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OntoStrength: An Ontology for Psychomotor Strength Development

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Abstract. An ontology is a formal, explicit description of concepts and relations from a domain while considering underlying properties, restrictions, and instances. With the advancement of the Semantic Web, the rise of the Educational Semantic Web, and the lack of uniformity between approaches for knowledge representation, ontologies are becoming more and more popular, including adaptive learning environments such as the Intelligent Tutoring Systems (ITSs). OntoStrength is an ontology developed to support the Selfit ITS, a platform that aims to improve the fundamental human psychomotor skills and, more specifically, bio-motor strength abilities. The goal of Selfit is to prevent the negative consequences of a sedentary lifestyle and accidents involving inadequate strength skills. Most ontologies in the sports domain support the development of digital solutions for sports performance and data collected during competitions. In contrast, OntoStrength's goal is to contribute to the development of digital solutions dedicated to bio-motor strength ability analysis. OntoStrength considers other bio-motor skills like speed, endurance, or flexibility, as well as other activities like muscle analysis, movement patterns, or training load management, to support sport, professional and daily-life activities. OntoStrength enables the personalization of strength development programs in the Selfit ITS by providing a comprehensive data layer for its student, domain, and tutoring models.

Keywords: Intelligent Tutoring System**,** Ontology, Strength skills, Strength Development, Personalization, Selfit

1 Introduction

An Intelligent Tutoring System (ITS) is an Artificial Intelligence-based computer system that provides an adaptive educational experience [1]. An ITS aims to enhance student learning experiences by creating immediate, customized instructions and feedback while collecting comprehensive information. Since its beginning, most approaches for building ITSs targeted cognitive skills – starting with Carbonel [2] in the 1970s - and argued for the success of the employed methods in various fields like mathematics or physics [3]. However, recent advancements in machine learning, computer vision, and software engineering opened the opportunity for ITS applications in the psychomotor skills field.

Psychomotor skills development is a lifelong process of learning how to move accordingly to a dynamic environment. A movement competence is a transaction between an individual and a movement task within a given environment. Essential movements, such as pushing, pulling, core, knee, or hip-dominant exercises are prerequisites for learning specialized, complex psychomotor tasks required by daily life, professional, or leisure activities. Learning to perform a movement safely and efficiently requires practicing an adequate volume of exercises for enhancing associated physical qualities, such as strength, flexibility, or endurance.

One of the main challenges for developing an ITS is the high cost when creating a strong knowledge base from scratch [4]. As stated by Zouaq et al. [4], an acute research issue is how the tutoring module of an ITS can be efficiently modeled, what kind of knowledge representations are available, and what kind of knowledge acquisition techniques can be applied.

Another challenge when developing such a system is to define the right tools and frameworks to acquire accurate student knowledge competencies for predicting progress, while training. Recent ITSs built for military training are often limited to laboratory settings on standard PCs and laptops, which focus on training cognitive skills (such as decision-making and problem solving) and may potentially limit the learning and retention of mastering physical tasks [5]. In addition, an ITS needs to mediate abstract knowledge with real trainees; as such, ITS performance is not only determined by the knowledge it carries, but also by the quality of the user experience.

In a traditional ITS, the domain knowledge representation has been implemented through: a) *black-box* models, where reasoning is not clearly explained, but the solutions are accurate; and b) *glass-box* models, where the reasoning is explained step by step [6]. There are two types of knowledge in both models: a) *declarative*, which is conceptual information; and b) *procedural*, for action sequences and problem-solving procedures. The goal of these representations is to ensure that the tutor module has access to structured knowledge and proper learning sequences [4]. Several representation formalisms have been proposed and used traditionally in ITS, such as simple rules, case-based reasoning, fuzzy logic, concept maps, topic maps, or conceptual graphs [4].

However, with the advancement of the Semantic Web, the rise of the Educational Semantic Web, and the lack of uniformity between the approaches used for knowledge representation [7], ontologies are now the key to increasing the speed of building ITSs. Ontologies enable the reuse of existing knowledge from similar systems, standardization of knowledge representations, and support bridging ITSs and eLearning resources [8]. A domain ontology is a strong alternative for knowledge representation when building ITSs for their standard formalism, ease of reuse of other ontologies, and modularity. System designers must integrate different ontologies to enforce the reuse and interconnection of various relevant resources.

An ontology is a shared vocabulary and representation of knowledge used to model a domain; ontologies define explicit descriptions of concepts and their relations and integrate computer-processable semantics for data on the Web [9]. In an ontology, all concepts must be explicitly defined in a machine-readable format. As part of the Semantic Web domain, ontologies are well fitted to support data integration, while concurrently organizing knowledge. Combining data from different ontologies may lead to the identification of new relationships between concepts while helping to eliminate or reduce the ambiguity between terms that belong to distinct sets of data [10]. One challenging task, however, is to match and record the relationships between entities in the linked ontologies, considering their continuous evolution.

This paper introduces OntoStrength, an Ontology for psychomotor skill development, more specifically strength development, and its integration within the Selfit ITS [11]. As per our findings, although there is an increasing demand for building digitalization solutions in the healthcare and sports training fields, there is no previous work performed on the psychomotor domain. In a society more and more interested in health, Selfit aims to improve general human psychomotor skills, with emphasis on strength bio-motor capacities. The ontological approach for knowledge representation in Selfit was motivated by recent developments in Intelligent Tutoring Systems, which are presented in the following section.

The paper is organized as follows. First, we introduce similar work in the ontology field, as well as knowledge representation practices in ITSs, together with solutions developed specifically for the psychomotor domain and the Selfit ITS. Afterward, we present our OntoStrength ontology to represent the knowledge required by Selfit. The last two sections illustrate its usage and potential future research directions.

2 Related work

2.1 Intelligent Tutoring Systems and Psychomotor Training

The GET-BITS model was built as a generic shell for developing ITSs, using at its core an object-oriented model, class hierarchies, and class design principles for knowledge representation [12]. The model defines five levels of abstraction, ranging from top-level (i.e., Integration, where Domain knowledge represents the curriculum, and the Student module stores the progress in group learning) to the bottom (i.e., Primitives, where Domain knowledge for a computer science topic may be represented as a logical expression or a clause, and the Student model considers learning speed, knowledge level, or the level of concentration).

However, Ali Ahmed and Kovacs [13] have presented many recent approaches which integrate ontologies into Intelligent Tutoring Systems. They build a tutor for learning Java programming language using Protégé for building the ontology and Python for the integration with the knowledge repository.

An ontology-driven method for an ITS was developed by Dermeval et al. [14]. The goal was to develop a gamification module in an ITS by connecting concepts in a standard and formalized manner. The knowledge base was structured in ontologies and covered concepts such as gamification, domain, student, and tutoring. The link between ITS concepts and gamification facilitated the automated reasoning of all the information handled by these systems, enabling their interoperability and defining good practices for creating a gamified ITS. The connection between the ontologies described by the authors relied on technologies such as RDF/OWL vocabularies (e.g., FOAF), and modeling in Protégé. Methontology [15], a methodology for building ontologies based on the IEEE standard criteria, was considered throughout the entire ontology life-cycle process.

Panagiotopoulos et al. [16] designed a student model for an ITS and enhanced it with semantics using an ontology. Their Student model integrated student characteristics and progress, while their ITS provided personalized educational content based on student learning and academic particularities. The study targeted facilitating the communication between intelligent agents through a domain-independent vocabulary while modeling student profiles. The ontology was developed in Protégé using Ontology Development 101 (OD101) methodology [10] and adopted OWL as a formal representation language. In addition, the authors developed inference mechanisms as a set of rules using Semantic Web Rule Language (SWRL) for the automated classification of the students into stereotypic profiles.

As ITSs were mainly built to develop cognitive capacities, no previous work was found in terms of ontologies used in ITS for psychomotor development. The closest work to OntoStrength can be found in the Generalized Intelligent Framework for Tutoring (GIFT) [17], which is a variation of the ITS architecture. Recent developments are presenting several results for GIFT projects that are more ontology-driven [17]. Other ontologies like the Sports Domain ontology [18] were previously developed as broad coverage of the sports domain using Protégé and following the Ontology Development 101 framework. Their conceptualization leveraged five sports – football, rugby, cricket, athletics, and tennis. The work presented 840 classes with their corresponding properties, relations, and axioms. The development process included the instantiation of the classes in the domain, and the evaluation was performed using ref – a Semantic Web framework written in Java, with features for parsing queries, model representation, or data visualizations.

Diaz-Rodriguez, Wikstrom, Lilius, Cuellar and Flores [19] developed an ontology in the psychomotor domain by using the Kinect 3D depth sensors for activity recognition, semantic reasoning, and semantic modeling in movement and human interaction. Their goal was to distinguish between human movement, human-object interaction, and human-computer interaction. The research team proposed as future work the implementation of a fuzzy approach, as the results obtained with the Kinect devices generate inaccurate data for their feature modeling experiments.

Our state-of-the-art survey did not identify ITS initiatives to develop bio-motor abilities, such as strength skills. Existing ontologies in the sports domain provide the foundation to develop digital solutions to recognize sports activities or support decision-making based on data collected during competitions. However, existing work does not provide the knowledge required to support the development of bio-motor abilities. The development of the OntoStrength ontology contributes to this field by providing a hierarchy of classes on strength skills, the strength development process, and variables used to provide personalized development programs. The choice to use Ontology 101 as a methodology for building OntoStrength was supported by similar recent works, presented above.

2.2 The Selfit Intelligent Tutoring System

Selfit [11] is an Intelligent Tutoring System (commonly referred to as ITS) for psychomotor development focused on strength development. Intelligent Tutoring Systems are computer systems that provide adaptive educational experiences through artificial intelligence algorithms [1]. An ITS can collect information and provide immediate, customized instructions and feedback to students.

By analyzing trainees' performance and training outcomes, the software can make inferences and propose strategies based on their strengths and weaknesses [1]. The most common architectural pattern empowered when designing an ITS is the four-component architecture [8], which contains a Domain model, a Tutoring model, a Student Model, and the User Interface.

The motivation of Selfit development is multifold, covering strength development, mitigation of negative consequences of a sedentary lifestyle, and prevention of professional accidents involving inadequate strength skills. Psychomotor development is a lifelong process of learning how to move accordingly to a dynamic environment. Essential movements, such as pushing, pulling, or core, are prerequisites for learning specialized, complex psychomotor tasks required for daily life or leisure activities.

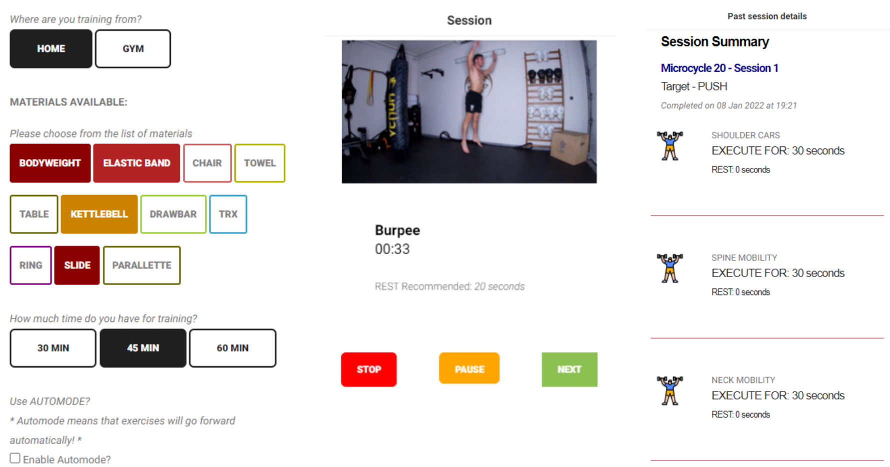
Selfit supports trainees in correctly and safely performing fundamental and specialized movements by generating training workouts adapted to their competence, fatigue, or availability. First, the system defines the general learning objectives by interacting with trainees and defining the movement skills to be acquired. The realization of representative movement tasks is marked through the evaluation of readiness to perform challenges and the calibration of an initial trainee profile. Then, the system generates strength development workouts by using strength development models and rules. Selfit refines the workout content by considering trainee signatures and responses to previous training sessions to find the most appropriate content. Regular tests support the evaluation of the effectiveness of development processes and, if necessary, their update.

The core of the Selfit personalization algorithm is a multi-armed bandit algorithm [20] that estimates trainee progress, optimizes the content of training sessions, and overcomes problems related to the trainees' lack of time for training, motivation, and complexity of user characteristics [11]. The algorithm handles the knowledge defined by the domain, student, and tutoring models.

The Graphical User Interface was developed as a Progressive Web Application [21], and provides functionalities for user authentication, user-level calibration, providing training instructions to users, videos to guide the exercise execution, and collecting user feedback, as can be seen in **Fig. 1**. Feedback is an essential dimension of psychomotor development and consequently Selfit efficiency [22]. Before starting a session, Selfit queries trainees to self-evaluate their fatigue level, motivation to train, sleep quality, and stress level. While training, Selfit asks trainees to self-evaluate the difficulty of each exercise at its end. After the training session, the system assesses trainee perception in terms of session difficulty.

3 Method

This section presents an overview of OntoStrength, the underlying engineering process, as well as details on the ontology. After presenting its structure, three subdomains are described: strength skills, strength skills development process, and personalized development variables.



(a) (b) (c)

Fig. 1. Selfit Graphical User Interface.

3.1 OntoStrength Design

The OntoStrength ontology aims to support the development of the Selfit ITS dedicated to enhancing psychomotor skills and associated bio-motor abilities, such as strength. A multidisciplinary team composed of computer scientists and sports scientists applied the seven steps of OD101 [10] to formalize the subject domain.

The first step consists in determining the domain and scope of the ontology by formalizing competency questions. The team characterized competency questions by considering trainee requirements, as well as the domain and tutoring modules from the Selfit system. The first set of competency questions raises the need for the ontology to cover the diversity of strength skills. Then, a second set considered the complexity of strength development. Finally, the third set of questions raised the need to model variables supporting the personalization of development processes for each trainee.

Then, the team performed the second step of the methodology design, consisting of the identification of existing ontologies. Typologies about muscles, strength development exercises, training planification rules, or injuries were collected. No similar ontologies were identified for these fields.

The third step of the methodology engineering process consisted of the identification of essential terms for the domain. The team reviewed empirical literature about strength training to compile the first list of terms to be considered by the ontology.

Steps four, five, and six were focused on defining classes, class hierarchies, and associated slots and facets; as such, 618 classes were created in OntoStrength. The last phase was centered on the instantiation of entities or individuals. This group of tasks was iteratively performed several times. The refinement of the ontology was based on expert validation and experiment sessions with Selfit.

The development team used the Protégé software to edit and refine classes, relationships, slots, and facets. GraphDB[1] was considered the semantic graph database for storing and querying the ontology, as well as for generating interactive data plots. The SPARQL query language [23] was used to test different training scenarios through queries.

3.2 OntoStrength Structure

Strength development is the domain covered by OntoStrength. Strength is defined as the maximal force or torque (rotational force) that a muscle or muscle group can generate or as the ability of the neuromuscular system to produce force against an external resistance [24].

Strength development includes a set of essential tasks, such as the assessment of trainee strength skills, the definition of a development program, and the monitoring of its application. The ontology provides knowledge to support the Selfit ITS functionalities. First, OntoStrength supports the Selfit domain module by providing classes that describe the diversity of strength skills. Second, classes on strength development processes support the tutoring module. Finally, OntoStrength supports the Selfit student module with knowledge about the different individual characteristics to consider for the personalization of strength program tasks.

3.3 Subdomains

The Strength Skill. The first OntoStrength sub-domain aims to describe strength skills. The domain module uses strength skills to provide development objectives, the student module uses it to design a trainee strength fingerprint, while the tutoring module generates and monitors training workouts as an input. When defining strength, Bompa [24] makes the distinction between general and specific strength. The first refers to the strength of the entire muscular system, whereas the second is the motor patterns of muscle groups that are essential to a given activity. He also defines three strength properties: power, maximum strength, and strength endurance. Power is the ability to develop force rapidly and at high velocities. Maximum strength refers to the highest force the neuromuscular system can generate during a maximum voluntary contraction.

[1] https://graphdb.ontotext.com/

Finally, strength endurance is the ability of the neuromuscular system to produce force repetitively over extended periods.

Hence, a strength skill combines a movement skill and a strength type in the OntoStrength ontology. OntoStrength considers four movement types: Muscular, Functional, Fundamental, and Specialized. The first two movements support the general strength skills. *Muscular* describes the different types of possible contractions for each muscle involved in human body movement. OntoStrength describes twenty-four muscles and four contraction modes: eccentric, concentric, isometric, and plyometric. *Functional* is related to actions performed by the human body joints while moving. The ontology includes ten joints (two for each hip, elbow, knee, neck, and shoulder) and associated actions (such as abduction, rotation, extension, and flexion). The fundamental and specialized movement types support the description of specific strength skills. *Fundamental* patterns are the building blocks that lead to specialized movement sequences required for adequate participation in organized and non-organized physical activities [25]. They include stability, locomotor, and manipulative motor patterns. *Specialized* movement skills include daily life, leisure, sports, and motor patterns specific to professionals.

The OntoStrength strength skills sub-domain includes three hierarchies of classes that can be used to describe skills such as “Biceps Eccentric Maximum Strength,” “Hip Flexion Strength Endurance,” and “Throwing Maximum Strength,” or “Lunge Power.” The classes used to represent the main concepts of this domain are the following: “Strength Skill”, “Movement Skill,” and “Strength Property”. The architecture of the OntoStrength strength skills sub-domain can be observed in Fig. 2.

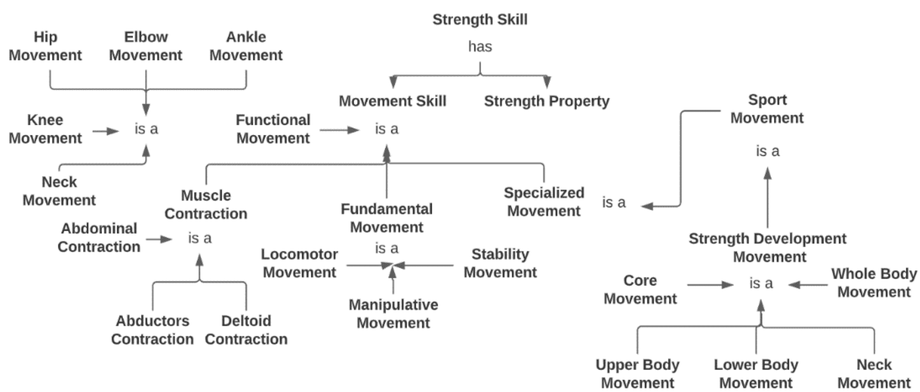


Fig. 2. OntoStrength sub-domains for strength skills.

A “Strength Skill” instance is composed of an instance of “Movement Skill” and an instance of “Strength Property”. Even though the OntoStrength ontology aims to support a digital solution for the strength development, the design process strived to ensure extensibility to the other bio-motor skills and other usages than strength development, such as risk prevention. The first three subclasses of “Movement Skill”: (i.e., “Muscle Contraction,” “Functional Movement,” and “Fundamental Movement”) are independent of any context and application and can be used to describe any movement. The “Specialized Movement” subclass focuses on movements used to develop strength skills. Moreover, this subclass provides the potential of reusing the ontology for any other movement skills and applications.

The “Muscle Contraction” class has twenty-three subclasses related to each essential muscle involved in human movements. For example, one of the classes is the “Biceps Contraction Class” with four subclasses: “Biceps Concentric Contraction”, “Biceps Eccentric Contraction”, and “Biceps Isometric Contraction”, and “Biceps Isometric Contraction”. The “Functional Movement” class has ten subclasses related to each joint movement. For example, one of the classes is the “Knee Movement” class with four subclasses: “Knee Extension”, “Knee Flexion”, “Knee Lateral Rotation”, and “Knee Medial Rotation” classes.

The “Fundamental Movement” class has three subclasses, each with specialized movements. For example, the “Locomotor Movement” class has associated the following subclasses: “Bounding,” “Dodging,” “Galloping,” and “Jumping”. The “Specialized Movement” class hierarchy supports the description of all movements associated with activities. They are structured by considering Sports, Professional, Leisure, and Daily Life categories. The OntoStrength ontology focuses more on a subclass of the “Sport Movement” class, namely the “Strength Development Movement” class used to develop strength skills. These skills are structured into five types: “Core Movement,” “Lower Body Movement,” “Neck Movement,” “Upper Body Movement,” and “Whole Body Movement”. Each of them has sub-classes, for example, “Anti-Extension Movement” and “Anti-Flexion Movement” for the “Core Movement”. Finally, classes related to exercise patterns were also represented – for example, the” Bird Dog” class is a “Hip Dominant Movement”.

Our ontology characterizes a strength development movement task with four attributes: a description of the movement, a typology of the movement (basic, ballistic, complementary) for selecting exercises when planning a workout, muscles targeted by its use, and joint movement actions involved. For example, an instance of the “Diamond Triceps Push Up” class is a basic task for developing “Triceps Brachii,” “Pectoralis Major,” and “Anterior Deltoid” by performing “Shoulder Transverse Flexion,” “Shoulder Flexion,” “Shoulder Girdle Protraction,” and “Elbow Extension”.

Strength development program. The second OntoStrength sub-domain supports the description of a strength development program. The domain module for Selfit uses this knowledge to provide relevant content to generate and schedule training workouts. The student module uses this knowledge to update trainee training components when performing workouts. Finally, the classes structure the behavior of the tutoring module.

Strength development consists of a well-organized process, where the body and mind are constantly exposed to varying volumes and intensity of stressors [24]. The implementation of a strength development program starts by defining the temporal units that structure the different phases of the strength development process. Depending on its duration, macro-cycles (six to twelve weeks), mesocycles (two to six weeks), microcycles (five to ten days), and workouts (thirty minutes to two hours) are used to generate the development program. Issurin [26] considers three types of mesocycle (i.e., Accumulation, Transmutation, and Realization), six types of micro-cycles (i.e., Adjustment, Competitive, Impact, Loading, Precompetitive, and Restoration), and seven types of blocks of tasks (i.e., Warmup, Combined, Conditioning, Exams, Tactical, Technical, and Cooldown). Afterward, training goals and content are defined for each temporal phase.

All strength training programs start with an initial preparation phase, named anatomical adaptation, which aims to get the body in a good shape and learn the exercise execution; the content and duration of this phase depend on the trainee's experience. According to the trainee's needs and objectives, goals can be either hypertrophy (i.e., an increase in muscular volume) or the development of maximal strength, power, or endurance. Exercises are then selected, and preliminary assessment tests are conducted to estimate the trainee's level for each strength skill. Finally, the workout content is defined. The content is composed of a set of exercises, with associated duration, intensity, tempo, and rest time. These variables depend on the session goal, the trainee's overall level, and his/her current shape, as well as the content from previous sessions. A full training history supports the monitoring of the development process and, if necessary, its refinement.

Hence, this subdomain centered on strength skill development includes two hierarchies of classes: one to describe different periods and one to represent strength development modalities. A simplified view of the subdomain can be seen in Fig. 3. The "Biomotor Development Period" class hierarchy consists of all possible temporal periods. Each period is characterized by temporal information about the beginning and the end, coupled with objectives. Furthermore, the "Macro Cycle" class is composed of three instances of the "Meso Cycle" class hierarchy: one of the "Accumulation Meso Cycle" class, one of the "Transmutation Meso Cycle" class, and one of the "Realization Meso Cycle" class.

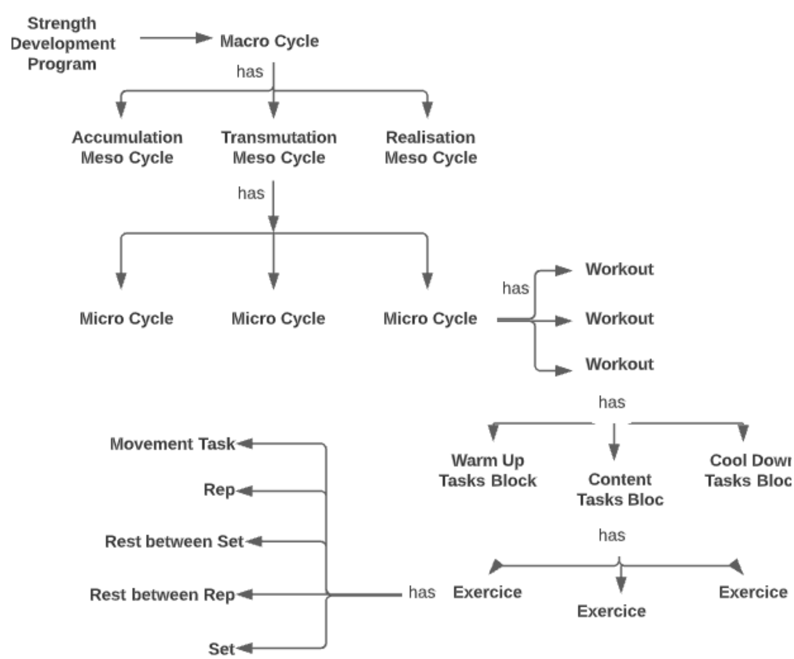


Fig. 3. OntoStrength sub-domains for strength skills development.

Each mesocycle is composed of two to six instances of the “Micro Cycle” class. Each “Micro Cycle” instance is composed of one to ten instances of the “Workout” class. An instance of the “Workout” class is composed of three instances of the “Tasks Block” class: an instance of the “Warm Up Block” class, an instance of the “Content Block” class, and an instance of the “Cool Down Block” class. An instance of the “Tasks Block” class is characterized by a ranked list of instances of the “Exercise” class. An instance of the “Exercise” class includes an instance of the “Movement task” class and an instance of the “Load” class. Instances of the “Load” class are characterized by: the number of sets, the number of repetitions, rest time duration between two sets, and rest time duration between two repetitions.

The “Training Target” class hierarchy consists of all possible training modalities integrated into the ontology. The “Strength Training Target” class hierarchy is related to the four strength training modalities represented by the classes “Anatomical Adaptation Target,” “Hypertrophy Target,” “Maximal Strength Target,” and “Endurance Strength Target”.

Personalized development for strength skills. The third OntoStrength sub-domain supports the description of variables used when defining strength training development programs adjusted to trainee’s characteristics. The student module from Selfit uses this knowledge to provide the tutoring module with specific knowledge about each trainee. In addition, the tutoring module uses this knowledge when defining workout content and updates it based on the received feedback. A typology of strength fingerprints structures these variables.

The “General Signature” class contains generic attributes such as the trainee’s name, age, gender, size, or weight. One specific signature is associated with each bio-motor ability. The “Strength Signature” includes all strength skills relevant to each trainee development program.

The “Anthropometric Signature” refers to body sizes, weight, and body composition. The “Injury Signature” includes each history of relevant injuries to be considered when performing a strength development program. The “Motor Signature” associates specific levels to the trainee, for each movement skill. Moreover, the ontology includes the level of each strength movement type for strength development. The “Strength Training Signature” describes the training history for each workout performed, the content, success evaluation, and associated feedback. Hence, the “Personalized Biomotor Development variables” organize all the different signatures in the OntoStrength ontology, as can be seen in Fig. 4.

3.4 OntoStrength content

The previously described major class hierarchies support the instantiation of strength development programs, from the macro-cycle level to the exercise level. In addition, SPARQL queries were implemented to solve specific training tasks – for example, to obtain exercises associated with a specific body part (wide triceps push-up, side to side pull-up, feet elevated pike push-up), or to obtain generic training templates for a training objective, based on trainee characteristics. GraphDB was used to test the queries and interact with the ontology. Through SPARQL, new data can also be added to the ontology.

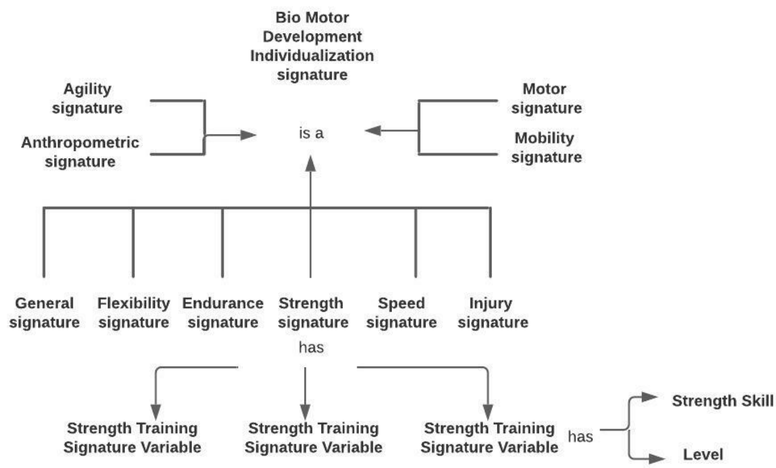


Fig. 4. OntoStrength sub-domains for personalized development of strength skills.

OntoStrength presents the instantiation of a Macrocycle entity, which has a Mesocycle entity as an object property, called hasMesoCycle. The Mesocycle entity has a Microcycle entity, an object property, called hasMicroCycle. The Microcycle has two object properties (hasWorkout and hasObjective), whereas the Microcycle is defined as a Push Workout and a Full Body Workout. The workouts are initialized with exercises following the rules defined by Bompa [24], for a beginner-level load. Each exercise instance describes a list of functional and fundamental movements, together with the muscle contractions involved in the execution. The SPARQL query from Fig. 5 retrieves all movements involved in a specific Microcycle defined in OntoStrength ("os" denotes the prefix specific to the OntoStrength ontology).

```
SELECT DISTINCT ?movement ?microCycle
WHERE {
  ?microC os:hasMicroCycle ?microCycle.
  ?wkout os:hasWorkout ?workout.
  ?cntBlck os:hasContentBlock ?contentBlock.
  ?ex os:hasExercice ?exercise.
  ?ld os:hasLoad ?load.
  ?mvmnt os:hasMovement ?movement.
}
```

Fig. 5. OntoStrength MicroCycle Movements query.

The query was applied in the GraphDB web interface, and it returns 11 unique movements, such as Archer Push Up, Chest Dip, or Feet Elevated Pike Push Up, which are applied as composed movements in all workout exercises. GraphDB has many options to display the results of a SPARQL query ranging from the Table view, Raw Response – JSON formatted data, and Pivot Table, to more advanced Google Charts. All unique functional movements for the defined macrocycle

MicroCycleAAPDupont_001 are displayed in **Fig. 6** using the Google Charts recommended view.

The inheritance hierarchy can be also visualized in GraphDB. OntoStrength relies on property inheritance between classes. Each exercise is represented as a class, which has specific base classes representing the type of movement involved, while the most generic one is the "Movement Skill" class. The "Exercise" class is inherited from the "Specialized Movement" class, which includes a list of "Functional Movements" to execute (such as "Elbow Extension," or "Shoulder Adduction"). Moreover, "Functional Movements" are composed of a list of "Muscle Contractions", such as "Hamstrings Concentric Contraction," "Quadriceps Eccentric Contraction," and "Teres Major Isometric Contraction".

movement	microCycle
:#ArcherPushUp	:#MicroCycleAAPDupont_001
:#ChestDip	:#MicroCycleAAPDupont_001
:#PushBack	:#MicroCycleAAPDupont_001
:#FeetElevatedFrontPlank	:#MicroCycleAAPDupont_001
:#Superman	:#MicroCycleAAPDupont_001
:#BirdDog	:#MicroCycleAAPDupont_001
:#FullSquat	:#MicroCycleAAPDupont_001
:#FeetElevatedInvertedRow	:#MicroCycleAAPDupont_001
:#BicepsChinUp	:#MicroCycleAAPDupont_001
:#FeetElevatedPikePushUps	:#MicroCycleAAPDupont_001
:#FrontPlank	:#MicroCycleAAPDupont_001

Fig. 6. GraphDB Google Chart SPARQL Query Results for Unique Functional Movements to train in a MicroCycle.

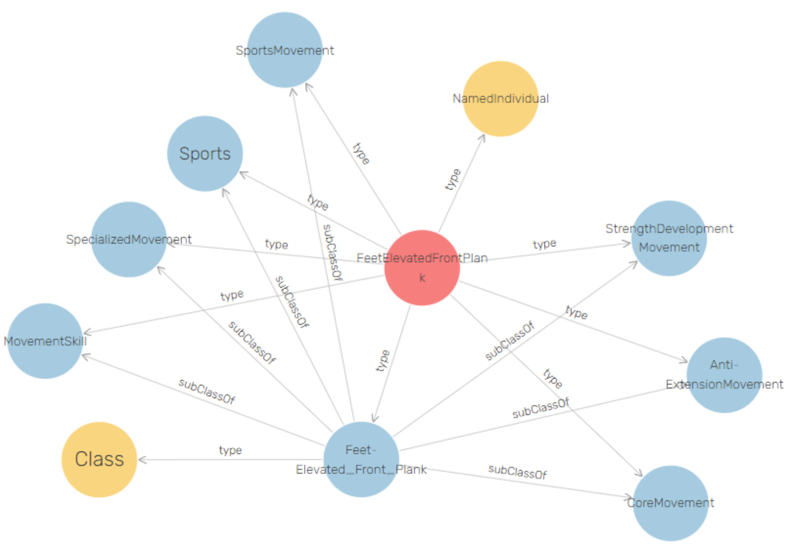


Fig. 7. GraphDB View of Feet Elevated Front Plank instance and class.

An instantiation of an "Exercise" class is the exercise itself, with its specific level and description. "Feet Elevated Front Plank" from Fig. 7 is an example of a named individual of the class with the same name, described as a Level 1 exercise, for the Anti-Extension Movement.

4 Results

The OntoStrength ontology supports the Selfit ITS by providing knowledge and relationships useful to different modules of the Selfit system. To this end, a RESTful API interacts with Selfit to provide microservices specific to the domain, student, and tutoring system functionalities. The following subsections illustrate the interactions of OntoStrength with Selfit via the RESTful API.

4.1 Trainee profiling

The Selfit Trainee profiling functionalities elaborate and refine trainee signature profiles used to personalize the definition of strength development workouts. The OntoStrength RESTful API provides queries to support the selection of signature variables used by the ITS, update signature variables, and obtain the values of signature variables, as seen in Table 1.

Table 1. OntoStrength RESTful API for the trainee profiling function.

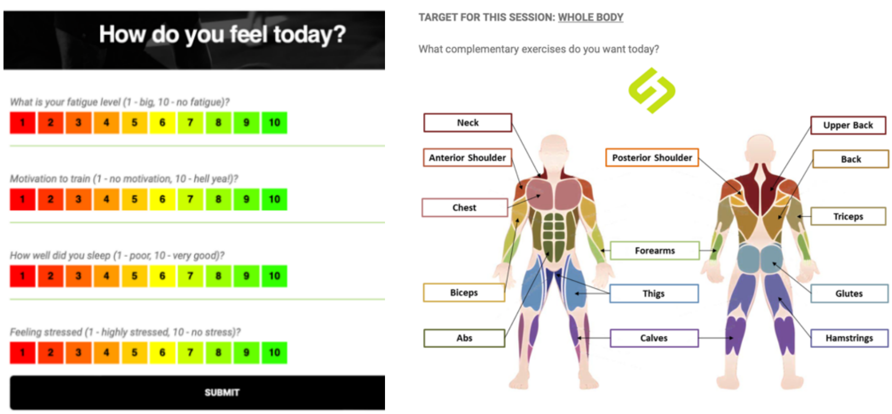
Query	Result	Input	Output
getSignatureList	Return all signatures associated with a profile	Trainee	List of signatures
getSignature	Return details of a specific signature associated with a profile	Trainee, Signature	Signature details
getSignatureVariables	Return the variables used to provide personalized development workouts for a given strength skill	Strength skill	List of signature variables
getSignatureValueForVariable	Return the value of a trainee signature variable	Trainee, signature variable	Value of the signature variable
setSignatureValueForVariable	Update the value of a trainee signature variable	Trainee, signature variable, new value	Status to confirm the update
getMovements	Return a list of movements	Movement class, level	List of movements

The strength individualization signature consists of a level ranging between 1-4 to match the level at which exercises can be safely performed, for all strength movement skills. The evaluation of these parameters is performed through an initial calibration workout session, which has an incremental complexity, until failure. For example, "Side to Side Push Up" for upper body area level 1 complexity or "Self-Assisted One Arm Push Up" for level 2. This Selfit calibration feature uses the RESTful API to obtain the exercises for a given strength movement skill and level, to get the actual trainee level for a selected strength movement skill, and to update the student profile after each exercise. Once an initial student calibration is performed, a strength development training program is generated and is continuously updated after each workout.

4.2 Workout generation and monitoring of training impact

The Selfit workout generation engine defines the content of the next workout session by using information about trainees' characteristics, past performances, and current fatigue levels. The tutoring module first identifies the workout target by predicting the most accurate template, based on the trainee's training history and actual fatigue signature. Once selected, the module generates appropriate content using training strategies and personalization signatures. The user can also customize training content by modifying his/her preferences about developing muscles, before starting a workout. At the end of each exercise, session phase, and workout, Selfit assesses success or failure, and asks trainees about their perceptions of the effort.

The Selfit tutoring module updates our ontology with training information updates submitted by users, such as the daily fatigue profile, or the perception of effort after achieving a training task. An example of the graphical interface can be seen in Fig. 8 (a), where the user subjectively assesses his physical shape before starting a training session; muscle development preferences are described in Fig. 8 (b).



(a) (b)

Fig. 8. (a) Daily fatigue monitoring interface. (b) Muscle development preferences interface.

The training program is continuously adjusted until the trainee development objective is achieved. Calibration challenges are required to be performed periodically for updating student competency levels and to provide personalized training sequences.

During training sessions, Selfit asks trainees to self-evaluate at the end of each content exercise; thus, trainees answer whether they could perform additional repetitions and, if yes, how many. After the training session, Selfit enquires about the perceived difficulty of the session on a scale from one (very hard) to ten (very easy).

Training sessions provide trainees with descriptions, which include a summary of warmup, content, and cooldown exercises. Training sessions are easily configurable; trainees can select the training location (home or gym), opt for various session templates, choose the available training materials (barbell, elastic band, machine, etc.), and select complementary muscles to target while training (anterior shoulder, biceps, forearms, thigs, etc.). While training, a video demonstrating the correct movements and details required to accomplish the correct load (i.e., number of sets, number of repetitions, rest between repetitions and between sets) is displayed for each exercise. Trainees can see their full training history, per microcycle and session, as well as their progress per trained body area.

5 Conclusions

This work presents the design and development processes of an ontology dedicated to strength psychomotor capacity called OntoStrength. As per our knowledge, although there is an increasing demand for building digitalization solutions in the healthcare and sports training fields, there is no previous work performed on the psychomotor domain.

Based on the related work described in 2.1, we considered OD101 for building OntoStrength, a micro-level methodology that proposes a practical and explicit guide for developing ontologies. The process, based on interdisciplinary teamwork, implied a clear definition of the domain and the scope, the reuse of existing ontologies, the definition of classes, and properties, and finally instance creation to complete the knowledge base.

The newly constructed ontology can be accessed using a microservices architecture, where specific endpoints are available to serve multiple queries for sports training purposes, such as exercises targeting a movement pattern, by difficulty, warm-up sessions generation, weekly training generic plans, based on objectives, and others. The microservices are also integrated into Selfit, an ITS for psychomotor development, and all Selfit core components (i.e., student, domain, and tutoring models) rely on our knowledge base for conceptualization and basic inferences.

In terms of limitations, the current approach does not consider sexual dimorphism, as well as the presence of injuries or diseases which may be critical for training schedules. The morphological, cognitive, and physiological differences between males and females impact the content development of the training sessions, together with associated risks of injuries and psychological disorders. Trainee's performance monitoring and feedback support load adjustment. When scheduling learning sessions for women, tutors must follow the same physiological temporal variables as for men. However, when designing sessions, they must synchronize with the menstrual cycle to define session content [27]. The consideration of female-specific risks of injuries, particularly ACL and female athlete triad, requires integrating appropriate tests of assessing the injury susceptibility. Results from these tests are used afterward to provide dedicated prophylaxis sessions and adjust learning sessions accordingly. These draw as limitations for the current OntoStrength ontology.

Future work includes the usage of the RESTful APIs to generate entire training chains, including workouts, microcycles, mesocycles, and macrocycles. OntoStrength will be published under an open-source license and will be further extended to include other psycho-motor abilities, such as Flexibility, Mobility, or Endurance skills.

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