Modelling Weightlifting "Training-Diet-Competition" Cycle Ontology with Domain and Task Ontologies

Piyaporn Tumnark[1,3], Miguel Abreu[2], Miguel Macedo[2], Paulo Cardoso[2], Jorge Cabral[2] and Filipe Conceição[1]
[1]*Faculty of Sport, University of Porto, Porto, Portugal*
[2]*Industrial Electronics Department, University of Minho, Braga, Portugal*
[3]*Faculty of Sports Science, Kasetsart University, Kamphaeng Saen Campus, Nakorn Pathom, Thailand*

Keywords: Ontology, Nutrition, Weightlifting, Biomechanics, Semantics, Reasoning.

Abstract: Studies in weightlifting have been characterized by unclear results, and paucity of information. This is due to the fact that enhancing the understanding of the mechanics of successful lift requires collaborative contributions of several stakeholders such as coach, nutritionist, biomechanist, and physiologist as well as the aid of technical advances in motion analysis, data acquisition, and methods of analysis. Currently, there are still a lack of knowledge sharing between these stakeholders. The knowledge owned by these experts are not captures, classified or integrated into an information system for decision-making. In this study, we propose an ontology-driven weightlifting knowledge model as a solution for promoting a better understanding of the weightlifting domain as a whole. The study aims to build a knowledge framework for Olympic weightlifting, bringing together related knowledge subdomains such as training methodology, biomechanics, and dietary while modelling the synergy among them. In so doing, terminology, semantics, and used concepts will be unified among researchers, coaches, nutritionists, and athletes to partially obviate the recognized limitations and inconsistencies. The whole weightlifting "*training-diet-competition*" (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.

1 INTRODUCTION

In weightlifting, enhancing the understanding of the mechanics of successful lift requires collaborative contributions of several stakeholders such as coach, nutritionist, biomechanist, and physiologist as well as the aid of technical advances in motion analysis, data acquisition, and methods of analysis. Currently, there are still a lack of knowledge sharing between these stakeholders. The knowledge owned by these experts are not captures, classified or integrated into an information system for decision-making. This challenge leads to the problem of paucity of information and inconsistencies of results regarding an integrated biomechanical analysis, training methodology, and nutrition analysis. In this study, we propose an ontology-driven weightlifting knowledge model as a solution for promoting a better under-standing of the weightlifting domain as a whole. Among many techniques, ontology is selected because it has been wide accepted as a useful method to simulate human proficiency in narrowly defined domain during the problem solving stage, by integrating descriptive, procedural, and reasoning knowledges. It can unify concepts and terminologies among weightlifting stakeholders, while partially helping obviate the paucity and heterogeneity of existing results. However, the weightlifting knowledge model should be scalable to easily integrate further related domain of weight-lifting, and also used to support the implementation of weightlifting recommender systems.

Literature about sport ontologies is rare. There are only few ontologies targeting sport domain. For example, Muthulakshmi (2015) 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 (2011) presented information retrieval from Sports Domain

Tumnark, P., Abreu, M., Macedo, M., Cardoso, P., Cabral, J. and Conceição, F.
Modelling Weightlifting "Training-Diet-Competition" Cycle Ontology with Domain and Task Ontologies.
DOI: 10.5220/0006929402070214
In *Proceedings of the 10th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management (IC3K 2018) - Volume 2: KEOD*, pages 207-214
ISBN: 978-989-758-330-8

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 use semantic relationships between ontology of concepts to retrieve more relevant and correct results. Zhai and Zhou (2010) 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. Although ontology-based works regarding to food and nutrition is not new and some of them already provided useful artefacts, there are not many studies using integrated ontology approach to combine knowledge from various domains to generate diet and exercise suggestions. Dragoni et al. (2017) presented PerKApp which aims to provide a full-fledged 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. (2011) proposed 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.

With respect to works discussed in the literature, this study aims to conceive and design an ontology-enriched knowledge model to guide and support the implementation of "*Recommender system of workout and nutrition for weightlifters*". In doing so, it will propose: (i) understanding the weightlifting training system, from both qualitative and quantitative perspectives, following a modular ontology modelling, (ii) understanding the weightlifting diet following a modular ontology modelling, (iii) semantically integrating weightlifting and nutrition ontologies to mainly promote nutrition and weightlifting snatch exercises interoperability, (iv) extending modular ontology scope by mining rules while analysing open data from the literature, and (v) devising reasoning capability toward an automated weightlifting "*training-diet-competition*" cycle supported by previously mined rules. To the best of our knowledge, this kind of design 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.

This paper is divided into four sections. Section 1 presents an introduction; Section 2 describes the followed methodology for the ontology development; Section 3 describes the constructed ontology and rules derived from the development process. Finally, some conclusion remarks are mentioned in the Section 4.

2 METHODS

Based on the guidelines proposed by Chi et al. (2015), the following approach is proposed to ontologically model and design of the weightlifting TDC cycle.

2.1 Establishing the Domain Scope and Analysing Problem Scenarios

Managing training and competition performance of weightlifters is a very challenging problem due to the interplay among multiple sources of unobserved heterogeneity at athletes' profile, competition, training model, dietary protocol, research, resource, or year level. It involves several knowledge sources, spreading into several information dimensions such as nutrition, training, and biomechanics (Figure 1).

Nutritional knowledge includes the definition of dietary protocol, energy expenditure estimation, energy balance, as well as food composition in terms of macro- and micro-nutrients. Dietary protocol as a concept, includes recommended food intake according to athletes' preferences and restrictions at specific training and competition instants. Coaching and training knowledge supports a qualitative analysis technique which includes a controlled vocabulary. It consists of common terms to alleviate semantic differences between training methods, lifting exercises and their phases concepts, as well as barbell and body kinematics and kinetics. The training dimension is mostly represented by descriptive terms or abstract values. They are regarding lifting exercises' performance which can be mapped to ground values measured in real-time by biomechanics analysis systems or energy expenditure measurement devices. Biomechanics knowledge supports a quantitative analysis approach based on ground values and it includes a controlled vocabulary consisting of sub-concepts (e.g., calibration method, acquisition method, and analysis method,) and concepts like lifting analysis, resource, and muscle activity.

To implement the problem scenarios analysis, we firstly tackle individually each information dimension of the training-diet-competition (TDC) cycle and only then formalize the problem solving according to the following two sets of non-logical axioms, required to estimate and/or measure performance, as well as to examine and monitor the designed and prescribed training to each individual athlete.

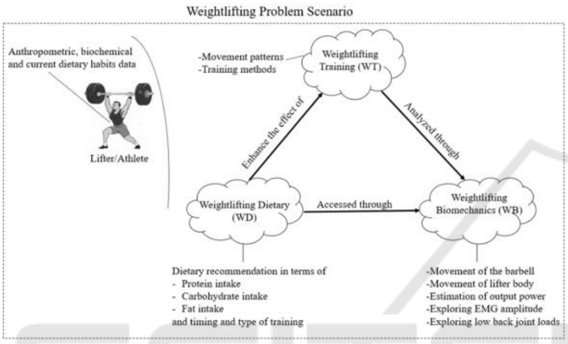

Figure 1: The problem solving for improving weightlifting ability.

2.1.1 Assessment and Monitoring of Nutrition Dietary Features

Several prediction equations and method of analyses will be required to estimate and measure the energy expenditure which depends on muscular activation and muscle contraction. Both anthropometric and metabolic measurements having been carried out because physical activities are usually classified in terms of their mutually dependent biomechanical and metabolic aspects, as well as their intensities and durations. Therefore, not only body composition should be assessed but also other potential sources of change in energy expenditure during lifting activities, through activation levels of major muscles groups. By assessing the energy expenditures while lifting, the prescribed energy intake will be examined to determine the energy balance status and then accordingly adjusted (i.e., in terms of macro-and micro-nutrients) for a more suitable dietary intake. For accurate measurement of energy expenditure and outcome assessment, accelerometer-, heart rate-, electromyography-, or calorimetric-based devices have been used to collected data related to diverse energy expenditure components.

2.1.2 Assessment and Monitoring of Biomechanics Features

To maintain consistence in each lift while enhancing performance, weightlifting biomechanics have been analysed following qualitative, quantitative, and predictive approaches, as well as combinations of them (Ho et al., 2014). Quantitative approaches have been toward kinetics and kinematics of barbell and weightlifter body, mainly trying to classify barbell trajectory, identify optimal lifting technique, quantify barbell parameters, joint angle, and applied force. In so doing, it required several devices such as motion capture systems, force plates, and EMG, as well as several and different method of analysis.

Having already defined the motivation for addressing issues related to the weightlifting TDC cycle, the following general competence questions were formulated to be answered by the ontology and so, limiting the ontology scope:

1) Did the athlete properly lift the barbell?
2) Did the athlete’s body move accordingly during exercises phases?
3) Was the athlete well-served in terms of macronutrients and micronutrients according to the training protocol specificity?
4) Did the rhythmic execution reflect an efficient snatch technique?

The rhythmic execution, should be understood as the definition presented by Ho et al. (2014) i.e., the coordination movement of the weightlifter-barbell system for an efficient and effective lift.

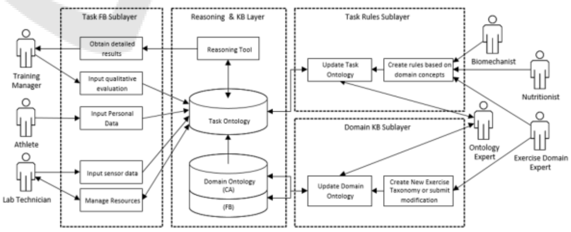

Figure 2: Weightlifting TDC-cycle OWL- and Rule-Knowledge-based System.

In Figure 2, each actor plays a fundamental role in the assessment task. The Reasoning and Knowledge Base layer encompasses three non-overlapping sublayers. The four perspectives are defined as follows. (i) *Task Fact Base (FB)* encloses task related instances. The Athlete creates its profile by inserting relevant personal data whereas the Training Manager and Lab Technician are in charge of updating the knowledge base with training data, respectively, providing qualitative and quantitative assessments. (ii) *Reasoning and Knowledge Base (KB)* is composed of all available knowledge over which the reasoning is performed. The *Task FB* input is used as a trigger to start the inference process, which is based on SWRL rules whereas the output of that process is given as a series of axioms, representing detailed results with practical, human readable data. (iii) *Task Rules* comprises all SWRL rules created to infer knowledge from training related instances. These rules may be created or updated by several experts from different domains. (iv) *Domain Knowledge Base* refers to the application-independent axioms, which can be updated to better cope with improvements in the understanding of applicable fields. Knowledge bases are implemented as ontologies, which were divided into assertion axioms (i.e., *Fact base; FB*) and terminological axioms (i.e., *Concepts and Attributes; CA*) to illustrate the interaction of both areas in the global architecture. Each *KB* and respective rules were created using Protégé and its plug-ins.

2.2 Modelling and Design of the Weightlifting Domain Ontology

To obtain a deep understanding of aspects and concrete entities comprising the weightlifting TDC cycle, repetitive collaboration meetings were organized between athletes, coaches, biomechanist and nutritionist along with electronics and software engineers. The following design artefacts express ontologies in the weightlifting TDC-cycle knowledge -based system i.e., TDC-Ontology = (CA, CV, FB, R, A):

2.2.1 Concepts and Attributes (CA)

Different concepts in the TDC-Ontology have been divided into four main knowledge sets: training, biomechanics, nutrition, and problem solving, complemented with an athlete profile concept as nearly all observation and measurement are around athlete's activities. The first three sets correspond to domain ontology which identifies general concepts and their relations in the field of weightlifting, while the fourth one is part of the task ontology.

Training-or coaching-related ontology subset refers to classes modelling exercises performed by athlete, with each exercise consisting of several phases. Basically, these concepts are used to promote a qualitative weightlifting analysis and are mainly represented by abstract values regarding observable lifting performance by a coach.

Biomechanics-related ontology subset is used to leverage a quantitative weightlifting analysis and are represented by the *ExerciseProperty* concept. The main purpose is complementing qualitative lifting performance values with biomechanics ground values measured during a lifting exercise phase, using biomechanics equipment.

Nutrition-related ontology subset is also used to leverage a quantitative weightlifting analysis and it is modelled by the following subclasses. The *Dietary Protocol* related to each workout period, the respective *NutrientPortions*, and the *Consumable* having nutrients. Nutritional ground values are measured for a lifting exercise phase, using a combination of energy expenditure measurement equipment, prediction equations, and methods of analysis. The *DietaryProtocol* concept prescribes the receipt of nutrient portions for a specified workout phase, the *NutrientPortions* concept identifies a specific nutrient and its amount in terms of macro- and micro-nutrients and the *Consumable* concept represents the food and drink that are sources of nutrients. In this prototype, *Consumable* concept are adopted from our previous work (Tumnark et al., 2013). However, in the future, we may consider adopting the food concept from other available literature in order to cover all available menus items.

2.2.2 The Controlled Vocabulary (CV)

Horizontal to concepts defined in *CA*, there is a list of authorized keywords, used across both domain and task ontology. The list contains nine subclasses and under each of them, authorized keywords are used to provide reference and indexing for communication with other concepts and instances. Subclasses are the *WorkoutPhase* concept defining periods for which a dietary protocol is prescribed, which is instantiated as authorized keywords *Preworkout, Duringworkout, and Postworkout.* The *DayPart* concept represents day time prescribed for weightlifting training and dietary intake which is instantiated as authorized keywords *Morning*, *Afternoon*, and *Evening*. The *Acquisition Method* concept establishes methods used to collect quantitative ground values, e.g., heart rate monitor, motion analysis, electromyography (EMG), or force measurement; *Muscle* concept defines muscles where activity should be measured, e.g., *VastusLateralis*, *Biceps Femoris*, *PectineusGracilis.* The *AnalysisMethod* concept establishes analysis methods used for the assessment of energy expenditure and biomechanics features from several kinds of collected data, such as kinetics, kinematics, and physiological. The *Calibration Method* concept establishes some known methods for proper calibration of biomechanics equipment which is instantiated as authorized keywords *OnePointCal*, *TwoPointCal*, and *Curve FittingCal*. The *Resource Type* concept defines resource types used for quantitative measurement of barbell/body kinematics and kinetics (e.g., video camera, infrared cameras, force plates), body composition, as well as training resource (e.g., barbell and weight plates). The *Nutrient* concept includes groups of macro- and micro-nutrients, as standard vocabulary used in energy expenditure assessment and dietary intake to promote optimal health and performance across different scenarios of weightlifting training. The *ExerciseMethod* concept classifies weightlifting training methods under Bulgarian or Russian frameworks and principles.

2.2.3 The Fact Base as a Set of Individual (FB)

Concepts in the domain ontology are further elaborated and terminal concepts are described in terms of instances. These individuals belonging to the ontology will act as the foundations of the knowledge base supporting the problem solving activity. The fact base is populated by a collection of facts generated through the elaboration of domain ontology concepts, i.e., terminal concepts are described in terms of instances. These instances contain measured nutritional and biomechanics ground values as well as observable training-related abstract values collected by coaches which are mapped to corresponding ground values.

2.2.4 Relationship between Classes (R)

Excluding the data properties presented in Table 1, the remaining relationships (i.e., among classes) are constructed as object properties. Figure 3 displays some individuals that represent the analysis of a phase of the Snatch exercise. The *Snatch* exercise individual is related to five phases/six positions by the object property *hasExercisePhase* and, for the *Firstpull* phase (*Liftoff*position), there are some *Exercise Property* individuals where each is related to a *Result* individual that belongs to an individual of the *PhaseAnalysis* concept, called *LiftoffAnalysis*.

2.3 Engineering the Task Ontology

To solve specific weightlifting TDC-cycle problems as previously formulated through competency questions, the task ontology will use the conceptual structure of the domain ontology expressing the semantic knowledge of biomechanics, nutrition, and training dimensions of the TDC-cycle, while defining other concepts’ constituent properties to describe the problem solving structure. Basically, (i) property values of known facts or unknown knowledge are defined to separate asserted properties from inferred ones, (ii) the corresponding domain and range of properties are asserted, and then, (iii) Semantic Web Rule Language (SWRL) rules supported by Sematic Query-Enhanced Web Rule Language (SQWRL) are created for reasoning about individuals on *FB* and so, addressing the insufficient expressivity of ontologies in properties association and operation required by the formulated competency questions.

Table 1: Data properties of each concept presented on the domain ontology.

Concept	Property	Type	Range
Consumable	HasNutrientPortion*	Asserted	NutrientPortion
	hasCalories	Asserted	(double)
Control Vocabulary			
Acquisition Method	hasAccuracy	Asserted	(double)
	hasIntrusionLevel	Asserted	(int)
Analysis Method	hasAccuracy	Asserted	(double)
Calibration Method	hasAccuracy	Asserted	(double)
Nutrient	hasName	Asserted	(string)
Dietary Protocol	hasAthlete*	Asserted	AthleteProfile Analysis
	hasAthletePreference*	Asserted	Consumable
	hasAthleteRestriction*	Asserted	Consumable
	hasNutrientPortion*	Asserted	NutrientPortion
	hasWorkoutPhase*	Asserted	WorkoutPhase
ExerciseProperty	hasMax	Asserted	(double)
	hasMin	Asserted	(double)
	hasName	Asserted	(string)
NutrientPortion	hasNutrient*	Asserted	Nutrient
	hasValue	Asserted	(double)

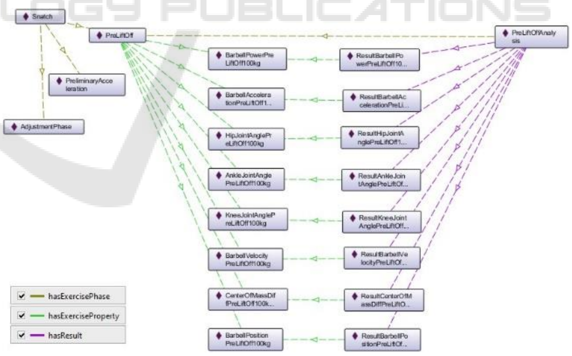

Figure 3: Some individuals and their associated object properties.

Generically, the problem solving structure consists of two main groups: nutrition analysis and training analysis (i.e., addressed both in terms of qualitative and quantitative analysis, being the latter achieved through biomechanics analysis) according to Figure 1 and also the aforementioned competency questions. Therefore, some concepts that constitute the problem solving structure are:

The AthleteProfileAnalysis concept contains 9 properties, being 8 asserted properties and 1 inferred from rule *EEE* (Exercise Energy Expenditure).

The *PhaseAnalysis* concept contains 8 properties. 6 are asserted properties and 2 are inferred properties, which are used for the evaluation of an exercise's phase. (see rule *analyse*).

The *ResourceAnalysis* concept contains 5 asserted properties and 1 inferred property that represents the accuracy of the resource. It is inferred using rule *topResources*.

The *ExercisePropertyAnalysis* concept contains 2 asserted properties and another property that is either asserted or inferred, to represent the evaluation of the result. When inferred, this evaluation maps to rules *evaluateMax*, *evaluateMin,* and *evaluateMinMax*.

The *TrainingDayAnalysis* concept contains 9 properties, where 3 are asserted and 6 are inferred. The exercise energy expenditure (EEE) is inferred by the rule *EEE*. The total energy needed (TEN) and the resting metabolic rate (RMR) are inferred by rules *TENmale* or *TENfemale*. The energy intake is inferred by the rule *EI* while the difference between consumed and energy needed is mapped to the Rule *balance.* One property was used to report dietary problems of the training day, which is inferred from rules *evaluateNutrientsMax* and *evaluateNutrientsMin*.

Three of these concepts are combined to form a complete biomechanics and nutrition analysis chain, being the core of the problem solving structure. Starting with the *ExercisePropertyAnalysis*, this concept analyses the individual biomechanics characteristics of an exercise which are mapped to the *ExerciseProperty* concept. Then, *PhaseAnalysis* focuses on several phases of each exercise and provides a broader analysis of the biomechanics of an exercise. Lastly, *TrainingDayAnalysis* encompasses the analysis of nutrition for a full training day of multiple exercises.

3 RESULTS

All the 11 inferred properties of the Task Ontology require semantic rules that relate facts and, thus, are able to infer new knowledge. In order to answer all the competency questions, SWRL-based rules and SQWRL queries have been used. Although SWRL is built on the same description logic foundation as OWL-DL, it provides strong formal guarantees when performing inference. It has considerably more expressive power than OWL alone, particularly when dealing with complex interrelationships between OWL individuals or when reasoning with data values (Dhingra and Bhatia, 2015). In this study, SWRL rules operate over the instances of the ontology and are expressed as a chain of atoms that, if all hold true, a consequence is produced. SQWRL queries work similarly to the SWRL rules but they are used for retrieving knowledge from the ontology instead of creating it. Also, query's result needs to be manually added to the ontology. Overall, 9 rules and 3 queries were created and these can be separated into three broad categories: Biomechanics, Nutrition, and Resource reliability.

3.1 Developing Semantic Rules

Due to the space limitations, only some of the drafted SWRL rules are described in detail.

Biomechanics/Coaching Rules

1) evaluateMinMax used for the evaluation of an exercise and it starts by evaluating if each of its properties are within a considered favorable range. It verifies whether the value of an exercise property's result is within the specified range, and in case of being true, it causes the result to receive a positive evaluation denoted by the word "OK". Breaking down the rule, it starts by obtaining an *Exercise PropertyAnalysis* individual called *r* (1) and its value (2) using the r's *hasValue* data property. Then it obtains, through the *hasExerciseProperty* object property, the *ExerciseProperty* individual *p* (3) and, like before, its min and max values (4-5) are retrieved using the *hasMin* and *hasMax* data properties, respectively. After obtaining all the necessary values, the rule then checks if the result's value is within the exercise property's range (6-7) and it asserts *r*'s evaluation as "OK" (8).

```
Rule: evaluateMinMax
ExercisePropertyAnalysis(?r)             (1)
^ hasValue(?r, ?v)                       (2)
^ hasExerciseProperty(?r, ?p)            (3)
^ hasMin(?p, ?min)                       (4)
^ hasMax(?p,?max)                        (5)
^swrlb:greaterThanOrEqual(?v,            (6)
?min)
^swrlb:lessThanOrEqual(?v, ?max)         (7)
-> hasEvaluation(?r, "OK")               (8)
```

2) evaluateMin/evaluateMax are used to evaluate if the value of the result is below the minimum or above the maximum. It uses the *ExerciseProperty*'s name to be easily identifiable, as this evaluation will be later used for the overall examination of the exercise.

3) analyse examines if the exercise was not properly executed by checking if there are any unsuccessful results and so, reporting all associated problems.

Nutrition Rules

4) EEE calculates the Exercise Energy Expenditure based on the formula EEE = METs * 0.0175 * Weight * Duration.

```
Rule: EEE
TrainingDayAnalysis(?tda)
^ hasPhaseAnalysis(?tda, ?pa)
^ hasResult(?pa, ?r)
^ hasExercisePhase(?pa, ?ep)
^ EPDuration(?p)
^ hasExerciseProperty(?r, ?p)
^ hasValue(?r, ?d)
^ hasTrainingDay(?tda, ?td)
^ hasAthlete(?td, ?a)
^ hasWeight(?a, ?w)
^ hasExerciseRoutine(?td, ?er)
^ hasExercise(?er, ?e)
^ hasExercisePhase(?e, ?ep)
^ hasMET(?e, ?m)
 ^ swrlb:multiply(?v0,"0.0175"^^
xsd:float, ?m)
^ swrlb:multiply(?v1, ?v0, ?d)
^ swrlb:multiply(?v2, ?v1, ?w)
˚ sqwrl:makeBag(?b, ?v2)
^ sqwrl:groupBy(?b, ?tda)
˚ sqwrl:sum(?s, ?b)
-> sqwrl:select(?tda, ?s)
```

5) femaleTEN calculates the RMR and the amount of energy needed (TEN) by an athlete.

6) balance compares the energy intake with the amount of energy needed to calculate the energy difference.

7) EI is used to calculate the necessary energy intake for a training day.

8) evaluateNutrinetsMin evaluates the athlete's nutrients intake for each workout phase. In this case, it evaluates if the intake is below the recommended level and reports a problem.

Resource Reliability Rule

9) topResources retrieves all the resources for each type in descending order of accuracy.

```
Rule: topResources
ResourceAnalysis(?res)
^ hasResourceType(?res, ?rt)
^ hasMethod(?res, ?m)
^ hasAccuracy(?m, ?ac)
˚ sqwrl:makeBag(?b, ?ac)
^ sqwrl:groupBy(?b, ?rt,?res)
˚ sqwrl:max(?max, ?b)
-> sqwrl:select(?rt,?res,?max)
```

3.2 Evaluation of the Knowledge Representation

To illustrate the reasoning process, a simple test case was inserted in Protégé. The athlete had to perform a full Snatch lift, while monitoring numerous biomechanical variables. To accomplish that, six instances of *PhaseAnalysis* were created along with several phase related sensor results. These values, which are *ExeciseProperyAnalysis* instances (Figure 4), were linked to the analysis instance via the *hasResult* object property.

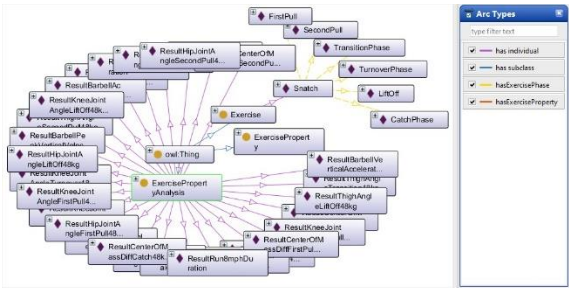

Figure 4: Snatch, its six phases and all associated exercise property analysis instances.

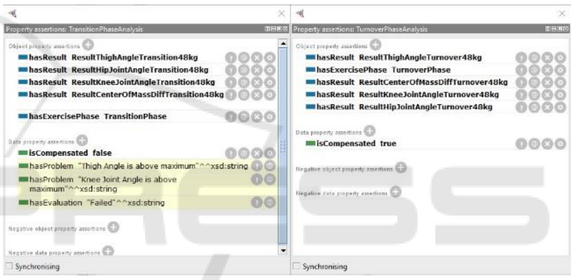

Figure 5: Rule based evaluation of Transition phase and Turnover phase of Snatch.

Upon comparison of the results with exercise ranges (domain knowledge), Pellet, which was the chosen reasoner, inferred the existence of 2 values out of bounds in the third phase of the exercise as presented in Figure 5. The value of thigh angle and knee joint angle were above maximum value and the exercise was not declared as compensated by *The training manager*. So, the evaluation was reported as "failed". It means that there were errors in lifting's technique of this athlete regarding the movement of thigh and knee and it was not approved by an expert. On the right side of the same figure, is presented a different case, i.e., the analysis of the fifth phase. The system generated no problems because it was manually reported as being compensated by the *Training Manager*. In this case, even there was an error in lifting's technique of an athlete, it was approved quantitatively by an expert.

4 CONCLUSIONS

This study demonstrated the use of Ontology Web Language (OWL) and SWRL to semantically model the whole weightlifting TDC-cycle, bringing together related knowledge subdomains, while modeling the synergy among them. Nutritional, biomechanics, and coaching/training facts were combined with SWRL rules representing rhythmic execution and energy balance to infer athlete' lifting performance. Moreover, these rules can be used to trigger and classify any qualitative-quantitative lifting mismatch as corner cases which will deserve deeper and future quantitative analysis, both regarding nutritional and biomechanics perspectives. Each KB and respective rules in TDC Competency Questions Engine Architecture were created using only Protégé and its plug-ins, resulting into: 43 classes, 57 properties, and 29 relationships. Overall, 9 SWRL rules, and 3 SQWRL queries were created and these can be separated into three broad categories: Biomechanics, Nutrition, and Resource reliability.

Beside the advantages that was mentioned earlier, coaches and athletes can be benefited from this system in several ways such as it can help coaches to identify errors in the technique during the lifting. This is due to the fact that errors can be overcome by compensatory movement and successful lift can still be achieved. This point causes a gap between the weightlifter's actual performance and what the weightlifter could potentially lift. This system could narrow this gap and help to identify which factors lead to efficient technique and which ones limit the performance. In case that the *FB* is large enough, the novel factors/relationships might be discovered.

In spite of the mentioned applicability of the proposed weightlifting TDC-cycle OWL knowledge-based system, few drawbacks have been identified to be later tackled in the next iterated TDC-ontology:

1) Re-design the TDC-Ontology to address domain-level modularity, as well as being more scalable.
2) Devise the integration of new concepts and properties which will ease the modeling of corner cases (i.e., qualitative-quantitative lifting mismatch).
3) Iteratively tune rhythmic execution SWRL rules according to identified corner cases, biomechanics analysis, and optimization approaches, as well as to reference top performance athletes, both in terms of rhythm and anthropometric features.

Furthermore, more tests should be made based not only on open data presented and discussed in the existing literature but also lively collected during weightlifting training.

REFERENCES

Chi, Y. L., Chen, T. Y. & Tsai, W. T. 2015. A chronic disease dietary consultation system using OWL-based ontologies and semantic rules. *Journal of Biomedical Informatics,* 53**,** 208-19.

Dhingra, V. & Bhatia, K. K. 2015. Development of Ontology in Laptop Domain for Knowledge Representation. *Procedia Computer Science,* 46**,** 249-256.

Dragoni, M., Bailoni, T., Eccher, C., Guerini, M. & Maimone, R. 2017. A semantic-enabled platform for supporting healthy lifestyles. *Proceedings of the Symposium on Applied Computing.* Marrakech, Morocco: ACM.

Ho, L. K., Lorenzen, C., Wilson, C. J., Saunders, J. E. & Williams, M. D. 2014. Reviewing current knowledge in snatch performance and technique: the need for future directions in applied research. *Journal of Strength and Conditioning Research,* 28**,** 574-86.

Mihnea, D., Madalina, I., Mihai, D. & Stefan, T. M. The Runner-Recommender System of Workout and Nutrition for Runners. 13th International Symposium on Symbolic and Numeric Algorithms for Scientific Computing, SYNASC 2011, 2011 Timisoara, Romania. 230-238.

Muthulakshmi, S. 2015. *Design and development of ontology Based e learning system for sports Domain.* Doctoral dissertation Doctoral dissertation, Anna University.

Nwe Ni Aung & Naing, T. T. Sports Information Retrieval with Semantic Relationships of Ontology 3rd International Conference on Information and Financial Engineering, 2011. IPEDR.

Tumnark, P., Conceição, F., Vilas-Boas, J. P., Oliveira, L., Cardoso, P., Cabral, J. & Santibutr, N. 2013. Ontology-based personalized dietary recommendation for weightlifting. *In:* Honghua, T. & Tingting, W. (eds.) *Advances in Intelligent Systems Research.* Atlantis Press.

Zhai, J. & Zhou, K. Semantic Retrieval for Sports Information Based on Ontology and SPARQL. ISME'2010, 7-8 Aug. 2010 2010. 395-398.