Ontology-Based Framework for Personalized Home-Based Rehabilitation in Cerebral Palsy Care

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Abstract: In the domain of cerebral palsy rehabilitation, advances in machine learning and semantic technologies offer promising solutions to enhance treatment strategies. This paper focuses on developing an ontology-based framework to support rehabilitation programs for children with cerebral palsy, addressing the need for personalized, home-based exercise programs (HEP). These programs aim to improve recovery by enabling patients to engage in tailored exercises outside clinical settings. However, the effectiveness of HEP depends on accurate monitoring and feedback, as improper execution of exercises can hinder progress. To address this challenge, we propose an intelligent system framework that integrates ontology-driven knowledge representation to oversee rehabilitation programs. The system analyzes patient profiles and progress data, recommending a personalized rehabilitation plan consisting of targeted exercises supported by healthcare professionals. The ontology serves as the backbone of this framework, enabling semantic representation of rehabilitation concepts and facilitating the management and improvement of cerebral palsy treatment pathways. Furthermore, this approach enhances patient outcomes by providing structured, context-aware rehabilitation plans while promoting interoperability and knowledge sharing across healthcare systems. By embedding the ontology within the framework, we enable greater reusability, semantic comprehension, and adaptability to multilingual healthcare environments. This work highlights the critical role of ontologies in advancing rehabilitation strategies for cerebral palsy and improving access to high-quality, personalized care.

1 INTRODUCTION

Physical therapy is for enhancing the functional abilities of individuals with disabilities or physical impairments. Research emphasizes its role in improving patient outcomes, showing a strong correlation between exercise levels and the success of rehabilitation programs. Rehabilitation therapy is particularly beneficial for patients after hospital discharge following an acute stroke or cerebral palsy (O'Neill and Forman, 2020). However, factors such as limited access to appropriate healthcare providers, higher costs that reduce the amount of care provided, and poor patient attendance limit the benefits of rehabilitation therapy. Furthermore, even when patients do benefit from rehabilitation therapy, it is often provided intermittently, with prolonged intervals between sessions, which limits the effectiveness of the treatment compared with the recommendations of high-quality clinical studies.

Home-based programs are generally recommended as part of rehabilitation programs to offer greater flexibility, while healthcare professionals create individualised rehabilitation plans with exercise suggestions. Significantly, more than 90% of rehabilitation programs are carried out at home, demonstrating the widespread adoption of this technique. (Komatireddy et al., 2014). Studies (Chen et al., 2014) (Ibeneme et al., 2024) (Ge et al., 2024) have shown that home exercise can be effective in improving various aspects of motor function and quality of life in patients with cerebral palsy. These studies have shown that home exercise programs, including tele-assisted robotic rehabilitation, computer-assisted upper limb exercises, and individualised interactive training, can lead to significant improvements in ankle range of motion, muscle strength, balance, self-reported function, quality of movement, daily activities, and upper and lower limb function.

A range of intelligent technologies, particularly those using machine learning, are increasingly being integrated into patient rehabilitation. Numerous

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studies highlight the potential of these technologies in stroke rehabilitation and home care, respectively. In (Mennella et al., 2023b) the author highlights the role of artificial intelligence in remote monitoring and intelligent assistance, particularly in activity recognition and clinical status prediction. This research (Fong et al., 2020) extends this discussion to the use of intelligent robotics and machine learning in functional capacity assessment and rehabilitation, particularly in the simulation of tasks in a suitable environment. These studies collectively highlight the potential of intelligent technologies to improve the efficiency and accessibility of patient rehabilitation. Technological advances are revolutionising the rehabilitation of people with cerebral palsy. Robotics, virtual reality, mobile applications, wearable sensors, and non-invasive brain stimulation all hold promise for improving movement, providing feedback, and motivating users (as studies have shown). These advances can ultimately improve a person's ability to carry out daily activities and participate more fully in life.

Therefore, a coherent conceptual framework and knowledge representation are highly desirable and necessary for the selection and recommendation of appropriate rehabilitation exercises and recovery from cerebral palsy. Several studies have proposed using an ontology to represent and model domain knowledge to overcome this problem. Ontology is a powerful tool for tackling semantic challenges and harmonizing disparate vocabularies by providing a formalized and structured representation of domain knowledge. This knowledge is encapsulated in a way that allows for clear definitions of concepts, relationships, and rules within a particular domain.

In section 1, we review related work, examining existing research and technological advancements in the field of cerebral palsy rehabilitation. In section 2, we focus on the architecture of the Ontological Intelligent Framework for Rehabilitation. This section outlines the system's architecture and core components. In section 3, we present a comprehensive overview of the ontology used in our system, discussing its structure and the methodology behind its development. Additionally, we focus on the Semantic Web Rule Language (SWRL) rules applied within the ontology to enhance its functionality and maintain semantic coherence. In Section 4, we delve into the implications of our findings, assess the effectiveness of the proposed system, and outline potential directions for future research. Section 5 concludes the article with a comprehensive summary of the key insights and outcomes, highlighting their significance.

2 RELATED WORK

Numerous studies have highlighted the need for rigorous monitoring of the development of children with cerebral palsy throughout their rehabilitation home-based exercise program. This research underlines the importance of a personalized approach, adapted to the specific needs of each child, in order to optimise therapeutic results.

2.1 Intelligent Technologies Used in Rehabilitation

Artificial intelligence, virtual reality, and wearable devices enable more personalized and effective rehabilitation. Virtual reality immerses patients in simulated environments to relearn movements, while exoskeletons assist those with motor difficulties. Machine learning analyzes patient data to adapt rehabilitation programs in real time, optimizing outcomes. Ontologies further enhance rehabilitation by structuring and representing knowledge formally. These technological advances accelerate recovery and improve the quality of life for individuals with disabilities or recovering from illness.

The paper (Chu et al., 2022) discusses how smart rehabilitation clinics are utilizing advanced technologies to improve patient care. The focus has shifted towards a holistic approach, prioritizing patient well-being and active participation for optimal results. The article examines the defining characteristics of these clinics, including the integration of digital tools, automation, big data analysis, and patient monitoring systems. These technologies have the potential to personalize and improve rehabilitation experiences. Ultimately, the paper presents a promising future for rehabilitation clinics that embrace cutting-edge technologies and prioritize patient engagement to improve overall quality of care and patient well-being.

Authors in (Lopes et al., 2021) emphasize the importance of digital platforms in optimizing healthcare in pandemics like COVID-19. Scientific research is crucial before deploying any digital products in this sector. The researchers also explore AI in biomedicine, healthcare care, and medical education, highlighting its potential for improved diagnostics, personalized treatment plans, and enhanced education.

The research (Senbekov et al., 2020) examines a new rehabilitation system for schizophrenia patients using virtual reality (VR) and serious games. The system focuses on patient engagement and includes three core modules: data integration, game design, and data visualization. The research suggests integrating this system with traditional treatments to create a comprehensive rehabilitation program in healthcare facilities.

2.2 Rehabilitation-Based Home Exercises in Healthcare

Chung et al. (Chung et al., 2019) discuss the application of IoT in healthcare, with a particular focus on exercise in cardiac rehabilitation at home. The system comprises a wearable device, a smartphone application, and a medical station to facilitate patient-provider interaction, accurate heart rate measurement, real-time exercise intensity recommendations, and exercise record tracking. The system has proven to be effective in maintaining heart rate within prescribed limits during exercise.

In addition, the main approach proposed in the study (Triantafyllidis et al., 2018) is the development of a computerized decision support system (DSS) for home-based rehabilitation in cardiovascular disease patients leverages rule-based logic to guide personalized exercise programs. By focusing on heart rate and movement accuracy, the system helps patients perform exercises effectively. Evaluations through simulations and real-life studies demonstrate its efficacy in maintaining optimal heart rate zones during exercise.

In (Mennella et al., 2023a), the researcher evaluates the use of deep learning-based systems to assess rehabilitation exercises, focusing on human pose estimation, movement classification, and the detection of compensatory movements. The systems discussed in the review show promising results in accurately classifying exercise movements and providing real-time feedback to patients during home-based rehabilitation programs.

Therefore, AI-based systems in rehabilitation offer real-time feedback, correct exercise execution, detect compensatory movements, and improve outcomes. Integration enhances patient engagement, enables cost-effective monitoring, and supports HEP. AI technologies accurately classify movements and detect patterns, improving physical function and quality of life in various populations. Further, validation studies in clinical settings are needed to assess their effectiveness fully.

2.3 Ontology-Driven Rehabilitation Frameworks

Existing ontologies in rehabilitation, such as the Rehabilitation Treatment Specification System (RTSS) (Gibson et al., 2023) and the Ontology for Neurological Rehabilitation (NeuRO) (Hier and Brint, 2020), provide foundational models for rehabilitation processes but lack specificity for cerebral palsy (CP) rehabilitation. RTSS standardizes rehabilitation treatments, including therapeutic exercises and modalities, but does not cover CP-specific interventions like spasticity management or neurodevelopmental facilitation. Similarly, NeuRO focuses on stroke and brain injury rehabilitation, omitting pediatric CP subtypes such as dyskinetic CP and adaptations for home-based exercises. In contrast, our ontology explicitly addresses these gaps by structuring CP-specific concepts (e.g., Motor_Rehabilitation_Techniques, Neuropsychological_Rehabilitation), integrating home-based exercise programs (HEP) with severity-driven rules (e.g., SWRL-based intensity adjustments), and linking motor assessments to personalized interventions, such as using ankle range-of-motion scores to trigger targeted exercises.

2.4 Rehabilitation HEP in Cerebral Palsy

In this section, we provide detailed information on articles relating to the type of study, study design, and intervention concerning HEP for cerebral palsy, detailed in the table 1.

Table 1: HEP for cerebral palsy. **F**: Feasibility study, **E**: Efficacy study, **C**: Comparative study, **RCT**: Randomized controlled trial, **N-RCT**: Non-Randomized controlled trial.

Authors	Study type	Intervention
(ling Chen et al., 2014)	E	Home-based Constraint-Induced Therapy
(Racic et al., 2014)	C	Home-based habilitation programme
(Demeke et al., 2023)	F	Home-based therapy programs for children with cerebral palsy
(Lorentzen et al., 2015)	N-RCT	Interactive home-based training delivered through the internet.
(Beckers et al., 2017)	F	Home-based occupational therapy and physiotherapy programmes
(Junior et al., 2021)	F	Home-based physiotherapy programmes
(Goswami et al., 2021)	E (RCT)	Home-centered activity-based therapy
(Macintosh et al., 2020)	F	Video game
(Ejaz et al., 2024)	E	Home-based intensive bimanual training

To summarize, home-based rehabilitation treatment programs, including various therapies such as intelligent training, restraint therapy, and virtual reality therapy, seem to ensure that children with cerebral palsy progress in their motor skills, useful abilities, and exercises of daily living. These methods offer potential rewards in terms of improved access, cost-effectiveness, and comfort for patients and their families. In-depth research is needed to optimize the agreements, evaluate long-term results, and decide on the most persuasive approaches for specific subsets of children with cerebral palsy. By leveraging advanced methodologies stakeholders can refine their approaches, ensuring that interventions are not only evidence-based but also highly adaptable to individual circumstances. This effort will pave the way for more impactful outcomes in their rehabilitation.

3 ARCHITECTURE OF THE ONTOLOGICAL INTELLIGENT FRAMEWORK FOR REHABILITATION

The proposed system architecture for home-based exercise programs (HEP) follows an interactive framework. The user submits a request through the interface, which is processed by the functional layer via an API. This layer leverages predictive models and personalized recommendations, generating a semantically coherent response with support from the semantic layer, which applies ontologies and inference rules. The data layer supplies necessary information for reasoning, and the final response is delivered back to the user, completing the interaction cycle.

Our architecture is composed of 4 layers (user layer, functional layer, semantic layer, data layer) as presented in the figure below:

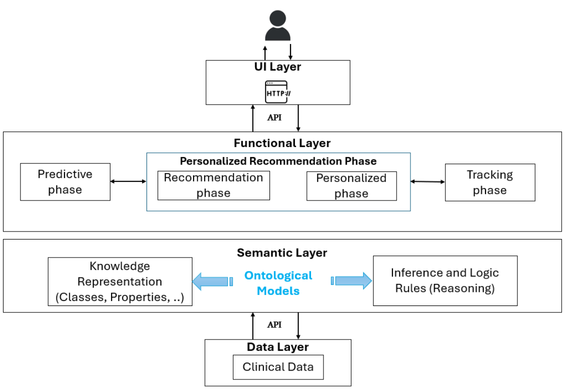

Figure 1: Architecture of HEP framework.

- The **user layer** (UI Layer) is the point of interaction between the user and the system. It takes the form of various interfaces, such as web or mobile applications. Thanks to this layer, users can not only formulate queries and consult the corresponding results, but also personalize their experience by configuring their preferences according to their specific needs.
- The **functional layer** manages all the system's functionalities, focusing on a personalized user experience. Using predictive models, it anticipates the user's needs by analysing their historical data and current context. These predictions form the basis for personalized recommendations that are continually refined as a function of the user's interactions with the system. In this way, the functional layer ensures that the user's preferences are monitored and analysed over time, making it possible to improve the relevance of recommendations over time and create an increasingly tailored user experience.
- The **semantic layer** constitutes the cognitive heart of the system, guaranteeing the coherence and unified interpretation of information. It houses a structured representation of the application domain's knowledge, using ontological models to define a common vocabulary and the relationships between concepts. These models, combined with inference and logic rules, enable the system to reason about the data and draw relevant conclusions. In this context, cerebral palsy rehabilitation, the semantic layer can establish links between specific symptoms and probable diseases, facilitating diagnosis and decision-making.
- The **data layer** contains a variety of clinical data such as examination results, treatment history and general medical information about the patient. This layer thus provides the raw material essential for the other layers of the system to carry out their treatments and generate relevant results.

This architecture offers a number of significant advantages. It offers a high degree of customisation by adapting its responses to the specific needs of each user. Moreover, its flexibility is ensured by the use of ontologies, making it easy to extend the system to new domains and integrate new knowledge. In addition, the reliability of the results is guaranteed by rigorous inference rules, while the explicability of the reasoning is reinforced by the transparency of the ontological models used, enabling a better understanding of the system's decision-making processes.

Participation to physical activity therapy by patients is seen as a crucial element in enhancing their overall health and wellness. It has been discovered that home-based physical activity therapies, used in homes or other settings, improve daily assessment and tutoring and help patients take part in regular physical exercise. Such interventions become much more valuable when they may be used conveniently, anytime, and unsupervised. This helps patients live independently. As a result, intelligent, individualized, durable, and adaptable computer systems for exercise-based rehabilitation are needed to meet patients' evolving needs and produce the desired health results.

The goal is to develop a system that provides patients with protected access to their personal profile, enables them to monitor their progress, and receives personalized recommendations for HEP. It explores the application of predictive analytics in following and assessing patients' rehabilitation progress in a smart HEP system and develops and evaluates video recommendation algorithms for HEP in an intelligent system. The approach consists of processing patient data, such as medical history, recent exercises, and progressive data, to generate personalized exercise recommendations: The implementation of a video recommendation algorithm in the intelligent HEP for rehabilitation introduces an important new feature to the system, offering a more interactive and engaging rehabilitation experience for patients by giving them tailor-made exercise videos that match their specific needs and abilities.

4 ONTOLOGICAL DESCRIPTION FOR REHABILITATION

Ontologies are crucial in rehabilitation medicine, especially in robotics, patient education, and physiotherapy (Palagin et al., 2023) (Spoladore et al., 2024). They provide structured information about rehabilitation robots, aid researchers and experts, develop multi-agent platforms for medical rehabilitation, assist physiotherapists in managing patients' evolution, and facilitate a formal model of rehabilitation interventions in computer-based decision support systems (Abdullah et al., 2022). Ontologies facilitate the development of multi-agent, semantic technology-supported rehabilitation interventions. They provide a foundational framework for home rehabilitation, enabling knowledge integration and sharing across domains. By defining relationships between key concepts such as patient status, therapy types, and feedback mechanisms, ontologies help create intelligent, personalized environments that optimize therapy effectiveness. Moreover, they enhance interoperability between different rehabilitation systems, ensuring a seamless and coherent experience. Ontologies also reduce experts' workload by simplifying the development of rehabilitation practices, which is essential for maintaining patient engagement and improving outcomes. Ultimately, they play a crucial role in supporting a more effective and personalized approach to home rehabilitation.

The purpose of this work is to provide a framework for the ontology-based cerebral palsy rehabilitation system. Open Biomedical Ontologies (OBO) Foundry, one of the most popular and detailed approaches for ontology construction, serves as the foundation for the methodological approach used to create, execute, and portray the ontology in this study (Karray et al., 2021). The OBO Ontology recovery serves as the foundation for the OBO Foundry, which is a cooperative work within ontology researchers who have previously committed to implementing a wider range of norms outlining best practices for ontology development. These guidelines aim to guarantee a progressive enhancement of formal accuracy and reliability in ontologies, in order to satisfy the increasing needs of data and information integration in the biomedical field. In the following, we detail our ontology according to the proposed methodology.

Cerebral palsy is a neurological disorder affecting movement and coordination, often resulting from brain damage before, during, or after birth. Rehabilitation plays a crucial role in treatment, focusing on improving motor function, communication, and social participation. The ontology we propose aims to support home-based rehabilitation for cerebral palsy patients by integrating tools and treatments. Its development begins with a requirements analysis phase, identifying key concepts, attributes, relationships, and axioms. In the design phase, a structured conceptual model is created, progressively increasing in complexity to ensure coherence and effectiveness.

4.1 Ontology Overview

The ontology can be developed using editors such as Protégé or OWLGrinder. In this work, Protégé was used for ontology creation. This allowed for the transformation of knowledge about the required functionalities of the proposed rehabilitation software for children with cerebral palsy from an informal model into a semi-formal model accessible to both domain experts and ontology developers. To enhance the ontology's robustness and expressiveness, a comprehensive glossary was created, detailing key concepts and basic terminologies with precise definitions and explicit links to relevant resources.

The hierarchical structure of our model is explained in Figure 2. his structure organizes the key components of the pediatric rehabilitation ontology, enabling a comprehensive and systematic representation of the domain. In the following section, we will explore each class within the hierarchical structure of the pediatric rehabilitation ontology in greater detail. **Pediatric rehabilitation** focuses on improving the physical, cognitive, social, and emotional wellbeing of children with disabilities or developmental challenges. It aims to enhance their independence and quality of life through targeted interventions and therapies.

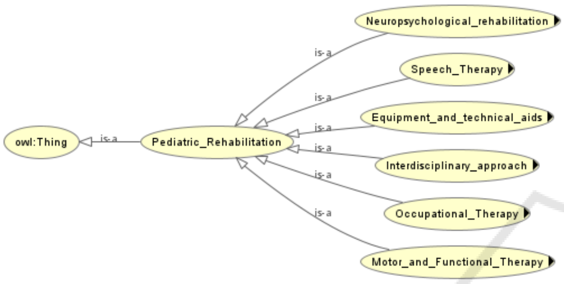

Figure 2: The hierarchical classes of the ontology.

This part in figure 3 of the ontology focuses on **Equipment and Technical Aids**. It categorizes different types of aids into three subclasses: Technological Aids, Specific Adaptations, and Mobility Aids.

- Technological Aids include various assistive technologies such as Environmental Control Systems, Computer Assistance Technologies, Communication Devices, Adapted Digital Interfaces, and Personalized Learning Tools. These are designed to enhance communication, learning, and environmental interaction for children in rehabilitation.
- Specific Adaptations cover customized solutions like Compensatory Technologies, Sensory Stimulation Equipment, School Adaptations, and Adapted Wheelchairs, tailored to meet the unique needs of each child in educational and daily living environments.
- Mobility Aids include Locomotion Aids, Orthoses and Appliances, and Positioning Systems, which support physical mobility, posture, and alignment, contributing to improved independence and comfort.

This part of the ontology (figure 4) explores the **Interdisciplinary Approach**, emphasizing collaborative methods for providing holistic care. It is divided into two main subclasses: Family-Centered Approach and Care Coordination.

Figure 3: The sub-classes of the Equipment_and_technical_aids class.

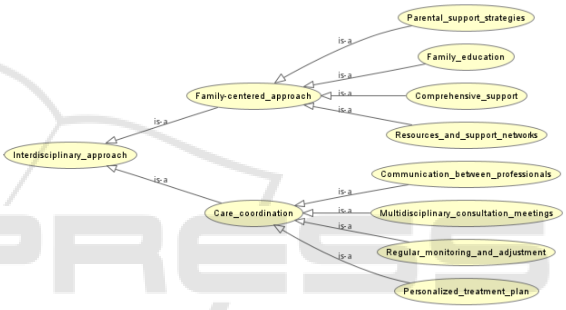

Figure 4: The sub-classes of the Interdisciplinary_approach class.

- Family-Centered Approach includes strategies that prioritize the involvement and support of the family in the rehabilitation process. It encompasses Parental Support Strategies, Family Education, Comprehensive Support, and Resources and Support Networks, aiming to empower families with knowledge, tools, and networks necessary for effective participation in their child's care.
- Care Coordination focuses on the organized and collaborative efforts among healthcare professionals. This includes Communication Between Professionals, Multidisciplinary Consultation Meetings, Regular Monitoring and Adjustment, and the creation of a Personalized Treatment Plan. These elements ensure that care is integrated, consistently monitored, and adapted to meet the evolving needs of the child.

This part of the ontology (figure 5) focuses on **Motor and Functional Therapy**, outlining key components of motor therapy. It is categorized into three main subclasses: Specialized Interventions, Initial Motor Assessment and Motor Rehabilitation Techniques.

- Specialized Interventions include targeted therapies such as Neurological Stimulation Approaches, Spasticity Management, Orthopedic Rehabilitation, Motor Control Techniques, and Muscle Tone Analysis. These interventions address specific motor impairments and aim to enhance motor control and reduce spasticity.
- Initial Motor Assessment covers the foundational evaluation processes like Analysis of Posture and Body Alignment, Spasticity Assessment, Assessment of Joint Amplitudes, and other diagnostic measures crucial for creating therapy plans.
- Motor Rehabilitation Techniques consist of methods like Muscle Strengthening Techniques, Neurodevelopmental Facilitation Therapy, Joint Mobilization Techniques, Neurological Physiotherapy, and Muscle Relaxation Techniques. These techniques are designed to improve motor function, flexibility, and overall physical well-being.

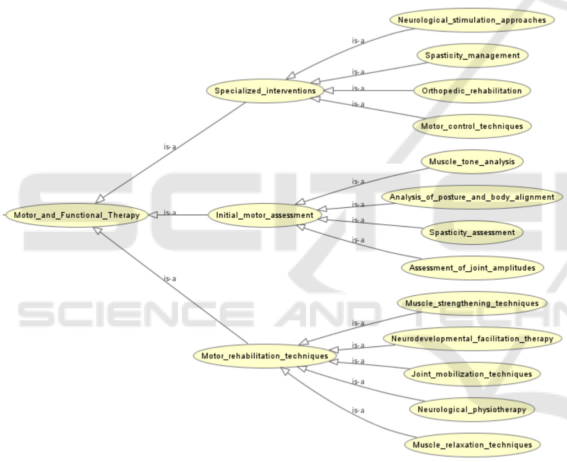

Figure 5: The sub-classes of the Motor_and_Functional_Therapy class.

This part focuses on the subdomain of **Neuropsychological Rehabilitation**, a critical area within pediatric rehabilitation that focuses on the intersection of neurological and psychological care. It aims to address the cognitive, emotional, and behavioral challenges faced by children with neurological conditions or developmental disorders. It is subdivided into categories such as Psychological Support, Cognitive Assessment, and Cognitive Interventions.

- Psychological Support encompasses therapies such as Behavioral and Emotional Therapies, Stress and Adaptation Management, Family Support, and targeted support like Psychological Support for the Child, all aimed at addressing emotional well-being and family dynamics.
- Cognitive Assessment includes methods to evaluate various cognitive functions, such as Analysis of Attentional Abilities, Assessment of Cognitive Functions, Memory and Learning Assessment, and Targeted Cognitive Stimulation, enabling precise diagnostics of cognitive challenges.
- Cognitive Interventions involves strategies for rehabilitation, including Cognitive Compensation Strategies, Management of Associated Disorders, Cognitive Rehabilitation Techniques, and Behavioral Therapies, all focused on improving cognitive and functional abilities. a critical area within pediatric rehabilitation that focuses on the intersection of neurological and psychological care.

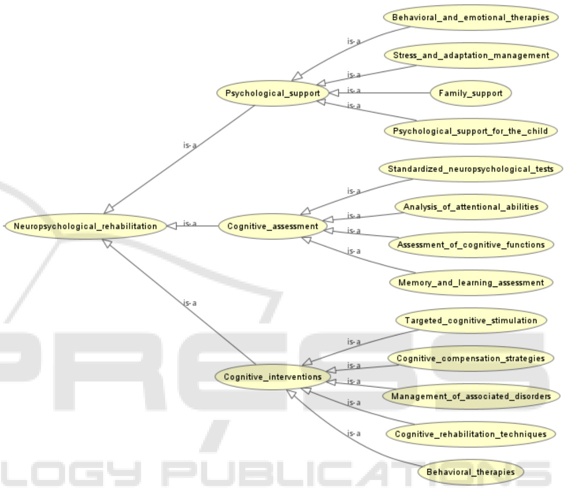

Figure 6: The sub-classes of the Neuropsychological_rehabilitation class.

This ontology represents the structure of **Occupational Therapy** within the broader domain of Pediatric Rehabilitation. It is designed to support children in achieving greater independence and improving their quality of life through functional and adaptive interventions tailored to their unique needs. The ontology organizes this domain into key concepts and categories that reflect the diverse aspects of occupational therapy.

- Functional Assessment focuses on evaluating the child's capabilities through methods such as Analysis of Home and School Environment, Assessment of Activities of Daily Living, Analysis of Fine Motor Skills, and Evaluation of Autonomy, which together provide a comprehensive understanding of the child's functional abilities and areas for improvement.
- Adaptive Interventions includes practical strategies to improve daily functioning, such as Compensation Techniques, Learning Daily Activities,

Adaptation of Tools and Equipment, Behavioral Adaptation Strategies, and Development of Fine Motor Skills, with an emphasis on personalized tools and methods.

- Environmental Adaptations aims to modify the child's surroundings to better suit their needs. This includes Sensory Compensation Strategies, Adapting Furniture, Accessibility Recommendations, and Design of Personalized Technical Aids, ensuring the environment facilitates the child's rehabilitation and independence.

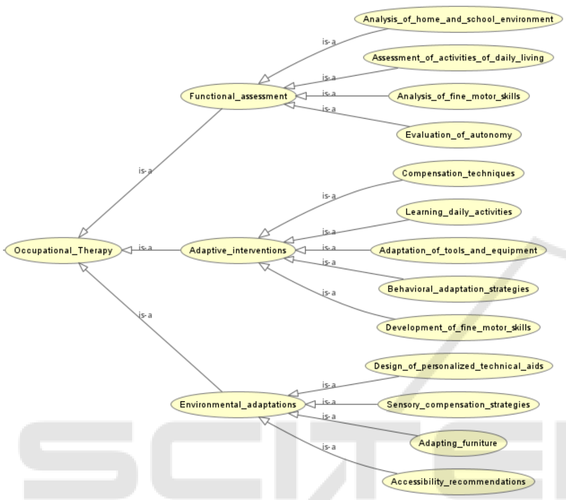

Figure 7: The sub-classes of the Occupational_Therapy class.

This part, shown in figure 8 illustrates the **Speech Therapy** domain within Pediatric Rehabilitation. Speech therapy is a critical discipline aimed at addressing communication, language, and swallowing difficulties in children, empowering them to interact effectively with their environment and enhance their quality of life. The ontology organizes this domain into specific categories that reflect the comprehensive nature of speech therapy interventions.

- Communication Assessment encompasses evaluating various aspects of communication, such as Analysis of Orofacial Functions, Swallowing Assessment, Analysis of Expressive and Receptive Language, and Assessment of Communication Skills, while also exploring Alternative Communication Techniques to support children with specific challenges.
- Therapeutic Interventions targets the development and enhancement of communication abilities through methods like Development of Language Skills, Swallowing Therapy, Articulation Rehabilitation, and Language Stimulation Techniques, often integrating Use of Technological Devices to assist in therapy.
- Communication Tools provides resources to support speech therapy, including Voice Assistance Technologies, Adapted Communication Systems, and Augmentative and Alternative Communication methods, ensuring tailored support for each child's unique needs.

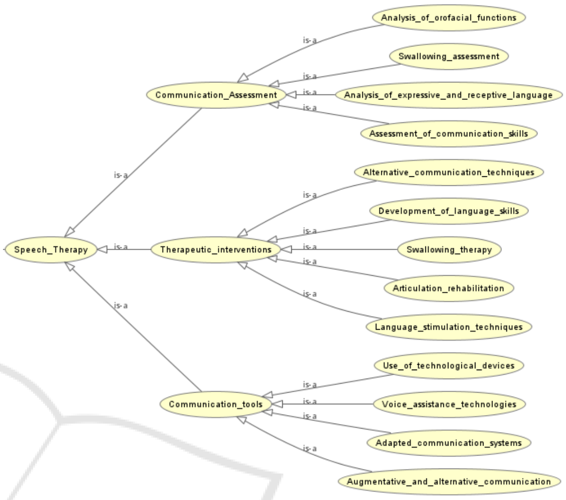

Figure 8: The sub-classes of the Speech_Therapy class.

4.2 SWRL Rules

In addition, to enhance the ontology's reasoning capabilities, a set of SWRL rules has been meticulously developed.

These rules, organized in the form of a structured list, enable new knowledge to be inferred from existing information within the ontology. This rigorous approach guarantees a formal and coherent representation of domain knowledge, enabling the ontology to be better understood and used more effectively.

Query 1:

$$\mathrm{Patient}(?p) \wedge \mathrm{hasAssessment}(?p, ?a) \wedge \mathrm{hasAssessmentType}(?a, \text{"Functional"}) \wedge \mathrm{hasAssessmentScore}(?a, ?\mathrm{score}) \wedge \mathrm{lessThan}(?\mathrm{score}, 40.0) \rightarrow \mathrm{requiresAdaptation}(?p, \mathrm{Environmental\_Adaptation})$$

This logical rule is designed to automate decision-making processes within the ontology, ensuring that patients with limited functional abilities (as indicated by a low assessment score) are identified for environmental modifications to support their rehabilitation needs. It incorporates both semantic reasoning and threshold-based logic for personalized recommendations.

Table 2: Object Properties.

Data properties	Definition
PatientID	Represents the unique identifier assigned to a patient.
Condition	Describes the medical condition or diagnosis of the patient.
AdmissionDate	Indicates the date on which the patient was admitted to the program.
DischargeDate	Specifies the date on which the patient was discharged from the program.
ProgressScore	Represents the progress score of the patient, measured on a scale of 0.0 to 10.0.
AssessmentDate	Specifies the date when the assessment was conducted.
AssessmentScore	Represents the score obtained in the assessment, on a scale of 0.0 to 100.0.
AssessmentType	Indicates the type or category of the assessment.
Recommendation	Provides recommendations based on the assessment.
SessionDate	Specifies the date when the therapy session occurred.
SessionDuration	Represents the duration of the therapy session, in minutes.
TherapyGoal	Describes the goal or objective of the therapy session.
ProgressNotes	Provides notes about the progress made during the session.
Frequency	Indicates the frequency of therapy sessions (e.g., sessions per week).
IntensityLevel	Specifies the intensity level of the therapy session (Low, Medium, or High).
EquipmentID	Represents the unique identifier assigned to a piece of equipment.
MaintenanceDate	Specifies the date of the last maintenance of the equipment.
Specification	Describes the technical specifications of the equipment.
AvailabilityStatus	Indicates whether the equipment is currently available (True) or not (False).

Table 3: Data Properties.

Object properties	Definition
hasTherapist	Associates a patient with a therapist responsible for their rehabilitation.
assignedTo	Links a therapist to a specific rehabilitation program.
participatesIn	Indicates that a patient participates in a given therapy session.
supervises	Specifies that a therapist supervises a therapy session.
requiresEquipment	Indicates that a therapy session requires specific technical equipment.
hasAssessment	Links a patient to an assessment that evaluates their abilities or needs.
follows	Indicates that a patient follows a specific treatment plan.
collaboratesWith	Represents collaboration between two therapists.
supportedBy	Associates a patient with a family member providing support during their rehabilitation.
usesTool	Specifies that speech therapy uses a communication tool.
appliesTechnique	Indicates that motor therapy applies a specific rehabilitation technique.
requiresAdaptation	Indicates that a patient requires environmental adaptations for their rehabilitation.
utilizesAid	Specifies that a patient uses a mobility aid during therapy.
hasIntervention	Indicates that a therapy session includes a specific therapeutic intervention.
conductsAssessment	Specifies that a therapist conducts a given assessment.

Query 2:

$\text{Patient}(?p) \wedge \text{hasProgressScore}(?p, ?\text{score}) \wedge \text{lessThan}(?\text{score}, 6.0) \implies \text{requiresAssessment}(?p, \text{Cognitive\_Assessment})$

This rule identifies patients who need a cognitive assessment based on their progress score. If a Patient (?p) has a Progress Score (?score) below the threshold of 6.0, the system infers that the patient requires a Cognitive Assessment. This ensures that cognitive evaluations are prioritized for individuals showing signs of limited progress, potentially highlighting areas requiring intervention.

Query 3:

$$\text{Patient}(?p) \wedge \text{hasAssessment}(?p, ?a) \wedge \text{hasAssessmentScore}(?a, ?\text{score}) \wedge \text{lessThan}(?\text{score}, 50.0) \wedge \text{hasTherapyType}(?p, \text{Motor\_Therapy}) \implies \text{hasIntensityLevel}(?p, "High")$$

This rule focuses on adjusting the intensity of motor therapy based on assessment scores. If a Patient (?p) has undergone an Assessment (?a) with an Assessment Score (?score) below 50.0 and is already undergoing Motor Therapy, the system recommends increasing the therapy's intensity by setting the Intensity Level of the patient to "High". This rule supports personalized treatment plans by dynamically adjusting motor therapy intensity based on a patient's performance and needs.

5 DISCUSSION

The development and implementation of our ontology-based framework for cerebral palsy rehabilitation presents several significant contributions and implications for home-based exercise programs (HEP). Our findings highlight both the potential benefits and challenges in implementing such a semantic framework for rehabilitation. The proposed ontological framework demonstrates several key advantages for cerebral palsy rehabilitation. The hierarchical structure of our ontology successfully integrates diverse aspects of rehabilitation, from equipment and technical aids to specialized therapies. This comprehensive approach ensures that all crucial elements of rehabilitation are systematically represented and interlinked. By adopting OBO Foundry principles, our ontology promotes standardization and interoperability with existing biomedical ontologies. This compatibility enhances the potential for knowledge sharing across different healthcare systems and rehabilitation platforms. Furthermore, the framework's ability to capture complex relationships between patient characteristics, rehabilitation techniques, and outcomes enables highly personalized treatment recommendations, which is particularly valuable for home-based exercise programs where individualized guidance is crucial.

The implementation of our framework has several important implications for clinical practice. The semantic rules and relationships defined in our ontology provide a robust foundation for clinical decision support systems, allowing healthcare providers to leverage this structured knowledge to make more informed decisions about rehabilitation protocols. The framework's comprehensive modeling of rehabilitation concepts enables better remote monitoring of patient progress, which is essential for home-based exercise programs and particularly relevant given the increasing importance of telerehabilitation solutions. Additionally, the standardized representation of rehabilitation concepts and procedures helps maintain consistency in treatment delivery and assessment, even in remote settings. Several technical aspects warrant discussion in our implementation. While our ontology successfully models the complex domain of cerebral palsy rehabilitation, considerations must be made for scaling the system to handle larger patient populations and additional rehabilitation protocols. The implementation of semantic rules through SWRL presents challenges in terms of computational efficiency and real-time processing, suggesting that future work should focus on optimizing rule execution for time-sensitive applications. Moreover, the comprehensive nature of our ontology raises important considerations about data privacy and security, particularly when handling sensitive patient information in home-based settings.

Based on our findings, several areas merit further investigation. Future work should explore the integration of machine learning algorithms with our ontological framework to enhance the adaptive capabilities of rehabilitation recommendations. The framework should be expanded to accommodate cultural and linguistic variations in rehabilitation practices, ensuring broader applicability across different healthcare systems. Large-scale clinical validation studies are needed to assess the framework's effectiveness in improving rehabilitation outcomes compared to traditional approaches. Additionally, the development of mobile applications that can seamlessly interact with the ontological framework would enhance accessibility and user engagement in home-based settings.

Several limitations of our current work should be acknowledged. The current validation of the ontology has been primarily theoretical and would benefit from extensive real-world testing in clinical settings. The implementation of our framework requires significant technical infrastructure, which may limit its adoption in resource-constrained environments. While comprehensive for cerebral palsy rehabilitation, the ontology may require substantial modifications for application to other rehabilitation domains.

The proposed ontology-based framework represents a significant step forward in structuring and delivering home-based rehabilitation programs for cerebral palsy patients. However, its successful implementation will require careful consideration of both technical and practical challenges, along with continued refinement based on clinical feedback and technological advancements.

6 CONCLUSION

In conclusion, our ontology for cerebral palsy rehabilitation marks a significant advancement in home-based exercise programs. By integrating diverse rehabilitation components within a hierarchical structure and adhering to OBO Foundry principles, it ensures standardization and interoperability with existing biomedical ontologies. This comprehensive framework facilitates personalized treatment recommendations and supports clinical decision-making through well-defined semantic rules and relationships.

The implementation has shown great potential in enhancing remote monitoring and ensuring consistency in treatment delivery, which is especially vital for home-based rehabilitation. However, challenges remain, such as scalability and optimizing rule execution for time-sensitive applications, indicating areas for future improvement.

Future research should prioritize integrating machine learning algorithms to improve adaptability, addressing cultural and linguistic diversity, and validating the framework through large-scale clinical studies. Developing accessible mobile applications could enhance user engagement in home-based settings. While challenges such as real-world testing and technical infrastructure persist, the framework establishes a solid foundation for advancing rehabilitation practices.

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