An Ontology to Integrate Multiple Knowledge Domains of Training-Dietary-Competition in Weightlifting: A Nutritional Approach

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ABSTRACT

This study is a part of weightlifting "*Training-Dietary-Competition*" (TDC) cycle ontology. The main objective of TDC-cycle is to build a knowledge framework for Olympic weightlifting, bringing together related fields such as training methodology, weightlifting biomechanics, and nutrition while modelling the synergy among them. In so doing, terminology, semantics, and used concepts are unified among athletes, coaches, nutritionists, and researchers to partially obviate the problem of unclear results and paucity of information. The uniqueness of this ontology is its ability to solve the knowledge sharing problem in which the knowledge owned by these experts in each field are not captures, classified or integrated into an information system for decision-making. The whole weightlifting TDC-cycle is semantically modelled by conceiving, designing, and integrating domain and task ontologies with the latter devising reasoning capability toward an automated and tailored weightlifting TDC-cycle. However, this study will focus mainly on the nutrition domain. The intended application of this part of ontology is to provide a useful decision-making platform for a sport nutritionist who gathers and integrate relevant scientific information, equation, and tools necessary when providing nutritional services. The system is constructed by using Web Ontology Language (OWL), Semantic Web Rule Language (SWRL), and Semantic Query-Enhanced Web Rule Language (SQWRL). The use of weightlifting TDC-cycle ontology can be helpful for nutritionists to create a well-planned nutrition program for athletes (especially, in the process of nutrition monitoring to identify energy imbalance in athletes) by reducing time consumption and calculation errors.

Keywords: Ontology, Semantic, Nutrition, Weightlifting

Manuscript received on June 21, 2018 ; revised on January 20, 2019.
Final manuscript received on February 24, 2019.
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1. INTRODUCTION

Sport nutrition is considered as a new area of study involving the application of nutritional principles to enhance sports performance. The nutritional requirements of athlete are different in different sports and are influenced by many factors such as body mass and amount and intensity of training load. For weightlifters, the main nutrition goal is to obtain the adequate energy and necessary nutrients for fuelling of resistance training, recovery from this training, and promotion of training adaptations. A summary of the reported dietary intake of adult strength-power athletes in training [1-3] showed that weightlifters did not achieve optimal dietary practice with the emphasis placed on protein consumption (with high fat) at the expense of adequate carbohydrate ingestion. It is challenging for them to meet their energy needs due to their high body weight and high volume intense training. Therefore, they require a well-planned nutrition program. Traditional consultation and development of athletes' nutrition plans require sport nutritionists to perform a series of steps including nutrition assessment, nutrition evaluation, nutrition intervention, and nutrition monitoring to determine and measure the amount of progress from nutrition plan. These general steps involve many type of information such as athlete's condition (e.g., anthropometric data, biochemical data, and current dietary habits), type of sport (e.g., specific sport, training program and time line), nutrition requirements (e.g., special nutrient needs/restrictions, and food nutrition composition). Therefore, to develop a specific nutrition plan for an individual, the sport nutritionist must be able to integrate the complex logical relationships between the athlete's metrics and the various concept from literature. This study intended to create an ontology useful for a nutritionist to use during the process of nutrition assessment, evaluation, and monitoring. It should be noted that these steps are combined or related because the data which nutritionists use are similar, or even the same. However, the data purpose and usage are distinct. Nutrition assessment and evaluation involves initial data collection, but also continual reassessment and analysis of athlete's status compared to specified criteria. This contrasts with nutrition monitoring data where data is used to determine changes in athlete behaviour or nutritional status and the efficacy of nutrition intervention. Examples of terminology for nutrition assessment, evaluation, and monitoring are food/nutrition-related history data (e.g., food and nutrient intake and physical activity), anthropometric measurement data (e.g., height, weight, muscle mass, fat mass), and biochemical data (e.g., lab data and tests). Among all data, dietary intake data seems to be the most challenging. Dietary intake can be assessed by observation (e.g., a duplicate diet approach, food consumption record) or subjective report (e.g., 24-hour dietary recall, dietary record). However, these methods tend to be time-consuming, laborious, and highly expensive to implement. This study applies an ontological development approach with focus on the construction of knowledge models and knowledge reasoning with logical rules intended to assist nutritionists in (i) reduce their time and resource for collecting and handling data, (ii) improve consistency of data, and (iii) calculate dietary intakes automatically.

This study is a part of weightlifting "*Training-Dietary-Competition*" (TDC) cycle ontology which the main goal is to build a knowledge framework for Olympic weightlifting, bringing together related fields such as training methodology, weightlifting biomechanics, and nutrition while modelling the synergy among them. The integration of domain knowledge across several domains make this work unique. However, this paper will focus mainly on the nutrition domain. To obtain a deep understanding of aspects and concrete entities comprising the weightlifting TDC cycle, repetitive collaboration meetings were organized among athletes, coaches, and multidisciplinary researchers, in this case, nutritionists, electronics, and software engineers. We applied a two-level analysis technique: the lower-level statistical analysis and the higher-level semantic analysis. The statistical analysis, data, devices, and optimization methods are extracted and identified from literature review to be later transformed or applied into semantics artefacts (i.e., data properties and SWRL rules). We believe that such a two level-analysis is crucial for the integration of observed and measured data to enhance the understanding of weightlifting, in both biomechanical and nutritional aspects.

The rest of the paper is structured as follows. Firstly, we give some backgrounds as well as some related works in Section 2. Section 3 describes our methodology for the ontology development. Section 4 presents the constructed ontology and rules derived from the development process. Finally, some conclusion remarks are mentioned in the Section 4.

2. BACKGROUND AND RELATED WORK

In this section, we describe the background of ontology including definition, main elements, advantages, and development methodology in section 2.1. and 2.2, respectively. Section 2.3 is referred to nutrition background and section 2.4 presents the related works that is not only similar to our work, but support our contributions.

2.1 Ontology

Philosophically, ontology is the study of being, kinds, and structures of objects. It includes properties, events, processes, and relations in every area of reality. It also deals with all questions about entities, and concerns how they are hierarchically classified according to similarities and differences. From an artificial intelligence perspective [4, 5], ontology is the outcome of analysis and modelling that makes use of the concepts of modularity and connection. It translates into an explicit and structured framework of concepts and semantics, with the capacity to present novel relationships. Hence, ontology is viewed as a data model describing concepts in a specific domain. This data model is presented as classes along with classes' relationship. It conceptualizes the domain by explicitly defining all primitives, concepts, and constraints. It is represented by a formal language that can be processed by computers. Ontology was successfully used to share concepts across applications and exchange information based on semantics rather than using syntax. Another way to understand the meaning of ontology is by direct comparison to object-orientation where the focus is on classes' methods and decisions assisted by operational properties of classes, while in ontology decisions are based on the structural properties of classes. Ontology can also be compared to taxonomy (Figure 1). While the former includes cardinality and restrictions, the latter is limited to "*is a*" kind of relationship. In other words, it organizes controlled vocabulary terms into a tree-like structure, being the controlled vocabulary the list of authorized keywords used to describe individuals of a taxonomy or ontology [6].

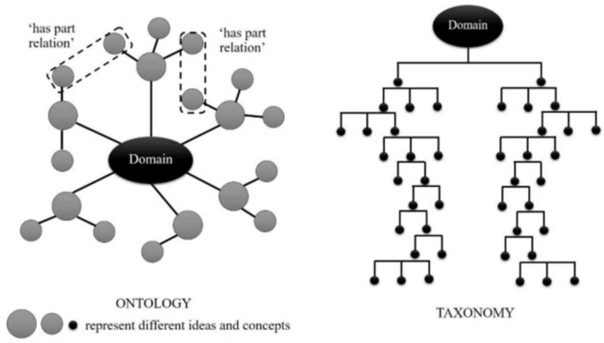

Fig.1: *Ontology versus Taxonomy [6].*

The main elements of an ontology are classes, individuals, properties, and relationships. An ontology together with a set of individual instances of classes constitutes a knowledge base. It is stored as entities and the relationships between them. Classes are collections of objects, sets or abstract groups, describing concepts in specific domain. They can contain both a subclass describing more specific concepts and an individual. An example of a class would be a *Food* class that would contain various subclasses like *food type* and *food group*. Individuals may be concrete concepts like a specific menu or an *ingredient* or an abstract concept like *food preference*. Properties are related to individuals or classes, as they are something that defines or explains them. Individuals can have two types of properties: either a data type, which is used to assign a value to a property or class, (e.g., a menu *hasEnergy*150kcal)) or the object type, which is used to attribute one object to another one (e.g., a menu *hasIngredient*). Relationships are unlimited not only in quantitative terms but also in complexity. They made modularity become a necessary demand for ontology modelling. Modularity allows researchers to model a given domain in many different ways. For example, a domain can consist of objects that relate to each other, possess attributes, participate in processes, may have one or more states or situations defining values of its attributes, react to events triggering the change of its state, and contain other objects. However, by using a logical description based on their properties to describe ontologies, the following relations must be presented: (i) relation between classes, (ii) relation between individuals or classes instances, and (iii) the relations between classes and individuals.

Ontologies have been used for: (i) expressing domain-general terms in a top-level framework, (ii) knowledge sharing, for communication in multi-agent systems, (iii) natural language understanding, (iv) making document navigation easier, browsing and search, (v) consistency checking, (vi) con?guration support, (vii) interoperability of tools and data, (viii) system engineering support, among many others. In system engineering, ontology has been used to identify system requirements and constraints, as well as to de?ne relationships among components and subsystems that compose a system. Additionally, it can be used to support reuse-by-design of modules among different software systems.

2.2 Ontology Development Methodology

Several generation of methodologies for building ontologies has been reported. Among them the following ones are enumerated:

1) *First generation* with main focus on the ontology modelling and development process while ignoring issues such as maintenance and reuse [7]. It is mainly represented by methodologies applied in TOVE [8] and ENTERPRISE [9], both consisting of the following steps: (i) identification of the ontology purpose, (ii) domain knowledge acquisition, formally coding of the domain knowledge, and (iii) ontology evaluation. In TOVE a set of competence questions identified during the first step is compared against the formally expressed ontology.

2) *Second generation* with main focus on performing speci?cation, conceptualization, integration, and implementation as often as required, during the ontology lifetime. It is mainly represented by the methodology described in the first version of Methontology [10] which uses translators to generate the ontology from a set of intermediate representations.

3) *Third generation* with main focus on reusability and configuration management as activities of the development process. It is best represented by On-To-Knowledge [11] which focused on content-driven knowledge management through evolving ontologies. On-To-Knowledge leverages the use of ontologies for various tasks of information integration tasks and mediation.

4) *Fourth generation* with main focus on strengthening modularity and reuse of engineering design ontologies to better deal with the complexity of knowledge that is required to be brought together to support the design of knowledge-based decision-making system. It is mainly represented by the novel knowledge-based engineering (KBE) framework which adopts best practices from previous ontology development methods along with a model-driven architecture style to implement platform-independent knowledge-enabled product design systems, e.g., within the aerospace industry [12]. Another representative of this generation is the middle-out approach suggested by Obrst et al. [13], mixing aspects of top-down and bottom-up analyses. Bottom-up and top-down analyses require understanding the semantics of the underlying data sources which are to be integrated and the end-users who will actually use the resulting ontology informed, semantically integrated set of data sources, respectively.

The NeOn methodology [14] follows a completely different approach for ontology engineering than previous ones as it does not prescribe a rigid workflow. Instead it suggests a variety of pathways for developing ontologies. Basically, it is a scenario-based methodology for building ontologies and ontology networks through collaborative aspects of ontology development and reuse. Scenarios consist of several processes or activities that can be combined in flexible ways to achieve the expected goal.

In this study, as we follow the fourth generation methodologies, ontological modelling and designing of the weightlifting TDC cycle demands collaborative contributions of several stakeholders such as athletes, coaches, nutritionist, biomechanist, knowledge engineer, and device designer to better construct concepts into a domain ontology and process/task ontology, representing declarative and procedural knowledge, respectively. These two kind of knowledge must be complemented with facts or instances, as well as inference knowledge to build the weightlifting TDC cycle knowledge base.

2.3 Nutrition for Weightlifting

Many research reported that weightlifters did not achieve optimal dietary practice [1-3]. These results are in accordance with our preliminary study [15] which reported that a high proportion of Thai national team weightlifters were not in energy balance and so, failed to meet carbohydrate, protein, and micronutrient recommendations. The primary reason for such inadequate diets may come from the fact that some athletes lack of nutrition knowledge and express some nutritional misconceptions, so they are unable to make appropriate food choices. Therefore, they require a well-planned nutrition program. To develop a nutrition program, a nutritionist requires to perform a series of steps in nutrition process. This process demonstrates how nutritionist integrates professional knowledge and skill into evidence based decision making. It consists of (i) *nutrition assessment* to get to know the athlete and understand his/her situation and his/her objectives, (ii) *nutrition evaluation* to determine the athlete's calories and nutrients need, address the goal, and determine the athlete's nutrient timing needs for training and for competition day, (iii) *nutrition intervention* to create nutrition and hydration plan for all phases of training and completion cycle as well as provide a specific amount of nutrients recommendation, and (iv) *nutrition monitoring* refer to review and measurement of athlete's nutrition status and dietary intake at planned intervals with regard to the nutrition intervention plan, goals, and outcomes. It includes monitoring of the implementation of the plan.

The first nutritional priority for all athletes is to meet their energy needs. Energy intake supports optimal body function, determines the capacity of macro- and micro-nutrient, and assists in manipulating body composition [16]. For weightlifters, it is challenging to meet their energy needs due to their high body weight and high-volume intense training. According to Scala et al. [17], energy expenditures of elite weightlifters can be as high as 600-1,000 kcal/hour or >3,000 kcal/week during the preparation phase. However, it will be lower during tapering. Nevertheless, even in the same type of sport, the energy and nutrients requirement for each athlete is different. It depends on body size, physique, event, training load, and training volume on the periodized training and competition cycle. The classic energy balance equation states that if energy intake (total kilocalories consumed) equals energy expenditure (total kilocalories expended), then weight is maintained. The maintenance of body weight and body composition over time requires not only that the energy intake to be equal to the energy expenditure but also that intakes of protein, carbohydrate and fat to be equal to their oxidation rates. Athletes who meet these criteria are in energy balance. Energy expenditure is one side of the energy balance equation. Any alternation in energy expenditure can result in weight gain or loss if energy intake and consumption are held constant [18]. The predicting energy expenditure based on age, gender, and anthropometric measurements are used to estimate energy expenditure of an athlete. In this paper, to avoid confusion with other terms, we will use the term "Total energy needed (TEN)" to refer to the value obtained from equation 1 or a predicting energy expenditure equation based on age, gender, and anthropometric measurements. TEN is calculated by the factorial method (Equation 1). It comprises the Resting metabolic rate (RMR), Thermic effect of food (TEF), and Energy expended in physical activity, which includes activities of daily living calculated by General activity factor (GAF) and planned exercise events calculated by Exercise energy expenditure (EEE). RMR is calculated by the Harris-Benedict equation [19] (Equation 2 for male and Equation 3 for female). Once a values of RMR has been obtained, TEN can be estimated by a variety of factorial methods which depend on the type and intensity of activity. In this study, both GAF and EEE will be estimated. While the former represents energy expended for everyday activities (e.g., walking, driving, watching TV, and going to the class), the latter is the activity expended in planned or purposeful activity (e.g., running, swimming, and weight training) for a scheduled amount of time and at a specific level of intensity. Those factors are calculated as indicate below:

$$\text{TEN}=(\text{RMR x GAF})+\text{EEE}+\text{TEF} \tag{1}$$

$$\text{RMR}=66.47+13.75\ (\text{weight})+5\ (\text{height})-6.76\ (\text{age}) \tag{2}$$

$$\text{RMR}=655.1+9.56\ (\text{weight})+1.85\ (\text{height})-4.68\ (\text{age}) \tag{3}$$

$$\text{EEE}=0.0175\times\text{METs}\times\text{Body weight}\times\text{Duration of activity} \tag{4}$$

$$\text{TEF}=10\%\ ((\text{RMR}\times\text{GAF}) + \text{EEE}) \tag{5}$$

General Activity Factor (GAF) will be determined for the time the athlete is not participating in specific activities, which is then multiply by the predicted RMR. GAF can be as low as 10-20% of RMR for a sedentary person and as high as more than 100% of RMR for a very active person. Although many researches establish unique activity factors for their research setting, factor of 1.2-1.6 are commonly used with sedentary people and those who have light activity. This factor can be applied to either the whole day or a weighted activity factor.

Exercise Energy Expenditure (EEE) is determined by using the standardized and comprehensive list of energy cost values for a wide variety of activities published by Ainsworth et al. [20] which is reported in metabolic equivalents (METs). MET is a unit of measurement that represents the work rate or oxygen uptake (VO2). One MET is equal to a VO2 of 3.5 mL·kg-1·min-1 which can be converted to kcal·kg-1·min-1 equal 0.0175 kcal·kg-1·min-1. Therefore, EEE is calculated according to the following steps. Firstly, multiply the value of METs (mL·kg-1·min-1) by 0.0175 to convert it to kcal·kg-1·min-1 and then, multiply the obtained value by the kilogram body weight of the individual and the number of minutes spent in the activity (Equation 4).

Thermic Effect of Food (TEF) represents the increase in energy expenditure above RMR that results from the consumption of food and beverage throughout the day. TEF includes the energy cost of food, digestion, absorption, transport, metabolism, and storage within the body. It is generally accounts for 6-10% of total daily energy needed (Equation 5), but vary from 4-15%, depending on size of the meal and its composition [18].

2.4 Related Works

Ontology-based works regarding to food and nutrition is not new and some of them already provided useful artefacts. For example, Snae & Bruckner [21] presented Food-Oriented Ontology-Driven System (FOODS), a counselling system for food or menu planning in a restaurant. The ontology contains specifications of ingredients, substances, nutrition facts, recommended daily intakes for different regions, dishes, and menus. This expert system assists in finding the appropriate dish for the consumers based on their individual nutrition profiles. FOODS comprises of a food ontology, an expert system using the ontology, and some knowledge about cooking methods and prices. For diabetes control, Hong et al [22] implemented web-based expert system for nutrition counselling and management, also based on ontologies. This system uses food, dish, and menu database which are fundamental data to assess the nutrient analysis. Users can search food composition and conditional food based on nutrient name and amount. The system is able to organize food according to Korean menus, and it is able to read nutrient composition of each food, dish, and menu. Chi et al. [23] integrated multiple knowledge domains such as chronic kidney disease, food nutrient composition, and problem solving method to implement a chronic disease dietary consultation system. The system consists of three major design components: a domain ontology, a task ontology, and semantic rules. They describe the task ontology in terms of conceptual structure as well as in terms of problem solving knowledge while separating asserted properties from inferred properties with the latter described through the use of SWRL and SQWRL.

However, literature about sport ontologies is rare. There are only few ontologies targeting sport domain. For example, Muthulakshmi [24] developed an ontology for sport training through e-learning which is based on a query template for a storage and retrieval of sports information. It has a basic concept of sports ontology complemented with physiological variable measured before and after events, as well as with physical activity. Nwe Ni Aung and Naing [25] presented information retrieval from Sports Domain Ontology using First-Order Logic rules and they retrieved relevant semantic relationships between concepts from it. Contrary to most of existing ontology-based information retrieval systems which use concepts mapping, they used semantic relationships between ontology of concepts to retrieve more relevant and correct results. Zhai and Zhou [26] proposed a sport ontology addressing fine-grained granularity and wide coverage of information for semantic retrieval for sports information in www. They used SPARQL query language to realize the intelligent retrieval at semantic level according to the relations of "*synonymy of*", "*kind of*", and "*part of*" between sports concepts.

There are not many studies using integrated ontology approach to combine knowledge from various domains to generate diet and exercise suggestions. Dragoni et al. [27] presented PerKApp which aims to provide a full-?edged platform supporting the monitoring of people behaviours while persuading them to follow healthy lifestyles. They used semantic technologies for modelling all relevant information and for fostering reasoning activities by combining user-generated data and domain knowledge. The integrated ontology supports the creation of the dynamic interfaces used by domain experts for designing monitoring rules. Mihnea et al. [28] proposed a recommender system of workout and nutrition for runners by integrating web crawling and ontology. The system is a mixture between experts' knowledge and a social dimension in generating the nutrition and workout plan. The system provides information to users regarding the workout and treatment recommendations, in case of injury, alongside diet plan that best suits them, based on their profile information, food preferences, and goals.

To the best of our knowledge, our designed ontology is innovative with respect to the other systems due to the collaborative contributions of several stakeholders such as coach, nutritionist, and biomechanist for supporting the monitoring of training and nutriton status of weightlifter.

3. METHODOLOGY

The modelled weightlifting TDC cycle, which will be described in this session, is a second-iterated model. It is contrary to the previous one [29] in which it is much more flexible, modular, and scalable as dictated by fourth generation methodologies.

The domain ontology contains several areas of domain knowledge (i.e., training, nutrition, and biomechanics knowledge) of the weightlifting TDC cycle in which each information dimension is declaratively extended and modelled by its own ontology. Then, each of them is accordingly interrelated with the other ones through object properties and well-designed heuristics and procedural rules. The method proposed in this paper consists in a two-level analysis technique: the lower-level statistical analysis and the higher-level semantic analysis. The statistical analysis, data, devices, and optimization methods are extracted and identified from literature review to be later transformed or applied into semantics artefacts (i.e., data properties and SWRL rules). We believe that such a two level-analysis is crucial for the integration of observed and measured data to enhance the understanding of weightlifting, in both biomechanical and nutritional aspects.

3.1 Ontology-Assisted Weightlifting TDC-Cycle Knowledge Representation

As mentioned earlier that this study is a second-iterated model in which the first-iterated ontology [29] was designed by (i) establishing the domain scope and analyzing the problem scenarios, (ii) modelling each individual domain as a subset of the domain ontology, (iii) modelling each individual task ontology as a subset of the task ontology, and (iv) developing semantic rules. The design of the new weightlifting TDC cycle declarative knowledge was driven through the following steps. Firstly, collecting new insights about weightlifting TDC cycle during modelling of the first-iterated ontology. Secondly, leveraging the concept of bring the problem to a broader context by partially approaching the automated scenario-based training (SBT) as proposed by Peeters et al [30]. SBT is a practical training form in high-risk professions during which learners engage in interactive role-playing exercises, called 'scenarios'. Scenarios are usually staged within a simulated environment. Therefore, the previous weightlifting TDC-cycle was refactored in a similar way to the domain ontology proposed for SBT, but excluding the scenario generator and the associated system or design ontology. Additionally, another main focus was toward the extended ontologies for each dimension of weightlifting TDC cycle and the existing interoperability among them. This feature will help us to identify and define corner cases under the mismatching of two binomials: coaching-biomechanics (e.g., mismatched lifting rhythm) and planned energy intake-total energy needed (e.g., energy imbalance) for a given training day or session. Considering nutrition process, this feature will be useful for the process of nutrition monitoring. Such corner cases, are characterized by both qualitative (e.g., coach and nutritionist observations) and quantitative (biomechanics measurement and nutrition assessment), which are expressed by well-designed heuristics and procedural rules. However, as mentioned earlier, this paper will focus only on the domains related to nutrition.

Before the refactoring of the previously constructed domain ontology [36] starts, it was reviewed by the indicated domains' experts and stakeholders. This is to ensure that the required knowledge to reason about the problem scenarios of the weightlifting TDC cycle are fully covered. This process was achieved by the two following steps. Firstly, the previous domain ontology was evaluated for consistency and applicability by experts specialized in the related subject of weightlifting as well as software engineering. This review session led to the identification of the four drawbacks as follows: (i) weak modularity and scalability, (ii) missing corner cases modelling, (iii) inaccurate measurement of energy expenditure, and (iv) inaccurate modelling of rhythmic execution. Secondly, it was evaluated for completeness. As a result, this second review session suggested (i) addition of some concepts (e.g., anthropometric features) to more clearly differentiate qualitative from quantitative parameters, (ii) loose-coupling those parameters through axioms which model the coaching-biomechanics and energy intake-expenditure binomials, and (iii) improvement of modularity and scalability. These suggestions led to the adjustment of the previous domain ontology at the Task Rules Sublayer. The following paragraphs describe the refactored TDC-Ontology starting with each individual ontology on training, nutrition, and stakeholder domains.

3.2 The Nutrition Domain

In the *nutrition domain* ontology (taxonomically shown in Figure 2), the central concept is the *DietaryProtocol*. It is also a composite which relates to the Consumable concept through prescribes and its inverse (i.e., *prescribedby*) relationships. Each dietary protocol can prescribe several consumables from different food categories as expressed by the following subclasses of Drink, *NaturalFood*, and *DietarySupplement*. In this prototype, *Consumable* concept are adopted from our previous work [31]. However, in the future, we may consider adopting the food concept from other available literature in order to cover all available menus items. Individually, each consumable contains a certain amount of macro- and micro-nutrients. Micronutrients consist of three key nutrients expressed by the concepts of *Protein*, *Fat* and *Carbohydrate*, alongside the multiple cardinality relationship of *contains*. Micronutrients contain two groups of nutrients represented through *VitaminGroup* and *MineralGroup* concepts. Traditionally, a dietary protocol is administrated on several pre-, during-, and post-workout, or competition day, accordingly to an established timing sequence. The energy expenditure analysis is applied on each dietary protocol after its administration and at the end of the above four stages of pre-, during-, and post-workout, or competition day. It uses collected metabolic rate measurements as performed by using both technologically and analytically approaches. Analytical technique for determination of energy-expenditure is achieved based on specific configuration or Setting given by a set of data property (e.g., age, gender, weight, height, GAF, EEE and METs).

In the *training domain* ontology (see Figure 2), the central concept is the *Exercise*. Exercises are performed in an *Environment*. An environment has specific configuration or *Setting*. The setting is expressed as a set of data properties, while exercises targeting specific athlete's goals and dietary programs are represented through relationships *hasAthleteGoal* and changes of *DietaryPlan*, respectively.

All domain, as presented in Figure 2, demand for information provided by key involved stakeholders in the weightlifting sports. In the stakeholder domain, the central concept is the Actor. The Actor concept involves, in this case, *vAgent (virtual agent), Athlete, Coach, and nutritionist*. Key role of a virtual agent, if implemented, will be alerting coaches and nutritionists for the occurrences of abnormal observations or measurements. The main concern is the corner cases (e.g., unbalanced energy and rhythm) according to designed SWRL rules. Furthermore, a coach is also notified or alerted of any abnormal observations/measurements by nutritionist.

3.3 The Refactored Task Ontology

With all individual domain ontologies already designed, the whole weightlifting TDC-Cycle ontology wraps them all together while being extended by integrating the task domain ontology. The task domain is extended with concepts required to establish relation between individual domains of nutrition and training in order to later infer about nutrition balance. Compared to the previous task domain ontology [29], the new task domain was refactored around more generic concepts of *Training Day, AthleteNutritionReference*, and *TrainingReference*. It hosts individuals of nutrition, and training domains, required for SWRL reasoning nutrition balance. They represent an athlete's training days, prescribe nutrients to an athlete, and a top reference athlete data, respectively. It is worth noting that the *TrainingReference* class contains not only anthropometric features but also quantitative rhythmic execution parameters. The anthropometric feature was created to ensure that the athletes are comparable in the same weight class.

4. RESULTS

The implemented TDC-cycle taxonomy of the new refactored ontology (i.e., representing a class hierarchy based only on *is-a* kind of relations) is shown as a Protégé taxonomy in Figure 2.

For practical reasons, it should be noted that each name inside its associated domain/class are preceded by the domain name (e.g., *TrainingEnvironment* and Training Exercise are classes from the training domain). In domain, the *TrainingExerciseMovement* class and its sub-classes are added to create terminology for positions and phases of an exercise. The implemented class hierarchy of the nutrition domain is presented in Figure 3 with its associated object properties (Figure 4). While the *NutritionDietaryOccasion* class was created to group the meals/nutrient prescription occasions, the *NutritionDietaryProtocol* class was implemented to model both meals and nutrients prescriptions (Figure 5, 6). A meal (i.e., an individual of *NutritionDietaryProtocol* class) has consumables which is given by the *hasNutritionDPPresribesConsumable* relationship. Each consumable has nutrients (i.e., has *NutritionNutrient*) in which each nutrient has a nutritional value (i.e., *hasNutritionNutrientValue*).

Unlike the previous first-iterated version where the task domain ontology had their own data properties, in this version all data properties are "inherited" from the various domains (i.e., through the *TrainingReference*, Athlete *NutritionReference*, and *TrainingDay*). For example, the *TrainingReference* class is a wrapper for a set of two *TrainingExercise*. It represents the range of parameters for a successful rhythmic execution, according to a top reference athlete. Therefore, the task domain ontology implicitly uses the data properties of *TrainingExercise* class individuals. The same approach applies for data properties of *AthleteNutritionReference* class individuals. Figure 10 presents the description of the *TrainingDay* concept as an integrator class for all domains and it is composed by some exercises, performed by an athlete, and the meals taken during that day. In fact, the individuals of such class became the foundation for most of drafted SWRL rules. One can see that there is no reference to the biomechanics features as they are implicit to the exercise, shown in bottom of Figure 7. By executing the reasoner, two different individuals of training sessions *TD1A1* and *TD1A2* were identified.

4.1 The Refactored Set of Axioms

Having the *FB* already populated, SWRL rules are designed by relating individuals' asserted data properties to create new knowledge, for instance, about energy expenditure and rhythm execution quality. Each inferred data property is related to a SWRL rule, which is composed by chaining the concept in which such property belongs to other individuals. Furthermore, these SWRL rules are drafted according to the literature review. For example, equations

Fig.2: *Fragment of the TDC-Cycle taxonomy on the second iteration.*

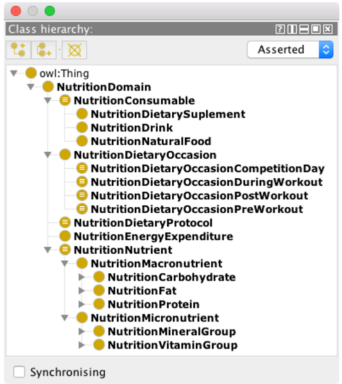

Fig.3: *Nutrition domain class hierarchy.*

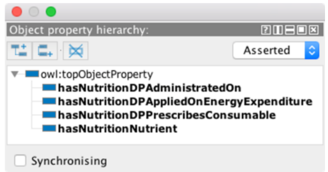

Fig.4: *Object properties of the nutrition domain.*

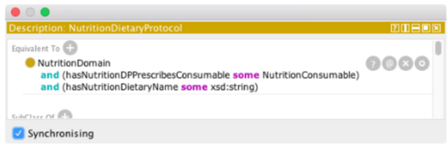

Fig.5: *Definition of the NutritionDietaryProtocol class.*

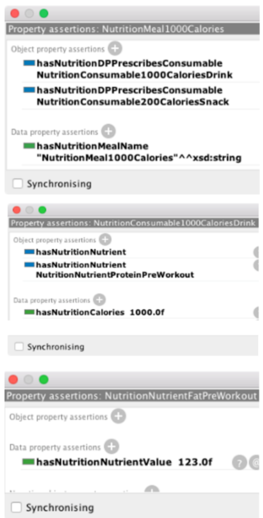

Fig.6: *Set of individuals composing a meal domain.*

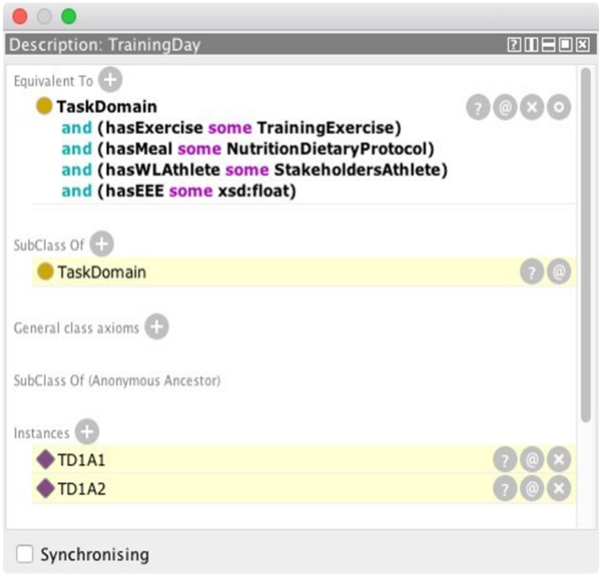

Fig.7: *The Description of the TrainingDay Concept.*

for determining energy requirement are found in [18], the energy cost values of activities published in [20], the dietary recommendations used are based on the guideline from ADA, ACSM, IOC, and sport-specific nutrition guideline for strength and power sports [16, 32-34]. The menus list and nutrients value information are based on the database from INMUCAL-Nutrient Software [35] and Nutritive values of Thai foods [36]. Only the drafted SWRL rules which related to energy balance, are described here.

Energy and nutrients intake data are obtained from menus in which nutritionist prescribed for an athlete in a given training day, whereas energy and nutrients expenditure data are obtained from applying energy expenditure equations and the nutrients reference values. The *ExerciseEnergyExpenditure* rule (Table 1) is a SQWRL which uses the analytical equation of energy expenditure in equation 4 to calculate the expended energy for a training day. Its obtained result will be used in the TEN calculations and its atoms are chained as follows. At line (1) a *TrainingDay* has an associated athlete with his weight. At line (2) is expressed that such athlete performed a set of exercises, each exercise has its own duration and METs value. At line (3) the above EEE formula is applied using as inputs data properties retrieved using preceding atoms. At line (4) the result is outputted per each training day and used to assert the HAS_EEE data property in the respective *TrainingDay* individual.

The *TENFemale* rule (Table 2) calculates the TEN (total energy needed) and RMR (resting metabolic rate) of an athlete, in this case, a female athlete, although the latter value is not used by now. The rule uses the analytical equations as presented earlier in equation 1, 2, and 3. The chaining of its associated

Table 1: *The ExerciseEnergyExpenditure rule.*

Rule: *ExerciseEnergyExpenditure*	
TrainingDay(?td) ^ hasWLAthlete(?td, ?ta) ^ hasWeight(?ta,?taw)	(1)
^ hasExercise(?td, ?te) ^ hasTrainingExerciseMET (?te, ?MET)^ hasTrainingExerciseDuration (?te, ?ed)	(2)
swrlb:multiply(?METw, "0.0175"^^xsd:float, ?MET)^^ swrlb:multiply(?r1, ?ed, ?METw) ^ swrlb:multiply (?r2, ?r1,?taw) . sqwrl:makeBag(?b, ?r2)	(3)
-> sqwrl:select(?td, ?EEE)	(4)

atoms starts at line (1) expressing that a *TrainingDay* has a *hasEEE* data property, as calculated earlier. At line (2), each training day also refers to an athlete from which is selected several attributes. At line (3) these attributes are used to calculate the RMR, while at line (4) the previous result is also retrieved to obtain the TEN. Finally, at line (5) both obtained results are used to assert *hasRMR* and *hasTEN* data properties of the involved *TrainingDay* individual. A *TENMale* rule is similarly drafted and implemented.

Table 2: *The TENFemale rule.*

Rule: *TENFemale*	
TrainingDay(?td) ^ hasEEE(?td, ?eee)	(1)
^ hasWeight(?ta,?taw) ^ hasWLAthlete(?td, ?ta) ^ hasWLAthleteGender(?ta, AthleteGenderFemaleClassInst) ^ hasHeight(?ta, ?hgt) ^ hasWeight(?ta, ?wgt) ^ hasAge(?ta, ?age) ^ hasGAF (?ta, ?gaf)	(2)
^swrlb:multiply(?a1, "4.68"8sd:float, ?age)^ swrlb:multiply(?h1, "1.85"^^xsd:float, ?hgt)^ swrlb:multiply(?w1, "9.56"^^xsd:float, ?wgt)^swrlb:add (?r1, "655.1"^^xsd:float, ?w1)^swrlb:add(?r2, ?r1, ?hgt)^ swrlb:subtract(?rmr, ?r2, ?a1)	(3)
^swrlb:multiply(?r3, ?rmr, ?gaf)^swrlb:add(?r4, ?eee, ?r3)^swrlb:multiply(?ten, "1.1"^^xsd:float, ?r4)	(4)
-> hasRMR(?td, ?rmr)^hasTEN(?td, ?ten)	(5)

The *EnergyIntake* rule is a SQWRL which calculates the energy intake for a training day, based on the meals consumption for that day. The chaining of its atoms starts at line (1) addressing each taken meal of a *TrainingDay*. At line (2) consumables are selected and from each of them it is individually selected the caloric value. At line (3) the result accumulatively added to those from other consumables from all other meals in that training day. Finally, at line (4) the results are outputted per each training day, while the HAS_EI data property in the respective *TrainingDay* individual is asserted.

The following Figure 8 presents the result of the execution of the *EEE, TEN, EnergyIntake*, and *Energy Balance* rules. In this example, the athlete has energy intake of 3,000 kcal which is less than his energy needed of 3,585 kcal. So, it means that the athlete presents a negative energy imbalance of 585 kcal.

Table 3: *The EnergyIntake rule.*

Rule: *EnergyIntake*	
TrainingDay(?td)^hasMeal(?td, ?m)	(1)
^hasNutritionDPPrescribesConsumable(?m, ?mc)^ hasNutritionCalories(?mc, ?cal)	(2)
.sqwrl:makeBag(?b, ?r1) . sqwrl:sum(?EI, ?b)	(3)
-> sqwrl:select(?td, ?EI)	(4)

The *Balance* rule compares the energy intake as calculated by the *EnergyIntake* rule, with the amount of energy needed (i.e., the previously computed TEN value) to calculate the energy difference.

Table 4: *The EnergyBalance rule.*

Rule: *EnergyBalance*
TrainingDay(?td)^hasEnergyIntake(?td,?i)^hasTEN(?td,?e) ^swrlb:subtract(?r,?i,?e)
->hasEnergyDifference(?td,?r)

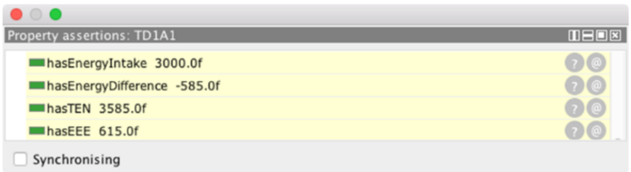

Fig.8: *Output info generated after executing the EEE, TEN, EnergyIntake, and EnergyBalance rules.*

The *TotalNutrients* rule (Table 1) is a SQWRL which sums all the nutrients for a given meal. Its chaining starts at line (1) by selecting the consumables for each meal in a training day. At line (2) is expressed that each consumable has a set of nutrients, with a name and value. At line (3) a set of these values is created, grouped by meal and training day, and added according to its grouping. Finally, at line (4) the results are provided in a tabular form, while they are used to assert or populate the data properties such as *HAS_VitaminA*, *HAS_Iron*, etc. in the respective meal individuals.

Table 5: *The TotalNutrients rule.*

Rule: *The TotalNutrients rule*	
TrainingDay(?td)^hasMeal(?td, ?m)^ hasNutritionDPPrescribesConsumable(?m, ?mc)	(1)
^hasNutritionNutrient(?mc, ?mn)^ hasNutritionNutrientName(?mn, ?mnn)^ hasNutritionNutrientValue(?mn, ?mnv)	(2)
. sqwrl:makeBag(?b, ?mnv)^sqwrl:groupBy(?b, ?td, ?m, ?mnn) . sqwrl:sum(?NUT, ?b) swrlb:multiply(?r1, ?cal) . sqwrl:makeBag(?b, ?r1) . sqwrl:sum(?EI, ?b)	(3)
-> sqwrl:select(?td, ?m, ?mnn, ?NUT)^ sqwrl:columnNames(“TrainingDay”, ”Meal”, “NutritionNutrientName”,“NutritionNutrientValue”)	(4)

The following Figure 9 presents the result of the execution of the *TotalNutrients* rule.

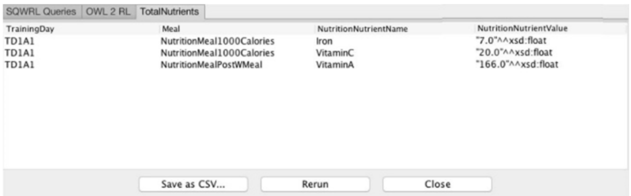

Fig.9: *Tabular form with results of the TotalNutrients SQWRL query-based rule execution.*

Based on the results obtained from the execution of the *TotalNutrients* rule, several other rules were created to check if each result is in accordance with the respective athlete's nutritional profile. In Table 6 is presented the *NutritionEvaluationVitaminAMin* rule for the evaluation of the level of vitamin A in a consumed meal according to a given athlete's nutritional profile. Similar rules were also created for the evaluation of other nutrients such as Vitamin B, C, Iron, etc. The atom chaining of Nutrition *EvaluationVitaminAMin* rule starts at line (1) by selecting the athlete and his/her intake meals for a given training day. At line (2) is expressed that each meal has its scheduled intake time or nutritional occasion (i.e., pre, post or during workout). At line (3) and line (4) are expressed that a meal has a total of vitamin A and an athlete has associated a nutritional reference values, respectively. At line (5) the respective occasion reference values must be chosen in order to compare them to meal values, while at line (6) is guaranteed that the nutrition element must be the same. At line (7) the comparison is performed and a string with the result is constructed in case of a problem. Finally, at line (8) a property is asserted in the meal individual. The following Figure 13 presents the result of the execution of the *NutritionEvaluationVitaminAMin* rule.

Table 6: *The NutritionEvaluationVitaminAMin rule.*

Rule: *NutritionEvaluationVitaminAMin*	
TrainingDay(?td)^hasWLAthlete(?td, ?at)^hasMeal (?td,?m)^hasNutritionMealName(?m, ?mn)	(1)
^hasNutritionDPAdministratedOn(?m, ?ao) ^hasNutritionProtocolName(?ao, ?aon)	(2)
^HAS_VITAMINA(?m, ?v)	(3)
^AthleteNutritionReference(?ar) ^hasWLAthleteReference(?ar, ?at)	(4)
^hasNutritionDPAdministratedOn(?ar, ?ao)	(5)
^hasNutritionReferenceMin(?ar, ?nrm) ^hasNutritionDPPrescribesConsumable (? nrm, ?nrmc) ^hasNutritionNutrient(?nrmc, ?nnr)^VitaminA(?nnr) ^hasNutritionNutrientValue(?nnr, ?nnrv)	(6)
^swrlb:lessThan(?v, ?nnrv)^swrlb:stringConcat (?s1, “In meal ”, ?mn, ” (at occasion ”, ?aon, ”) VitaminA intake is below recommended level”)	(7)
-> hasDietaryProblem(?td, ?s1)	(8)

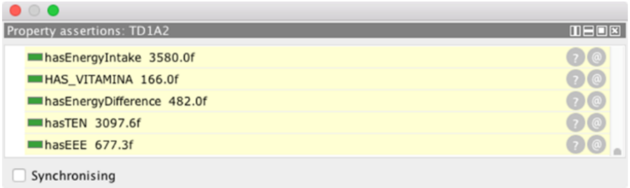

Fig.10: *Results of the NutritionEvaluation VitaminAMin SWRL rule execution.*

5. CONCLUSIONS AND FUTURE WORK

This second-iterated TDC-ontology consists of 110 classes, 50 object properties, 92 data properties, 167 inheritance relationships concepts, in a total of 1761 axioms, alongside 23 SWRL rules. It was mainly refactored toward better domain-level modularity, and scalability. In term of nutrition, weightlifters are often challenged with dietary management because there are many factors associated: it requires high energy intake to meet their energy needs due to their high body weight and high volume intense training, unable to receive frequent and detailed dietary consultation, and lack of nutrition knowledge. This study has contributed to dietary management in the following aspects: (i) building weightlifting TDC-cycle which collaborates contributions of several stakeholders such as coach, nutritionist, and biomechanist for supporting the monitoring of training and nutriton status of weightlifter, (ii) modeling ontology based on knowledge gathering from multiple related domains, and (iii) the design of task ontology with semantic rules for problem solving. However, after a considerable effort to populate the FB with all individuals required to exercises the prescribed rules, promising results and knowledge regarding the energy imbalance were collected. Under standard scenarios, the use of weightlifting TDC-cycle ontology can be helpful for nutritionist to manage dietary for athletes by reducing time consumption and calculation errors. In the future, with the major advantage of using open knowledge integration and knowledge base extensibility, this system can be expanded for other sports.

ACKNOWLEDGMENT

The authors would like to thank Prof.Adriano Tavares for his guidance and providing necessary information regarding the project.

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