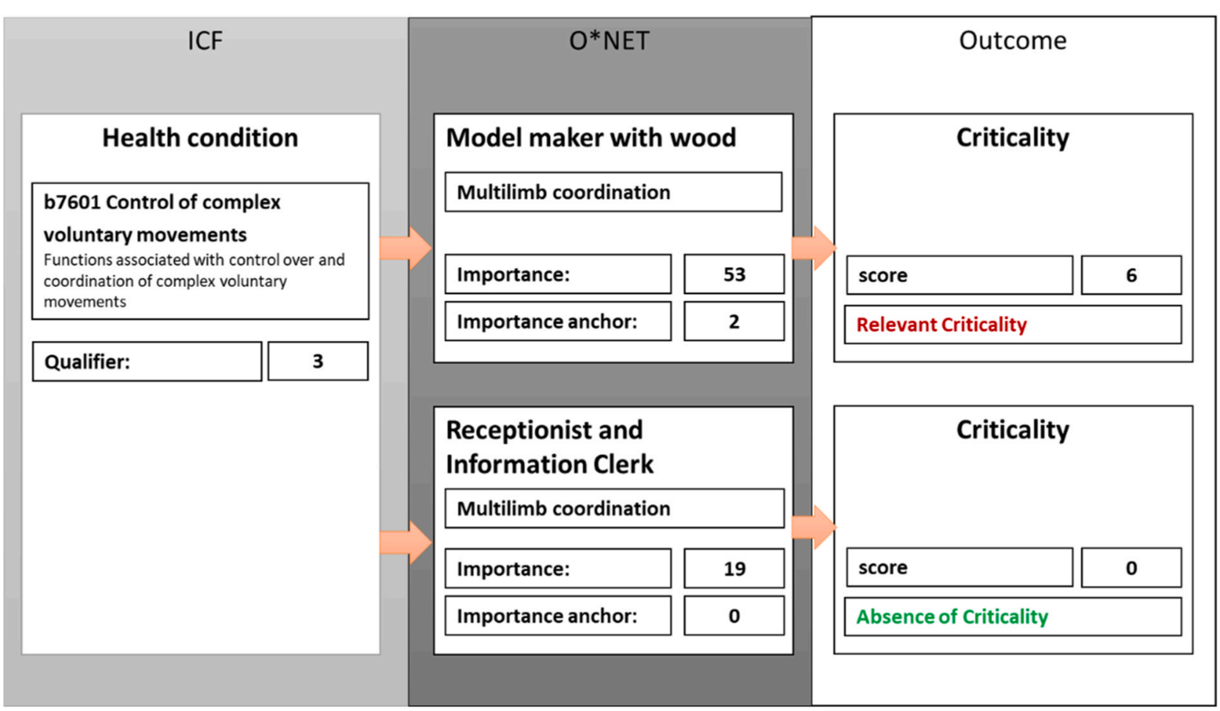


Fig. 3. A schema illustrating how a severe impairment can have different impacts in the computation of criticality scores for different professions.

(AISA). Concerning GCS computation, the following procedure was applied:

(1) The products obtained for each O*NET Skill or Ability importance and the associated ICF qualifier were computed. In the example reported in Section 3.4: ICF qualifier was 3, O*NET importance (for Model maker with wood) was 2.
(2) The result of the multiplication was normalized considering the maximum possible value, i.e., ICF qualifier equal to 4, and O*NET importance equal to 3. Going on with the example, the obtained value is $6/12 = 0.5$.
(3) All the normalized values for a specific user were then averaged to obtain a *general criticality score* (GCS); such a value was multiplied by 100 to get a percentage score (*GCS%*).

The second index, i.e., AISA, was computed as the ratio between the number of Skills and Abilities with a criticality score > 0 and all the Skills and Abilities used to describe a profession.

Given the lack of previous works on which we could rely to extract the overall Job Suitability (JS), we used an empirical method based on real use cases provided by INAIL that were presented in Section 4. Such opHCs – characterized by both physical and cognitive impairments – were evaluated for the same ten jobs presented to the operator, and GCS and AISA were retrieved for all of them.

The results provided by the DSS are summarized in Table 4:

The results obtained from the expert assessment were then compared to GCS and AISA (considered in %) by graphically plotting the grouped jobs in a dispersion plot (Fig. 4). From the plot, it was then possible to determine graph regions corresponding to suitable jobs (green area), suitable jobs with precautions (yellow area), and non-suitable jobs (red area), and thus to extract mathematical formulas to assess JS based on GCS and AISA (%). In particular, the slope and the intercept of the line dividing the yellow and the red areas were computed considering the two points (31.08;7.30) and (32.88; 7.64) from opHC1 that, although very close, belonged to two different areas. The second line was traced accordingly, considering the same slope.

5.3. The ontology-based Rientr@ DSS

The Rientr@ DSS leverages the ontological representation of WU's health condition – expressed with ICF – to compute criticality scores for each job's Skill and Ability. Following the algorithm presented in the previous Sections, GCS and AISA are retrieved and used to assess JS. Fig. 5 illustrates the input, processes, and outputs of the DSS. The ontology is accessible online.[10]

5.3.1. Ontology engineering process

Since reusing knowledge sources is one of the best practices in ontology engineering [51], the classifications and their connections presented in Sections 3 and 4 were reused, following the AgiSCOnt methodology (Section 3.4). In particular, the ICF is already formalized in an OBO ontology [59], and it was pruned of *Environmental factors* and *Body structure* components, thus limiting the model to the *Body functions* and *Activities and participation* components and categories. To provide a formal description of WUs' personal data, the Friend of a Friend (FOAF) vocabulary [17] – a model that allows describing people's contacts and records – was reused, while relevant parts of the O*NET online database [33] were modelled into an ontology (specifically, O*NET Skills and Abilities as detailed in Section 3.3).

The ontology is composed of four modules, each modelling a domain: the WU and his/her personal data together with his/her health condition and its characterization based on ICF; a set of jobs and their characterization with O*NET Skills and Abilities categories; the "translation" of these O*NET categories with ICF. A set of SWRL rules completes the ontology. The following subsection delves into the description of these modules and their development. Fig. 6 provides a graphical representation of the domains involved in Rientr@ in a conceptual map.

5.3.2. WU and health condition module

Each WU is modelled as an OWL individual (belonging to the class rientra:Wheelchair_user), and the representation of his/her personal data relies on some of FOAF properties (foaf:givenName, foaf:lastName, foaf:title, foaf:phone, foaf:mbox, foaf:gender, foaf:birthday, foaf:age). The module also provides a class hierarchy of the ICF codes involved in the TBI, SCI, STR, VRH core sets, and each of the classes contains an OWL individual representing the code. Since some of the core sets refer to the same codes, the classes representing them are modelled in each Core set and considered equivalent (for instance, the ICF category "d410 Changing basic body position" is represented in both TBI and SCI core sets, and then both the classes are modelled in the respective core set, then set equivalent: tbi:d410 ≡ sci:d410). Each WU is then linked to his/her health condition via an object property (rientra:isInHealthCondition), further detailed by ICF codes and qualifiers. To link the qualifiers to the ICF codes and a specific health condition, Rientr@ exploits an ontology design pattern (ODP) [14] that makes use of named OWL individuals (belonging to the rientra:HCDescriptors class), necessary to characterize the quality of an ICF code in a specific health condition [15, 48]. In this way, each OWL individual representing an ICF code is not directly associated with a qualifier, and thus, it can bused to describe other WUs' health conditions. As illustrated in Section 3.3, this module provides datatype properties to model the qualifiers for *Body functions* and *Activities and participation* categories. Fig. 7 provides a graphical representation of a WU and his health condition.

5.3.3. Jobs and their characterization with O*NET Skills and Abilities module

This module provides the class and properties to list the jobs (rientra:Job) and represents a set of ten professions as OWL individuals (listed in Table 4). It also models the hierarchy of concepts composing O*NET Abilities and Skills (except for Technical Skills descriptor and its categories) and provides OWL individuals for each O*NET category considered in Rientr@ . Each of these OWL individuals is used to further describe a profession, with triples indicating which Skills or Ability are required by a job and the importance score associated with them in a specific profession. This model exploits the same ODP adopted for connecting health conditions with ICF codes and qualifiers (as described in the previous Section 4.1): each OWL individual representing a job is connected to at least one descriptor individual (from the class of rientra:Job_Descriptor), which is linked via an object property (rientra:concerns) to an OWL individual representing an O*NET category (i.e. a specific Skill or Ability) and via a datatype property (rientra:hasScore) to the score this particular Skill or Ability holds in the profession considered.

In this way, the module reproduces (an excerpt of) the O*NET database, describing the professions, the Skills and Abilities they involve, and their importance scores.

5.3.4. Linking between O*NET and ICF module

The operation of associating each O*NET category to the ICF code(s) that translates it is performed simply through the rientra:isDescribedWithICFCode object property, which links each Skill or Ability to the respective ICF codes. In such a manner, it is possible to represent the results of the linking process (described in Section 3.3) in a straightforward way.

5.3.5. SWRL set for identifying WU's criticalities in performing job activities

Each of the combinations of the matrix (Fig. 2) can be represented by

[10] Available as an OWL file (serialized in Turtle): https://www.stiima.cnr.it/progetti-ricerca/rientr/

Table 4
The results of the three operational health conditions with ten professions.

Health condition	DSS output	*File Clerks*	*Carpenters*	*Gem and diamond workers*	*Word processors and typists*	*Postal service clerks*	*Landscaping and ground-keeping workers*	*Travel guides*	*Billing-cost-rate clerks*	*Construction labourers*	*Receptionists*
opHC1	GCS%	8.67	9.93	7.64	6.87	9.23	8.22	7.30	6.76	11.15	6.42
	AISA%	34.42	43.84	32.88	28.37	37.84	43.23	31.08	28.37	47.30	25.67
opHC2	GCS%	3.65	7.19	4.33	3.15	4.61	5.85	3.60	2.92	6.87	2.14
	AISA%	23.28	35.61	23.29	21.62	25.67	35.13	21.92	17.57	37.84	14.86
opHC3	GCS%	4.22	6.62	3.99	3.11	5.06	5.74	3.35	2.81	6.53	2.59
	AISA%	28.76	38.35	28.76	24.32	32.43	35.13	26.03	22.97	39.19	10.27

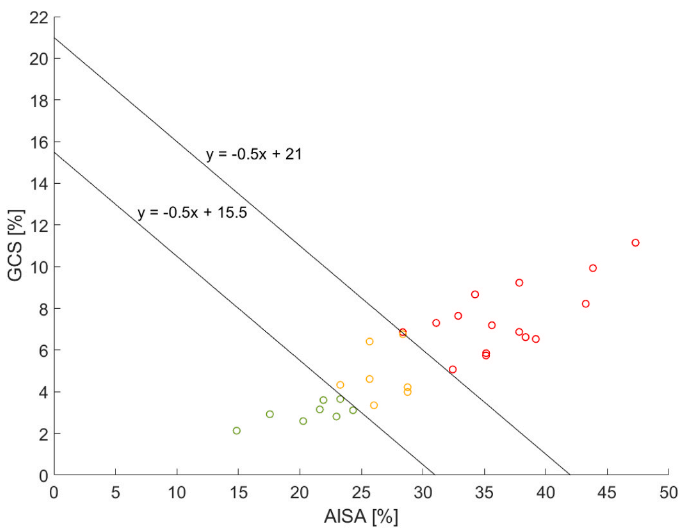


Fig. 4. The graphic representation of Job Suitability obtained empirically by combining GCS% and AISA%. The area indicated by green dots represents suitable jobs, whereas red dots indicate non-suitable jobs. The graph area between green and red represents all those jobs that could be performed with assistive devices.

a rule in SWRL, while their elements are represented as an object property that links the WU to the Skill or Ability, as in the following example:

Person(?p) ˆ isInHealthCondition(?p, ?hc) ˆ Health_Condition(?hc) ˆ isDescribedBy(?hc, ?des) ˆ HC_Descriptor(?des) ˆ involvesICFCode(?des, ?icf) ˆ ICF(?icf) ˆ AP1qual(?des, ?x) ˆ isEvaluatedForJob(?p, ?job) ˆ Job(?job) ˆ requires(?job, ?jde) ˆ Job_Descriptor(?jde) ˆ concerns(?jde, ?skab) ˆ (Abilities or Skills)(?skab) ˆ isTranslatedWithICFCode(?skab, ?icf) ˆ isVeryImportantFor(?skab, ?job) ˆ multiply(?res, ?x, 3) -> hasSpecificCriticality(?skab, ?res).

This rule models the situation in which a WU has an impairment of any severity while the job he/she is being evaluated for requires a Skill or Ability that has a score of importance included greater than or equal to 75 (O*NET anchor 3). This set of rules exploits SWRL built-ins [34] to compare the importance score and the level of impairment and provides, as a consequence, a triple indicating the criticality of a Skill or Ability (involved in the specified job) for the WU considered in the rule.

5.3.6. SPARQL for job suitability retrieval

Using a DL reasoner, it is possible to infer the specific criticality score for each Skill and Ability involved in the definition of a profession, as detailed in step (1) of Sect 3.4. We tested the model with Pellet reasoner [45] and with the DL reasoning profile of the Stardog repository. With SPARQL query language, the GCS% score can be calculated and retrieved, thus providing a summary value regarding the suitability of a job for a specific WU. In fact, SPARQL's operators enable the operative steps from (2) to (4), and the AISA% illustrated in Sect 5.2. Also, the query language allows to calculate GCS% value of each profession so that – using the equations provided in Fig. 3 – it is possible to position a profession on the plot, thus stating whether or not it falls into the "suitable jobs area", or the "jobs with precautions area", or the "non--suitable jobs". In this way, the JS can be represented and retrieved. The correctness of the mathematical results was assessed and confirmed.

5.3.7. Graphical user interface and DSS architecture

The application prototype is developed to help therapists and clinicians in easily navigating through the ontology structure via a simple graphical user interface (GUI). This is designed and implemented to let the clinicians interact with the whole system while hiding the most complex aspects, such as the underlying ontology, from the end users. Thus, the GUI act as the DSS interface for all the personnel involved in the RTW process.

Its functionalities enable to access the semantic repository stored on the Stardog server, run the SPARQL queries based on the SWRL rules, and retrieve the reasoned information. It is designed to be a standalone application that can be easily installed and implemented on different devices with ready-to-use features. The application interface guides the therapists/clinicians through some easy steps where they can find the WU's information and retrieve their skills and abilities in order to perform a specific job. Additionally, the Java application provides the therapists/clinicians a visual representation of the Wus' skills and abilities in a table based on the color-coded matrix illustrated in Fig. 2. This visual and color-coded representation of the skills and abilities can support the therapists in having an instant grasp of WU's abilities in a glance. Furthermore, the application generates a graph to demonstrate the relationship between GCS and AISA, thus it delivers the job suitability based on the graph in Fig. 4 for the WU. Fig. 8 and Fig. 9 show the screenshot of the Java application illustrating the color-coded skills and

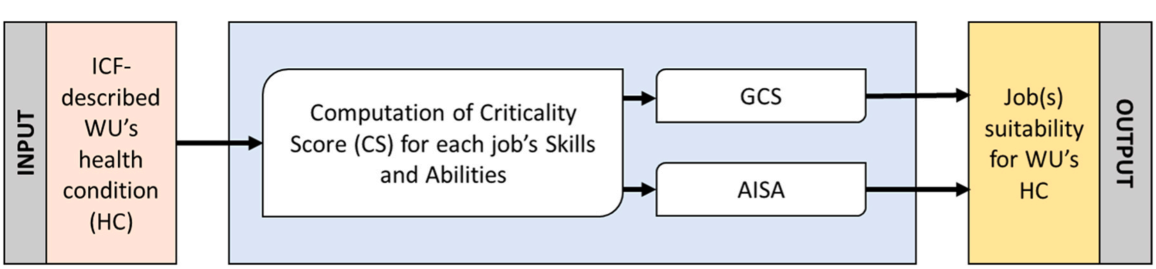


Fig. 5. An Input-Output Diagram [6] of the Rientr@ DSS.

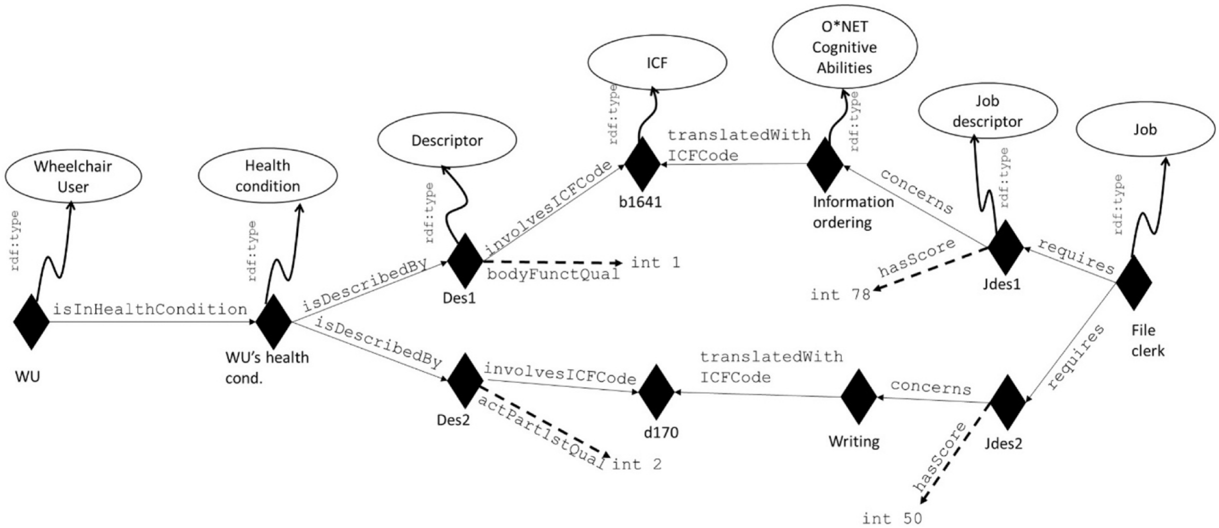


Fig. 6. An excerpt of the Rientr@ ontology illustrating the formalization of a WU and his/her health condition, represented through ICF categories, which in turn are used to "translate" O*NET Skills and Abilities. Diamonds represent OWL individuals; arrows represent roles (dashed arrows for datatype properties, full-line arrows for object properties), and circles represent concepts (classes). The type of an OWL individual is represented with curved arrows.

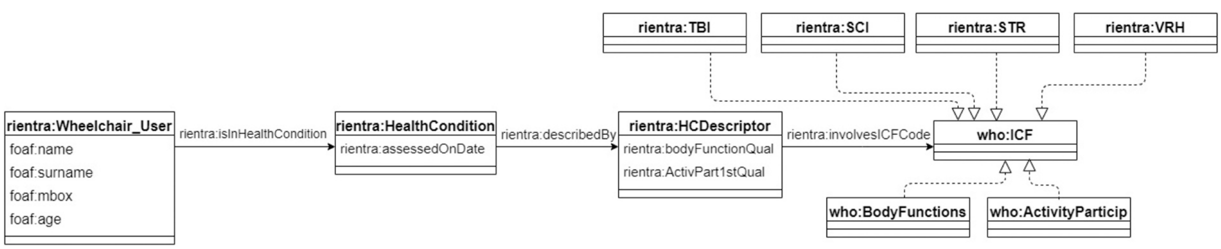


Fig. 7. A class diagram representing the classes composing the ontology related to WUs and their health conditions. Full arrows indicate object property, and dashed arrows indicate the "rdfs:subclassOf" relation. Datatype properties are listed within the class box.

abilities matrix and the corresponding graphical representation of GCS and AISA.

Personnel involved in the RTW process of WUs can also use the application to access and modify the WU's health condition (as described in [47]): in this way, the application enables the (clinician-supervised) update of the WU's health condition, triggering the update of the semantic data pertaining to the specific WU.

The ontology-based system described in this work is expected to be further developed to potentially support all clinical personnel and social workers involved in the RTW process of WUs. However, a pure ontology-based solution may be difficult to sustain (since the ontological layer is expected to increase its ABox). Therefore, to make the prototypical DSS operative, an Ontology-Based Data Access architecture leveraging WUs' data from relational databases may be a promising solution for the deployment of Rientr@ DSS on a large scale.

5.4. Preliminary validation of the inferences provided by the DSS

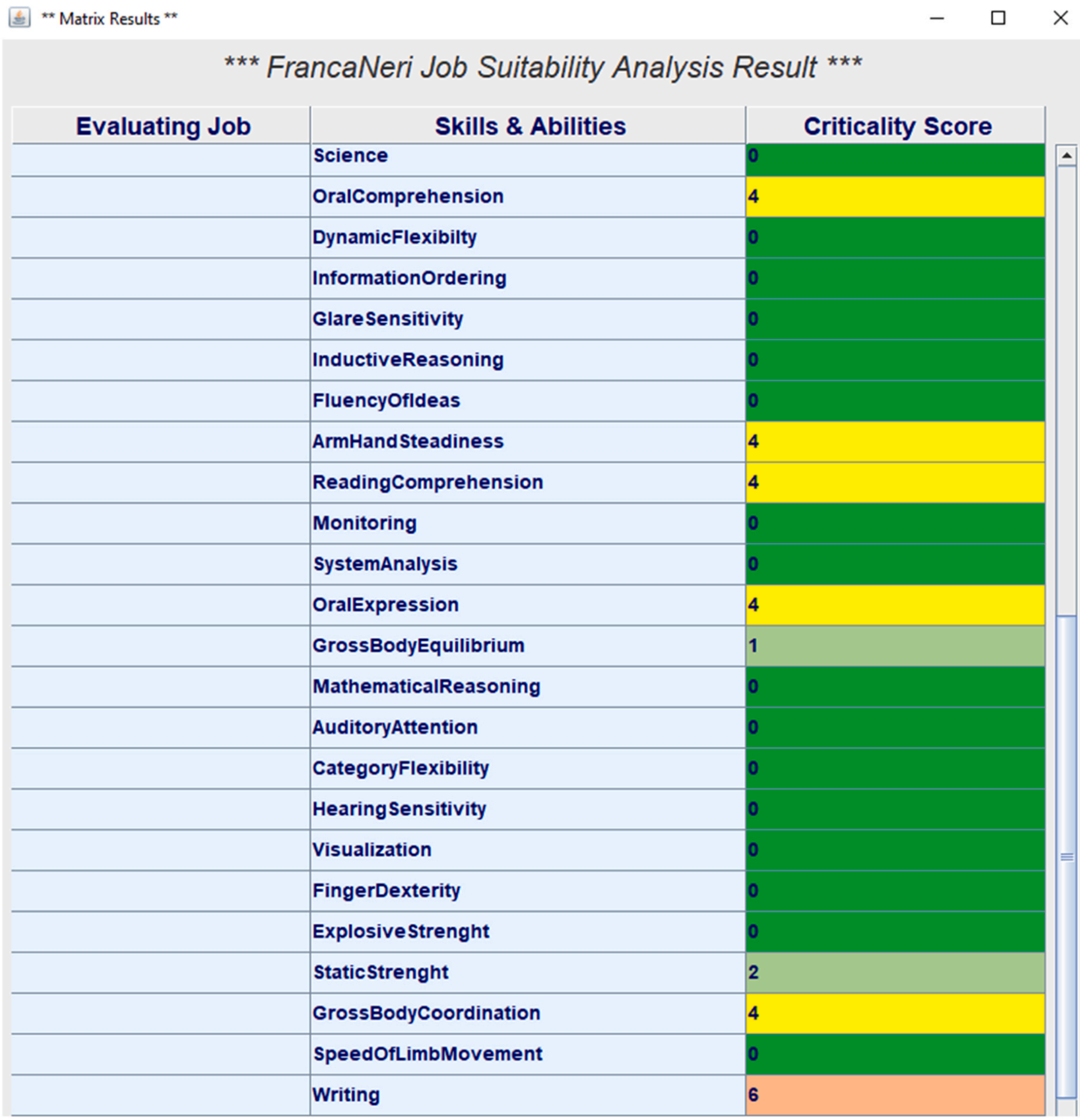
The output of the DSS for each patient (the four TestHC presented in Section 4) is reported in Fig. 10. The comparison among DSS outputs and experts' opinions is presented in Fig. 11. In general, the decisions made by the experts were heterogeneous and highlighted different opinions in several cases.

Regarding the results computed by the DSS, a first analysis highlights differences depending on the severity of the considered health condition. TestHC1 was characterized by severe limitations both at the motor and cognitive levels. In this case, the DSS was more conservative than the human assessors and mostly returned that the job was not suitable for person 1. In the case of an absent-to-mild disability (excluding the primary motor impairment), either in the motor domain (TestHC3 had a good residual functioning of upper limbs) or in the cognitive domain (TestHC2 has mild cognitive issues), the DSS was slightly more "permissive" than the vocational personnel and returned, for some jobs, higher suitability output. Finally, in the TestHC4 situation, where motor and cognitive disabilities were moderate, the DSS results were primarily in between humans' judgments.

6. Discussion, limitations, and future steps

The Rientr@ DSS provides clinical and non-clinical personnel involved in RTW processes with a knowledge-based tool able to identify the criticalities a WU may face in performing some activities. Eventually, the DSS can be used to decide whether a WU's physical and cognitive abilities are compatible with a particular profession. Therefore, the DSS can guide vocational therapists in redefining some aspects of the job for which the patient is being evaluated. Starting from the qualification of specific ICF codes, it allows retrieving a list of suitable jobs by exploiting an objective methodology that considers motor, cognitive, and sensory impairments. Nonetheless, Rientr@ DSS can also help identifying specific Skills and Abilities that may jeopardize the WU's safety, thus adopting tailored interventions to reduce such a risk. Moreover, especially in the case of jobs that are "suitable with precautions", the DSS could enable the identification of those codes that present more difficulties (i.e., they present high GCS), thus allowing the vocational therapist to plan on-the-workplace ad-hoc interventions and to revise the job description with the employer, tailoring the job's activities on the patient's ability.

The DSS's preliminary evaluation allowed a first analysis of the


** Matrix Results **

*** FrancaNeri Job Suitability Analysis Result ***

Evaluating Job	Skills & Abilities	Criticality Score
	Science	0
	OralComprehension	4
	DynamicFlexibilty	0
	InformationOrdering	0
	GlareSensitivity	0
	InductiveReasoning	0
	FluencyOfIdeas	0
	ArmHandSteadiness	4
	ReadingComprehension	4
	Monitoring	0
	SystemAnalysis	0
	OralExpression	4
	GrossBodyEquilibrium	1
	MathematicalReasoning	0
	AuditoryAttention	0
	CategoryFlexibility	0
	HearingSensitivity	0
	Visualization	0
	FingerDexterity	0
	ExplosiveStrenght	0
	StaticStrenght	2
	GrossBodyCoordination	4
	SpeedOfLimbMovement	0
	Writing	6

Fig. 8. An example of the Java applicationg-generated table of skills and abilities and the criticality score of each skill/ability based on color representation in Fig. 2.

results returned by the system compared to vocational personnel's judgments. On the one hand, the wide variety of the results obtained from the different assessors indicated the difficulty of RTW in complex situations, highlighting the need for such an instrument [42]. The different expertise of the personnel involved in this study may have also played a role, i.e., social workers are generally more focused on the activities to be performed while working; instead, orthopedic technicians usually address issues related to mobility, assistive devices, and environmental barriers. Clearly, given the limited size of our sample, any conclusions must be very cautious.

On the other hand, the DSS suggestions agreed only partially with human assessors ones. This behavior may have different explanations. First, the DSS originated from linking ICF and O*NET, as presented in Section 3. O*NET, which – although very comprehensive – is an instrument developed for healthy workers. Thus, O*NET deems important walking or standing on lower limbs only in jobs requiring high physical demands (e.g., construction laborer); therefore, walking and standing are possibly taken for granted in the majority of jobs. Moreover, the direct effect of a complete impairment (ICF score: 4) at the lower limbs level necessarily impacts a limited number of job activities in the O*NET systems. Thus, having only lower limbs impairments – although very severe – cannot affect (correctly) the accomplishment of the whole work. Furthermore, the impact of using a wheelchair may be often underrated because, when assessing the "mobility"-related abilities and considering performances (i.e., the capability of moving around in a real setting and with assistive devices), a WU can result fully functional in the ICF-based perspective. All these considerations can plausibly explain the results obtained and for some emblematic cases in particular (e.g., for TestHC2 when evaluated for construction laborer, which resulted in "suitable with precautions").

Other biases may be due to the geographical, social, and work-related differences that are present between Italy, where the study was performed, and the USA, where O*NET was developed. Finally, the last potential cause of differences is related to the inclusion of social, personal, and environmental factors in the decisional process of human assessors – as mentioned before, this may occur to different extents,

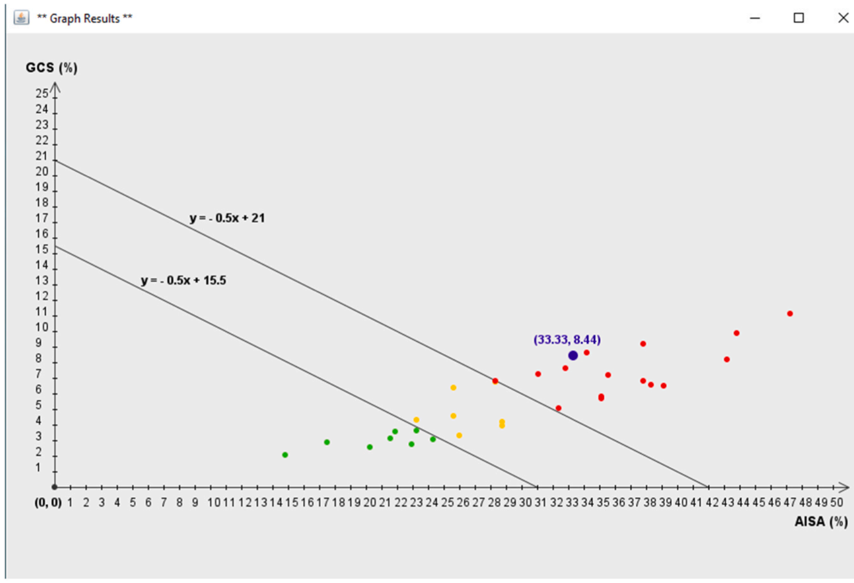


Fig. 9. An example of the graphical representation of the relationship between GCS and AISA for a WU evaluated for the job “File clerk” (blue dot) based on Fig. 4.

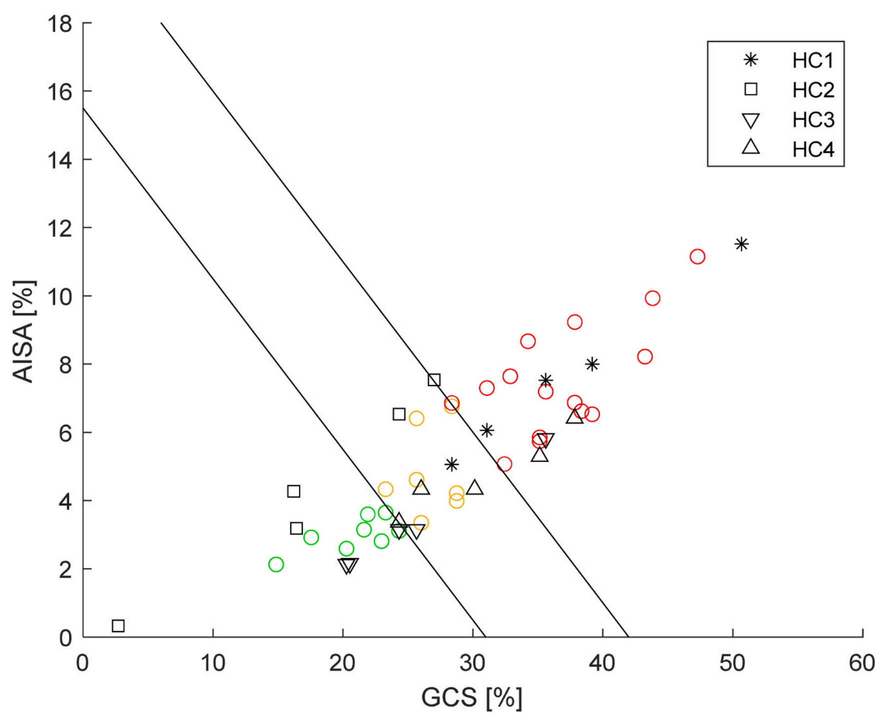


Fig. 10. The output of the DSS for the four test health conditions (TestHCs) – superimposed on the graph presented in Fig. 4.

depending on the expertise of the person involved in the vocational process.

If, from one side, it is worth noting that part of the DSS limitations was due to limitations related to selected instruments, it is also true that both ICF and O*NET have the advantage of being a “universal language”, able to foster cooperation among the different professionals involved in RTW. Indeed, while clinical personnel have a deep knowledge of ICF and its structure, the WHO classification is still accessible also to non-clinical personnel, who – with a little training – can understand and use the structure of ICF to get a glimpse of the WU’s health condition. Moreover, the use of ICF Core sets makes it easier for clinical personnel to evaluate those codes that contribute to the definition of the cause of the WU’s impairment. It is also worth noting that by extending the evaluation to the codes that are involved in the “translation” of O*NET’s Skills and Abilities into ICF and including physical and cognitive characteristics (from the VRH Core set), it is possible to cover all the aspects that have an active role in determining the suitability of a profession for a specific WU. Moreover, the ontology structure’s modularity allows to add new relevant Core sets as soon as they are developed (e.g., a Core set for persons following an amputation is under development [25] and can be added to Rientr@).

The adoption of O*NET as a base to develop the knowledge related to professions and their Skills and Abilities was motivated by the lack of any other standard knowledge source. To the best of authors’ knowledge, O*NET is the only classification that links each profession to a set of required and classified by importance physical and cognitive

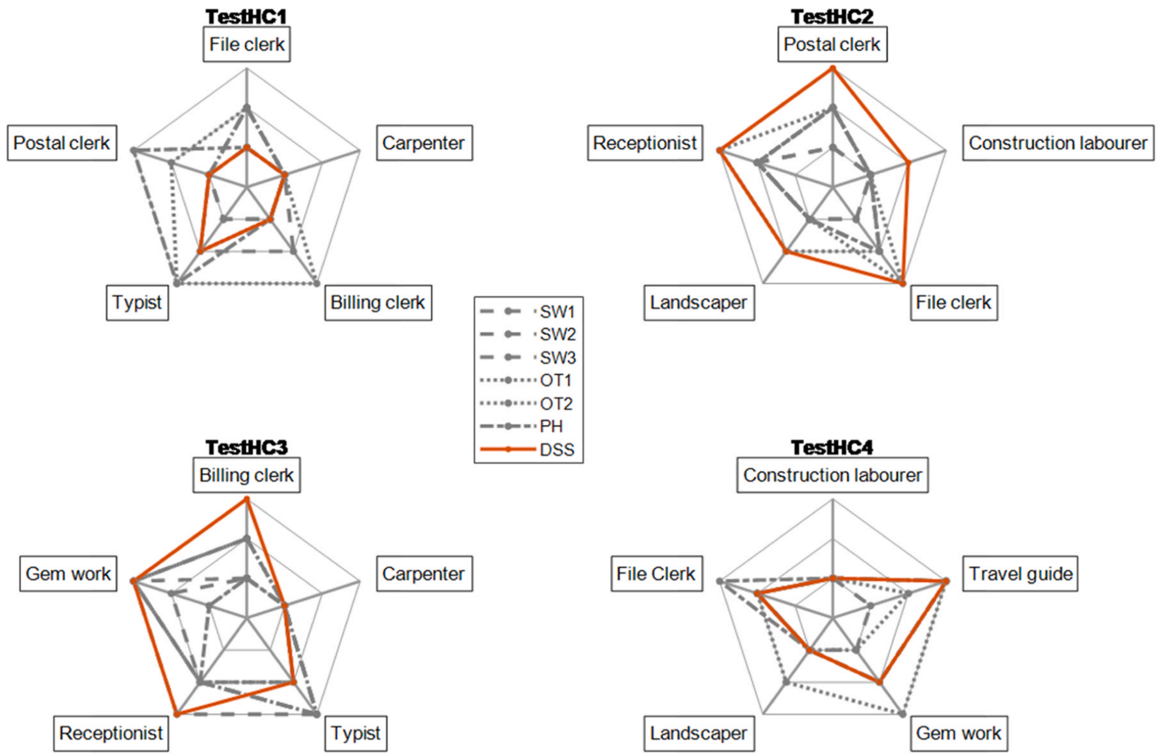


Fig. 11. Diagrams showing the comparisons between experts' and DSS decisions for each of the four test health conditions (TestHCs). Job suitability is represented in a radial fashion with external points meaning "suitable", midpoints "suitable with precautions", and internal "non-suitable" job; SW: social worker, OT: orthopedic technician, PH: physiatrist, DSS: decision support system.

requisites. As mentioned in Section 2, another relevant ontology in the field of formalization of professions is ESCO, which adopts a different perspective than O*NET, and does not take into account the physical requirements for a profession. Instead, it provides a list of competencies (in terms of skills, attitudes, values, and knowledge) necessary to perform the job. Therefore, to match a WU's with a profession and his/her physical and cognitive requirements, O*NET proved to be the best option. The focus on these two job requisites did not allow to draw any conclusion regarding the suitability of a job in terms of users' education and soft skills. Indeed, it could emerge that a person may RTW as an English teacher, even if he/she does not know English as a foreign language: in such a case, the role of the social workers or vocational therapists remains pivotal, as they have to evaluate (together with the WU) for which jobs the WU's condition should be tested. However, other relevant O*NET's domains (e.g., Worker requirements, Experience requirements) can be modelled to provide a match, also taking into account non-physical, training, and educational requirements. A future research direction aimed at enhancing the Rientr@ DSS consists of the development of new O*NET domains to represent the required level of education and working experience for a profession, which can be mapped with the competencies represented in ESCO. In this way, the DSS would be able to match a WU to one or more professions based on his/her residual capabilities and considering his/her background, thus providing a complete tool to human operators.

The development process of Rientr@ ontology has been conducted with clinicians and vocational therapists from INAIL, who also provided the three health conditions (opHCs) to define it. However, the empirical choices of the indices (GCS, AISA, JS) and their computation methods are far from perfect and may require some tuning. Indeed, no other previous attempt to design such a type of DSS has been found in the literature. Consequently, Rientr@ DSS represents a preliminary result and does not aim to be considered a working system but a working proof-of-concept. Future works must consider the development of additional use cases to properly evaluate the efficacy of the inferences. The procedure performed in Section 3.5 should be performed again to either confirm or re-compute the regions corresponding to "suitable jobs", "jobs with precautions", and "non-suitable jobs" after the inclusion of additional patients' health conditions. This process may also imply the interpolation of results with higher-grade equations, which may better represent the regions of interest.

From a technological perspective, the Rientr@ DSS can be interacted via the GUI. Although an Ontology-Based Data Access approach could foster the scalability of the system, there are still some technological issues that need to be faced. Above all, the DSS needs to access to the databases that currently contain WUs' data. Thus, it needs to connect to provincial and regional databases and to adhere to their specifics. Moreover, retrieved data may not be fully interoperable with Rientr@ (e.g., regional databases may be in a relational form), thus requiring further data manipulation before their use. Therefore, the process for making Rientr@ scalable enough still requires to survey the current state of the available databases (both for WUs and available professions). Once the data interoperability is achieved, a more extensive evaluation of the whole system is necessary to identify potential security issues and to acquire end-users (clinicians, social workers, personnel involved in the RTW) feedback regarding usability and acceptance to further modify the GUI and, possibly, evolve the DSS functionalities.

7. Conclusions

This work presents a novel ontology-based decision support system aimed at matching wheelchair users with jobs they are physically and cognitively able to perform. Rientr@ DSS was developed to help clinical and non-clinical personnel involved in the process of RTW discover which job-related activities can be difficult or unsafe for WUs. Moreover, it can deliver an objective evaluation of the suitability of a series of specific jobs. Further, the DSS can contribute to helping clinical and vocational personnel in planning job and environmental modifications (including the adoption of facilitators and aids) by identifying the most critical job-related tasks for the WU.

Future works foresee the possibility of extending the knowledge base by including more O*NET domains, mapping Rientr@ with the ESCO ontology, extending and fine-tuning the DSS with more health conditions. Also, the DSS will be connected with existing databases containing WUs and professions' data to test its scalability. The resulting system will be tested by both clinical and non-clinical personnel with regard to its usability and acceptance.

Ethical Approval

All participants to the experiments signed a written informed consent form to participate; all participants to the experiments signed a written informed consent for publications of the results, collected anonymously.

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CRediT authorship contribution statement

Marco Sacco: Funding acquisition, Project administration, Resources, Writing – review & editing. **Atieh Mahroo:** Software, Visualization, Writing – review & editing. **DANIELE SPOLADORE:** Conceptualization, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft, Supervision. **Luca Negri:** Conceptualization, Methodology, Writing – original draft. **Sara Arlati:** Conceptualization, Data curation, Methodology, Validation, Writing – original draft. **Margherita Fossati:** Conceptualization. **Emilia Biffi:** Conceptualization, Methodology, Validation, Writing – original draft. **Angelo Davalli:** Conceptualization, Resources, Writing – review & editing, Project administration, Supervision. **Alberto Trombetta:** Formal analysis, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Appendix A. A table illustrating the three health conditions adopted to calculate the cutoffs for the Rientr@ DSS. As described in Sect. 3.3, the qualifier for codes belonging to Activity and participation component is “performance with assistance”. Each health condition reports only those code with a qualifier ≥ 1.

HC01		
ICF Code	Name of ICF Code	Qualifier
b117	Intellectual functions	1
b1261	Agreeableness	1
b130	Energy and drive functions	1
b1408	b1408_(Auditory_attention)	1
b1560	Auditory perception	1
b1568	b1568_(Flexibility_of_Closure)	1
b167	Mental functions of language	2
b16700	Reception of spoken language	2
b176	Mental functions of sequencing comple movements	2
b210	Seeing functions	1
b21002	Binocular acuity of near vision	2
b21003	Monocular acuity of near vision	2
b21028	b21028_(Glare_Sensitivity)	1
b21028	b21028_(Night_Vision)	1
b2304	Lateralization of sound	1
b310	Voice functions	2
b320	Articulation functions	2
b330	Fluency and rhythm of speec functions	2
b710	Mobility of joint functions	1
b715	Stability of joint functions	1
b730	Muscle power functions	2
b7305	Power of muscles of the trunk	2
b7306	Power of all muscles of the body	2
b7308	b7308_(Explosive_strength)	2
b735	Muscle tone functions	2
b740	Muscle endurance functions	2
b7401	Endurance of muscle groups	2
b750	Motor reflex functions	1
b755	Involuntary movement reaction functions	1
b760	Control of voluntary movement functions	2
b7603	Supportive functions of arm or leg	2
b7608	b7608_(Rate_Control)	2
b7608	b7608_(Response_Orientation)	1
b7608	b7608_(Speed_of_Limb_Movement)	2

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HC01		
ICF Code	Name of ICF Code	Qualifier
b7602	Coordination of voluntary movements	1
b770	Gait pattern functions	4
b789	b789_(Dynamic_Flexibility)	3
d160	Focusing attention	2
d166	Reading	2
d170	Writing	3
d310	Communicating with - receiving - spoken messages	2
d315	Communicating with - receiving- nonverbal messages	2
d325	Communicating with - receiving - witten messages	2
d329	d329_(Active_Listening)	2
d330	Speaking	2
d3300	Producing meaningful sounds	1
d3301	Producing simple spoken messages	1
d3302	Producing complex spoken messages	2
d350	Conversation	2
d360	Using communication devices and techniques	2
d398	d398_(Instructing)	2
d430	Lifting and carrying objects	2
d450	Walking	4
d455	Moving around	4
d460	Moving around in different locations	2
d3558	d3558_(Negotiation)	1
d3558	d3558_(Persuasion)	1
d710	Basic interpersonal interactions	1
d720	Complex interpersonal interactions	1
d750	Informal social relationships	1
HC02		
ICF Code	Name of ICF Code	Qualifier
b1143	Orientation to objects	2
b1261	Agreeableness	1
b130	Energy and drive functions	1
b140	Attention functions	1
b1400	Sustaining attention	1
b1401	Shifting attention	2
b1440	Short-term memory	2
b1441	Long-term memory	2
b1442	Retrieval and processing of memory	1
b147	Psychomotor functions	2
b1478	b1478_(Reaction_Time)	1
b1565	Visuospatial perception	2
b1646	Problem Solving	1
b1641	Organization and planning	1
b1642	Time management	1
b1643	Cognitive flexibility	1
b176	Mental function of sequencing complex movements	2
b210	Seeing functions	1
b2101	Visual acuity functions	1
b21000	Binocular acuity of distant vision	1
b21001	Monocular acuity of distant vision	1
b455	Exercise tolerance functions	2
b710	Mobility of joint functions	2
b730	Muscle power functions	1
b7305	Power of muscles of the trunk	1
b7306	Power of all muscles of the body	1
b7308	b7308_(Explosive_strength)	2
b735	Muscle tone functions	1
b7401	Endurance of muscle groups	1
b755	Involuntary movement reaction functions	1
b760	Control of voluntary movement functions	1
b7608	b7608_(Rate_Control)	1
b7608	b7608_(Speed_of_Limb_Movement)	2
b789	b789_(Dynamic_Flexibility)	1
d155	Acquiring skills	1
d160	Focusing attention	2
d198	d198_(Active_Learning)	1
d230	Carrying out daily routine	1
d430	Lifting and carrying objects	2
d4408	d4408_(Wrist-Finger_Speed)	1
d445	Hand and arm use	1
d450	Walking	4
d455	Moving around	4
HC03		
ICF Code	Name of ICF Code	Qualifier
b130	Energy and drive functions	1

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(*continued*)

HC01		
ICF Code	Name of ICF Code	Qualifier
b1401	Sustaining attention	2
b1408	b1408_(Auditory_attention)	2
b1440	Short-term memory	2
b1441	Long-term memory	2
b1442	Retrieval and processing of memory	1
b1478	b1478_(Reaction_Time)	1
b1568	b1568_(Perceptual_Speed)	1
b1568	b1568_(Flexibility_of_Closure)	1
b1600	Pace of thought	1
b265	Touch function	1
b28010	Pain in head and neck	1
b28014	Pain in upper limb	1
b4550	Functions of the thoracic respiratory muscles	2
b710	Mobility of joint functions	2
b730	Muscle power functions	2
b7308	b7308_(Explosive_strength)	2
b735	Muscle tone functions	1
b7305	Power of muscles of the trunk	1
b740	Muscle endurance functions	1
b7401	Endurance of muscle groups	1
b760	Control of voluntary movement functions	1
b7602	Coordination of voluntary movements	1
b7603	Supportive functions of arm or leg	2
b7608	b7608_(Speed_of_Limb_Movement)	2
b7608	b7608_(Response_Orientation)	1
b770	Gait pattern functions	4
b789	b789_(Dynamic_Flexibility)	2
d160	Focusing attention	3
d166	Reading	1
d170	Writing	1
d172	Calculating	1
d1751	Solving complex problems	1
d177	Making decisions	1
d198	d198_(Active_Learning)	1
d198	d198_(Learning_Strategies)	1
d329	d329_(Active_Listening)	1
d4100	Lying down	3
d4102	Kneeling	4
d4104	Standing	4
d4105	Bending	4
d4106	Shifting the body’s centre of gravity	3
d4500	Walking short distances	4
d4501	Walking long distances	4
d4502	Walking on different surfaces	4
d4503	Walking around obstacles	4
d455	Moving around	4

Appendix B. A table illustrating the four health conditions adopted to validate Rientr@ DSS. As described in Sect. 3.3, the qualifier for codes belonging to Activity and participation component is “performance with assistance”. Each health condition reports only those code with a qualifier ≥ 1.

TestHC01		
ICF Code	Name of ICF Code	Qualifier
b1143	Orientation to objects	2
b1261	Agreeableness	2
b130	Energy and drive functions	2
b140	Attention functions	1
b1400	Sustaining attention	2
b1401	Shifting attention	2
b1408	Auditory_attention	1
b1144	Orientation to space	1
b147	Psychomotor functions	3
b1478	Reaction_Time	2
b1560	Auditory perception	1
b1565	Visuospatial perception	2
b1568	Perceptual_Speed	1
b1568	Flexibility_of_Closure	2
b1640	Abstraction	1
b1646	Problem Solving	2

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TestHC01		
ICF Code	Name of ICF Code	Qualifier
b1642	Time management	1
b1643	Cognitive flexibility	2
b1648	Monitoring	1
b176	Mental function of sequencing complex movements	2
b189	Deductive_Reasoning	2
b189	Inductive_Reasoning	2
b2301	Sound discrimination	2
b2302	Localization of sound source	2
b2303	Lateralization of sound	2
b2304	Speech discrimination	1
b2351	Vestibular function of balance	1
b455	Exercise tolerance functions	2
b710	Mobility of joint functions	3
b730	Muscle power functions	2
b7305	Power of muscles of the trunk	1
b7306	Power of all muscles of the body	2
b7308	Explosive_strength	2
b735	Muscle tone functions	2
b7401	Endurance of muscle groups	2
b755	Involuntary movement reaction functions	2
b760	Control of voluntary movement functions	2
b7608	Rate_Control	2
b7608	Response_Orientation	1
b789	Dynamic_Flexibility	2
d155	Acquiring skills	1
d160	Focusing attention	2
d1751	Solving complex problems	1
d177	Making decisions	1
d198	Active_Learning	1
d198	Learning Strategies	1
d230	Carrying out daily routine	1
d329	Active_Listening	2
d398	Instructing	2
d430	Lifting and carrying objects	2
d450	Walking	4
d455	Moving around	4
d720	Complex interpersonal interactions	1
d859	Management_of_Personnel_Resources	2
d859	Management_of_Material_Resources	2
d860	Basic economic transactions	1
d865	Complex economic transactions	2
TestHC02		
ICF Code	Name of ICF Code	Qualifier
b1401	Shifting attention	1
b1478	Reaction_Time	2
b1642	Time management	2
b2351	Vestibular function of balance	1
b455	Exercise tolerance functions	3
b4550	General physical endurance	3
b710	Mobility of joint functions	2
b7305	Power of muscles of the trunk	2
b7306	Power of all muscles of the body	2
b7308	Explosive_strength	2
b735	Muscle tone functions	2
b7401	Endurance of muscle groups	2
b755	Involuntary movement reaction functions	2
b760	Control of voluntary movement functions	2
b7602	Coordination of voluntary movements	2
b7603	Supportive functions of arm or leg	2
b7608	Rate_Control	2
b7608	Response_Orientation	2
b7608	Speed_of_Limb_Movement	2
b770	Gait pattern functions	3
b789	Dynamic_Flexibility	3
d430	Lifting and carrying objects	2
d440	Fine hand use	1
d4402	Manipulating	1
d4408	Wrist-Finger_Speed	1
d445	Hand and arm use	2
d450	Walking	4
d455	Moving around	4
TestHC03		
ICF Code	Name of ICF Code	Qualifier
b1400	Sustaining attention	1

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(*continued*)

TestHC01		
ICF Code	Name of ICF Code	Qualifier
b1401	Shifting attention	1
b1440	Short-term memory	1
b1441	Long-term memory	1
b1442	Retrieval and processing of memory	1
b1568	Perceptual_Speed	1
b1568	Flexibility_of_Closure	1
b1600	Pace of thought	1
b1646	Problem Solving	1
b1641	Organization and planning	1
b1642	Time management	1
b1643	Cognitive flexibility	1
b1645	Judgement	1
b189	Deductive_Reasoning	1
b189	Inductive_Reasoning	1
b455	Exercise tolerance functions	1
b710	Mobility of joint functions	1
b730	Muscle power functions	1
b7305	Power of muscles of the trunk	1
b7306	Power of all muscles of the body	2
b7308	Explosive_strength	1
b735	Muscle tone functions	1
b760	Control of voluntary movement functions	1
b7602	Coordination of voluntary movements	1
b7603	Supportive functions of arm or leg	1
b7608	Rate_Control	1
b7608	Response_Orientation	1
b7608	Speed_of_Limb_Movement	1
b789	Dynamic_Flexibility	2
d160	Focusing attention	1
d170	Writing	1
d1751	Solving complex problems	1
d177	Making decisions	1
d450	Walking	4
d455	Moving around	4
TestHC04		
ICF Code	Name of ICF Code	Qualifier
b1401	Shifting attention	1
b1641	Organization and planning	1
b1642	Time management	1
b1643	Cognitive flexibility	1
b1648	Fluency_of_Ideas	1
b1648	Originality	1
b1720	Simple calculation	1
b189	Deductive_Reasoning	1
b189	Inductive_Reasoning	1
b21002	Binocular acuity of near vision	2
b21003	Monocular acuity of near vision	2
b21028	Glare_Sensitivity	1
b2351	Vestibular function of balance	1
b280	Sensation of pain	2
b455	Exercise tolerance functions	1
b4550	General physical endurance	1
b710	Mobility of joint functions	2
b7305	Power of muscles of the trunk	1
b7306	Power of all muscles of the body	1
b7308	Explosive_strength	1
b735	Muscle tone functions	1
b7401	Endurance of muscle groups	1
b760	Control of voluntary movement functions	1
b7602	Coordination of voluntary movements	1
b7603	Supportive functions of arm or leg	2
b7608	Rate_Control	2
b7608	Speed_of_Limb_Movement	2
b770	Gait pattern functions	1
b789	Dynamic_Flexibility	2
d160	Focusing attention	1
d172	Calculating	1
d1751	Solving complex problems	1
d450	Walking	4
d455	Moving around	4
d865	Complex economic transactions	1

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.csbj.2024.05.013.

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