Explicit Exercise Coaching for Health Promotion based on Bio-mechanics and Ontology Engineering

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ABSTRACT
Effective exercise coaching is critical for helping people master the correct forms of movements in order to gain the benefit of exercise. However, the potential ambiguity of verbal instructions in exercise coaching may become a hindrance to effective coaching. This study proposes a framework to support explicit and objective exercise coaching. We first present the two components of the proposed framework: (1) quantifying the differences between the correct and the wrong forms of a movement using bio-mechanics, and (2) modelling the sequence of muscle and joint activation in the correct form using ontology engineering. We then provide two examples of applying the proposed framework to exercise coaching on two basic movements. The ultimate aim of the study is to reduce unnecessary injury and to improve the quality of coaching services in the context of health promotion.

Author Keywords
Health; exercise; coaching; knowledge engineering; biomechanics; ontology; support system; m-Health.

ACM Classification Keywords
J.3. Life and medical sciences: Health; H.1.2 User/Machine systems: Human information processing.

INTRODUCTION
In Japan, the ratio of aged population is expected to reach 30% of the whole population by 2020. The government is making great effort to promote healthy lifestyle as a proactive strategy to reduce healthcare cost. Among various aspects of a healthy lifestyle, exercise is a simple and established intervention that improves overall health and life quality in both normal and pathological populations [1-2]. For people with chronic and pathological conditions, proper exercise training can help correct abnormalities and facilitate rehabilitation [3]. However, the benefits of exercise can only be obtained when people perform the movements correctly. Practicing the wrong forms for movements may impose unnecessary burdens to joints and muscles, and may even cause injuries. Therefore, effective coaching is extremely important that helps people master the correct forms for movements in exercises. One potential hindrance of effective coaching in health promotion is the ambiguity of verbal and spoken instructions. Because human movement is achieved through complex interaction among bones, muscles, and joints, giving clear instructions on how to perform the correct form for a movement is therefore a challenging task for coaches. Verbal coaching in many cases is subjective and may cause misunderstanding in the learners.

This study aims to address the above problem by establishing a framework for explicit, quantitative and standardized coaching for health promotion. The proposed framework has two components. The first component aims to quantify the differences between the correct and the wrong form for a movement using biomechanical variables. We apply biomechanics in combination with statistical and machine learning techniques to identify the key biomechanical variables whose values are statistically different in the correct form and the wrong form for a movement. The second component aims to model the sequence of muscle and joint activation (i.e. the process) in the correct form for a movement using ontology engineering. Movement ontology organizes the knowledge

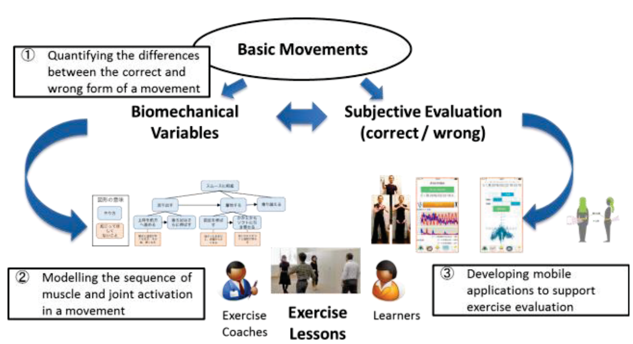

Figure 1. Overview of proposed framework for explicit, quantitative and objective coaching.

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of movement processes in a structured fashion, which can be easily shared between coaches and learners as well as between different coaches to support effective coaching and assessment, benefiting learners and coaches. This framework aims to create quantitative, structured, and thus explicit knowledge for exercise coaching in the context of health promotion. Furthermore, the proposed framework can be used to develop intelligent mobile applications to support exercise coaching and learners' self-practice. The whole picture of this study is illustrated in Figure 1. The establishment of a standardized and explicit coaching framework would contribute to the improved overall health and life quality of the population, and eventually to the reduced healthcare cost of the country.

RELATED WORK

Exercise is considered as an important aspect of a healthy lifestyle, benefiting both normal people and patients [1, 2, 3, 24]. Exercise coaching has become an established research area in which quantitative, qualitative or mixed methodologies have been adopted [4]. A range of methods and analysis techniques have been employed in this area to answer a variation of questions [5]. As information and computing technologies advance, exercise coaching is becoming more integrated to people's daily life through portable electronic devices. However, none of these digital tools intended to change the qualitative nature of exercise coaching [6]. The potential ambiguity in exercise coaching remains to be an under-investigated topic, though a few studies already suggest a possible negative impact of ambiguous instructions [7-8].

In our proposal, we apply biomechanics and ontology engineering to achieve the goal of explicit and objective exercise coaching. Biomechanics studies the continuum mechanics (i.e., the loads, motion, stress, and strain of solids and fluids) of biological systems. The study of biomechanics of humans spread throughout multiple levels, ranging from the molecular and cellular level (e.g. the circulation of blood cells) [9], to the tissue and organ level (e.g. tissue repair) [10, 14], and to the system level (e.g. the movement of human body) [11]. On the system level, typical measurement instruments are motion capture system, electromyogram, and force plates. These devices are used to measure biomechanical variables such as angle, acceleration, moments of joints, as well as muscle activities. The other field of knowledge that our proposal based on is ontology engineering. Ontologies are the formal representations of a set of concepts with a domain and the relationships between those concepts [12]. Ontology engineering studies the methods and methodologies for building ontologies [15], and it has been applied in many health-related fields such as assisted nutrition [16], behavior recognition [17], and context recognition in personalized physical therapy [18]. In our proposed framework, we apply ontology engineering to model the sequence of muscle and joint activation during the correct form for a movement and organize this knowledge into a coaching ontology in the form for a tree structure. This knowledge tree can be easily shared, can be merged to other knowledge tree, and can be further extended as more knowledge is added.

PROPOSED FRAMEWORK FOR EXPLICIT EXERCISE COACHING

Quantifying Differences between Correct and Wrong Forms for Basic Movements

Knowing what is the correct or most appropriate form for a movement and being able to perform the movement accordingly is the ultimate goal of exercise training. When explain the correct forms for a movement, however, coaches usually use abstract and qualitative words such as "natural", "relaxed", "smooth", "steady", and "powerful". The interpretation of these words could be different from one person to another. On the other hand, it is difficult to articulate the process how coaches assess learner's movements. Based on their long term training experience, exercise coaches can intuitively assess whether a movement was performed according to its correct forms or how close a movement was performed to its best form. Since the assessment is subjective and qualitative in nature, the feedback from coaches may provide little actionable knowledge, and exercise learners may find it difficult to improve their movements based on the feedback.

We set out to understand coaches' assessment process in a quantitative way. We attempt to identify the key biomechanical variables (e.g. joint angle, joint moment, muscle EMG) that take on different values when a movement is performed in its correct and wrong forms. We do not intend to model the mechanical function of the musculoskeletal system using the principles of mechanical physics. Instead, we focus on modelling the quantitative relationship between the performance of a movement and the biomechanical variables of the movement using statistical and machine learning techniques.

The biomechanical variables of human movements can be measured using a number of devices including motion capture systems, force plates, accelerometers, and electromyography. For exercises that involve intensive brain activities, electroencephalography may be used to measure brainwave as well. In the meanwhile, the subjective assessment of a movement can be collected from coaches. To ensure inter-rater reliability, assessments by multiple coaches (≥ 2) with 80% agreement between raters is the minimum required [13]. Using statistical and machine learning techniques, we can identify the key variables that have strong discriminating power between the correct and the wrong forms for a movement.

Modeling Correct Forms for Basic Movements using Ontology Engineering

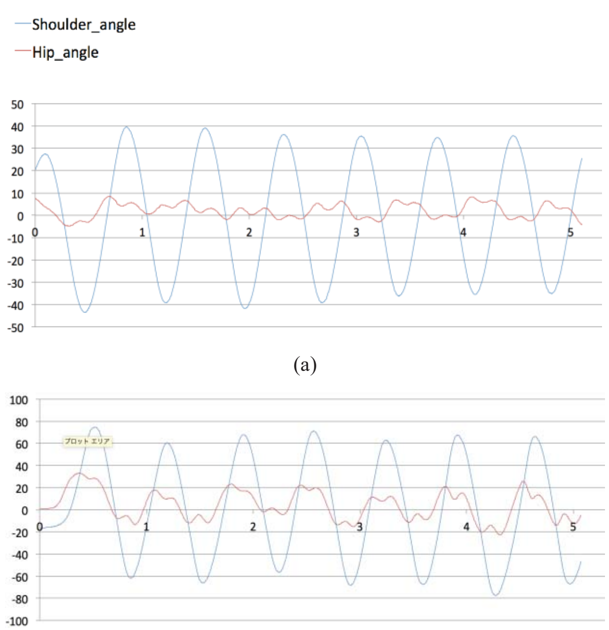
In exercise coaching, the description of the correct form for a movement is subject to the style and preference of a coach. The description of the same form may vary from coach to coach due to personal experience and interpretation, making it difficult for learners to gain a consistent view of how a

For Learners	- Help visualize the sequence of muscle and joint activation on the micro-level that are otherwise overlooked. - Make it possible for self-assessment.
For Coaches	- Standardize the words and phrases used for exercise instructions. - Aid in objective and consistent assessment on the performance of movements. - Assist information sharing among coaches, and between coaches and learners. - Can be further extended and tailored. - Provide a bottom-up approach for modelling complex activities.

Table 1. Advantages of constructing knowledge trees for exercise coaching.

movement should be performed. Although coaches would generally demonstrate the correct form for a movement on their own, physical demonstration does not convey explicitly the correct sequence of muscle and joint activation, and learners may miss important details that are not visually straightforward.

In our proposal, we use ontology engineering to extract the important information from coaches' instructions, and we structure the information into a knowledge tree to model the process (i.e. the sequence of muscle and joint activation) of the correct form for a movement, i.e. the extraction of the atomic movement. To facilitate information collection and sharing, we developed a mobile application named DANCE.



(a)

(b)

Figure 2: Shoulder angle and hip angle. (a) Correct form; (b) wrong form.

Coaches can use this system to record their verbal instructions on the correct forms for basic movements, to log their observations in classes, and to store their assessments on learners' performance. We regularly analyze and categorize all the collected data, merge similar topics and eliminate redundant information. We then use ontology engineering in combination with thematic analysis to construct knowledge trees which can be shared among coaches and learners. The established knowledge trees can be further expanded when new knowledge is added. They can also be combined together to model more complex movements and activities. The advantages of constructing knowledge trees for correct forms for movements are summarized in Table 1.

CASE STUDIES

In this section, we apply the proposed framework to body trunk torsion movement which is a basic movement in many sports and exercises such as dance and martial arts.

Firstly, we attempted to quantify the differences between natural and unnatural body trunk rotation movements. One professional dancer was invited to perform the correct form (the result of the efficient usage of outer and inner muscle; natural and steady) and the wrong form (the result of over-usage of solely outer muscle; uncoordinated and shaky) for the rotation movements respectively. We used motion capture system and a force plate to measure hip angle, shoulder angle, and floor torque.

In our experiment, 8 markers were placed at ears (REAR, LEAR), shoulders (RSHO, LSHO), hip joints (RHIP, LHIP), and ankles (RANK, LANK). Shoulder angle was calculated as the angle between the line connecting RSHO and LSHO and the (x, y) plane. In a similar fashion, hip angle was calculated as the angle between the line connecting RHIP and LHIP and the (x, y) plane. Rotation angle was calculated as the difference between shoulder angle and hip angle.

The time series data of shoulder and hip angle measured by the motion capture system are shown in Figure 2. The range of hip angle was much smaller than that of shoulder angle, and the frequency of hip movement was approximately 4 times of that of shoulder, in both the correct form (Figure 2a) and the wrong form (Figure 2b). The correct form distinct from the wrong form in the two aspects: the magnitude of shoulder and hip angle, and the phase difference between shoulder and hip. On one hand, the magnitude of shoulder angle was approximately within the range of [-40°, 40°] in the correct form, whereas the range doubled in the wrong form. On the other hand, the phase difference between shoulder and hip was approximately 180° in the correct form, whereas the phase difference in the wrong form was approximately 0°, probably due to the overuse of outer muscles.

Secondly, we constructed a knowledge tree for body trunk torsion movement. In order to collect knowledge from coaches' instructions, we organized a dance workshop in

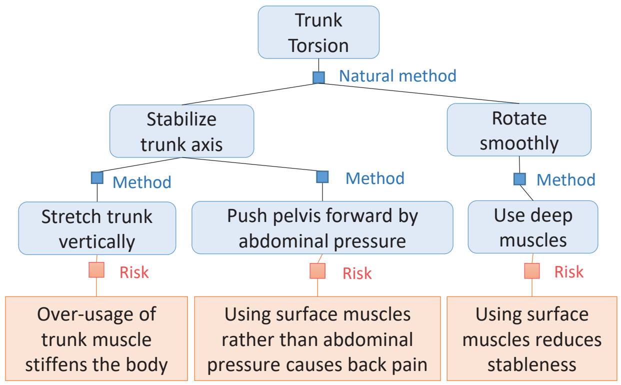


Figure 3: The Knowledge Tree of Body Trunk Torsion.

the Omori Dance Studio in Japan to practice the correct form for body trunk torsion as part of a dance lesson. Two professional dance-sports teachers and 28 dance learners participated in the workshop.

We video-recorded the whole workshop and transcribed the verbal instructions given by the coaches. A knowledge tree for how to perform natural body trunk torsion was constructed using ontology engineering in combination with thematic analysis, which is shown in Figure 4. The blue and red blocks represent tasks and typical mistakes. As is shown in Figure 3, the key to natural body trunk torsion is stabilizing trunk axis and rotating upper body smoothly. The latter further requires the correct usage of deep and surface muscles.

CONCLUSION

In this paper, we presented our proposal for explicit and objective exercise coaching. The proposed framework has two components: quantifying the differences between the correct and wrong forms for a movement using biomechanical engineering, and modelling the sequence of muscle and joint activation of the correct form for a movement using ontology engineering. We presented a case study to exemplify the application of the proposed framework to body trunk torsion movement. In the next step, we will collect knowledge from a large cohort to establish models for more basic movements.

REFERENCES

1. M. Roig, K. Skriver, J. Lundbye-Jensen, et al. 2012. A single bout of exercise improves motor memory. PLoS ONE 7, 9:e44594.
2. M. A. Hirsch, B. G. Farley. 2009. Exercise and neuroplasticity in persons living with Parkinson's disease. *European Journal of Physical and Rehabilitation Medicine* 45, 2: 215–29.
3. J. North. 2013. Philosophical underpinnings of coaching practice research. *Quest* 65, 3:278-299.
4. E. Cope. 2014. *Research methods in sports coaching*. Routledge, London.
5. W. D. Cilbert, P. Trudel. 2004. Analysis of coaching science research published from 1970-2001. *Research Quarterly for Exercise and Sport* 75, 388-399.
6. H. Akker, V. M. Jones, H. J. Hermens. 2014. Tailoring real-time physical activity coaching systems: a literature survey and model. *User Modeling and User-Adapted Interaction* 24, 5:351-392.
7. M. R. Beauchamp, S. R. Bray, M. A. Eys, & A. V. Carron. 2002. Role ambiguity, role efficacy, and role performance: Multidimensional and mediational relationships within interdependent sport teams. *Group Dynamics: Theory, Research, and Practice* 6, 229-242.
8. M. R. Beauchamp, S. R. Bray, M. A. Eys, & A. V. Carron. 2003. The effect of role ambiguity on competitive state anxiety. *Journal of Sport& Exercise Psychology* 25, 1:77-92.
9. K. B. Chandran, S. E. Rittgers, A. P. Yoganathan. 2012. *Biofluid Mechanics: The Human Circulation*, Second Edition. CRC Press.
10. M. A. Swartz. 2015. Tissue mechanics: cell jam. *Nature Materials* 14, 970-971.
11. R. M. Howard, R. Conway, A. J. Harrison. 2017. Muscle activity in sprinting: a review. *Sports Biomechanics*, 1-17.
12. A. A. Clarance. 2014. Proposal for the creation of a dance ontology. *In Proceedings of the 4th International Conference on Arts and Technology*, 86-99.
13. N. Burns, S. K. Grove. (2001). *The practice of nursing research* 4th Edition. Philadelphia, PA: WA Saunders Co.
14. R. G. Wells. 2013. Tissue mechanics and fibrosis. *Biochim Biophys Acta* 1832, 7:884-890.
15. G. Alterovitz, M. Xiang, D. P. Hill, et al. 2010. Ontology engineering. *Nature Biotechnology* 28, 2:128-130.
16. V. Espin, M. V. Hurtado, M. Noguera. 2014. Towards holistic support of active aging through cognitive stimulation, exercise and assisted nutrition. *International Workshop on Ambient Assisted Living*, 312-319.
17. N. D. Rodriguez, M. P. Guellar, J. Lilius, et al. 2014. A survey on ontologies for human behavior recognition. *ACM Computing Surveys* 46, 4:Article 43.
18. R. Fisher, T. Kollar, R. Simmons. 2013. Building and learning from a contextual knowledge base for personalized physical therapy coach. *In Proceedings of the 30th International Conference on Machine Learning*.